Operations Management *8th edition*

PART ONE

Introduction

Chapter 1 introduces you to the field of operations management. It describes the nature and scope of operations management, and how operations management relates to other parts of the organization. Among the important topics it covers are a comparison of manufacturing and service operations, a brief history of operations management, and a list of trends in business that relate to operations. After you have read this chapter, you will have a good understanding of what the operations function of a business organization encompasses.

Chapter 2 discusses operations management in a broader context, and presents the issues of competition, strategy, and productivity. After you have read Chapter 2, you will understand the importance of the operations function relative to the goals of a business organization. This chapter also describes time-based strategies, which many organizations are now adopting as they seek to become more competitive and to better serve their customers.

Introduction to operations management includes two chapters:

CHAPTER 1

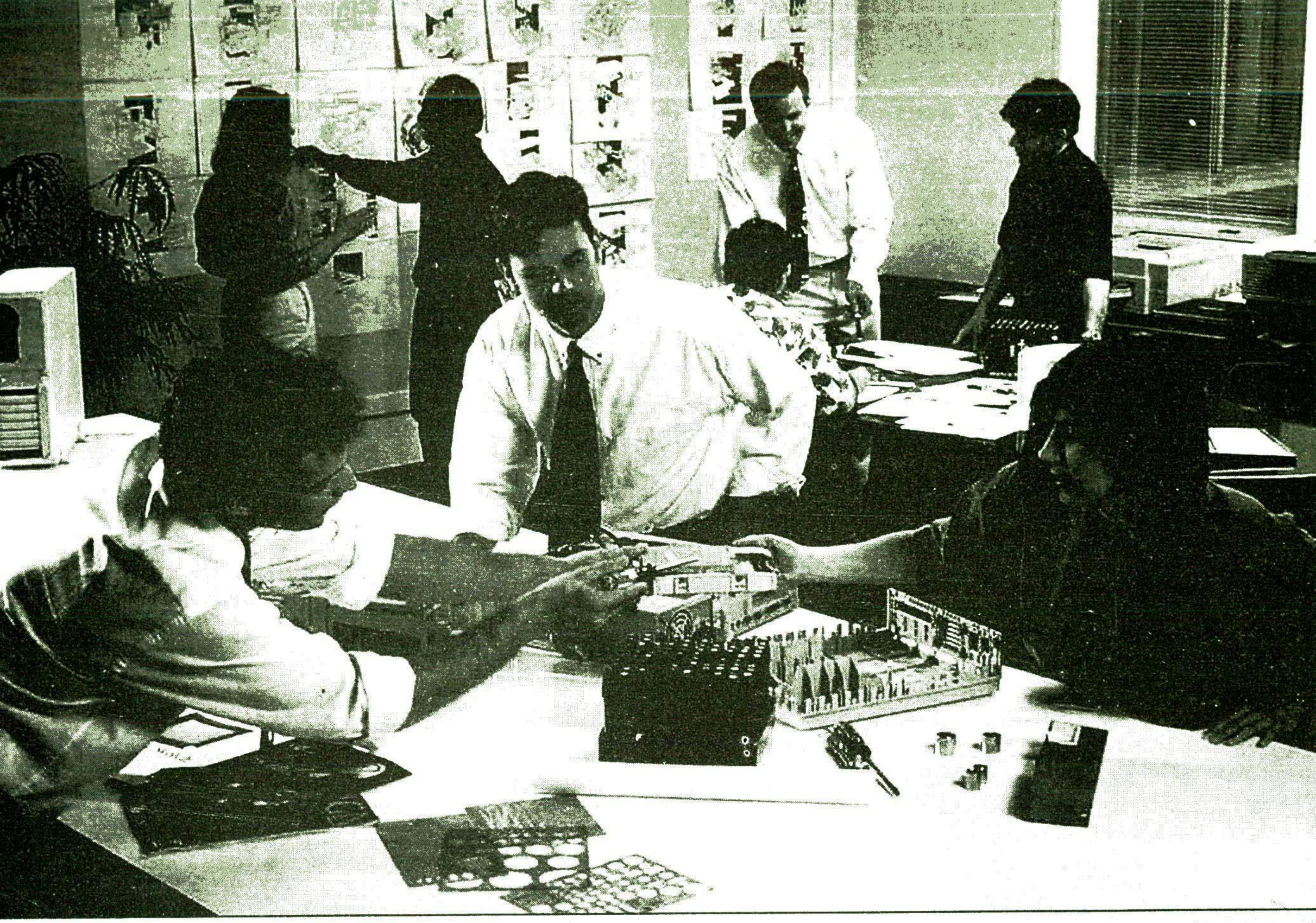
Introduction to Operations Management

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Define the term *operations management.*
2. Identify the three major functional areas of organizations and describe how they interrelate.
3. Compare and contrast service and manufacturing operations.
4. Describe the operations function and the nature of the operations manager's job.
5. Differentiate between design and operation of production systems.
6. Describe the key aspects of operations management decision making.
7. Briefly describe the historical evolution of operations management.
8. Identify current trends in business that impact operations management.

CHAPTER OUTLINE



In the late 1970s, Wal-Mart was a niche marketer, with about 200 stores, mostly in the South. At the time, Sears, JC Penney, and Kmart dominated the retail market. Over the years, Wal-Mart gained market share at the expense of the previous market leaders, and it has now become the largest and most profitable retailer in the world!

In the 1990s, the Boeing Company ran into trouble when it could not meet production deadlines. As a result, Boeing lost some orders, which had a negative impact on earnings and its stock price.

Why do some companies thrive while others struggle or fail? There are a variety of reasons, to be sure. However, an important key in a company's success or failure is how well it *manages its operations.*

This book is about operations management. The subject matter is fascinating and timely: productivity, quality, e-business, global competition, and customer service are very much in the news, and all are part of operations management. This first chapter presents an introduction and overview of operations management. Among the issues it addresses are: What is operations management? Why is it important? What do operations management professionals do?

The chapter also provides a brief description of the historical evolution of operations management and a discussion of the trends that impact operations management.

INTRODUCTION

Operations management is the management of that part of an organization that is responsible for producing goods and/or services. There are examples of these goods and services all around you. Every book you read, every video you watch, every e-mail you send, every telephone conversation you have, and every medical treatment you receive involves the operations function of one or more organizations. So does everything you wear, eat, travel in, sit on, and access the Internet with.

Business organizations typically have three basic functional areas, as depicted in Figure 1.1: finance, marketing, and operations. It doesn't matter if the business is a retail store, a hospital, a manufacturing firm, a car wash, or some other type of business; it is true for all business organizations.

Finance is responsible for securing financial resources at favorable prices and allocating those resources throughout the organization, as well as budgeting, analyzing investment proposals, and providing funds for operations. Marketing is responsible for assessing consumer wants and needs, and selling and promoting the organization's goods or services. And operations is primarily responsible for producing the goods or providing the services offered by the organization. To put this into perspective, if a business organization were a car, operations would be its engine. And just as the engine is the core of what a car does, in a business organization, operations is the core of what the organization does. Operations management is responsible for managing that core. Hence, **operations management** is the management of systems or processes that create goods and/or provide services.

operations management The management of systems or processes that *create goods and/or provide services.*

The creation of goods or services involves transforming or converting inputs into outputs. Various inputs such as capital, labor, and information are used to create goods or services using one or more *transformation processes* (e.g., storing, transporting, cutting). To ensure that the desired outputs are obtained, measurements are taken at various points in the transformation process (*feedback*) and then compared with previously established standards to determine whether corrective action is needed (*control*). Figure 1.2 depicts the conversion process.

Table 1.1 provides some examples of inputs, transformation processes, and outputs. Although goods and services are listed separately in Table 1.1, it is important to note that goods and services often occur jointly. For example, having the oil changed in your car is a service, but the oil that is delivered is a good. Similarly, house painting is a service, but the paint is a

FIGURE 1.1

The three basic functions of business organizations

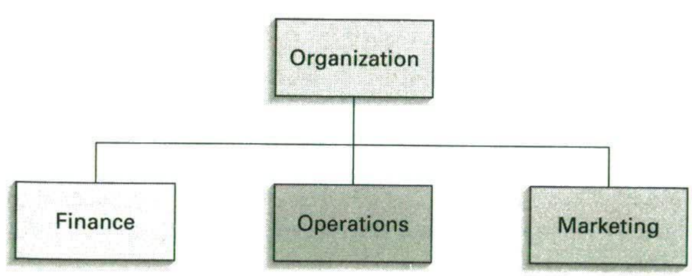
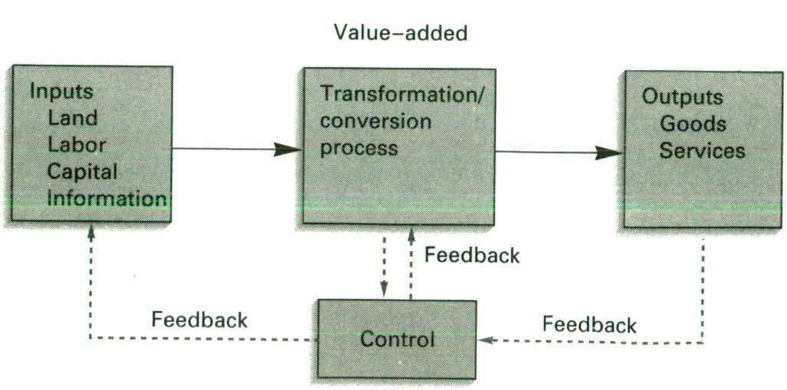


FIGURE 1.2

The operations function involves the conversion of inputs into outputs



good. The goods–service combination is a continuum. It can range from primarily goods, with little service, to primarily service, with few goods. Figure 1.3 illustrates this continuum.

Table 1.2 provides some specific illustrations of the transformation process.

The essence of the operations function is to *add value* during the transformation process: **Value-added** is the term used to describe the difference between the cost of inputs and the value or price of outputs. In nonprofit organizations, the value of outputs (e.g., highway construction, police and fire protection) is their value to society; the greater the value added, the greater the effectiveness of these operations. In for-profit organizations, the value of outputs is measured by the prices that customers are willing to pay for those goods or services. Firms use the money generated by value-added for research and development, investment in new facilities and equipment, paying workers, and *profits.* Consequently, the greater the value-added, the greater the amount of funds available for these purposes.

value-added The difference between the cost of inputs and the value or price of outputs.

Production of Goods versus Delivery of Services

Although goods and services often go hand in hand, there are some very basic differences between the two, differences that impact the management of the goods portion versus management of the service portion. This section explores those differences.

Production of goods results in a *tangible output,* such as an automobile, eye glasses, a golf ball, a refrigerator—anything that we can see or touch. It may take place in a factory, but can

TABLE 1.1
Examples of inputs, transformation, and outputs

Inputs	Transformation	Outputs
Land	Processes	High goods percentage
Human	Cutting, drilling	Houses
Physical	Transporting	Automobiles
Intellectual	Teaching	Clothing
Capital	Farming	Computers
Raw materials	Mixing	Machines
Energy	Packing	Televisions
Water	Copying, faxing	Food products
Metals		Textbooks
Wood		CD players
Equipment		High service percentage
Machines		Health care
Computers		Entertainment
Trucks		Car repair
Tools		Delivery
Facilities		Legal
Hospitals		Banking
Factories		Communication
Retail stores		
Other		
Information		
Time		

FIGURE 1.3

The goods–service continuum

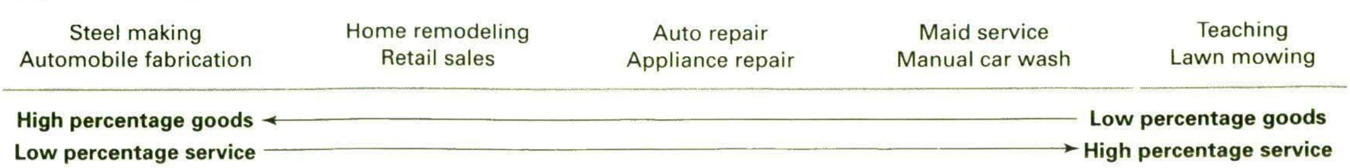


TABLE 1.2
Illustrations of the transformation process

Food Processor	Inputs	Processing	Output
	Raw vegetables	Cleaning	Canned vegetables
	Metal sheets	Making cans	
	Water	Cutting	
	Energy	Cooking	
	Labor	Packing	
	Building	Labeling	
	Equipment		
Hospital	**Inputs**	**Processing**	**Output**
	Doctors, nurses	Examination	Healthy patients
	Hospital	Surgery	
	Medical supplies	Monitoring	
	Equipment	Medication	
	Laboratories	Therapy	

occur elsewhere. For example, farming produces *nonmanufactured* goods. Delivery of service, on the other hand, generally implies an *act*. A physician's examination, TV and auto repair, lawn care, and projecting a film in a theater are examples of services. The majority of service jobs fall into these categories:

Government (federal, state, local).

Wholesale/retail (clothing, food, appliances, stationery, toys, etc.).

Financial services (banking, stock brokerages, insurance, etc.).

Health care (doctors, dentists, hospitals, etc.).

Personal services (laundry, dry cleaning, hair/beauty, gardening, etc.).

Business services (data processing, e-business, delivery, employment agencies, etc.).

Education (schools, colleges, etc.).

Manufacturing and service are often different in terms of *what* is done but similar in terms of *how* it is done. For example, both involve design and operating decisions. Manufacturers must decide what size factory is needed. Service organizations (e.g., hospitals) must decide what size building is needed. Both must make decisions on location, work schedules, capacity, and allocation of scarce resources.

Manufacturing and service organizations differ chiefly because manufacturing is goods-oriented and service is act-oriented. The differences involve the following:

1. Degree of customer contact
2. Uniformity of input
3. Labor content of jobs
4. Uniformity of output
5. Measurement of productivity
6. Production and delivery
7. Quality assurance
8. Amount of inventory

Let us consider each of these differences.

1. Often, by its nature, service involves a much higher degree of customer contact than manufacturing. The performance of a service often occurs at the point of consumption. For example, repairing a leaky roof must take place where the roof is, and surgery requires the

presence of the surgeon and the patient. On the other hand, manufacturing allows a separation between production and consumption, so that manufacturing can occur away from the consumer. This permits a fair degree of latitude in selecting work methods, assigning jobs, scheduling work, and exercising control over operations. Service operations, because of their contact with customers, can be much more limited in their range of options. Moreover, customers are sometimes a part of the system (e.g., self-service operations such as gas stations, shopping), so tight control is impossible. In addition, product-oriented operations can build up inventories of finished goods (e.g., cars, refrigerators), enabling them to absorb some of the shocks caused by varying demand. Service operations, however, cannot build up inventories of *time* and are much more sensitive to demand variability—banks and supermarkets alternate between lines of customers waiting for service and idle tellers or cashiers waiting for customers.

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2. Service operations are subject to greater variability of inputs than typical manufacturing operations. Each patient, each lawn, and each auto repair presents a specific problem that often must be diagnosed before it can be remedied. Manufacturing operations often have the ability to carefully control the amount of variability of inputs and thus achieve low variability in outputs. Consequently, job requirements for manufacturing are generally more uniform than those for services.

3. Many services involve a higher labor content than manufacturing operations.

4. Because high mechanization generates products with low variability, manufacturing tends to be smooth and efficient; service activities sometimes appear to be slow and awkward, and output is more variable. Automated services are an exception to this.

5. Measurement of productivity is more straightforward in manufacturing due to the high degree of uniformity of most manufactured items. In service operations, variations in demand intensity and in requirements from job to job make productivity measurement considerably more difficult. For example, compare the productivity of two doctors. One may have a large number of routine cases while the other does not, so their productivity appears to differ unless a very careful analysis is made.

6. In many instances customers receive the service as it is performed (e.g., haircut, dental care).

7. Quality assurance is more challenging in services when production and consumption occur at the same time. Moreover, the higher variability of input creates additional opportunity for the quality of output to suffer unless quality assurance is actively managed. Quality at the point of creation is typically more evident for services than for manufacturing, where errors can be corrected before the customer receives the output.

8. Due to the nature of manufacturing, manufacturing systems usually have more inventory on hand (e.g., raw materials, partially completed items, finished goods inventories) than service firms. Nonetheless, all business organizations carry at least some items in inventory that are necessary for the operation of their businesses (e.g., office supplies, spare parts for equipment). And some service organizations have substantial amounts of inventory (e.g., firms that supply replacement parts for automobiles, construction equipment, or farm equipment). Hence, in spite

An employee checks the cork flooring inventory at the Ipocork plant in Santa Paio de Oleiros, Portugal.

TABLE 1.3
Typical differences between goods and services

Characteristic	Goods	Services
Output	Tangible	Intangible
Uniformity of output	High	Low
Uniformity of input	High	Low
Labor content	Low	High
Measurement of productivity	Easy	Difficult
Customer contact	Low	High
Opportunity to correct quality problems before delivery to customer	High	Low
Evaluation	Easier	More difficult
Patentable	Usually	Not usually

of differing inventory requirements, managers in both manufacturing and service organizations must make decisions concerning inventory (e.g., which items to stock, how much to stock, when to reorder).

Service jobs are sometimes categorized as professional or nonprofessional. Wholesale/retail and personal services generally fall into the nonprofessional category. Often these jobs tend to be on the low end of the pay scale, whereas professional services (e.g., surgery, consulting) tend to be on the high end of the pay scale. Manufacturing jobs, on the other hand, don't show this bimodal tendency, and few salaries fall in either the high or low range.

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Table 1.3 gives an overview of the differences between production of goods and service operations. Remember, though, that most systems are a blend of goods and services.

THE SCOPE OF OPERATIONS MANAGEMENT

The scope of operations management ranges across the organization. Operations management people are involved in product and service design, process selection, selection and management of technology, design of work systems, location planning, facilities planning, and quality improvement of the organization's products or services.

The operations function includes many interrelated activities, such as forecasting, capacity planning, scheduling, managing inventories, assuring quality, motivating employees, deciding where to locate facilities, and more.

We can use an airline company to illustrate a service organization's operations system. The system consists of the airplanes, airport facilities, and maintenance facilities, sometimes spread out over a wide territory. Most of the activities performed by management and employees fall into the realm of operations management:

Forecasting such things as weather and landing conditions, seat demand for flights, and the growth in air travel.

Capacity planning, essential for the airline to maintain cash flow and make a reasonable profit. (Too few or too many planes, or even the right number of planes but in the wrong places, will hurt profits.)

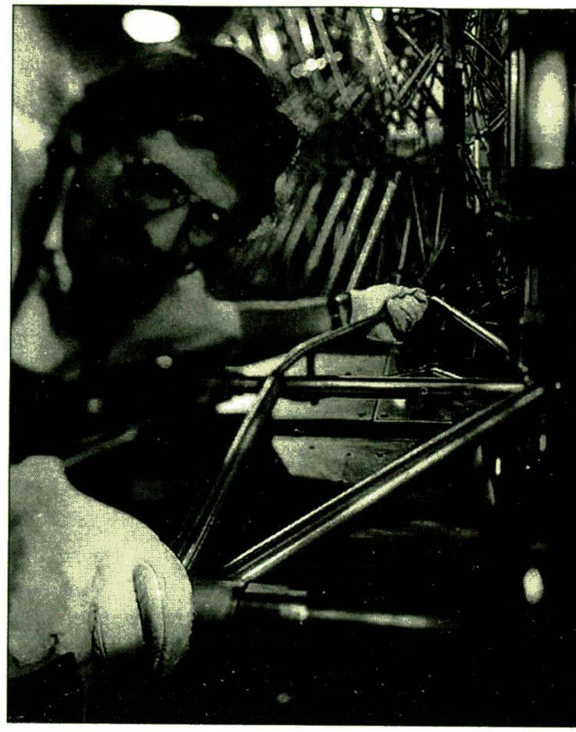
Scheduling of planes for flights and for routine maintenance; scheduling of pilots and flight attendants; and scheduling of ground crews, counter staff, and baggage handlers.

Managing inventories of such items as foods and beverages, first-aid equipment, in-flight magazines, pillows and blankets, and life preservers.

Assuring quality, essential in flying and maintenance operations, where the emphasis is on safety, and important in dealing with customers at ticket counters, check-in, telephone and electronic reservations, and curb service, where the emphasis is on efficiency and courtesy.

Motivating and training employees in all phases of operations.

Locating facilities according to managers' decisions on which cities to provide service for, where to locate maintenance facilities, and where to locate major and minor hubs.



Assembly at Trek Bicycle Company in Waterloo, Wisconsin, world headquarters for Trek. Trek is a world leader in bicycle products and accessories, with 1,500 employees worldwide. Designers and engineers incorporate the most advanced technology into Trek products, resulting in award winning bikes and components.

www.trekbikes.com

Now consider a bicycle factory. This might be primarily an *assembly* operation: buying components such as frames, tires, wheels, gears, and other items from suppliers, and then assembling bicycles. The factory also might do some of the *fabrication* work itself, forming frames, making the gears and chains, and buy mainly raw materials and a few parts and materials such as paint, nuts and bolts, and tires. Among the key management tasks in either case are scheduling production, deciding which components to make and which to buy, ordering parts and materials, deciding on the style of bicycle to produce and how many, purchasing new equipment to replace old or worn out equipment, maintaining equipment, motivating workers, and ensuring that quality standards are met.

Obviously, an airline company and a bicycle factory are completely different types of operations. One is primarily a service operation, the other a producer of goods. Nonetheless, these two operations have much in common. Both involve scheduling of activities, motivating employees, ordering and managing supplies, selecting and maintaining equipment, satisfying quality standards, and—above all—satisfying customers. And in both businesses, the success of the business depends on short- and long-term planning.

The operations function consists of all activities *directly* related to producing goods or providing services. Hence, it exists both in manufacturing and assembly operations, which are *goods-oriented,* and in areas such as health care, transportation, food handling, and retailing, which are primarily *service-oriented.* Table 1.4 provides examples of the diversity of operations management settings.

A primary function of an operations manager is to guide the system by decision making. Certain decisions affect the *design* of the system, and others affect the *operation* of the system.

System design involves decisions that relate to system capacity, the geographic location of facilities, arrangement of departments and placement of equipment within physical structures, product and service planning, and acquisition of equipment. These decisions usually, but not

TABLE 1.4
Examples of types of operations

Type of Operations	Examples
Goods producing	Farming, mining, construction, manufacturing, power generating
Storage/transportation	Warehousing, trucking, mail service, moving, taxis, buses, hotels, airlines
Exchange	Retailing, wholesaling, financial advising, renting or leasing, library loans, stock exchange
Entertainment	Films, radio and television, plays, concerts, recording
Communication	Newspapers, radio and TV newscasts, telephone, satellites, the Internet

TABLE 1.5
Design and operating decisions

Decision Area	Chapter	Basic Issues
Forecasting	3	What will demand be?
Design		
Product and service design	4	What do customers want? How can products and services be improved?
Capacity (long range)	5	How much capacity will be needed? How can the organization best meet capacity requirements?
Process selection	6	What processes should the organization use?
Layout	6	What is the best arrangement for departments, equipment, work flow, and storage in terms of cost, productivity?
Design of work systems	7	What is the best way to motivate employees? How can productivity be improved? How to measure work? How to improve work methods?
Location	8	What is a satisfactory location for a facility (factory, store, etc.)?
Operation		
Quality	9	How is quality defined? How are quality goods and services achieved and improved?
Quality control	10	Are processes performing adequately? What standards should be used? Are standards being met?
Aggregate planning	12	How much capacity will be needed over the intermediate range? How can capacity needs best be met?
Inventory management	11, 13	How much to order? When to reorder? Which items should get the most attention?
Materials requirements planning	13	What materials, parts, and subassemblies will be needed, and when?
Just-in-time and lean systems	14	How to achieve a smooth, balanced flow of work using fewer resources?
Scheduling	15	How can jobs and resources best be scheduled? Who will do which job?
Supply chain management	16	How to achieve effective flows of information and goods throughout the chain?
Project management	17	Which activities are the most critical to the success of a project? What are the goals of a project? What resources will be needed, and when will they be needed?
Waiting lines	18	What service capacity is appropriate?

always, require long-term commitments. *System operation* involves management of personnel, inventory planning and control, scheduling, project management, and quality assurance. In many instances, the operations manager is more involved in day-to-day operating decisions than with decisions relating to system design. However, the operations manager has a vital stake in system design because *system design essentially determines many of the parameters of system operation.* For example, costs, space, capacities, and quality are directly affected by design decisions. Even though the operations manager is not responsible for making all design decisions, he or she can provide those decision makers with a wide range of information that will have a bearing on their decisions. Table 1.5 provides additional insights on operations management.

There are also a number of other areas that are part of the operations function. They include purchasing, industrial engineering, distribution, and maintenance.

> *Purchasing* has responsibility for procurement of materials, supplies, and equipment. Close contact with operations is necessary to ensure correct quantities and timing of purchases. The purchasing department is often called on to evaluate vendors for quality, reliability, service, price, and ability to adjust to changing demand. Purchasing is also involved in receiving and inspecting the purchased goods.

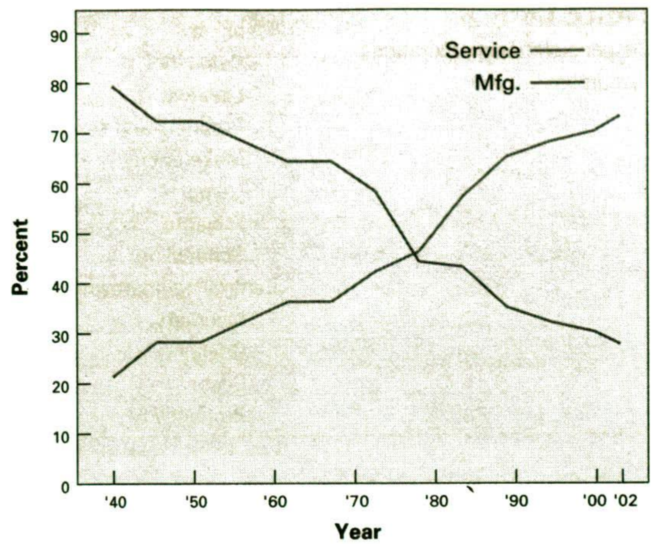


FIGURE 1.4

U.S. manufacturing versus service employment, 1940–2002

Source: U.S. Bureau of Labor Statistics.

Industrial engineering is often concerned with scheduling, performance standards, work methods, quality control, and material handling.

Distribution involves the shipping of goods to warehouses, retail outlets, or final customers.

Maintenance is responsible for general upkeep and repair of equipment, buildings and grounds, heating and air-conditioning; removing toxic wastes; parking; and perhaps security.

The importance of operations management, both for organizations and for society, should be fairly obvious: The consumption of goods and services is an integral part of our society. Operations management is responsible for creating those goods and services. Organizations exist primarily to provide services or create goods. Hence, operations is the *core function* of an organization. Without this core, there would be no need for any of the other functions—the organization would have no purpose. Given the central nature of its function, it is not surprising that more than half of all employed people in this country have jobs in operations. Furthermore, the operations function is responsible for a major portion of the assets in most business organizations.

The service sector and the manufacturing sector are both important to the economy. The service sector now accounts for more than 70 percent of jobs in the United States. Moreover, the number of people working in services is increasing, while the number of people working in manufacturing is not. (See Figure 1.4.) More and more the U.S. economy is becoming a service economy.

THE OPERATIONS MANAGER AND THE MANAGEMENT PROCESS

The operations manager is the key figure in the system: he or she has the ultimate responsibility for the creation of goods or provision of services.

The kinds of jobs that operations managers oversee vary tremendously from organization to organization largely because of the different products or services involved. Thus, managing a banking operation obviously requires a different kind of expertise than managing a steelmaking operation. However, in a very important respect, the jobs are the same: They are both essentially *managerial*. The same thing can be said for the job of any operations manager regardless of the kinds of goods or services being created. In every case, the operations manager must coordinate the use of resources through the management process of planning, organizing, staffing, directing, and controlling.

TABLE 1.6
Responsibilities of operations managers

Planning	Organizing
Capacity	Degree of centralization
Location	Process selection
Products and services	Staffing
Make or buy	Hiring/laying off
Layout	Use of overtime
Projects	Directing
Scheduling	Incentive plans
Controlling/improving	Issuance of work orders
Inventory	Job assignments
Quality	
Costs	
Productivity	

Examples of the responsibilities of operations managers according to these classifications are given in Table 1.6.

OPERATIONS MANAGEMENT AND DECISION MAKING

The chief role of an operations manager is that of planner and decision maker. In this capacity, the operations manager exerts considerable influence over the degree to which the goals and objectives of the organization are realized. Most decisions involve many possible alternatives that can have quite different impacts on costs or profits. Consequently, it is important to make *informed* decisions.

Operations management professionals make a number of key decisions that affect the entire organization. These include

What: What resources will be needed, and in what amounts? How will resources be allocated?

When: When will each resource be needed? When should the work be scheduled? When should materials and other supplies be ordered? When is corrective action needed?

Where: Where will the work be done?

How: How will the product or service be designed? How will the work be done (organization, methods, equipment)?

Who: Who will do the work?

Throughout this book, you will encounter the broad range of decisions that operations managers must make, and you will be introduced to the tools necessary to handle those decisions. This section describes general approaches to decision making, including the use of models, quantitative methods, analysis of trade-offs, establishing priorities, ethics, and the systems approach.

Models

model An abstraction of reality; a simplified representation of something.

A **model** is an abstraction of reality, a simplified version of something. For example, a child's toy car is a model of a real automobile. It has many of the same visual features (shape, relative proportions, wheels) that make it suitable for the child's learning and playing. But the toy does not have a real engine, it cannot transport people, and it does not weigh 2,000 pounds.

Other examples of models include automobile test tracks and crash tests, formulas, graphs and charts, balance sheets and income statements, and financial ratios. Common statistical models include descriptive statistics such as the mean, median, mode, range, and standard deviation, as well as random sampling, the normal distribution, and regression equations.

Models are sometimes classified as physical, schematic, or mathematical:

Physical models look like their real-life counterparts. Examples include miniature cars, trucks, airplanes, toy animals and trains, and scale-model buildings. The advantage of these models is their visual correspondence with reality.

Schematic models are more abstract than their physical counterparts; that is, they have less resemblance to the physical reality. Examples include graphs and charts, blueprints, pictures, and drawings. The advantage of schematic models is that they are often relatively simple to construct and change. Moreover, they have some degree of visual correspondence.

Mathematical models are the most abstract: They do not look at all like their real-life counterparts. Examples include numbers, formulas, and symbols. These models are usually the easiest to manipulate, and they are important forms of inputs for computers and calculators.

The variety of models in use is enormous. Nonetheless, all have certain common features: They are all decision-making aids and simplifications of more complex real-life phenomena. Real life involves an overwhelming amount of detail, much of which is irrelevant for any particular problem. Models ignore the unimportant details so that attention can be concentrated on the most important aspects of a situation, thus increasing the opportunity to understand a problem and its solution.

Because models play a significant role in operations management decision making, they are heavily integrated into the material of this text. For each model, try to learn (1) its purpose, (2) how it is used to generate results, (3) how these results are interpreted and used, and (4) what assumptions and limitations apply.

The last point is particularly important because virtually every model has an associated set of requirements that indicate the conditions under which the model is valid. Failure to satisfy all of the assumptions (i.e., to use a model where it isn't meant to be used) will make the results suspect. Attempts to apply the results to a problem under such circumstances can lead to disastrous consequences. Hence, it is extremely important to be aware of the assumptions and limitations of each model.

Managers use models in a variety of ways and for a variety of reasons. Models are beneficial because they

1. Are generally easy to use and less expensive than dealing directly with the actual situation.
2. Require users to organize and sometimes quantify information and, in the process, often indicate areas where additional information is needed.
3. Provide a systematic approach to problem solving.
4. Increase understanding of the problem.
5. Enable managers to analyze "what if?" questions.
6. Require users to be specific about objectives.
7. Serve as a consistent tool for evaluation.
8. Enable users to bring the power of mathematics to bear on a problem.
9. Provide a standardized format for analyzing a problem.

This impressive list of benefits notwithstanding, models have certain limitations of which you should be aware. Two of the more important limitations are

1. Quantitative information may be emphasized at the expense of qualitative information.
2. Models may be incorrectly applied and the results misinterpreted. The widespread use of computerized models adds to this risk because highly sophisticated models may be placed in the hands of users who are not sufficiently knowledgeable to appreciate the subtleties of a particular model; thus, they are unable to fully comprehend the circumstances under which the model can be successfully employed.

Quantitative Approaches

Quantitative approaches to problem solving often embody an attempt to obtain mathematically optimal solutions to managerial problems. *Linear programming* and related mathematical techniques are widely used for optimum allocation of scarce resources. *Queuing techniques* are useful for analyzing situations in which waiting lines form. *Inventory models* are widely used to control inventories. *Project models* such as PERT (program evaluation and review technique) and CPM (critical path method) are useful for planning, coordinating, and controlling large-scale projects. *Forecasting techniques* are widely used in planning and scheduling. *Statistical models* are currently used in many areas of decision making.

In large measure, *quantitative approaches* to decision making in operations management (and in other functional business areas) have been accepted because of calculators and high-speed computers capable of handling the required calculations. Computers have had a major impact on operations management. Moreover, the growing availability of software packages covering virtually every quantitative technique has greatly increased management's use of the computer.

Because of the emphasis on quantitative approaches in operations management decision making, it is important not to lose sight of the fact that managers typically use a combination of qualitative and quantitative approaches, and many important decisions are based on qualitative approaches.

Analysis of Trade-Offs

Operations personnel frequently encounter decisions that can be described as *trade-off* decisions. For example, in deciding on the amount of inventory to stock, the decision maker must take into account the trade-off between the increased level of customer service that the additional inventory would yield and the increased costs required to stock that inventory. In selecting equipment, a decision maker must evaluate the merits of extra features relative to the cost of those extra features. And in the scheduling of overtime to increase output, the manager must weigh the value of the increased output against the higher costs of overtime (e.g., higher labor costs, lower productivity, lower quality, and greater risk of accidents).

Throughout this book you will be presented with decision models that reflect these kinds of trade-offs. Decision makers sometimes deal with these decisions by listing the advantages and disadvantages—the pros and cons—of a course of action to better understand the consequences of the decisions they must make. In some instances, decision makers add weights to the items on their list that reflect the relative importance of various factors. This can help them "net out" the potential impacts of the trade-offs on their decision. An example of this is the factor-rating approach described in Chapter 8 on facilities location.

A Systems Approach

system A set of interrelated parts that must work together.

A systems viewpoint is almost always beneficial in decision making. A **system** can be defined as a set of interrelated parts that must work together. In a business organization, the organization can be thought of as a system composed of subsystems (e.g., marketing subsystem, operations subsystem, finance subsystems), which in turn are composed of lower subsystems. The systems approach emphasizes interrelationships among subsystems, but its main theme is that *the whole is greater than the sum of its individual parts.* Hence, from a systems viewpoint, the output and objectives of the organization as a whole take precedence over those of any one subsystem. An alternative approach is to concentrate on efficiency within subsystems and thereby achieve overall efficiency. But that approach overlooks the fact that organizations must operate in an environment of scarce resources and that subsystems are often in direct competition for those scarce resources, so that an orderly approach to the allocation of resources is called for.

One undesirable result of the use of quantitative techniques is that many of the techniques tend to produce solutions that are optimal in a narrow sense but may not be optimal in a broader sense (e.g., in terms of a department, plant, division, or overall organization). Consequently, managers must evaluate "optimal" solutions produced by quantitative techniques in terms of the larger framework, and perhaps modify decisions accordingly.

A systems approach is essential whenever something is being designed, redesigned, implemented, improved, or otherwise changed. It is important to take into account the impact on all parts of the system. For example, if the upcoming model of an automobile will add antilock brakes, a designer must take into account how customers will view the change, instructions for using the brakes, chances for misuse, the cost of producing the new brakes, installation procedures, recycling worn-out brakes, and repair procedures. In addition, workers will need training to make and/or assemble the brakes, production scheduling may change, inventory procedures may have to change, quality standards will have to be established, advertising must be informed of the new features, and parts suppliers must be selected.

Establishing Priorities

In virtually every situation, managers discover that certain factors are more important than others. Recognizing this enables the managers to direct their efforts to where they will do the most good and to avoid wasting time and energy on insignificant factors.

Consider owning and operating an automobile. It has many parts and systems that can malfunction. Some of these are critical to the operation of the automobile: It would not function or would be dangerous to operate without them. Critical items include the engine and drive train, steering, brakes, tires, electrical system, and cooling system. In terms of maintaining and repairing the car, these items should receive the highest priority if the goal is to have safe, reliable transportation.

There are other items that are of much less importance, such as scratches in the paint, minor dents, a missing piece of chrome, and worn seatcovers. In terms of transportation, these should receive attention only after other, more important items have been attended to.

Between these two extremes lies a range of items of intermediate priority. These should be given attention corresponding to their importance to the overall goal. The list might include soft tires, weak battery, wheel alignment, noisy muffler, body rust, inoperative radio, and headlights out of adjustment.

Obviously, certain parts of an automobile are more critical to its operation than others. The same concept applies to management. By recognizing this and setting priorities, a manager will be in a position to deal more effectively with problems as they arise and to prevent many others from arising at all.

It is axiomatic that a relatively few factors are often most important, so that dealing with those factors will generally have a disproportionately large impact on the results achieved. This is referred to as the **Pareto phenomenon,** which means that all things are not equal; some things (a few) will be very important for achieving an objective or solving a problem, and other things (many) will not. The implication is that a manager should examine each situation, searching for the few factors that will have the greatest impact, and give them the highest priority. This is one of the most important and pervasive concepts in operations management. In fact, this concept can be applied at all levels of management and to every aspect of decision making, both professional and personal.

Pareto phenomenon A few factors account for a high percentage of the occurrence of some event(s).

Ethics

The financial difficulties of companies such as Enron, WorldCom, Global Crossings, Adelphia, Arthur Andersen, and ImClone Systems brought into question ethical standards and behavior of high-ranking company officials.

In making decisions, managers must consider how their decisions will affect shareholders, management, employees, customers, the community at large, and the environment. Finding solutions that will be in the best interests of all of these stakeholders is not always easy, but it is a goal that all managers should strive to achieve. Furthermore, even managers with the best intentions will sometimes make mistakes. If mistakes do occur, managers should act responsibly to correct those mistakes as quickly as possible, and to address any negative consequences.

Operations managers, like all managers, have the responsibility to make ethical decisions. Ethical issues arise in many aspects of operations management, including

- Financial statements: accurately representing the organization's financial condition.
- Worker safety: providing adequate training, maintaining equipment in good working condition, maintaining a safe working environment.
- Product safety: providing products that minimize the risk of injury to users or damage to property or the environment.
- Quality: honoring warranties, avoiding hidden defects.
- The environment: not doing things that will harm the environment.
- The community: being a good neighbor.
- Hiring and firing workers: don't hire under false pretenses (e.g., promising a long-term job when that is not what is intended).
- Closing facilities: taking into account the impact on a community, and honoring commitments that have been made.
- Workers' rights: respecting workers' rights, dealing with worker problems quickly and fairly.

WHY STUDY OPERATIONS MANAGEMENT?

If your major field of study is not operations management, you may be wondering why you need to study operations management. Actually, there are compelling reasons for studying operations management. One is that 50 percent or more of all jobs are in operations management or related fields. Also, recall the image of a business organization as a car, with operations as its engine. In order for that car to function properly, all of the parts must work together. So, too, all of the parts of a business organization must *work together* in order for the organization to function successfully.

Working together successfully means that everyone understand not only their own role, they also understand the roles of others. This is precisely why all business students, regardless of their particular major, are required to take a common core of courses that will enable them to learn about all aspects of business. Because operations management is central to the functioning of all business organizations, it is included in the core of courses business students are required to take. And even though individual courses have a narrow focus (e.g., accounting, marketing), in practice, there is significant interfacing and *collaboration* among the various functional areas, involving *exchange of information* and *cooperative decision making.* For example, although the three primary functions in business organizations perform different activities, many of their decisions impact the other areas of the organization. Consequently, these functions have numerous interactions, as depicted by the overlapping circles shown in Figure 1.5.

Finance and operations management personnel cooperate by exchanging information and expertise in such activities as the following:

1. *Budgeting.* Budgets must be periodically prepared to plan financial requirements. Budgets must sometimes be adjusted, and performance relative to a budget must be evaluated.
2. *Economic analysis of investment proposals.* Evaluation of alternative investments in plant and equipment requires inputs from both operations and finance people.
3. *Provision of funds.* The necessary funding of operations and the amount and timing of funding can be important and even critical when funds are tight. Careful planning can help avoid cash-flow problems.

Marketing's focus is on selling and/or promoting the goods or services of an organization. Marketing is also responsible for assessing customer wants and needs, and for communicating

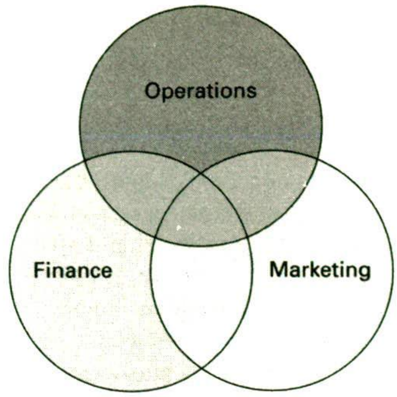


FIGURE 1.5

The three major functions of business organizations overlap

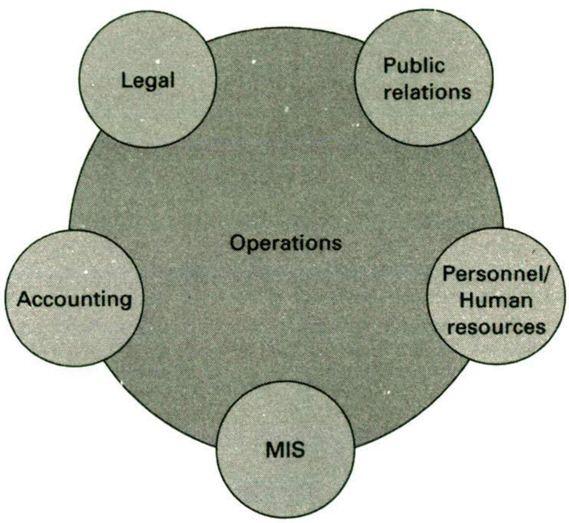


FIGURE 1.6

Operations interfaces with a number of supporting functions

those to operations people (short term) and to design people (long term). That is, operations needs information about demand over the short to intermediate term so that it can plan accordingly (e.g., purchase materials or schedule work), while design people need information that relates to improving current products and services and designing new ones. Marketing, design, and production must work closely together to successfully implement design changes and to develop and produce new products. Marketing can provide valuable insight on what competitors are doing. Marketing also can supply information on consumer preferences so that design will know the kinds of products and features needed; operations can supply information about capacities and judge the *manufacturability* of designs. Operations will also have advance warning if new equipment or skills will be needed for new products or services. Finance people should be included in these exchanges in order to provide information on what funds might be available (short term) and to learn what funds might be needed for new products or services (intermediate to long term). One important piece of information marketing needs from operations is the manufacturing or service **lead time** in order to give customers realistic estimates of how long it will take to fill their orders.

lead time The time between ordering a good or service and receiving it.

Thus, marketing, operations, and finance must interface on product and process design, forecasting, setting realistic schedules, quality and quantity decisions, and keeping each other informed on the other's strengths and weaknesses.

Operations also interacts with other functional areas of the organization, including legal, management information systems (MIS), accounting, personnel/human resources, and public relations, as depicted in Figure 1.6.

The *legal* department must be consulted on contracts with employees, customers, suppliers, and transporters, as well as on liability and environmental issues.

Accounting supplies information to management on costs of labor, materials, and overhead, and may provide reports on items such as scrap, downtime, and inventories.

Management information systems (MIS) is concerned with providing management with the information it needs to effectively manage. This occurs mainly through designing systems to capture relevant information and designing reports. MIS is also important for managing the control and decision-making tools used in operations management.

The *personnel* or *human resources* department is concerned with recruitment and training of personnel, labor relations, contract negotiations, wage and salary administration, assisting in manpower projections, and ensuring the health and safety of employees.

Public relations has responsibility for building and maintaining a positive public image of the organization. Good public relations provides many potential benefits. An obvious one is in the marketplace. Other potential benefits include public awareness of the organization as a good place to work (labor supply), improved chances of approval of zoning change requests, community acceptance of expansion plans, and instilling a positive attitude among employees.

Career Opportunities

There are many career opportunities in the operations management field. Among the numerous job titles are operations manager, production analyst, production manager, industrial engineer, time study analyst, inventory manager, purchasing manager, schedule coordinator, distribution manager, supply chain manager, quality analyst, and quality manager.

If you are thinking of a career in operations management, you can benefit by joining one or more of the professional societies.

www.apics.org

American Production and Inventory Control Society (APICS)
500 West Annandale Road, Falls Church, Virginia 22046-4274

www.asq.org

American Society for Quality (ASQ)
230 West Wells Street, Milwaukee, Wisconsin 53203

www.ism.ws

Institute of Supply Management (ISM)
2055 East Centennial Circle, Tempe, Arizona 85284

www.infoanalytic.com/asm/

Association for Systems Management
P.O. Box 38370, Cleveland, Ohio 44130-0307

www.informs.org

Institute for Operations Research and the Management Sciences (INFORMS)
901 Elkridge Landing Road, Linthicum, Maryland 21090-2909

www.poms.org

The Production and Operations Management Society (POMS)
College of Engineering, Florida International University, EAS 2460,
10555 West Flagler Street, Miami, Florida 33174

www.pmi.org

The Project Management Institute (PMI)
4 Campus Boulevard, Newtown Square, Pennsylvania 19073-3299

APICS and ISM both offer a practitioner certification examination that can enhance your qualifications. Information about job opportunities can be obtained from all of these societies as well as from other sources, such as the Decision Sciences Institute (University Plaza, Atlanta, Georgia, 30303) and the Institute of Industrial Engineers (25 Technology Park, Norcross, Georgia, 30092).

THE HISTORICAL EVOLUTION OF OPERATIONS MANAGEMENT

Systems for production have existed since ancient times. The Great Wall of China, the Egyptian pyramids, the ships of the Roman and Spanish empires, and the roads and aqueducts of the Romans provide examples of the human ability to organize for production. Even so, most of these examples could be classified as "public works" projects. The production of goods for sale, at least in the modern sense, and the modern factory system had their roots in the Industrial Revolution.

The Industrial Revolution

The Industrial Revolution began in the 1770s in England and spread to the rest of Europe and to the United States during the nineteenth century. Prior to that time, goods were produced in small shops by craftsmen and their apprentices. Under that system, it was common for one person to be responsible for making a product, such as a horse-drawn wagon or a piece of furniture, from start to finish. Only simple tools were available; the machines that we use today had not been invented.

Then, a number of innovations in the eighteenth century changed the face of production forever by substituting machine power for human power. Perhaps the most significant of these was the steam engine, because it provided a source of power to operate machines in factories. The spinning jenny and the power loom revolutionized the textile industry. Ample supplies of coal and iron ore provided materials for generating power and making machinery. The new machines, made of iron, were much stronger and more durable than the simple wooden machines they replaced.

In the earliest days of manufacturing, goods were produced using **craft production:** highly skilled workers using simple, flexible tools produced goods according to customer specifications.

craft production System in which highly skilled workers use simple, flexible tools to produce small quantities of customized goods.

Craft production had major shortcomings. Because products were made by skilled craftsmen who custom fitted parts, production was slow and costly. And when parts failed, the replacements also had to be custom made, which was also slow and costly. Another shortcoming was that production costs did not decrease as volume increased; there were no *economies of scale,* which would have provided a major incentive for companies to expand. Instead, many small companies emerged, each with its own set of standards.

A major change occurred that gave the industrial revolution a boost: the development of standard gauging systems. This greatly reduced the need for custom-made goods. Factories began to spring up and grow rapidly, providing jobs for countless people who were attracted in large numbers from rural areas.

Despite the major changes that were taking place, management theory and practice had not progressed much from early days. What was needed was an enlightened and more systematic approach to management.

Scientific Management

The scientific-management era brought widespread changes to the management of factories. The movement was spearheaded by the efficiency engineer and inventor Frederick Winslow Taylor, who is often referred to as the father of scientific management. Taylor believed in a "science of management" based on observation, measurement, analysis and improvement of work methods, and economic incentives. He studied work methods in great detail to identify the best method for doing each job. Taylor also believed that management should be responsible for planning, carefully selecting and training workers, finding the best way to perform each job, achieving cooperation between management and workers, and separating management activities from work activities.

Taylor's methods emphasized maximizing output. They were not always popular with workers, who sometimes thought the methods were used to unfairly increase output without a corresponding increase in compensation. Certainly some companies did abuse workers in their quest for efficiency. Eventually, the public outcry reached the halls of Congress, and hearings were held on the matter. Taylor himself was called to testify in 1911, the same year in which his classic book, *The Principles of Scientific Management,* was published. The publicity from those hearings actually helped scientific management principles to achieve wide acceptance in industry.

A number of other pioneers also contributed heavily to this movement, including the following:

> *Frank Gilbreth* was an industrial engineer who is often referred to as the father of motion study. He developed principles of motion economy that could be applied to incredibly small portions of a task.

Henry Gantt recognized the value of nonmonetary rewards to motivate workers, and developed a widely used system for scheduling, called Gantt charts.

Harrington Emerson applied Taylor's ideas to organization structure and encouraged the use of experts to improve organizational efficiency. He testified in a congressional hearing that railroads could save a million dollars a day by applying principles of scientific management.

www.ford.com

Henry Ford, the great industrialist, employed scientific management techniques in his factories.

During the early part of the twentieth century, automobiles were just coming into vogue in the United States. Ford's Model T was such a success that the company had trouble keeping up with orders for the cars. In an effort to improve the efficiency of operations, Ford adopted the scientific management principles espoused by Frederick Winslow Taylor. He also introduced the *moving assembly line.*

mass production System in which low-skilled workers use specialized machinery to produce high volumes of standardized goods.

interchangeable parts Parts of a product made to such precision that they do not have to be custom fitted.

Among Ford's many contributions was the introduction of **mass production** to the automotive industry, a system of production in which large volumes of standardized goods are produced by low-skilled or semiskilled workers using highly specialized, and often costly, equipment. Ford was able to do this by taking advantage of a number of important concepts. Perhaps the key concept that launched mass production was **interchangeable parts,** sometimes attributed to Eli Whitney, an American inventor who applied the concept to assembling muskets in the late 1700s. The basis for interchangeable parts was to standardize parts so that any part in a batch of parts would fit any automobile coming down the assembly line. This meant that parts did not have to be custom fitted, as they were in craft production. The standardized parts could also be used for replacement parts. The result was a tremendous decrease in assembly time and cost. Ford accomplished this by standardizing the gauges used to measure parts during production and by using newly developed processes to produce uniform parts.

division of labor Breaking up a production process into small tasks, so that each worker performs a small portion of the overall job.

A second concept used by Ford was the **division of labor,** which Adam Smith wrote about in *The Wealth of Nations* (1776). Division of labor means that an operation, such as assembling an automobile, is divided up into a series of many small tasks, and individual workers are assigned to one of those tasks. Unlike craft production, where each worker was responsible for doing many tasks, and thus required skill, with division of labor the tasks were so narrow that virtually no skill was required.

Together, these concepts enabled Ford to tremendously increase the production rate at his factories using readily available inexpensive labor. Both Taylor and Ford were despised by many workers, because they held workers in such low regard, expecting them to perform like robots. This paved the way for the human relations movement.

The Human Relations Movement

Whereas the scientific-management movement heavily emphasized the technical aspects of work design, the human relations movement emphasized the importance of the human element in job design. Lillian Gilbreth, a psychologist and the wife of Frank Gilbreth, worked with her husband, focusing on the human factor in work. (The Gilbreths were the subject of a classic 1950s film, *Cheaper by the Dozen.*) Many of her studies in the 1920s dealt with worker fatigue. In the following decades, there was much emphasis on motivation. During the 1930s, Elton Mayo conducted studies at the Hawthorne division of Western Electric. His studies revealed that in addition to the physical and technical aspects of work, worker motivation is critical for improving productivity. During the 1940s, Abraham Maslow developed motivational theories, which Frederick Hertzberg refined in the 1950s. Douglas McGregor added Theory X and Theory Y in the 1960s. These theories represented the two ends of the spectrum of how employees view work. Theory X, on the negative end, assumed that workers do not like to work, and have to be controlled—rewarded and punished—to get them to do good work. This attitude was quite common in the automobile industry and in some other industries, until the threat of global competition forced them to rethink that approach. Theory Y, on the other end of the spectrum, assumed that workers enjoy the physical and mental aspects of work and become committed to work. The Theory X approach resulted in an adversarial environment, whereas the Theory Y approach resulted in empowered workers and a more cooperative spirit. In the 1970s, William Ouchi added Theory Z, which combined the Japanese approach with such features as lifetime employment, employee problem solving, and consensus building, and the traditional Western approach that features short-term employment, specialists, and individual decision making and responsibility.

Decision Models and Management Science

The factory movement was accompanied by the development of several quantitative techniques. F. W. Harris developed one of the first models in 1915: a mathematical model for inventory management. In the 1930s, three coworkers at Bell Telephone Labs, H. F. Dodge, H. G. Romig, and W. Shewhart, developed statistical procedures for sampling and quality control. In 1935, L. H. C. Tippett conducted studies that provided the groundwork for statistical-sampling theory.

At first, these quantitative models were not widely used in industry. However, the onset of World War II changed that. The war generated tremendous pressures on manufacturing output, and specialists from many disciplines combined efforts to achieve advancements in the military and in manufacturing. After the war, efforts to develop and refine quantitative tools for decision making continued, resulting in decision models for forecasting, inventory management, project management, and other areas of operations management.

During the 1960s and 1970s, management science techniques were highly regarded; in the 1980s, they lost some favor. However, the widespread use of personal computers and user-friendly software in the workplace contributed to a resurgence in the popularity of these techniques.

The Influence of Japanese Manufacturers

A number of Japanese manufacturers developed or refined management practices that increased the productivity of their operations and the quality of their products. This made them very competitive, sparking interest in their approaches by companies outside Japan. Their approaches emphasized quality and continual improvement, worker teams and empowerment, and achieving customer satisfaction. The Japanese can be credited with spawning the "quality revolution" that occurred in industrialized countries, and with generating widespread interest in time-based management (just-in-time production).

The influence of the Japanese on U.S. manufacturing and service companies has been enormous and promises to continue for the foreseeable future. Because of that influence, this book will provide considerable information about Japanese methods and successes.

Table 1.7 provides a chronological summary of some of the key developments in the evolution of operations management.

TRENDS IN BUSINESS

Business organizations must be cognizant of current trends and take them into account in their strategic planning. In this section you will learn about some major trends as well as some other important trends.

Major Trends

Advances in information technology and global competition have influenced the major trends. Although different organizations have different priorities, and hence are differently affected by various trends, a representative list of major trends includes

- The Internet, e-commerce, and e-business
- Management of technology
- Globalization
- Management of supply chains
- Agility

TABLE 1.7
Historical summary of operations management

Approximate Date	Contribution/Concept	Originator
1776	Division of labor	Adam Smith
1790	Interchangeable parts	Eli Whitney
1911	Principles of scientific management	Frederick W. Taylor
1911	Motion study; use of industrial psychology	Frank and Lillian Gilbreth
1912	Chart for scheduling activities	Henry Gantt
1913	Moving assembly line	Henry Ford
1915	Mathematical model for inventory management	F. W. Harris
1930	Hawthorne studies on worker motivation	Elton Mayo
1935	Statistical procedures for sampling and quality control	H. F. Dodge, H. G. Romig, W. Shewhart, L. H. C. Tippett
1940	Operations research applications in warfare	Operations research groups
1947	Linear programming	George Dantzig
1951	Commercial digital computers	Sperry Univac, IBM
1950s	Automation	Numerous
1960s	Extensive development of quantitative tools	Numerous
1975	Emphasis an manufacturing strategy	W. Skinner
1980s	Emphasis on quality, flexibility, time-based competition, lean production	Japanese manufacturers, especially Toyota, and Taiichi Ohno
1990s	Internet, supply chain management	Numerous
2000s	Applications service providers and outsourcing	Numerous

The *Internet* offers great potential for business organizations, but the potential as well as the risks must be clearly understood in order to determine if and how to exploit this potential. In many cases, the Internet has altered the way companies compete in the marketplace.

e-business Use of the Internet to transact business.

e-commerce Consumer-to-business transactions.

Electronic business, or **e-business,** involves the use of the Internet to transact business. E-business is changing the way business organizations interact with their customers and their suppliers. Most familiar to the general public is **e-commerce,** consumer–business transactions such as buying online or requesting information. However, business-to-business transactions such as e-procurement represent an increasing share of e-business. E-business is receiving increased attention from business owners and managers in developing strategies, planning, and decision making.

Management of technology is high on the list, and it promises to be high well into the future. For example, computers have had a tremendous impact on businesses in many ways, including new product and service features, process management, medical diagnosis, production planning and scheduling, data processing, and communication. Advances in materials, methods, and equipment also have had an impact on competition and productivity. Advances in information technology also have had a major impact on businesses. Obviously there have been—and will continue to be—many benefits from technological advances. However, technological advance also places a burden on management. For example, management must keep abreast of changes and quickly assess both their benefits and risks. Predicting advances can be tricky at best, and new technologies often carry a high price tag and usually a high cost to operate or repair. And in the case of computer operating systems, as new systems are introduced, support for older versions is discontinued, making periodic upgrades necessary. Conflicting technologies can exist that make technological choices even more difficult. Technological innovations in both *products* and *processes* will continue to change the way businesses operate, and hence, require continuing attention.

FIGURE 1.7

A simple product supply chain

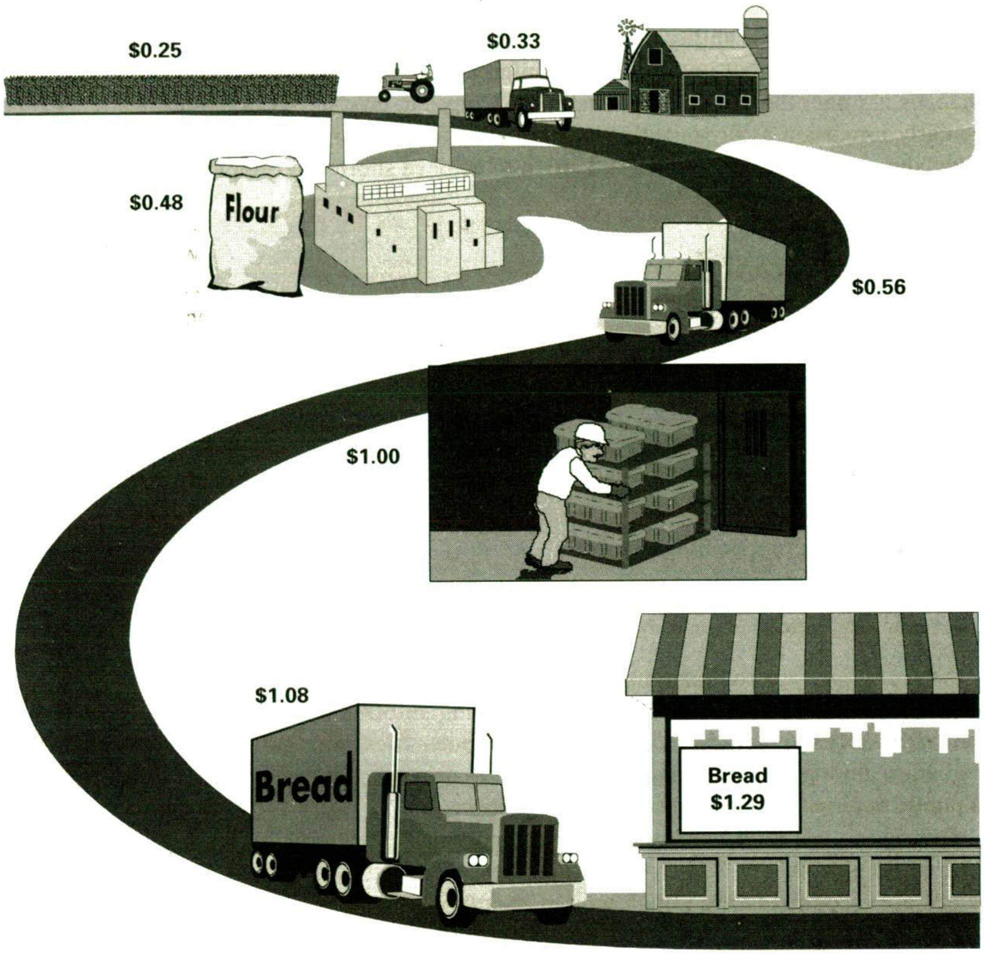


FIGURE 1.8

A supply chain for bread

The North American Free Trade Agreement (NAFTA) opened borders for trade between the U.S. and Canada and Mexico. The General Agreement on Tariffs and Trade (GATT) of 1994 reduced tariffs and subsidies in many countries, expanding world trade. The resulting global competition and global markets have had an impact on the strategies and operations of businesses large and small around the world. One effect is the importance business organizations are giving to management of their *supply chains.*

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, as seen in Figure 1.7. Facilities might include warehouses, factories, processing centers, offices, distribution centers, and retail outlets. Functions and activities include forecasting, purchasing, inventory management, information management, quality assurance, scheduling, production, distribution, delivery, and customer service. Figure 1.8 provides another illustration of a supply chain: a chain that begins with wheat growing on a farm and ends with a customer buying a loaf of bread in a supermarket. Notice that the value of the product increases as it moves through the supply chain.

supply chain A sequence of activities and organizations involved in producing and delivering a good or service.

A growing aspect of supply chain management is *outsourcing*—that is, buying goods or services rather than producing goods or performing services within the organization.

Globalization and the need for global supply chains have broadened the scope of supply chain management. However, tightened border security in certain instances has slowed some movement of goods and people. Moreover, in some cases, organizations are reassessing their use of offshore outsourcing.

agility The ability of an organization to respond quickly to demands or opportunities.

Agility refers to the ability of an organization to respond quickly to demands or opportunities. It is a strategy that involves maintaining a flexible system that can quickly respond to changes in either the volume of demand or changes in product/service offerings. This is particularly important as organizations scramble to remain competitive and cope with increasingly shorter product life cycles and strive to achieve shorter development times for new or improved products and services.

Other Important Trends

While the preceding issues are getting much needed attention, there are also other important issues that must be addressed. These include greater emphasis on

- Ethical behavior
- Operations strategy
- Working with fewer resources
- Cost control and productivity
- Quality and process improvement
- Increased regulation and product liability issues
- Lean production

Ethical issues are commanding increased attention of management at all levels. Accounting scandals, stock brokers releasing misleading information of stocks, product liability claims, breaches in privacy and security of computer files, and sharing personal customer information among financial and other businesses are just some of the behaviors that have led to public outcries and congressional investigations.

During the 1970s and 1980s, many companies neglected to include *operations strategy* in their corporate strategy. Some of them paid dearly for that neglect. Now more and more companies are recognizing the importance of operations strategy on the overall success of their business as well as the necessity for relating it to their overall business strategy.

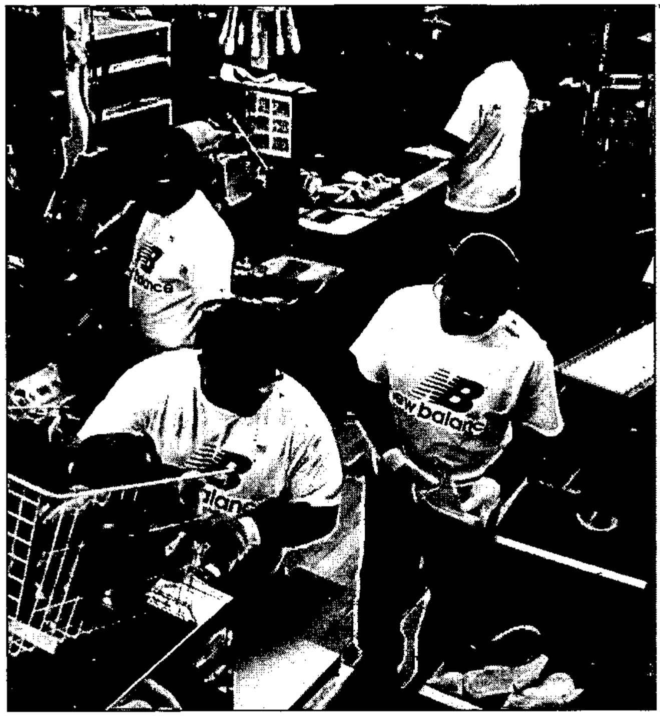
Working with fewer resources due to layoffs, corporate downsizing, and general cost cutting is forcing managers to make trade-off decisions on resource allocation, and to place increased emphasis on cost control and productivity improvement.

Cost control has always been at least somewhat important, but lately it has taken on added significance due to a combination of economic pressures and increased competition. And *productivity*—output relative to input—is gaining added attention as organizations attempt to remain competitive while they tighten their belts.

Given a boost by the "quality revolution" of the 1980s and 1990s, *quality* is now ingrained in business. Some businesses use the term *total quality management (TQM)* to describe their quality efforts. A quality focus emphasizes *customer satisfaction* and often involves *teamwork. Process improvement* can result in improved quality, cost reduction, and *time reduction.* Time relates to costs and to competitive advantage, and businesses seek ways to reduce the time to bring new products and services to the marketplace, replenish supplies, and fill orders to gain a competitive edge. If two companies can provide the same product at the same price and quality, but one can deliver it four weeks earlier than the other, the quicker company will invariably get the sale. Time reductions are being achieved in processing, information retrieval, product design, and the response to customer complaints. Kodak was able to cut in half the time needed to bring a new camera to market; Union Carbide was able to cut $400 million of fixed expenses; and Bell Atlantic was able to cut the time needed to hook up long-distance carriers from 15 days to less than 1 day, at a savings of $82 million.

Increased *regulation* and some very costly *product liability* claims have continued to make these issues important management issues. These issues are discussed in Chapter 4.

Lean production, a new approach to production, emerged in the 1990s. It incorporates a number of the recent trends listed here, with an emphasis on quality, flexibility, time reduction, and teamwork. This has led to a *flattening* of the organizational structure, with fewer levels of management.



New Balance Athletic Shoe, Inc., Lawrence, Massachusetts facility. This facility handles the entire manufacturing process, from cutting raw materials to assembly. While New Balance employs more than 2,400 associates over 120 countries, it is the only company manufacturing athletic shoes in the U.S.

www.newbalance.com

Lean production systems are so named because they use much less of certain resources than mass production systems use—less space, less inventory, and fewer workers—to produce a comparable amount of output. Lean production systems use a highly skilled workforce and flexible equipment. In effect, they incorporate advantages of both mass production (high volume, low unit cost) and craft production (variety and flexibility). And quality is higher than in mass production.

lean production System that uses minimal amounts of resources to produce a high volume of high-quality goods with some variety.

The skilled workers in lean production systems are more involved in maintaining and improving the system than their mass production counterparts. They are taught to stop production if they discover a defect, and to work with other employees to find and correct the cause of the defect so that it won't recur. This results in an increasing level of quality over time, and eliminates the need to inspect and rework at the end of the line.

Because lean production systems operate with lower amounts of inventory, additional emphasis is placed on anticipating when problems might occur *before* they arise, and avoiding those problems through careful planning. Even so, problems still occur at times, and quick resolution is important. Workers participate in both the planning and correction stages. Technical experts are still used, but more as consultants rather than substitutes for workers. The focus is on designing a system (products and process) so that workers will be able to achieve high levels of quality and quantity.

Compared to workers in traditional systems, much more is expected of workers in lean production systems. They must be able to function in teams, playing active roles in operating and improving the system. Individual creativity is much less important than team success. Responsibilities also are much greater, which can lead to pressure and anxiety not present in traditional systems. Moreover, a flatter organizational structure means career paths are not as steep in lean production organizations. Workers tend to become generalists rather than specialists, another contrast to more traditional organizations.

Unions often oppose conversion from a traditional system to a lean system because they view the added responsibility and multiple tasks as an expansion of job requirements without comparable increases in pay. In addition, workers sometimes complain that the company is the primary beneficiary of employee-generated improvements.

Table 1.8 provides a comparison of craft production, mass production, and lean production. Keep in mind that all three of these modes of production are in existence today.

TABLE 1.8 A comparison of craft, mass, and lean production

	Craft Production	Mass Production	Lean Production
Description	High variety, customized output, with one or a few skilled workers responsible for an entire unit of output.	High volume of standardized output, emphasis on volume. Capitalizes on division of labor, specialized equipment, and interchangeable parts.	Moderate to high volume of output, with more variety than mass production. Fewer mass production buffers such as extra workers, inventory, or time. Emphasis on quality. Employee involvement and teamwork important.
Examples of Goods and Services	Home remodeling and landscaping, tailoring, portrait painting, diagnosis and treatment of injuries, surgery.	Automobiles, computers, calculators, sewing machines, compact discs, mail sorting, check clearing.	Similar to mass production.
Advantages	Wide range of choice, output tailored to customer needs.	Low cost per unit, requires mostly low-skilled workers.	Flexibility, variety, high quality of goods.
Disadvantages	Slow, requires skilled workers, few economies of scale, high cost, and low standardization.	Rigid system, difficult to accommodate changes in output volume, product design, or process design. Volume may be emphasized at the expense of quality.	No safety nets to offset any system breakdowns, fewer opportunities for employee advancement, more worker stress, requires higher-skilled workers than mass production.

SUMMARY

Operations management is that part of a business organization responsible for planning and coordinating the use of the organization's resources to convert inputs into outputs. The operations function is one of three primary functions of business organizations; the other two are marketing and finance.

The operations function is present in both service-oriented and product-oriented organizations. Operations decisions involve design decisions and operating decisions. Design decisions relate to capacity planning, product design, process design, layout of facilities, and selecting locations for facilities. Operating decisions relate to quality assurance, scheduling, inventory management, and project management.

The chapter also presents a brief overview of the historical evolution of operations management and it ends with a list of strategic issues that are currently high priority for business organizations. At the top of that list are the Internet and e-business, supply chain management, management of technology, and agility.

KEY TERMS

agility, 24
craft production, 19
division of labor, 20
e-business, 22
e-commerce, 22
interchangeable parts, 20
lead time, 17
lean production, 25
mass production, 20
model, 12
operations management, 4
Pareto phenomenon, 15
supply chain, 23
system, 14
value-added, 5

DISCUSSION AND REVIEW QUESTIONS

1. Briefly describe the term *operations management.*
2. Identify the three major functional areas of business organizations and briefly describe how they interrelate.
3. Describe the operations function and the nature of the operations manager's job.
4. List five important differences between goods production and service operations.
5. Briefly discuss each of these terms related to the historical evolution of operations management:
   a. Industrial Revolution
   b. Scientific management

   c. Interchangeable parts
   d. Division of labor
6. Why are services important? Why is manufacturing important? What are nonmanufactured goods?
7. What are models and why are they important?
8. Can you think of a business that doesn't have operations management?
9. List the trade-offs you would consider for each of these decisions:
   a. Driving your own car versus public transportation.
   b. Buying a computer now versus waiting for an improved model.
   c. Buying a new car versus buying a used car.
   d. Speaking up in class versus waiting to get called on by the instructor.
10. Describe each of these systems: craft production, mass production, and lean production.
11. Why might some workers prefer not to work in a lean production environment? Why might some managers resist a change from a more traditional mode of production to lean production?
12. How has technological change affected you? Are there any downsides to technological change? Explain.
13. Identify some of the current trends in operations management and relate them to recent news items or to personal experience.
14. Why do people do things that are unethical?
15. Explain the term *value added.*
16. Load the CD-ROM that accompanies this book. Which items do you think will be most useful to you?

TAKING STOCK

This item appears at the end of each chapter. It is intended to focus your attention on three key issues for business organizations in general, and operations management in particular. Those issues are trade-off decisions, collaboration among various functional areas of the organization, and the impact of technology. You will see three or more questions relating to these issues. Here is the first set of questions:

1. What are trade-offs? Why is careful consideration of trade-offs important in decision making?
2. Why is it important for the various functional areas of a business organization to collaborate?
3. In what general ways does technology have an impact on operations management decision making?

CRITICAL THINKING EXERCISE

This item also will appear in every chapter. It allows you to critically apply information you learned in the chapter to a practical situation. Here is the first exercise:

Many organizations offer a combination of goods and services to their customers. As you learned in this chapter, there are some key differences between production of goods and delivery of services. What are the implications of these differences relative to managing operations?

Why Manufacturing Matters

READING

The U.S. economy is becoming more and more service based. The percentage of employment in manufacturing continues to decrease while the percentage employed in services continues to increase. However, it would be unwise to assume that manufacturing isn't important to the economy, or that service is more important. Let's see why.

In a press release issued by the office of the White House press secretary, a number of key points were made:

1. Over 18 million workers are employed in manufacturing jobs.
2. Manufacturing accounts for over 70 percent of the value of U.S. exports.
3. The average full-time manufacturing worker's total compensation package is about 20 percent greater than the average of all workers in the United States. Compared to service workers, manufacturing workers are more likely to have access to benefits such as health and life insurance, disability, retirement plans, and vacation and sick leave.
4. Productivity growth in manufacturing in the last five years has been more than double that of the U.S. economy at large due to the investments made in technology development and diffusion.

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5. Manufacturing industries are the economy's most prolific creators and disseminators of technology, accounting for more than half the total R&D performed.

Additional insight comes from testimony before a California Senate committee:

6. While service jobs range from highly paid to minimum wage, California manufacturing workers earn an average of about $25,000 a year more than workers in service jobs.
7. When a California manufacturing job is lost, an average of 2.5 service jobs also disappear.

Questions

1. Why do you suppose the percentage of workers employed in manufacturing in the United States is decreasing?
2. Should business leaders and government officials be concerned when manufacturing jobs are lost?

Source:"Why Manufacturing Matters to the U.S. Economy," Press release, Office of the White House Press Secretary, February 5 ,2000; from testimony given by Dorothy Rothrock, vice president of the California Manufacturers & Technology Association, before a California Senate committee, October 10, 2002.

The Challenges of Managing Services

READING

Services can pose a variety of managerial challenges for managers—challenges that in manufacturing are either much less or nonexistent. And because services represent an increasing share of the economy, this places added importance to understanding and dealing with the challenges of managing services. Here are some of the main factors:

1. Jobs in service environments are often less structured than in manufacturing environments.
2. Customer contact is usually much higher in services.
3. In many services, worker skill levels are low compared to manufacturing workers.
4. Services are adding many new workers in low-skill, entry-level positions.
5. Employee turnover is often higher, especially in the low-skill jobs.
6. Input variability tends to be higher in many service environments than in manufacturing.

Because of these factors, quality and costs are more difficult to control, productivity tends to be lower, the risk of customer dissatisfaction is greater, and employee motivation is more difficult.

Questions

1. What managerial challenges do services present that manufacturing does not?
2. Why does service management present more challenges than manufacturing?

Hazel

CASE

Hazel had worked for the same Fortune 500 company for almost 15 years. Although the company had gone through some tough times, things were starting to turn around. Customer orders were up, and quality and productivity had improved dramatically from what they had been only a few years earlier due to a companywide quality improvement program. So it came as a real shock to Hazel and about 400 of her coworkers when they were suddenly terminated following the new CEO's decision to downsize the company.

After recovering from the initial shock, Hazel tried to find employment elsewhere. Despite her efforts, after eight months of searching she was no closer to finding a job than the day she started. Her funds were being depleted and she was getting more discouraged. There was one bright spot, though: She was able to bring in a little money by mowing lawns for her neighbors. She got involved quite by chance when she heard one neighbor remark that now that his children were on their own, nobody was around to cut the grass. Almost jokingly, Hazel asked him how much he'd be willing to pay. Soon Hazel was mowing the lawns of five neighbors. Other neighbors wanted

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her to work on their lawns, but she didn't feel that she could spare any more time from her job search.

However, as the rejection letters began to pile up, Hazel knew she had to make an important decision in her life. On a rainy Tuesday morning, she decided to go into business for herself—taking care of neighborhood lawns. She was relieved to give up the stress of job hunting, and she was excited about the prospect of being her own boss. But she was also fearful of being completely on her own. Nevertheless, Hazel was determined to make a go of it.

At first, business was a little slow, but once people realized Hazel was available, many asked her to take care of their lawns. Some people were simply glad to turn the work over to her; others switched from professional lawn care services. By the end of her first year in business, Hazel knew she could earn a living this way. She also performed other services such as fertilizing lawns, weeding gardens, and trimming shrubbery. Business became so good that Hazel hired two part-time workers to assist her and, even then, she believed she could expand further if she wanted to.

Questions

1. In what ways are Hazel's customers most likely to judge the quality of her lawn care services?
2. Hazel is the operations manager of her business. Among her responsibilities are forecasting, inventory management, scheduling, quality assurance, and maintenance.
   a. What kinds of things would likely require forecasts?
   b. What inventory items does Hazel probably have? Name one inventory decision she has to make periodically.
   c. What scheduling must she do? What things might occur to disrupt schedules and cause Hazel to reschedule?
   d. How important is quality assurance to Hazel's business? Explain.
   e. What kinds of maintenance must be performed?
3. What are some of the trade-offs that Hazel probably considered relative to:
   a. Working for a company instead of for herself?
   b. Expanding the business?
   c. Launching a website?
4. The town is considering an ordinance that would prohibit putting grass clippings at the curb for pickup because local landfills cannot handle the volume. What options might Hazel consider if the ordinance is passed? Name two advantages and two drawbacks of each option.
5. Hazel decided to offer the students who worked for her a bonus of $25 for ideas on how to improve the business, and they provided several good ideas. One idea that she initially rejected now appears to hold great promise. The student who proposed the idea has left, and is currently working for a competitor. Should Hazel send that student a check for the idea? What are the possible trade-offs?

Total Recall

CASE

In mid-2000, the Firestone Tire Company issued a recall of some of its tires—those mounted on certain sport utility vehicles (SUVs) of the Ford Motor Company. This was done in response to reports that tire treads on some SUVs separated in use, causing accidents, some of which involved fatal injuries as vehicles rolled over.

At first, Firestone denied there was a problem with its tires, but it issued the recall under pressure from consumer groups and various government agencies. All of the tires in question were produced at the same tire plant, and there were calls to shut down that facility. Firestone suggested that Ford incorrectly matched the wrong tires with its SUVs. There was also the suggestion that the shock absorbers of the SUVs were rubbing against the tires, causing or aggravating the problem.

Both Ford and Firestone denied that this had been an ongoing problem. However, there was a public outcry when it was learned that Firestone had previously issued recalls of these tires in South America, but had not informed officials in other countries. Moreover, both companies had settled at least one lawsuit involving an accident caused by tread separation several years earlier.

This case raises a number of issues, some related to possible causes, as well as ethical issues.

Discuss each of these factors and their actual or potential relevance to what happened:

1. Product design.
2. Quality control.
3. Ethics.

Wegmans Food Markets

OPERATIONS TOUR

www.wegmans.com

Wegmans Food Markets, Inc., is one of the premier grocery chains in the United States. Headquartered in Rochester, New York, Wegmans operates over 70 stores, mainly in Rochester, Buffalo, and Syracuse. There are also a handful of stores elsewhere in New York State, New Jersey, and Pennsylvania. The company employs over 37,000 people, and has annual sales of over $3.0 billion. In addition to supermarkets, the company operates Chase-Pitkin Home and Garden Centers and an egg farm.

Wegmans has a strong reputation for offering its customers high product quality and excellent service. Through a combination of market research, trial and error, and listening to its customers, Wegmans has evolved into a very successful organization. In fact, Wegmans is often recognized as the best-run supermarket chain in the nation.

Superstores

Many of the company's stores are giant 100,000-square-foot superstores, double or triple the size of average supermarkets. You can get an idea about the size of these stores from this: they usually have between 25 and 35 checkout lanes, and during busy periods, all of the checkouts are in operation. A superstore typically employs from 500 to 600 people.

Individual stores differ somewhat in terms of actual size and some special features. Aside from the features normally found in supermarkets, they generally have a full-service deli (typically a 40-foot display case), a 500-square-foot fisherman's wharf that has perhaps 10 different fresh fish offerings most days, a large bakery section (each store bakes its own bread, rolls, cakes, pies, and pastries), and extra large produce sections. They also offer film processing, a complete pharmacy, a card shop, video rentals, and an Olde World Cheese™ section. In-store floral shops range in size up to 800 square feet of floor space and offer a wide variety of fresh-cut flowers, flower arrangements, vases, and plants. In-store card shops cover over 1,000 square feet of floor space. The bulk foods department provides customers with the opportunity to select the quantities they desire from a vast array of foodstuffs and some nonfood items such as birdseed and pet food.

Each store is a little different. Among the special features in some stores are a dry cleaning department, a wokery, and a salad bar. Some stores feature a Market Café™ that has different food stations, each devoted to preparing and serving a certain type of food. For example, one station will have pizza and other Italian specialties, and another oriental food, and still another chicken or fish. There also will be a sandwich bar, a salad bar, and a dessert station. Customers often wander among stations as they decide what to order. In some Market Cafes, diners can have wine with their meals and have brunch on Sundays. In several affluent locations, customers can stop in on their way home from work and choose from a selection of freshly prepared dinner entrees such as medallions of beef with herb butter, chicken Marsala, stuffed flank steak with mushrooms, grilled

Wegmans' Pattisserie is an authentic French pastry shop.

salmon, Cajun tuna, and crab cakes, and accompaniments such as roasted red potatoes, grilled vegetables, and Caesar salad. Many Wegmans stores offer ready-made sandwiches as well as made-to-order sandwiches. Some stores have a coffee shop section with tables and chairs where shoppers can enjoy regular or specialty coffees and a variety of tempting pastries.

Produce Department

The company prides itself on fresh produce. Produce is replenished as often as 12 times a day. The larger stores have produce sections that are four to five times the size of a produce section in an average supermarket. Wegmans offers locally grown produce in season. Wegmans uses a "farm to market" system whereby some local growers deliver their produce directly to individual stores, bypassing the main warehouse. That reduces the company's inventory holding costs and gets the produce into the stores as quickly as possible. Growers may use specially designed containers that go right onto the store floor instead of large bins. This avoids the bruising that often occurs when fruits and vegetables are transferred from bins to display shelves and the need to devote labor to transfer the produce to shelves.

Meat Department

In addition to large display cases of both fresh and frozen meat products, many stores have a full-service butcher shop that offers a variety of fresh meat products and where butchers are available to provide customized cuts of meat for customers.

Ordering

Each department handles its own ordering. Although sales records are available from records of items scanned at the checkouts, they are not used directly for replenishing stock. Other factors, such as pricing, special promotions, local circumstances (e.g., festivals, weather conditions) must all be taken into account. However, for seasonal periods, such as holidays, managers often check scanner records to learn what past demand was during a comparable period.

The superstores typically receive one truckload of goods per day from the main warehouse. During peak periods, a store may receive two truckloads from the main warehouse. The short lead time greatly reduces the length of time an item might be out of stock, unless the main warehouse is also out of stock.

The company exercises strict control over suppliers, insisting on product quality and on-time deliveries.

Inventory Management

Wegmans uses a companywide system to keep track of inventory. Departments take a monthly inventory count to verify the amount shown in the companywide system. Each department is responsible for ordering product. Departments receive a periodic report indicating how many days of inventory the department has on hand. Having an appropriate amount on hand is important to department managers: If they have too much inventory on hand, that will add to their department's costs, whereas having too little inventory will be reflected in low profits for the department.

Employees

The company recognizes the value of good employees. It typically invests an average of $7,000 to train each new employee. In addition to learning about store operations, new employees learn the importance of good customer service and how to provide

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Fresh seafood is delivered daily, often direct from boat to store the same day it was caught.

Wegmans' chefs fill the Chef's Case with ready-to-eat and ready-to-heat entrees, side dishes, and salads.

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it. The employees are helpful, cheerfully answering customer questions or handling complaints. Employees are motivated through a combination of compensation, profit sharing, and benefits. In a survey of employees on the best companies to work for in the United States, Wegmans ranks in the top 10.

Quality

Quality and customer satisfaction are utmost in the minds of Wegmans management and its employees. Private label food items as well as name brands are regularly evaluated in test kitchens, along with potential new products. Managers are responsible for checking and maintaining product and service quality in their departments. Moreover, employees are encouraged to report problems to their managers.

If a customer is dissatisfied with an item, and returns it, or even a portion of the item, the customer is offered a choice of a replacement or a refund. If the item is a Wegmans brand food item, it is then sent to the test kitchen to determine the cause of the problem. If the cause can be determined, corrective action is taken.

Questions:

1. How do customers judge the quality of a supermarket?
2. Indicate how and why each of these factors is important to the successful operation of a supermarket:
   a. Customer satisfaction.
   b. Forecasting.
   c. Capacity planning.
   d. Location.
   e. Inventory management.
   f. Layout of the store.
   g. Scheduling.

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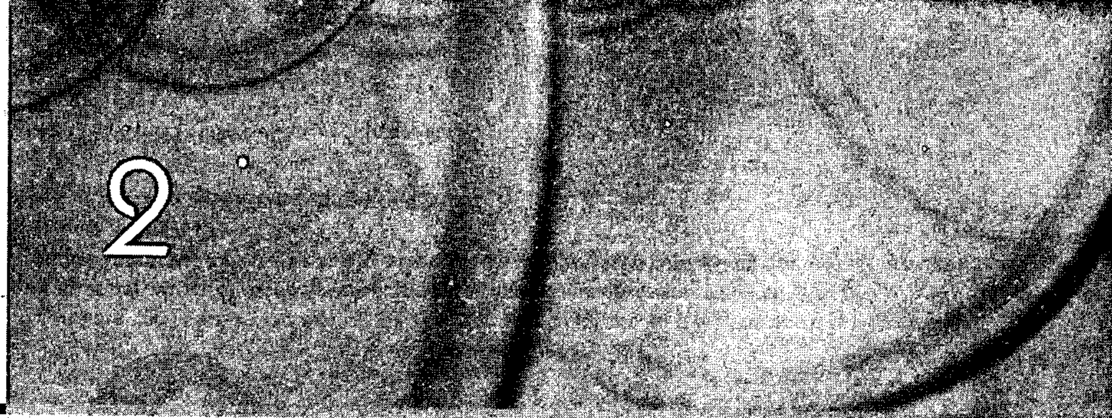
CHAPTER 2



Competitiveness, Strategy, and Productivity

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. List and briefly discuss the primary ways that business organizations compete.
2. List five reasons for the poor competitiveness of some companies.
3. Define the term *strategy* and explain why strategy is important for competitiveness.
4. Contrast *strategy* and *tactics*.
5. Discuss and compare organization strategy and operations strategy, and explain why it is important to link the two.
6. Describe and give examples of *time-based* strategies.
7. Define the term *productivity* and explain why it is important to organizations and to countries.
8. List some of the reasons for poor productivity and some ways of improving it.

CHAPTER OUTLINE

THE COLD HARD FACTS

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The name of the game is competition. The playing field is global. Those who understand how to play the game will succeed; those who don't are doomed to failure. And don't think the game is just companies competing with each other. In companies that have multiple factories or divisions producing the same good or service, factories or divisions sometimes find themselves competing with each other. When a competitor—another company or a sister factory or division in the same company—can turn out products better, cheaper, and faster, that spells real trouble for the factory or division that is performing at a lower level. The trouble can be layoffs or even a shutdown if the managers can't turn things around. The bottom line? Better quality, higher productivity, lower costs, and the ability to quickly respond to customer needs are more important than ever, and the bar is getting higher. Business organizations need to develop solid strategies for dealing with these issues.

This chapter discusses competitiveness, strategy, and productivity: three separate but related topics that are vitally important to business organizations. *Competitiveness* relates to how effective an organization is in the marketplace compared with other organizations that offer similar products or services; *strategy* relates to the plans that determine the direction an organization takes in pursuing its goals; and *productivity* relates to effective use of resources.

Slumping productivity gains in the late 1980s and the impressive successes of foreign competition in the U.S. marketplace caused many U.S. companies to rethink their strategies and to place increased emphasis on *operations strategy.*

INTRODUCTION

In this chapter you will learn about the different ways companies compete and why some firms do a very good job of competing. You will learn how effective strategies can lead to competitive organizations, and you will learn what productivity is, why it is important, and what organizations can do to improve it.

COMPETITIVENESS

competitiveness How effectively an organization meets the wants and needs of customers relative to others that offer similar goods or services.

Companies must be **competitive** to sell their goods and services in the marketplace. Competitiveness is an important factor in determining whether a company prospers, barely gets by, or fails.

Business organizations compete through some combination of their marketing and operations functions. Marketing influences competitiveness in several ways, including identifying consumer wants and needs, pricing, and advertising and promotion.

1. *Identifying consumer wants and/or needs* is a basic input in an organization's decision-making process, and central to competitiveness. The ideal is to achieve a perfect match between those wants and needs and the organization's goods and/or services.
2. *Pricing* is usually a key factor in consumer buying decisions. It is important to understand the trade-off decision consumers make between price and other aspects of a product or service such as quality.
3. *Advertising and promotion* are ways organizations can inform potential customers about features of their products or services, and attract buyers.

Operations influences competitiveness through product and service design, cost, location, quality, response time, flexibility, inventory and supply chain management, and service. Many of these are interrelated.

1. *Product and service design* should reflect joint efforts of many areas of the firm working together to achieve a match between financial resources, operations capabilities, supply chain capabilities, and consumer wants and needs. Also, special characteristics or features of a product or service can be a key factor in consumer buying decisions.
2. *Cost* of an organization's output is a key variable that affects pricing decisions, productivity, and profits. Cost reduction efforts are generally ongoing in business organizations.
3. *Location* can be important in terms of cost and convenience for customers. Location near inputs can result in lower input costs. Location near markets can result in lower transportation costs and quicker delivery times. Convenient location is particularly important in the retail sector.
4. *Quality* refers to materials, workmanship, and design. Consumers judge quality in terms of how well they think a product or service will satisfy its intended purpose. Customers are generally willing to pay more for a product or service if they perceive the product or service has a higher quality than that of a competitor.
5. *Quick response* can be a competitive advantage. One way is quickly bringing new or improved products or services to the market. Another is being able to quickly deliver existing products and services to a customer after they are ordered, and still another is quickly handling customer complaints.
6. *Flexibility* is the ability to respond to changes. Changes might relate to alterations in design features of a product or service, or to the volume demanded by customers, or the mix of products or services offered by an organization. High flexibility can be a competitive advantage in a changeable environment.
7. *Inventory management* can be a competitive advantage by effectively matching supplies of goods with demand.
8. *Supply chain management* involves coordinating internal and external operations (buyers and suppliers) to achieve timely and cost-effective delivery of goods throughout the system.

"Competitiveness" at Saratoga Springs: Thoroughbreds at the finish line in a New York Racing Association contest.

9. *Service* might involve after-sale activities that are perceived by customers as value-added, such as delivery, setup, warranty work, and technical support. Or it might involve extra attention while work is in progress, such as courtesy, keeping the customer informed, and attention to details.
10. *Managers* and *workers* are the people at the heart and soul of an organization, and if they are competent and motivated, they can provide a distinct competitive edge by their skills and the ideas they create. One skill that is often overlooked is answering the telephone. How complaint calls or requests for information are handled can be a positive or a negative. For example, if automated answering is used, that can turn off some callers. If the person answering the call is rude, not helpful, or cuts off the call, that can produce a negative image. Conversely, if calls are handled promptly and cheerfully, that can produce a positive image and, potentially, a competitive advantage.

An issue that can be overlooked in the drive to be more competitive is the importance of *ethical behavior;* it is something that all managers should adhere to and stress to their subordinates.

Why Some Organizations Fail

Organizations fail, or perform poorly, for a variety of reasons. Being aware of those reasons can help managers avoid making similar mistakes. Among the chief reasons are the following:

1. Putting too much emphasis on short-term financial performance at the expense of research and development.
2. Failing to take advantage of strengths and opportunities, and/or failing to recognize competitive threats.
3. Neglecting operations strategy.
4. Placing too much emphasis on product and service design and not enough on process design and improvement.
5. Neglecting investments in capital and human resources.
6. Failing to establish good internal communications and cooperation among different functional areas.
7. Failing to consider customer wants and needs.

The key to successfully competing is to determine what customers want and then directing efforts toward meeting (or even exceeding) customer expectations. There are two basic issues that must be addressed. First: What do the customers want? (Which items on the preceding list of the ways business organizations compete are important to customers?) Second: What is the best way to satisfy those wants?

Operations must work with marketing to obtain information on the relative importance of the various items to each major customer or target market.

Understanding competitive issues can help managers develop successful strategies.

STRATEGY

strategies Plans for achieving organizational goals.

Strategies are plans for achieving organizational goals. The importance of strategies cannot be overstated; an organization's strategies have a major impact on what the organization does and how it does it. Strategies can be long term, intermediate term, or short term. To be effective, strategies must be designed to support the organization's mission and its organizational goals.

Mission and Goals

mission The reason for the existence of an organization.

mission statement States the purpose of an organization.

goals Provide detail and scope of the mission.

An organization's **mission** is the reason for its existence. It is expressed in its **mission statement,** which states the purpose of an organization. For a business organization, the mission statement should answer the question "What business are we in?" Missions vary from organization to organization, depending on the nature of their business. Table 2.1 provides several examples of mission statements.

A mission statement serves as the basis for organizational **goals,** which provide more detail and describe the scope of the mission. The mission and goals often relate to how an organization wants to be perceived by the general public, and by its employees, suppliers, and customers. Goals serve as a foundation for the development of organizational strategies. These, in turn, provide the basis for strategies and tactics of the functional units of the organization.

Strategies and Tactics

If you think of goals as destinations, then strategies are the roadmaps for reaching the destinations. Strategies provide *focus* for decision making. Generally speaking, organizations have overall strategies called *organizational strategies,* which relate to the entire organization. They also have *functional strategies,* which relate to each of the functional areas of the organization. The functional strategies should support the overall strategies of the organization, just as the organizational strategies should support the goals and mission of the organization.

tactics The methods and actions taken to accomplish strategies.

Tactics are the methods and actions used to accomplish strategies. They are more specific in nature than strategies, and they provide guidance and direction for carrying out actual *operations,* which need the most specific and detailed plans and decision making in an organization. You might think of tactics as the "how to" part of the process (e.g., how to reach the destination, following the strategy roadmap) and operations as the actual "doing" part of the process. Much of this book deals with tactical operations.

IS IT A STRATEGIC, TACTICAL, OR OPERATIONAL ISSUE?

Sometimes the same issue may apply to all three levels. However, a key difference is the time frame. From a strategic perspective, long-term implications are most relevant. From tactical and operational perspectives, the time frames are much shorter. In fact, the operational time frame is often measured in days.

It should be apparent that the overall relationship that exists from the mission down to actual operations is *hierarchical* in nature. This is illustrated in Figure 2.1.

A simple example may help to put this hierarchy into perspective.

EXAMPLE 1

Rita is a high school student in Southern California. She would like to have a career in business, have a good job, and earn enough income to live comfortably.

TABLE 2.1
Selected company mission or vision statements

Krispy Kreme	We create the tastes for good times and warm memories for everyone, everywhere. With our Original Glazed doughnut as our signature and standard, we will continually improve our customers' experience through innovative ideas, highest quality, and caring service. Copyright © 2003 Krispy Kreme, Inc.
McDonald's Restaurants	McDonald's vision is to be the world's best quick service restaurant experience. Being the best means providing outstanding quality, service, cleanliness and value, so that we make every customer in every restaurant smile. To achieve our vision, we are focused on three worldwide strategies: • Be the best employer for our people in each community around the world. • Deliver operational excellence to our customers in each of our restaurants. • Achieve enduring profitable growth by expanding the brand and leveraging the strengths of the McDonald's system through innovation and technology. Used with permission from McDonald's Corporation.
Southwest Airlines	The mission of Southwest Airlines is dedication to the highest quality of Customer Service delivered with a sense of warmth, friendliness, individual pride, and Company Spirit. To Our Employees: We are committed to provide our Employees a stable work environment with equal opportunity for learning and personal growth. Creativity and innovation are encouraged for improving the effectiveness of Southwest Airlines. Above all, Employees will be provided the same concern, respect, and caring attitude within the organization that they are expected to share externally with every Southwest Customer. Courtesy of Southwest Airlines.
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www.krispykreme.com

www.mcdonalds.com

www.southwestairlines.com

www.ibm.com

A possible scenario for achieving her goals might look something like this:

Mission: Live a good life.

Goal: Successful career, good income.

Strategy: Obtain a college education.

Tactics: Select a college and a major; decide how to finance college.

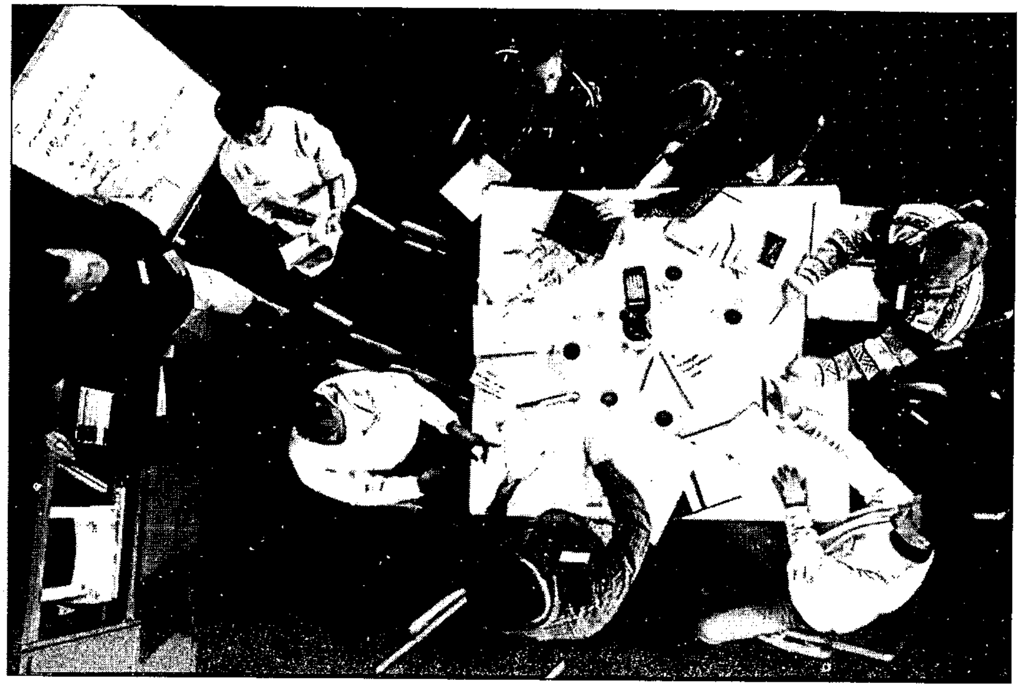
Operations: Register, buy books, take courses, study.

Here are some examples of different strategies an organization might choose from:

Low cost. Outsource operations to third-world countries that have low labor costs.

Scale-based strategies. Use capital-intensive methods to achieve high output volume and low unit costs.

Specialization. Focus on narrow product lines or limited service to achieve higher quality.

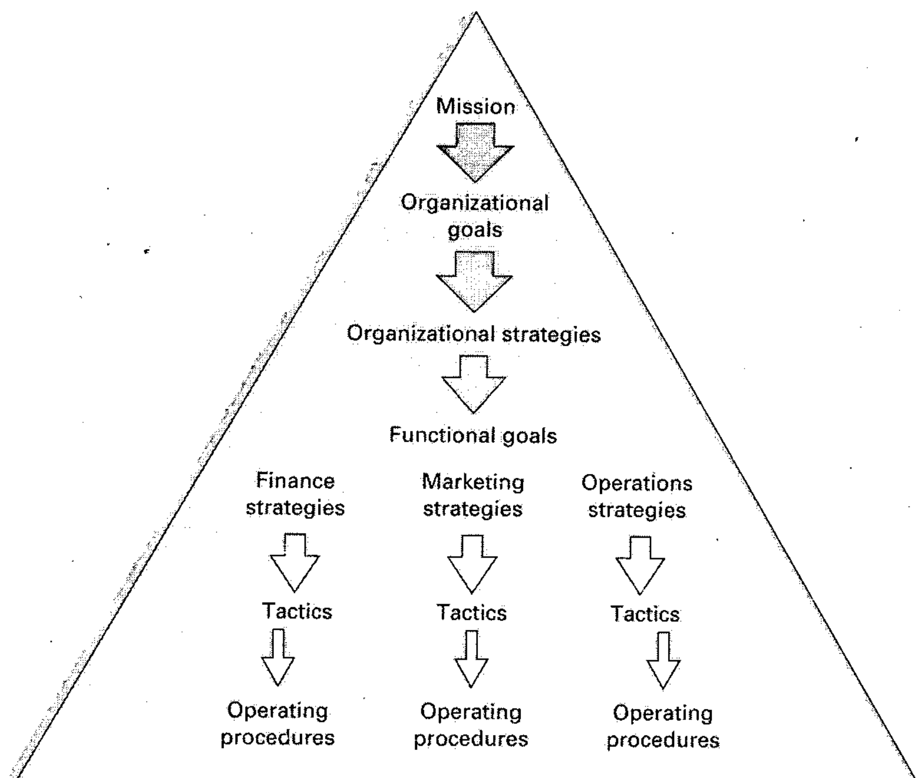


Jack Welch Leadership Development Center in Crotonville, New York, the main hub for training and skill development within General Electric.

www.ge.com

FIGURE 2.1

Planning and decision making is hierarchical in organizations



Flexible operations. Focus on quick response and/or customization.

High quality. Focus on achieving higher quality than competitors.

Service. Focus on various aspects of service (e.g., helpful, courteous, reliable, etc.).

Sometimes organizations will combine two or more of these or other approaches into their strategy. However, unless they are careful, they risk losing focus and not achieving advantage

TABLE 2.2
Examples of distinctive competencies

Factor	Competency	Examples of Companies or Services
Price	Low cost	U.S. first-class postage Motel-6, Red Roof Inns Southwest Airlines
Quality	High-performance design and/or high quality	Sony TV Lexus Disneyland Five-star restaurants or hotels
	Consistent quality	Coca-Cola, PepsiCo Kodak, Xerox, Motorola Electrical power
Time	Rapid delivery	McDonald's restaurants Express Mail UPS, FedEx
	On-time delivery	One-hour photo FedEx Express Mail
Flexibility	Variety	Burger King ("Have it your way") Hospital emergency room
	Volume	McDonald's ("Buses welcome") Toyota Supermarkets (additional checkouts)
Service	Superior customer service	Disneyland Hewlett-Packard IBM Nordstrom
Location	Convenience	Supermarkets, dry cleaners Mall stores Service stations Banks, ATMs

in any category. Generally speaking, strategy formulation takes into account the way organizations compete and a particular organization's assessment of its own strengths and weaknesses in order to take advantage of its *distinctive competencies.*

Distinctive competencies are those special attributes or abilities possessed by an organization that give it a *competitive edge.* Table 2.2 lists the major distinctive competencies and examples of services and companies that exhibit those competencies.

The most effective organizations use an approach that develops distinctive competencies based on customer needs as well as on what the competition is doing. Marketing and operations work closely to match customer needs with operations capabilities. Competitor competencies are important for several reasons. For example, if a competitor is able to supply

distinctive competencies The special attributes or abilities that give an organization a competitive edge.

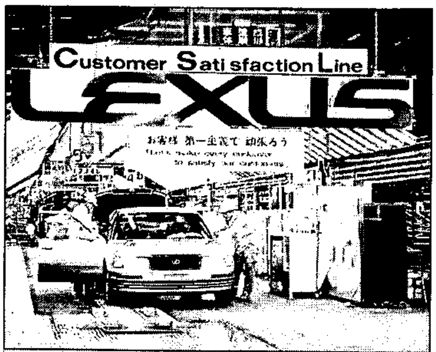
www.xerox.com

Xerox's New Strategy

NEWSCLIP

The Xerox Corporation has devised a strategic initiative it hopes will help the company grow. Former emphasis was on technical performance and listing machines that had pricey features. The new strategy is to have a design that makes its copiers and printers look attractive, and a "bottom-up" pricing strategy that allows buyers to order low-end machines and add features on an à la carte basis.

Source: Based on "Xerox Builds Friendlier, Eye-Catching Copiers" by Richard Mullins, *Rochester Democrat and Chronicle*, May 1, 2003, p. 1A.

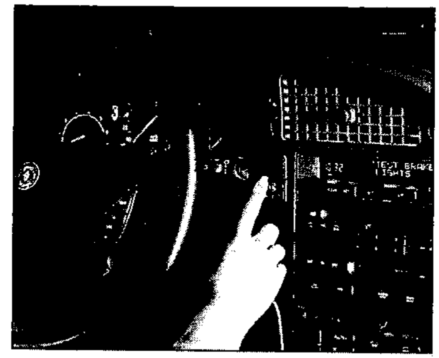


Toyota, Japan's largest automobile manufacturer, makes and markets the upscale, award winning Lexus line. Quality is paramount, and workers have the authority to stop the production line if quality problems are encountered.

www.lexus.com

At Hertz, there is no paperwork and no waiting line once the customer is enrolled in their 'Gold' services. Customers get directly into the rental car where keys and the rental agreement are waiting.

www.hertz.com



With the press of a button, using innovative satellite technology, OnStar provides motorist assistance 24 hours a day, including travel information and directions, roadside help, and remote diagnostics.

www.onstar.com

TABLE 2.3 Comparison of mission, organization strategy, and operations strategy

		Management Level	Time Horizon	Scope	Level of Detail	Relates to
The Overall Organization	Mission	Top	Long	Broad	Low	Survival, profitability
	Strategy	Senior	Long	Broad	Low	Growth rate, market share
Production/ Operations	Strategic	Senior	Moderate to long	Broad	Low	Product design, choice of location, choice of technology, new facilities
	Tactical	Middle	Moderate	Moderate	Moderate	Employment levels, output levels, equipment selection, facility layout
	Operational	Low	Short	Narrow	High	Scheduling personnel, adjusting output rates, inventory management, purchasing

high-quality products, it may be necessary to meet that high quality as a baseline. However, merely *matching* a competitor is usually not sufficient to gain market share. It may be necessary to exceed the quality level of the competitor or gain an edge by excelling in one or more other dimensions, such as rapid delivery or service after the sale.

Operations Strategy

operations strategy The approach, consistent with the organization strategy, that is used to guide the operations function.

The organization strategy provides the overall direction for the organization. It is broad in scope, covering the entire organization. **Operations strategy** is narrower in scope, dealing primarily with the operations aspect of the organization. Operations strategy relates to products, processes, methods, operating resources, quality, costs, lead times, and scheduling. Table 2.3 provides a comparison of an organization's mission, its overall strategy, and its operations strategy, tactics, and operations.

In order for operations strategy to be truly effective, it is important to link it to organization strategy; that is, the two should not be formulated independently. Rather, formulation of organization strategy should take into account the realities of operations' strengths and weaknesses, capitalizing on strengths and dealing with weaknesses. Similarly, operations strategy must be consistent with the overall strategy of the organization, and with the other functional units of the organization. This requires that senior managers work with functional units to formulate strategies that will support, rather than conflict with, each other and the overall strategy of the organization. As obvious as this may seem, it doesn't always happen in practice. Instead, we may find power struggles between various functional units. These struggles are detrimental to the organization because they pit functional units against each other rather than focusing their energy on making the organization more competitive and better able to serve the customer. Some of the latest approaches in organizations, involving teams of managers and workers, may reflect a growing awareness of the synergistic effects of working together rather than competing internally.

Operations strategy can have a major influence on the competitiveness of an organization. If it is well designed and well executed, there is a good chance that the organization will be successful; if it is not well designed or executed, the chances are much less that the organization will be successful.

In the 1970s and early 80s, operations strategy in the United States was often neglected in favor of marketing and financial strategies. That may have occurred because many chief executive officers did not come from operations backgrounds and perhaps did not fully appreciate the importance of the operations function. Mergers and acquisitions were common; leveraged buyouts were used, and conglomerates were formed that joined dissimilar operations. These did little to add value to the organization; they were purely financial in nature. Decisions were often made by individuals who were unfamiliar with the business, frequently to the detriment of that business. Meanwhile, foreign competitors began to fill the resulting vacuum with a careful focus on operations strategy.

In the late 1980s and early 90s, many companies began to realize this approach was not working. They recognized that they were less competitive than other companies. This caused them to focus attention on operations strategy. A key element of both organization strategy and operations strategy is strategy formulation.

Strategy Formulation

To formulate an effective strategy, senior management must take into account the *distinctive competencies* of the organizations, and they must *scan the environment.* They must determine what competitors are doing, or planning to do, and take that into account. They must critically examine other factors that could have either positive or negative effects. This is sometimes referred to as the *SWOT* approach (strengths, weaknesses, opportunities, and threats). Strengths and weaknesses have an internal focus and are typically evaluated by operations people. Threats and opportunities have an external focus and are typically evaluated by marketing people. SWOT is often regarded as the link between organizational strategy and operations strategy.

In formulating a successful strategy, organizations must take into account both order qualifiers and order winners. Terry Hill, in his book *Manufacturing Strategy,* describes **order qualifiers** as those characteristics that potential customers perceive as minimum standards of acceptability for a product to be considered for purchase. However, that may not be sufficient to get a potential customer to purchase from the organization. **Order winners** are those characteristics of an organization's goods or services that cause them to be perceived as better than the competition.

order qualifiers Characteristics that customers perceive as minimum standards of acceptability to be considered as a potential for purchase.

order winners Characteristics of an organization's goods or services that cause it to be perceived as better than the competition.

Characteristics such as price, delivery reliability, delivery speed, and quality can be order qualifiers or order winners. Thus, quality may be an order winner in some situations but, in others, only an order qualifier. Over time, a characteristic that was once an order winner may become an order qualifier, and vice versa.

Obviously, it is important to determine the set of order qualifier characteristics and the set of order winner characteristics. It is also necessary to decide on the relative importance of each characteristic so that appropriate attention can be given to the various characteristics. Marketing must make that determination and communicate it to operations.

environmental scanning The considering of events and trends that present threats or opportunities for a company.

Environmental scanning is the considering of events and trends that present either threats or opportunities for the organization. Generally these include competitors' activities; changing consumer needs; legal, economic, political, and environmental issues; the potential for new markets; and the like.

Another key factor to consider when developing strategies is technological change, which can present real opportunities and threats to an organization. Technological changes occur in products (high-definition TV, improved computer chips, improved cellular telephone systems, and improved designs for earthquakeproof structures); in services (faster order processing, faster delivery); and in processes (robotics, automation, computer-assisted processing, point-of-sale scanners, and flexible manufacturing systems). The obvious benefit is a competitive edge; the risk is that incorrect choices, poor execution, and higher-than-expected operating costs will create competitive *disadvantages*.

Important factors may be internal or external. The key external factors are

1. *Economic conditions.* These include the general health and direction of the economy, inflation and deflation, interest rates, tax laws, and tariffs.
2. *Political conditions.* These include favorable or unfavorable attitudes toward business, political stability or instability, and wars.
3. *Legal environment.* This includes antitrust laws, government regulations, trade restrictions, minimum wage laws, product liability laws and recent court experience, labor laws, and patents.
4. *Technology.* This can include the rate at which product innovations are occurring, current and future process technology (equipment, materials handling), and design technology.
5. *Competition.* This includes the number and strength of competitors, the basis of competition (price, quality, special features), and the ease of market entry.
6. *Markets.* This includes size, location, brand loyalties, ease of entry, potential for growth, long-term stability, and demographics.

The organization also must take into account various *internal factors* that relate to possible strengths or weaknesses. Among the key internal factors are

1. *Human resources.* These include the skills and abilities of managers and workers; special talents (creativity, designing, problem solving); loyalty to the organization; expertise; dedication; and experience.
2. *Facilities and equipment.* Capacities, location, age, and cost to maintain or replace can have a significant impact on operations.
3. *Financial resources.* Cash flow, access to additional funding, existing debt burden, and cost of capital are important considerations.
4. *Customers.* Loyalty, existing relationships, and understanding of wants and needs are important.
5. *Products and services.* These include existing products and services, and the potential for new products and services.
6. *Technology.* This includes existing technology, the ability to integrate new technology, and the probable impact of technology on current and future operations.
7. *Suppliers.* Supplier relationships, dependability of suppliers, quality, flexibility, and service are typical considerations.
8. *Other.* Other factors include patents, labor relations, company or product image, distribution channels, relationships with distributors, maintenance of facilities and equipment, access to resources, and access to markets.

After assessing internal and external factors and an organization's distinctive competence, a strategy or strategies must be formulated that will give the organization the best chance of success. Among the types of questions that may need to be addressed are the following:

What role, if any, will the Internet play?

Will the organization have a global presence?

To what extent will *outsourcing* be used?

To what extent will new products or services be introduced?

What rate of growth is desirable and *sustainable?*

What emphasis, if any, should be placed on lean production?

How will the organization differentiate its products and/or services from competitors?

The organization may decide to have a single, dominant strategy (e.g., be the price leader) or to have multiple strategies. A single strategy would allow the organization to concentrate on one particular strength or market condition. On the other hand, multiple strategies may be needed to address a particular set of conditions.

Many companies are increasing their use of outsourcing to reduce overhead, gain flexibility, and take advantage of suppliers' expertise. Dell Computers provides a great example of some of the potential benefits of outsourcing as part of a business strategy.

www.dell.com

In 1984, Michael Dell, then a college student, started selling personal computers from his dorm room. He didn't have the resources to make computer components, so he let others do that, choosing instead to concentrate on selling the computers. And, unlike the major computer producers, he didn't sell to dealers. Instead, he sold directly to PC buyers, eliminating some intermediaries, which allowed for lower cost and faster delivery. Although direct selling of PCs is fairly commonplace now, in those days it was a major departure from the norm.

What did Dell do that was so different from the big guys? To start, he bought components from suppliers instead of making them. That gave him tremendous leverage. He had little inventory, no R&D expenditures, and relatively few employees. And the risks of this approach were spread among his suppliers. Suppliers were willing to do this because Dell worked closely with them, and kept them informed. And because he was in direct contact with his customers, he gained tremendous insight into their expectations and needs, which he communicated to his suppliers.

Having little inventory gave Dell several advantages over his competitors. Aside from the lower costs of inventory, when new, faster computer chips became available, there was little inventory to work off, so he was able to offer the newer models much sooner than competitors with larger inventories. Also, when the prices of various components dropped, as they frequently did, he was able to take advantage of the lower prices, which kept his average costs lower than competitors'.

Today the company is worth billions, and so is Michael Dell.

Growth is often a component of strategy, especially for new companies. A key aspect of this strategy is the need to seek a growth rate that is sustainable. In the 1990s, fast-food company Boston Markets dazzled investors and fast-food consumers alike. Fueled by its success, it undertook rapid expansion. By the end of the decade, the company was nearly bankrupt; it had overexpanded. In 2000, it was absorbed by fast-food giant McDonald's.

As globalization has increased, many companies realized that strategic decisions with respect to globalization must be made. One issue companies must face is that what works in one country or region will not necessarily work in another, and strategies must be carefully crafted to take these variabilities into account. Another issue is the threat of political or social upheaval. Still another issue is the difficulty of coordinating and managing far-flung operations. Indeed, "In today's global markets, you don't have to go abroad to experience international competition. Sooner or later the world comes to you."[1]

Two factors that tend to have universal strategic importance relate to quality and time. The following section discusses quality and time strategies.

[1]Christopher A. Bartlett and Sumantra Ghoshal. "Going Global: Lessons from Late Movers," *Harvard Business Review,* March–April 2000, p. 139.

DHL courier and van in Istanbul, Turkey. Offering dependable, on-time overnight delivery, DHL serves customers throughout the U.S. and internationally in the delivery of urgent packages.

www.dhl.com

Quality and Time Strategies

Traditional strategies of business organizations have tended to emphasize cost minimization or product differentiation. While not abandoning those strategies, many organizations have embraced strategies based on *quality* and/or *time.*

quality-based strategy Strategy that focuses on quality in all phases of an organization.

Quality-based strategies focus on maintaining or improving the quality of an organization's products or services. Quality is generally a factor in both attracting and retaining customers. Quality-based strategies may be motivated by a variety of factors. They may reflect an effort to overcome an image of poor quality, a desire to catch up with the competition, a desire to maintain an existing image of high quality, or some combination of these and other factors. Interestingly enough, quality-based strategies can be part of another strategy such as cost reduction, increased productivity, or time, all of which benefit from higher quality.

time-based strategy Strategy that focuses on reduction of time needed to accomplish tasks.

Time-based strategies focus on reducing the time required to accomplish various activities (e.g., develop new products or services and market them, respond to a change in customer demand, or deliver a product or perform a service). By doing so, organizations seek to improve service to the customer and to gain a competitive advantage over rivals who take more time to accomplish the same tasks.

Time-based strategies focus on reducing the time needed to conduct the various activities in a process. The rationale is that by reducing time, costs are generally less, productivity is higher, quality tends to be higher, product innovations appear on the market sooner, and customer service is improved.

Organizations have achieved time reduction in some of the following:

Planning time: The time needed to react to a competitive threat, to develop strategies and select tactics, to approve proposed changes to facilities, to adopt new technologies, and so on.

Product/service design time: The time needed to develop and market new or redesigned products or services.

Processing time: The time needed to produce goods or provide services. This can involve scheduling, repairing equipment, methods used, inventories, quality, training, and the like.

Changeover time: The time needed to change from producing one type of product or service to another. This may involve new equipment settings and attachments, different methods, equipment, schedules, or materials.

Delivery time: The time needed to fill orders.

Response time for complaints: These might be customer complaints about quality, timing of deliveries, and incorrect shipments. These might also be complaints from employees about working conditions (e.g., safety, lighting, heat or cold), equipment problems, or quality problems.

Agile manufacturing is a strategic approach to operations for competitive advantage that emphasizes the use of flexible operations to adapt and prosper in an environment of change. Agility involves a blending of several distinct competencies such as cost, quality, and reliability along with flexibility. Processing aspects of flexibility include quick equipment changeovers, scheduling, and innovation. Product or service aspects include varying output volumes and product mix.

Successful agile manufacturing requires a careful planning to achieve a system that includes people, flexible equipment, and information technology. Reducing the time needed to perform work is one of the ways an organization can improve a key metric: *productivity.*

Productivity Gains Curb Inflation

NEWSCLIP

www.burgerking.com

Wage increases can lead to inflationary pressure—they can cause the prices consumers pay for products and services to rise. Unless, that is, they are offset by gains in productivity, which lead to an increase in profits. If that happens, a portion of the resulting profits can be used to cover the wage increases without having to raise prices.

Some Burger Kings were recently able to increase the starting pay of new workers by $1 by achieving productivity gains. The restaurants restructured the menu, combining items into meal packages such as a burger, fries, and soft drink. This enabled the counter staff to enter orders with a single key stroke instead of multiple key strokes on their point-of-sale machines, reducing the time needed to take an order. That, in turn, enabled them to take orders more quickly, increasing productivity and, consequently, reducing labor requirements, which produced higher profits.

Source: Based on "Despite Pay Increases, Gains in Productivity, Profits Curb Inflation," *The Wall Street Journal*, May 22, 1997, p. A1.

PRODUCTIVITY

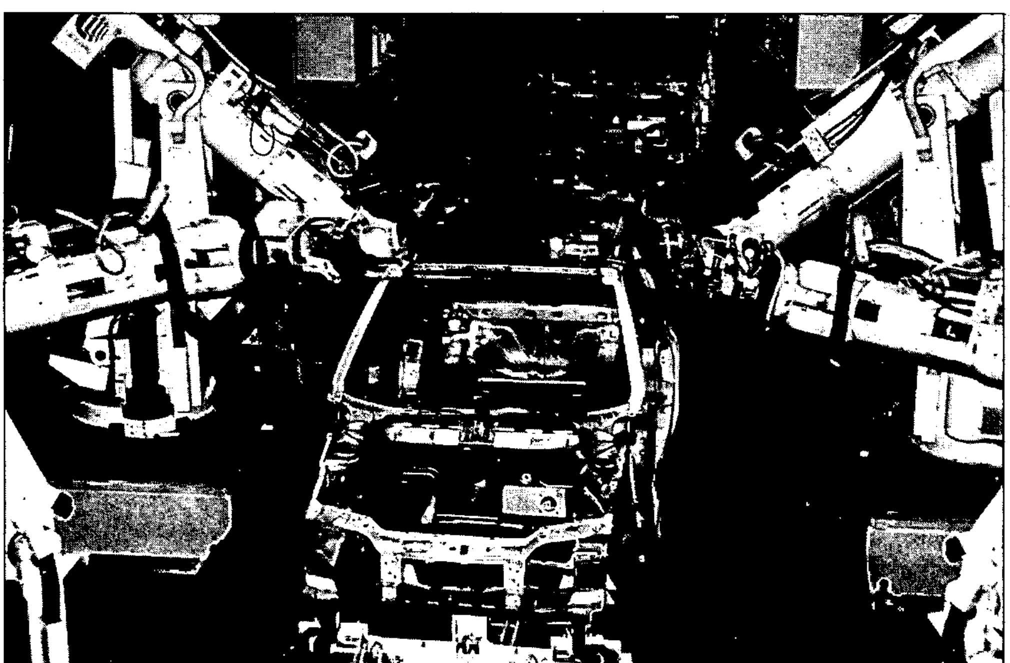
One of the primary responsibilities of a manager is to achieve *productive use* of an organization's resources. The term *productivity* is used to describe this. **Productivity** is an index that measures output (goods and services) relative to the input (labor, materials, energy, and other resources) used to produce them. It is usually expressed as the ratio of output to input:

productivity A measure of the effective use of resources, usually expressed as the ratio of output to input.

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} \qquad (2\text{–}1)$$

A productivity ratio can be computed for a single operation, a department, an organization, or an entire country. In business organizations, productivity ratios are used for planning workforce requirements, scheduling equipment, financial analysis, and other important tasks.

Productivity has important implications for business organizations and for entire nations. For nonprofit organizations, higher productivity means lower costs; for profit-based organizations, productivity is an important factor in determining how competitive a company is. For a nation,



Productivity and quality in manufacturing can be enhanced through the use of robotic equipment. Robots such as these building a Fiat Punto at the Melfi, Italy plant, can operate for long periods of time in extreme temperatures with consistent precision and speed.

www.fiat.com

the rate of *productivity growth* is of great importance. Productivity growth is the increase in productivity from one period to the next relative to the productivity in the preceding period. Thus,

$$\text{Productivity growth} = \frac{\text{Current period productivity} - \text{Previous period productivity}}{\text{Previous period productivity}} \times 100 \qquad (2\text{–}2)$$

For example, if productivity increased from 80 to 84, the growth rate would be

$$\frac{84 - 80}{80} \times 100 = 5\%$$

Productivity growth is a key factor in a country's rate of inflation and the standard of living of its people. Productivity increases add value to the economy while keeping inflation in check. Productivity growth was a major factor in the long period of sustained economic growth in the United States in the 1990s.

Computing Productivity

Productivity measures can be based on a single input (partial productivity), on more than one input (multifactor productivity), or on all inputs (total productivity). Table 2.4 lists some examples of productivity measures. The choice of productivity measure depends primarily on the purpose of the measurement. If the purpose is to track improvements in labor productivity, then labor becomes the obvious input measure.

Partial measures are often of greatest use in operations management. Table 2.5 provides some examples of partial productivity measures.

The units of output used in productivity measures depend on the type of job performed. The following are examples of labor productivity:

$$\frac{\text{Yards of carpet installed}}{\text{Labor hours}} = \text{Yards of carpet installed per labor hour}$$

$$\frac{\text{Number of motel rooms cleaned}}{\text{Number of workers}} = \text{Number of motel rooms cleaned per worker}$$

Similar examples can be listed for *machine productivity* (e.g., the number of pieces per hour turned out by a machine).

TABLE 2.4
Some examples of different types of productivity measures

Partial measures	$\frac{\text{Output}}{\text{Labor}}$	$\frac{\text{Output}}{\text{Machine}}$	$\frac{\text{Output}}{\text{Capital}}$	$\frac{\text{Output}}{\text{Energy}}$
Multifactor measures	$\frac{\text{Output}}{\text{Labor + Machine}}$		$\frac{\text{Output}}{\text{Labor + Capital + Energy}}$	
Total measure	$\frac{\text{Goods or Services produced}}{\text{All inputs used to produce them}}$			

TABLE 2.5
Some examples of partial productivity measures

Labor productivity	Units of output per labor hour
	Units of output per shift
	Value-added per labor hour
	Dollar value of output per labor hour
Machine productivity	Units of output per machine hour
	Dollar value of output per machine hour
Capital productivity	Units of output per dollar input
	Dollar value of output per dollar input
Energy productivity	Units of output per kilowatt-hour
	Dollar value of output per kilowatt-hour

EXAMPLE 2

Determine the productivity for these cases:

a. Four workers installed 720 square yards of carpeting in eight hours.

b. A machine produced 68 usable pieces in two hours.

SOLUTION

a. $$\text{Productivity} = \frac{\text{Yards of carpet installed}}{\text{Labor hours worked}} = \frac{720 \text{ square yards}}{4 \text{ workers} \times 8 \text{ hours/worker}} = \frac{720 \text{ yards}}{32 \text{ hours}} = 22.5 \text{ yards/hour}$$

b. $$\text{Productivity} = \frac{\text{Usable pieces}}{\text{Production time}} = \frac{68 \text{ pieces}}{2 \text{ hours}} = 34 \text{ pieces/hour}$$

Calculations of multifactor productivity measure inputs and outputs using a common unit of measurement, such as cost. For instance, the measure might use cost of inputs and units of the output:

$$\frac{\text{Quantity of production at standard price}}{\text{Labor cost} + \text{Materials cost} + \text{Overhead}} \quad (2\text{–}3)$$

EXAMPLE 3

Determine the multifactor productivity for the combined input of labor and machine time using the following data:

Output: 7,040 units @$1.10 each

Input

Labor: $1,000

Materials: $520

Overhead: $2,000

SOLUTION

$$\text{Multifactor productivity} = \frac{\text{Output}}{\text{Labor} + \text{Materials} + \text{Overhead}} = \frac{7{,}040 \text{ units} \times \$1.10\text{/unit}}{\$1{,}000 + \$520 + \$2{,}000} = 2.20 \text{ units per dollar input}$$

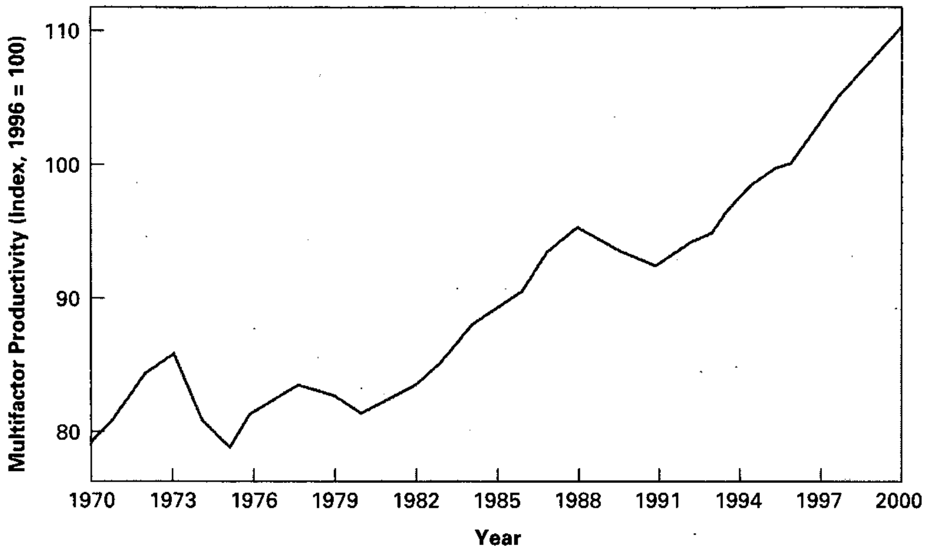
Productivity measures are useful on a number of levels. For an individual department or organization, productivity measures can be used to track performance *over time.* This allows managers to judge performance and to decide where improvements are needed. For example, if productivity has slipped in a certain area, operations staff can examine the factors used to compute productivity to determine what has changed and then devise a means of improving productivity in subsequent periods.

Productivity measures also can be used to judge the performance of an entire industry or the productivity of a country as a whole. These productivity measures are *aggregate* measures.

In essence, productivity measurements serve as scorecards of the effective use of resources. Business leaders are concerned with productivity as it relates to *competitiveness:* If two firms both have the same level of output but one requires less input because of higher productivity, that one will be able to charge a lower price and consequently increase its share of the market.

FIGURE 2.2

U.S. multifactor productivity, 1970–2000



Or that firm might elect to charge the same price, thereby reaping a greater profit. Government leaders are concerned with national productivity because of the close relationship between productivity and a nation's standard of living. High levels of productivity are largely responsible for the relatively high standards of living enjoyed by people in industrial nations. Furthermore, wage and price increases not accompanied by productivity increases tend to create inflationary pressures on a nation's economy.

Productivity growth in the United States in the 1970s and 80s lagged behind that of other leading industrial countries, most notably Japan, Korea, the U.K., and West Germany. That caused concern among government officials and business leaders. Although U.S. productivity was still among the highest in the world, it was losing ground to other nations. Moreover, a significant portion of U.S. productivity could be attributed to high *agricultural* productivity; *manufacturing* productivity tended to be lower. It slowed during the late 70s and early 80s, but it was strong in the mid to late 90s. (See Figure 2.2.)

Why Productivity Matters

READING

It is sometimes easy to overlook the importance of productivity. National figures are often reported in the media. They may seem to be ho hum; there's nothing glamorous about them to get our attention. But make no mistake; they are key economic indicators—barometers, if you will, that affect everybody. How? High productivity and high standard of living go hand-in-hand. If a country becomes more service-based, as the United States has become, some (but not all) high productivity manufacturing jobs are replaced by lower-productivity service jobs. That makes it more difficult to support a high standard of living.

Productivity levels are also important for industries and companies. For companies, a higher productivity relative to their competitors gives them a competitive advantage over their competitors in the marketplace. With a higher productivity, they can afford to undercut competitors' prices to gain market share, or charge the same prices but realize greater profits! For an industry, higher relative productivity means it is less likely to be supplanted by foreign industry.

Questions

1. Why is high productivity important for a nation?
2. Why do you suppose that service jobs have lower productivity than manufacturing jobs?
3. How can a company gain a competitive advantage over its competitors by having higher productivity than they have?

Productivity in the Service Sector

Service productivity is more problematic than manufacturing productivity. In many situations, it is more difficult to measure, and thus to manage, because it involves intellectual activities and a high degree of variability. Think about medical diagnosis, surgery, consulting, legal services, customer service, and computer repair work. This makes productivity improvements more difficult to achieve. Nonetheless, because service is becoming an increasingly large portion of our economy, the issues related to service productivity will have to be dealt with.

Factors That Affect Productivity

Numerous factors affect productivity. Generally, they are methods, capital, quality, technology, and management.

A commonly held misconception is that workers are the main determinant of productivity. According to that theory, the route to productivity gains involves getting employees to work harder. However, the fact is that many productivity gains in the past have come from *technological* improvements. Familiar examples include:

Fax machines	Automation
Copiers	Calculators
The Internet	Computers
Voice mail, cellular phones	E-mail
Computerized billing	Software

However, technology alone won't guarantee productivity gains; it must be used wisely and thoughtfully. Without careful planning, technology can actually *reduce* productivity, especially if it leads to inflexibility, high costs, or mismatched operations. Another current productivity pitfall results from employees' use of computers for non–work-related activities (playing games or checking stock prices or sports scores on the Internet). Beyond all of these is the dip in productivity that results while employees learn to use new equipment or procedures that will eventually lead to productivity gains after the learning phase ends.

Other factors that affect productivity include

Standardizing processes and procedures wherever possible to reduce variability can have a significant benefit for both productivity and quality.

Quality differences may distort productivity measurements. One way this can happen is when comparisons are made over time, such as comparing the productivity of a factory now with one 30 years ago. Quality is now much higher than it was then, but there is no simple way to incorporate quality into productivity measurements.

Use of the Internet can lower costs of a wide range of transactions, thereby increasing productivity. It is likely that this effect will continue to increase productivity in the foreseeable future.

Computer viruses can have an immense negative impact on productivity.

Searching for lost or misplaced items wastes time, hence negatively affecting productivity.

Scrap rates have an adverse effect on productivity, signaling inefficient use of resources.

New workers tend to have lower productivity than seasoned workers. Thus, growing companies may experience a productivity lag.

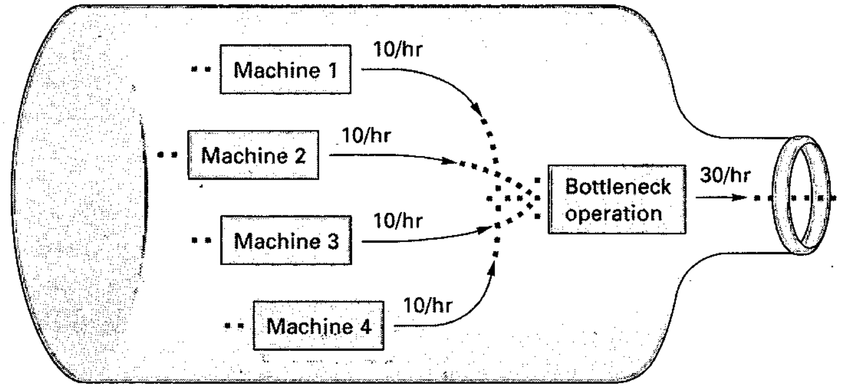
Safety should be addressed. Accidents can take a toll on productivity.

A shortage of information technology workers and other technical workers hampers the ability of companies to update computing resources, generate and sustain growth, and take advantage of new opportunities.

Layoffs often affect productivity. The effect can be positive and negative. Initially, productivity may increase after a layoff, because the workload remains the same but fewer workers do the work—although they have to work harder and longer to do it. However,

FIGURE 2.3

Bottleneck operation



as time goes by, the remaining workers may experience an increased risk of burnout, and they may fear additional job cuts. The most capable workers may decide to leave.

Labor turnover has a negative effect on productivity; replacements need time to get up to speed.

Design of the workspace can impact productivity. For example, having tools and other work items within easy reach can positively impact productivity.

Incentive plans that reward productivity increases can boost productivity.

And there are still other factors that affect productivity, such as *equipment breakdowns, shortages* of parts or materials, and inadequate *training* of employees.

Improving Productivity

A company or a department can take a number of key steps toward improving productivity:

1. Develop productivity measures for all operations; measurement is the first step in managing and controlling an operation.
2. Look at the system as a whole in deciding which operations are most critical; it is overall productivity that is important. This concept is illustrated in Figure 2.3, which shows several operations feeding their output into a *bottleneck* operation. The capacity of the bottleneck operation is less than the combined capacities of the operations that provide input, so units queue up waiting to be processed; hence the term *bottleneck.* Productivity improvements to any *non*bottleneck operation will not affect the productivity of the system. Improvements in the bottleneck operation *will* lead to increased productivity, up to the point where the output rate of the bottleneck equals the output rate of the operations feeding it.
3. Develop methods for achieving productivity improvements, such as soliciting ideas from workers (perhaps organizing teams of workers, engineers, and managers), studying how other firms have increased productivity, and reexamining the way work is done.
4. Establish reasonable goals for improvement.
5. Make it clear that management supports and encourages productivity improvement. Consider incentives to reward workers for contributions.
6. Measure improvements and publicize them.

Don't confuse productivity with *efficiency.* Efficiency is a narrower concept that pertains to getting the most out of a *fixed* set of resources; productivity is a broader concept that pertains to effective use of overall resources. For example, an efficiency perspective on mowing a lawn given a hand mower would focus on the best way to use the hand mower; a productivity perspective would include the possibility of using a power mower.

Productivity Improvement

NEWSCLIP

www.howmedica.com

In April 1999, Stryker Howmedica set up a team to improve the running of its packaging line. A strategy focus on productivity improvement was used. The team adopted an approach based on the production system of Toyota. The goal was to satisfy the customer expectations for delivery and quality, while achieving gains in productivity. After the team identified needs and set objectives, a number of improvements were implemented. A one-piece flow was established that reduced bottlenecks in the flow of devices through a clean room and the total time spent blister sealing devices was lowered. Within a short time, productivity nearly doubled from 36 devices per hour to 60 devices per hour, work-in-progress inventory fell, and a 10 percent reduction in the standard cost of product was achieved.

Source: Based on Lauraine Howley, "A Strategy for Company Improvement," *Medical Device Technology* 11, no. 2 (March 2000), p. 33.

SUMMARY

Competition is the driving force in many organizations. It may involve price, quality, special features or services, time, or other factors. To develop effective strategies for business, it is essential for organizations to determine what combinations of factors are important to customers, which factors are order qualifiers, and which are order winners.

Strategies are plans for achieving organizational goals. They provide focus for decision making. Strategies must take into account present and future customer wants, as well as the organization's strengths and weaknesses, threats and opportunities. These can run the gamut from what competitors are doing, or are likely to do, to technology, supply chain management, and e-business. Organizations generally have overall strategies that pertain to the entire organization and strategies that pertain to each of the functional areas. Functional strategies are narrower in scope and should be linked to overall strategies. Time-based strategies and quality-based strategies are among the most widely used strategies business organizations employ to serve their customers and to become more productive.

Productivity is a measure of the use of resources. There is considerable interest in productivity both from an organizational standpoint and from a national standpoint. Business organizations want higher productivity because it yields lower costs and helps them to become more competitive. Nations want higher productivity because it makes their goods and services more attractive, offsets inflationary pressures associated with higher wages, and results in a higher standard of living for their people.

KEY TERMS

competitiveness, 36
distinctive competencies, 41
environmental scanning, 43
goals, 38
mission, 38
mission statement, 38
operations strategy, 42
order qualifiers, 43
order winners, 43
productivity, 47
quality-based strategy, 46
strategies, 38
tactics, 38
time-based strategy, 46

SOLVED PROBLEMS

Problem 1

A company that processes fruits and vegetables is able to produce 400 cases of canned peaches in one-half hour with four workers. What is labor productivity?

Solution

$$\text{Labor productivity} = \frac{\text{Quanity produced}}{\text{Labor hours}} = \frac{400 \text{ cases}}{4 \text{ workers} \times 1/2 \text{ hour/worker}}$$

$$= 200 \text{ cases per labor hour}$$

(continued)

Problem 2

A wrapping paper company produced 2,000 rolls of paper one day. Standard price is $1/roll. Labor cost was $160, material cost was $50, and overhead was $320. Determine the multifactor productivity.

Solution

$$\text{Multifactor productivity} = \frac{\text{Quantity produced @ standard price}}{\text{Labor cost} + \text{Material cost} + \text{Overhead}}$$

$$= \frac{2{,}000 \text{ rolls} \times \$1/\text{roll}}{\$160 + \$50 + \$320} = 3.77 \text{ rolls output per dollar input}$$

A variation of the multifactor productivity calculation incorporates the standard price in the numerator by multiplying the units by the standard price, as shown above.

DISCUSSION AND REVIEW QUESTIONS

1. From time to time, various groups clamor for import restrictions or tariffs on foreign-produced goods, particularly automobiles. How might these be helpful? Harmful?
2. List the key ways that organizations compete.
3. Explain the importance of identifying and differentiating order qualifiers and order winners.
4. Select two stores you shop at, and state how they compete.
5. What are distinctive competencies and how do they relate to strategy formulation?
6. Contrast the terms *strategies* and *tactics.*
7. Contrast *organization strategy* and *operations strategy.*
8. Explain the term *time-based strategies* and give three examples.
9. What is productivity and why is it important? Who is primarily responsible for productivity in an organization?
10. List some factors that can affect productivity and some ways that productivity can be improved.
11. It has been said that a typical Japanese automobile manufacturer produces more cars with fewer workers than its U.S. counterpart. What are some possible explanations for this, assuming that U.S. workers are as hardworking as Japanese workers?
12. Boeing's strategy appears to focus on its 777 mid-size plane's ability to fly into smaller, non-hub airports. Rival European Airbus's strategy appears to focus on large planes. Compare the advantages and disadvantages of these two strategies.
13. Name 10 ways that banks compete for customers.
14. Explain the rationale of an operations strategy that seeks to increase the opportunity for use of technology by reducing variability in processing requirements.

TAKING STOCK

1. Who needs to be involved in formulating organizational strategy?
2. Name some of the competitive trade-offs that might arise in a fast-food restaurant.
3. How does technology improve each of these?
   a. Competitiveness
   b. Productivity

CRITICAL THINKING EXERCISE

A U.S. company has two manufacturing plants, one in the United States and another in a third world country. Both produce the same item, each for sale in their respective countries. However, their productivity figures are quite different. The analyst thinks this is because the U.S. plant uses more automated equipment for processing while the other plant uses a higher percentage of labor. Explain how that factor can cause productivity figures to be misleading. Is there another way to compare the two plants that would be more meaningful?

PROBLEMS

1. Suppose that a company produced 300 standard bookcases last week using eight workers and it produced 240 standard bookcases this week using six workers. In which period was productivity higher? Explain.
2. The manager of a crew that installs carpeting has tracked the crew's output over the past several weeks, obtaining these figures:

Week	Crew Size	Yards Installed
1	4	960
2	3	702
3	4	968
4	2	500
5	3	696
6	2	500

Compute the labor productivity for each of the weeks. On the basis of your calculations, what can you conclude about crew size and productivity?

3. Compute the multifactor productivity measure for each of the weeks shown. What do the productivity figures suggest? Assume 40-hour weeks and an hourly wage of $12. Overhead is 1.5 times weekly labor cost. Material cost is $6 per pound. Standard price is $140 per unit.

Week	Output (units)	Workers	Material (lbs)
1	300	6	45
2	338	7	46
3	322	7	46
4	354	8	48

4. A company that makes shopping carts for supermarkets and other stores recently purchased some new equipment that reduces the labor content of the jobs needed to produce the shopping carts. Prior to buying the new equipment, the company used five workers, who produced an average of 80 carts per hour. Workers receive $10 per hour and machine cost was $40 per hour. With the new equipment, it was possible to transfer one of the workers to another department, and equipment cost increased by $10 per hour while output increased by four carts per hour.
   a. Compute labor productivity under each system. Use carts per worker per hour as the measure of labor productivity.
   b. Compute the multifactor productivity under each system. Use carts per dollar cost (labor plus equipment) as the measure.
   c. Comment on the changes in productivity according to the two measures, and on which one you believe is the more pertinent for this situation.
5. An operation has a 10 percent scrap rate. As a result, 72 pieces per hour are produced. What is the potential increase in labor productivity that could be achieved by eliminating the scrap?
6. A manager checked production records and found that a worker produced 160 units while working 40 hours. In the previous week, the same worker produced 138 units while working 36 hours. Did the worker's productivity increase, decrease, or remain the same? Explain.

Productivity Gains at Whirlpool

READING

www.whirlpool.com

Workers and management at Whirlpool Appliance's Benton Harbor plant in Michigan have set an example of how to achieve productivity gains, which has benefited not only the company and its stockholders, but Whirlpool customers, and the workers themselves.

Things weren't always rosy at the plant. Productivity and quality weren't good. Neither were labor–management relations. Workers hid defective parts so management wouldn't find them, and when a machine broke down, workers would simply sit down until sooner or later someone came to fix it. All that changed in the late 1980s. Faced with the possibility that the plant would be shut down, management and labor worked together to find a way to keep the plant open. The way was to increase productivity—producing more without using more resources. Interestingly, the improvement in productivity didn't come by spending money on fancy machines. Rather, it was accomplished by placing more emphasis on quality. That was a shift from the old way, which emphasized volume, often at the expense of quality. To motivate workers, the company agreed to gain sharing, a plan that rewarded workers by increasing their pay for productivity increases.

The company overhauled the manufacturing process, and taught its workers how to improve quality. As quality improved,

(continued)

(concluded)

productivity went up because more of the output was good, and costs went down because of fewer defective parts that had to be scrapped or reworked. Costs of inventory also decreased, because fewer spare parts were needed to replace defective output, both at the factory and for warranty repairs. And workers were able to see the connection between their efforts to improve quality and productivity, and their pay.

Not only was Whirlpool able to use the productivity gains to increase workers' pay, it was also able to hold the lid on price increases and to funnel some of the savings into research, which added to cost savings and quality improvement.

Questions

1. What were the two key things that Whirlpool management did to achieve productivity gains?
2. Who has benefited from the productivity gains?
3. How are productivity and quality related?
4. How can a company afford to pay its workers for productivity gains?

Source: Based on "A Whirlpool Factory Raises Productivity—And Pay of Workers," by Rick Wartzman, from *The Wall Street Journal,* 1992

An American Tragedy: How a Good Company Died

CASE

Zachary Schiller

The Rust Belt is back. So say bullish observers as U.S. exports surge, long-moribund industries glow with newfound profits, and unemployment dips to lows not seen in a decade. But in the smokestack citadels, there's disquiet. Too many machine-tool and auto parts factories are silent; too many U.S. industries still can't hold their own.

What went wrong since the heyday of the 1960s? That's the issue Max Holland, a contributing editor of *The Nation,* takes up in his nutsy-boltsy but fascinating study, *When the Machine Stopped.**

The focus of the story is Burgmaster Corp., a Los Angeles-area machine-tool maker founded in 1944 by Czechoslovakian immigrant Fred Burg. Holland's father worked there for 29 years, and the author interviewed 22 former employees. His shop-floor view of this small company is a refreshing change from academic treatises on why America can't compete.

The discussions of spindles and numerical control can be tough going. But Holland compensates by conveying the excitement and innovation of the company's early days and the disgust and cynicism accompanying its decline. Moreover, the fate of Burgmaster and its brethren is crucial to the U.S. industrial economy: Any manufactured item is either made by a machine tool or by a machine made by a machine tool.

Producing innovative turret drills used in a wide variety of metalworking tasks, Burgmaster was a thriving enterprise by 1965, when annual sales amounted to about $8 million. The company needed backing to expand, however, so it sold out to Buffalo-based conglomerate Houdaille Industries Inc. Houdaille was in turn purchased in a 1979 leveraged buyout led by Kohlberg Kravis Roberts & Co. By 1982, when debt, competition, and a sickly machine-tool market had battered Burgmaster badly, Houdaille went to Washington with a petition to withhold the investment tax credit for certain Japanese-made machine tools.

Thanks to deft lobbying, the Senate passed a resolution supporting Houdaille's position, but President Reagan refused to go along. Houdaille's subsequent attempt to link Burgmaster up with a Japanese rival also failed, and Burgmaster was closed.

Holland uses Burgmaster's demise to explore some key issues of economic and trade policy. Houdaille's charge that a cartel led by the Japanese government had injured U.S. toolmakers, for example, became a rallying point for those who would blame a fearsome Japan Inc. for the problems of U.S. industry.

Holland describes the Washington wrangling over Houdaille in painful detail. But he does show that such government decisions are often made without much knowledge of what's going on in industry. He shows, too, that Japanese producers succeeded less because of government help than because they made better, cheaper machines.

For those who see LBOs as a symptom of what ails the U.S. economy, Holland offers plenty of ammunition. He argues persuasively that the LBO crippled Burgmaster by creating enormous pressure to generate cash. As Burgmaster pushed its products out as fast as possible, he writes, it routinely shipped defective machines. It promised customers features that engineers hadn't yet designed. And although KKR disputes the claim, Holland concludes that the LBO choked off Burgmaster's investment funds just when foreign competition made them most necessary. As for Houdaille, it was recapitalized and sold to Britain's Tube Investments Group.

*Max Holland, *When the Machine Stopped: A Contemporary Tale from Industrial America* (Boston, MA: Harvard Business School Press, 1988).

(continued)

(concluded)

But Burgmaster's problems had started even before the LBO. Holland's history of the company under Houdaille is a veritable catalog of modern management techniques that flopped. One of the most disastrous was a system for computerizing production scheduling that was too crude for complex machine-tool manufacturing. Holland gives a dramatic depiction of supply snafus that resulted in delays and cost increases.

As an independent company, "Burgmaster thrived because the Burgs knew their business," Holland writes. Their departure under Houdaille was followed by an "endless and ultimately futile search for a better formula." But, he concludes: "No formula was a substitute for management involvement on the shop floor."

In the end, however, Holland puts most of the blame for the industry's decline on government policy. He targets tax laws and macroeconomic policies that encourage LBOs and speculation instead of productive investment. He also criticizes Pentagon procurement policies for favoring exotic, custom machines over standard, low-cost models. This adds up to an industrial policy, Holland writes—a bad one.

The point is well taken, but Holland gives it excessive weight. Like their brethren in Detroit and Pittsburgh, domestic tool-makers in the 1970s were too complacent when imports seized the lower end of the product line. The conservatism that had for years served them in their cyclical industry left them ill-prepared for change. Even now some of the largest U.S. tool-makers are struggling to restructure. Blame the government, yes. But blame the industry, too.

Question

1. Write a brief report that outlines the reasons (both internal and external) for Burgmaster's demise, and whether operations management played a significant role in the demise.

Home-Style Cookies

CASE

The Company

The Lew-Mark Baking Company is located in a small town in western New York State. The bakery is run by two brothers, Lew and Mark, who formed the company after they purchased an Archway Cookie franchise. With exclusive rights in New York and New Jersey, it is the largest Archway franchise. The company employs fewer than 200 people, mainly blue-collar workers, and the atmosphere is informal.

The Product

The company's only product is soft cookies, of which it makes over 50 varieties. Larger companies, such as Nabisco, Sunshine, and Keebler, have traditionally produced biscuit cookies, in which most of the water has been baked out, resulting in crisp cookies. Archway cookies have no additives or preservatives. The high quality of the cookies has enabled the company to develop a strong market niche for its product.

The Customers

The cookies are sold in convenience stores and supermarkets throughout New York and New Jersey. Archway markets its cookies as "good food"—no additives or preservatives—and this appeals to a health-conscious segment of the market. Many customers are over 45 years of age, and prefer a cookie that is soft and not too sweet. Parents with young children also buy the cookies.

The Production Process

The company has two continuous band ovens that it uses to bake the cookies. The production process is called a batch processing system. It begins as soon as management gets orders from distributors. These orders are used to schedule production. At the start of each shift, a list of the cookies to be made that day is delivered to the person in charge of mixing. That person checks a master list, which indicates the ingredients needed for each type of cookie, and enters that information into the computer. The computer then determines the amount of each ingredient needed, according to the quantity of cookies ordered, and relays that information to storage silos located outside the plant where the main ingredients (flour, sugar, and cake flour) are stored. The ingredients are automatically sent to giant mixing machines where the ingredients are combined with proper amounts of eggs, water, and flavorings. After the ingredients have been mixed, the batter is poured into a cutting machine where it is cut into individual cookies. The cookies are then dropped onto a conveyor belt and transported through one of two ovens. Filled cookies, such as apple, date, and raspberry, require an additional step for filling and folding.

The nonfilled cookies are cut on a diagonal rather than round. The diagonal-cut cookies require less space than straight-cut cookies, and the result is a higher level of productivity. In addition, the company recently increased the length of each oven by 25 feet, which also increased the rate of production.

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As the cookies emerge from the ovens, they are fed onto spiral cooling racks 20 feet high and 3 feet wide. As the cookies come off the cooling racks, workers place the cookies into boxes manually, removing any broken or deformed cookies in the process. The boxes are then wrapped, sealed, and labeled automatically.

Inventory

Most cookies are loaded immediately onto trucks and shipped to distributors. A small percentage are stored temporarily in the company's warehouse, but they must be shipped shortly because of their limited shelf life. Other inventory includes individual cookie boxes, shipping boxes, labels, and cellophane for wrapping. Labels are reordered frequently, in small batches, because FDA label requirements are subject to change, and the company does not want to get stuck with labels it can't use. The bulk silos are refilled two or three times a week, depending on how quickly supplies are used.

Cookies are baked in a sequence that minimizes downtime for cleaning. For instance, light-colored cookies (e.g., chocolate chip) are baked before dark-colored cookies (e.g., fudge), and oatmeal cookies are baked before oatmeal raisin cookies. This permits the company to avoid having to clean the processing equipment every time a different type of cookie is produced.

Quality

The bakery prides itself on the quality of its cookies. Cookies are sampled randomly by a quality control inspector as they come off the line to assure that their taste and consistency are satisfactory, and that they have been baked to the proper degree. Also, workers on the line are responsible for removing defective cookies when they spot them. The company has also installed an X-ray machine on the line that can detect small bits of metal filings that may have gotten into cookies during the production process. The use of automatic equipment for transporting raw materials and mixing batter has made it easier to maintain a sterile process.

Scrap

The bakery is run very efficiently and has minimal amounts of scrap. For example, if a batch is mixed improperly, it is sold for dog food. Broken cookies are used in the oatmeal cookies. These practices reduce the cost of ingredients and save on waste disposal costs. The company also uses heat reclamation: The heat that escapes from the two ovens is captured and used to boil the water that supplies the heat to the building. Also, the use of automation in the mixing process has resulted in a reduction in waste compared with the manual methods used previously.

New Products

Ideas for new products come from customers, employees, and observations of competitors' products. New ideas are first examined to determine whether the cookies can be made with existing equipment. If so, a sample run is made to determine the cost and time requirements. If the results are satisfactory, marketing tests are conducted to see if there is a demand for the product.

Potential Improvements

There are a number of areas of potential improvement at the bakery. One possibility would be to automate packing the cookies into boxes. Although labor costs are not high, automating the process might save some money and increase efficiency. So far, the owners have resisted making this change because they feel an obligation to the community to employ the 30 women who now do the boxing manually. Another possible improvement would be to use suppliers who are located closer to the plant. That would reduce delivery lead times and transportation costs, but the owners are not convinced that local suppliers could provide the same good quality. Other opportunities have been proposed in recent years, but the owners rejected them because they feared that the quality of the product might suffer.

Questions

1. Briefly describe the cookie production process.
2. What are two ways that the company has increased productivity? Why did increasing the length of the ovens result in a faster output rate?
3. Do you think that the company is making the right decision by not automating the packing of cookies? Explain your reasoning. What obligation does a company have to its employees in a situation such as this? What obligation does it have to the community? Is the size of the town a factor? Would it make a difference if the company was located in a large city? Is the size of the company a factor? What if it was a much larger company?
4. What factors cause the company to carry minimal amounts of certain inventories? What benefits result from this policy?
5. As a consumer, what things do you consider in judging the quality of cookies you buy in a supermarket?
6. What advantages and what limitations stem from the company's not using preservatives in cookies?
7. Briefly describe the company's strategy.

Hazel Revisited

CASE

(Refer to p. 28 for the Hazel Case.)

1. What competitive advantage does Hazel have over a professional lawn care service?
2. Hazel would like to increase her profits, but she doesn't believe that it would be wise to raise her prices considering the current state of the local economy. Instead, she has given some thought to increasing productivity.
   a. Explain how increased productivity could be an alternative to increased prices.
   b. What are some ways that Hazel could increase productivity?
3. Hazel is thinking about the purchase of new equipment. One would be power sidewalk edgers. She believes edgers will lead to an increase in productivity. Another would be a chain saw, which would be used for tree pruning. What trade-offs should she consider in her analysis?
4. Hazel has been fairly successful in her neighborhood, and now wants to expand to other neighborhoods, including some that are five miles away. What would be the advantages and disadvantages of doing this?
5. Hazel does not have a mission statement or a set of objectives. Take one of the following positions and defend it:
   a. Hazel doesn't need a formal mission statement and objectives. Many small businesses don't have them.
   b. She definitely needs a mission statement and a set of objectives. They would be extremely beneficial.
   c. There may be some benefit to Hazel's business, and she should consider developing one.

The US Postal Service

OPERATIONS TOUR

"Neither rain, nor snow . . . "

The US Postal Service is the largest postal service in the world, handling about 41 percent (630 million pieces a day) of the world's mail volume. The second largest is Japan's, which handles only about 6 percent of the world's mail. The US Postal Service is huge by any standard. It employs over 760,000 workers, making it the largest civilian employer in the United States. It has over 300,000 mail collection boxes, 38,000 post offices, 130 million mail delivery points, more than 300 processing plants to sort and ship mail, and more than 75,000 pieces of mail processing equipment. It handles over 100 billion pieces of first-class mail a year, and ships about 3 billion pounds of mail on commercial airline flights, making it the airlines' largest shipper.

Processing First-Class Mail

The essence of processing the mail is sorting, which means organizing the mail into smaller and smaller subgroups to facilitate its timely delivery. Sorting involves a combination of manual and automatic operations. Much of the mail that is processed is first-class mail.

Most first-class mail is handled using automated equipment. A small portion that cannot be handled by automated equipment must be sorted by hand, just the way it was done in colonial times.

The majority of first-class mail begins at the advanced facer canceling system. This system positions each letter so that it is face up, with the stamp in the upper corner, checks to see if the address is handwritten, and pulls the hand-addressed letters off the line. It also rejects letters that have the stamp covered by tape, have no postage, are third-class mail, or have meter impressions that are too light to read. The rejects are handled manually. The remaining letters are cancelled and date stamped, and then sorted to one of seven stackers.

Next the letters go to the multiline optical character readers, which can handle both printed and pre-barcoded mail, but not hand-addressed mail. The optical reader sprays a barcode on the mail that hasn't been pre-barcoded, which represents up to an 11-digit ZIP code. For hand-addressed mail, a camera focuses on the front of the letter, and the image is displayed on a remote terminal, often in another city, where an operator views the image and provides the information that the optical readers could not determine so that a barcode can be added.

Barcode readers then sort the mail into one of 96 stackers, doing this at a rate of more than 500 a minute. The mail goes through another sort using manually controlled mechanical equipment. At that point, the mail is separated according to whether it is local or out-of-town mail. The out-of-town mail is placed into appropriate sacks according to its destination, and moved to the outgoing send area where it will be loaded on trucks.

The local mail is moved to another machine that not only sorts the mail into local carrier delivery routes, it sorts it according to delivery walk sequence!

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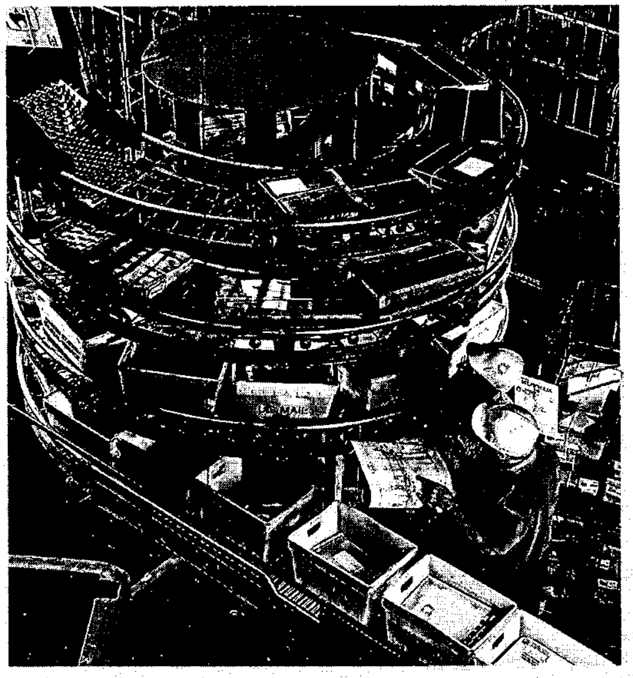

Small parcels, bundles of letters, and bundles of flats are sorted by a bundle-sorting machine.

Productivity

Over the years, the Postal Service has experienced an ever increasing volume of mail. Productivity has been an important factor for the Postal Service in keeping postal rates low and maintaining rapid delivery service. Two key factors in improved productivity have been the increased use of automation and the introduction of zip codes.

Mail processing underwent a major shift to mechanization during the 1950s and 1960s, which led to more rapid processing and higher productivity. In 1978, an expanded zip code was introduced. That was followed in 1983 by a four-digit expansion in zip codes. These changes required new, automated processing equipment, and the use of barcodes and optical readers. All of these changes added greatly to productivity. But even with these improvements, the Postal Service faced increasing competitive pressures.

Competition

In the late 1980s, the Postal Service experienced a slowdown in the volume of mail. Some of this was due to a slowing of the economy, but most of it was the result of increasing competition. Delivery giants FedEx and UPS, as well as other companies that offer speedy delivery and package tracking, gave businesses and the general public convenient alternatives for some mail services. At the same time, there was a growing use of fax machines and electronic communications and increased use of alternate forms of advertising such as cable TV, all of which cut into the volume of mail.

Strategies and Tactics Used to Make the Postal Service More Competitive

To meet these challenges, the Postal Service developed several strategies to become more competitive. These included reorganizing, continuing to seek ways to keep costs down, increasing productivity, and emphasizing quality and customer service. Here is an overview of the situation and the strategies and tactics used by the Postal Service.

The Postal Service began working more closely with customers to identify better ways to meet their needs and expanded customer conveniences such as stamps on consignment. With the help of business mailers, the Postal Service continued support for rates reflecting customer work-sharing features, many tied to automation, to give customers more flexibility. At the same time, the Postal Service began forming Customer Advisory Councils—groups of citizens who volunteered to work with local postal management on postal issues of interest to the community. In 1990, the Postal Service awarded two contracts to private firms to measure first-class mail service and customer satisfaction. In 1992, the Postal Service stepped up its quest to become more competitive by reducing bureaucracy and overhead in order to improve service and customer satisfaction, and to reduce the need to increase postage rates.

To help accomplish these goals, the Postal Service underwent a reorganization. Layers of management were eliminated and overhead positions were cut by about 30,000. Five regions and 73 field divisions were replaced by 10 areas, each with a manager for customer services and a manager for processing and distribution. Ten customer service areas were established, with managers for customer service and processing and distribution in each area, as well as a marketing and sales office. The new structure allowed postal managers to be focused, improved communications, and empowered employees to meet customer needs. The Postal Service also took other steps to improve service. In 1993 it implemented improvements in processing and mail delivery at major postal facilities, expanded retail hours, and developed a more user-friendly Domestic Mail Manual. In cooperation with business customers, the Postal Service began to develop new services to meet specific mailer needs and to overhaul and simplify its complex rate structure. It also awarded contracts for two more external tracking systems, one to measure satisfaction levels of business mailers, and the other to measure service performance of third-class mail.

The reorganization eliminated some programs, cut costs, attracted new business, and reduced the US Postal Service's projected deficit.

(continued)

(concluded)

Questions

1. Why is it important for the Postal Service to have a high volume of mail to process?
2. What caused productivity to increase?
3. What impact did competitive pressures have on the Postal Service?
4. What measures did the Postal Service adopt to increase competitiveness?
5. What results were achieved by the Postal Service's changes?
6. What effect will increased use of e-mail have on postal productivity?

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PART TWO

Forecasting

This part is devoted solely to forecasting. It is presented early in the book because forecasts are the basis for a wide range of decisions that are described in the following chapters. In fact, forecasts are basic inputs for many kinds of decisions in business organizations. Consequently, it is important for *all* managers to be able to understand and use forecasts. Although forecasts are typically developed by the marketing function, the operations function is often called on to assist in forecast development. More important, though, is the reality that operations is a major user of forecasts.

Chapter 3 provides important insights on forecasting as well as information on how to develop and monitor forecasts.

CHAPTER 3

Forecasting

LEARNING OBJECTIVES

After completing this chapter you should be able to:

1. List the elements of a good forecast.
2. Outline the steps in the forecasting process.
3. Describe at least three qualitative forecasting techniques and the advantages and disadvantages of each.
4. Compare and contrast qualitative and quantitative approaches to forecasting.
5. Briefly describe averaging techniques, trend and seasonal techniques, and regression analysis, and solve typical problems.
6. Describe two measures of forecast accuracy.
7. Describe two ways of evaluating and controlling forecasts.
8. Identify the major factors to consider when choosing a forecasting technique.

CHAPTER OUTLINE

Many new car buyers have a thing or two in common. Once they make the decision to buy a new car, they want it as soon as possible. They usually don't want to order it and then have to wait six weeks or more for delivery. If the car dealer they visit doesn't have the car they want, they'll look elsewhere. Hence, it is important for a dealer to *anticipate* buyer wants and to have those models, with the necessary options, in stock. The dealer who can correctly forecast buyer wants, and have those cars available, is going to be much more successful than a competitor who guesses instead of forecasting—and guesses wrong—and gets stuck with cars customers don't want. So how does the dealer know how many cars of each type to stock? The answer is, the dealer *doesn't* know for sure, but based on analysis of previous buying patterns, and perhaps making allowances for current conditions, the dealer can come up with a reasonable *approximation* of what buyers will want.

Planning is an integral part of a manager's job. If uncertainties cloud the planning horizon, managers will find it difficult to plan effectively. Forecasts help managers by reducing some of the uncertainty, thereby enabling them to develop more meaningful plans. A **forecast** is a statement about the future value of a variable such as demand.

forecast A statement about the future value of a variable of interest.

This chapter provides a survey of business forecasting. It describes the elements of good forecasts, the necessary steps in preparing a forecast, basic forecasting techniques, and how to monitor a forecast.

INTRODUCTION

People make and use forecasts all the time, both in their jobs and in everyday life. In everyday life, they forecast answers to questions and then make decisions based on their forecasts. Typical questions they may ask are: "Can I make it across the street before that car comes?" "How much food and drink will I need for the party?" "Will I get the job?" "When should I leave to make it to class, the station, the bank, the interview, . . . , on time?" To make these forecasts, they may take into account two kinds of information. One is current factors or conditions. The other is past experience in a similar situation. Sometimes they will rely more on one than the other, depending on which approach seems more relevant at the time.

Forecasting for business purposes involves similar approaches. In business, however, more formal methods are used to make forecasts and to assess forecast accuracy. Forecasts are the basis for budgeting, planning capacity, sales, production and inventory, personnel, purchasing, and more. Forecasts play an important role in the planning process because they enable managers to anticipate the future so they can plan accordingly.

Forecasts affect decisions and activities throughout an organization, in accounting, finance, human resources, marketing, MIS, as well as operations, and other parts of an organization. Here are some examples of uses of forecasts in business organizations:

Accounting. New product/process cost estimates, profit projections, cash management.

Finance. Equipment/equipment replacement needs, timing and amount of funding/borrowing needs.

Human resources. Hiring activities, including recruitment, interviewing, training, layoff planning, including outplacement, counseling.

Marketing. Pricing and promotion, e-business strategies, global competition strategies.

MIS. New/revised information systems, Internet services.

Operations. Schedules, work assignments and workloads, inventory planning, make-or-buy decisions, outsourcing, project management.

Product/service design. Revision of current features, design of new products or services.

In most of these uses of forecasts, decisions in one area have consequences in other areas. Therefore, it is important for managers in different areas to coordinate decisions. For example, marketing decisions on pricing and promotion affect demand, which, in turn, will generate requirements for operations.

There are two uses for forecasts. One is to help managers *plan the system* and the other is to help them *plan the use of the system*. Planning the system generally involves long-range plans about the types of products and services to offer, what facilities and equipment to have, where to locate, and so on. Planning the use of the system refers to short-range and intermediate-range planning, which involve tasks such as planning inventory and workforce levels, planning purchasing and production, budgeting, and scheduling.

Business forecasting pertains to more than predicting demand. Forecasts are also used to predict profits, revenues, costs, productivity changes, prices and availability of energy and raw materials, interest rates, movements of key economic indicators (e.g., GDP, inflation, government borrowing), and prices of stocks and bonds. For the sake of simplicity, this chapter will focus on the forecasting of demand. Keep in mind, however, that the concepts and techniques apply equally well to the other variables.

In spite of its use of computers and sophisticated mathematical models, forecasting is not an exact science. Instead, successful forecasting often requires a skillful blending of art and science. Experience, judgment, and technical expertise all play a role in developing useful forecasts. Along with these, a certain amount of luck and a dash of humility can be helpful, because the worst forecasters occasionally produce a very good forecast, and even the best forecasters sometimes miss completely. Current forecasting techniques range from the mundane to the exotic. Some work better than others, but no single technique works all the time.

Generally speaking, the responsibility for preparing demand forecasts in business organizations lies with marketing or sales rather than operations. Operations-generated forecasts often have to do with inventory requirements, resource needs, time requirements, and the like.

FEATURES COMMON TO ALL FORECASTS

A wide variety of forecasting techniques are in use. In many respects, they are quite different from each other, as you shall soon discover. Nonetheless, certain features are common to all, and it is important to recognize them.

1. Forecasting techniques generally assume that the same underlying causal system that existed in the past will continue to exist in the future.

Comment. A manager cannot simply delegate forecasting to models or computers and then forget about it, because unplanned occurrences can wreak havoc with forecasts. For instance, weather-related events, tax increases or decreases, and changes in features or prices of competing products or services can have a major impact on demand. Consequently, a manager must be alert to such occurrences and be ready to override forecasts, which assume a stable causal system.

2. Forecasts are rarely perfect; actual results usually differ from predicted values. No one can predict *precisely* how an often large number of related factors will impinge upon the variable in question; this, and the presence of randomness, preclude a perfect forecast. Allowances should be made for inaccuracies.
3. Forecasts for groups of items tend to be more accurate than forecasts for individual items because forecasting errors among items in a group usually have a canceling effect. Opportunities for grouping may arise if parts or raw materials are used for multiple products or if a product or service is demanded by a number of independent sources.
4. Forecast accuracy decreases as the time period covered by the forecast—the *time horizon*—increases. Generally speaking, short-range forecasts must contend with fewer uncertainties than longer-range forecasts, so they tend to be more accurate.

An important consequence of the last point is that flexible business organizations—those that can respond quickly to changes in demand—require a shorter forecasting horizon and, hence, benefit from more accurate short-range forecasts than competitors who are less flexible and who must therefore use longer forecast horizons.

ELEMENTS OF A GOOD FORECAST

A properly prepared forecast should fulfill certain requirements:

1. The forecast should be *timely.* Usually, a certain amount of time is needed to respond to the information contained in a forecast. For example, capacity cannot be expanded overnight, nor can inventory levels be changed immediately. Hence, the forecasting horizon must cover the time necessary to implement possible changes.
2. The forecast should be *accurate* and the degree of accuracy should be stated. This will enable users to plan for possible errors and will provide a basis for comparing alternative forecasts.
3. The forecast should be *reliable*; it should work consistently. A technique that sometimes provides a good forecast and sometimes a poor one will leave users with the uneasy feeling that they may get burned every time a new forecast is issued.
4. The forecast should be expressed in *meaningful units.* Financial planners need to know how many *dollars* will be needed, production planners need to know how many *units* will be needed, and schedulers need to know what *machines* and *skills* will be required. The choice of units depends on user needs.
5. The forecast should be *in writing.* Although this will not guarantee that all concerned are using the same information, it will at least increase the likelihood of it. In addition, a written forecast will permit an objective basis for evaluating the forecast once actual results are in.
6. The forecasting technique should be *simple to understand and use.* Users often lack confidence in forecasts based on sophisticated techniques; they do not understand either the circumstances in which the techniques are appropriate or the limitations of the techniques. Misuse of techniques is an obvious consequence. Not surprisingly, fairly simple forecasting

techniques enjoy widespread popularity because users are more comfortable working with them.

7. The forecast should be *cost-effective*: The benefits should outweigh the costs.

STEPS IN THE FORECASTING PROCESS

There are six basic steps in the forecasting process:

1. *Determine the purpose of the forecast.* How will it be used and when will it be needed? This will provide an indication of the level of detail required in the forecast, the amount of resources (personnel, computer time, dollars) that can be justified, and the level of accuracy necessary.
2. *Establish a time horizon.* The forecast must indicate a time interval, keeping in mind that accuracy decreases as the time horizon increases.
3. *Select a forecasting technique.*
4. *Gather and analyze relevant data.* Before a forecast can be made, data must be gathered and analyzed. Identify any assumptions that are made in conjunction with preparing and using the forecast.
5. *Make the forecast.*
6. *Monitor the forecast.* A forecast has to be monitored to determine whether it is performing in a satisfactory manner. If it is not, reexamine the method, assumptions, validity of data, and so on; modify as needed; and prepare a revised forecast.

APPROACHES TO FORECASTING

There are two general approaches to forecasting: qualitative and quantitative. Qualitative methods consist mainly of subjective inputs, which often defy precise numerical description. Quantitative methods involve either the projection of historical data or the development of associative models that attempt to utilize *causal (explanatory) variables* to make a forecast.

Qualitative techniques permit inclusion of *soft* information (e.g., human factors, personal opinions, hunches) in the forecasting process. Those factors are often omitted or downplayed when quantitative techniques are used because they are difficult or impossible to quantify. Quantitative techniques consist mainly of analyzing objective, or *hard,* data. They usually avoid personal biases that sometimes contaminate qualitative methods. In practice, either or both approaches might be used to develop a forecast.

In the following pages you will learn a variety of forecasting techniques that are classified as judgmental, time series, or associative.

judgmental forecasts Forecasts that use subjective inputs such as opinions from consumer surveys, sales staff, managers, executives, and experts.

time-series forecasts Forecasts that project patterns identified in recent time-series observations.

associative model Forecasting technique that uses explanatory variables to predict future demand.

Judgmental forecasts rely on analysis of subjective inputs obtained from various sources, such as consumer surveys, the sales staff, managers and executives, and panels of experts. Quite frequently, these sources provide insights that are not otherwise available.

Time series forecasts simply attempt to project past experience into the future. These techniques use historical data with the assumption that the future will be like the past. Some models merely attempt to smooth out random variations in historical data; others attempt to identify specific patterns in the data and project or extrapolate those patterns into the future, without trying to identify causes of the patterns.

Associative models use equations that consist of one or more *explanatory* variables that can be used to predict future demand. For example, demand for paint might be related to variables such as the price per gallon and the amount spent on advertising, as well as specific characteristics of the paint (e.g., drying time, ease of cleanup).

FORECASTS BASED ON JUDGMENT AND OPINION

In some situations, forecasters rely solely on judgment and opinion to make forecasts. If management must have a forecast quickly, there may not be enough time to gather and analyze quantitative data. At other times, especially when political and economic conditions are changing, available data may be obsolete and more up-to-date information might not yet be available. Similarly, the introduction of new products and the redesign of existing products or packaging suffer from the absence of historical data that would be useful in forecasting. In such instances, forecasts are based on executive opinions, consumer surveys, opinions of the sales staff, and opinions of experts.

Executive Opinions

A small group of upper-level managers (e.g., in marketing, operations, and finance) may meet and collectively develop a forecast. This approach is often used as a part of long-range planning and new product development. It has the advantage of bringing together the considerable knowledge and talents of various managers. However, there is the risk that the view of one person will prevail, and the possibility that diffusing responsibility for the forecast over the entire group may result in less pressure to produce a good forecast.

Salesforce Opinions

The sales staff or the customer service staff is often a good source of information because of their direct contact with consumers. They are often aware of any plans the customers may be considering for the future. There are, however, several drawbacks to this approach. One is that they may be unable to distinguish between what customers would *like* to do and what they actually *will* do. Another is that these people are sometimes overly influenced by recent experiences. Thus, after several periods of low sales, their estimates may tend to become pessimistic. After several periods of good sales, they may tend to be too optimistic. In addition, if forecasts are used to establish sales quotas, there will be a conflict of interest because it is to the salesperson's advantage to provide low sales estimates.

Consumer Surveys

Because it is the consumers who ultimately determine demand, it seems natural to solicit input from them. In some instances, every customer or potential customer can be contacted. However, there are usually too many customers or no way to identify all potential customers. Therefore, organizations seeking consumer input usually resort to consumer surveys, which enable them to *sample* consumer opinions. The obvious advantage of consumer surveys is that they can tap information that might not be available elsewhere. On the other hand, a considerable amount of knowledge and skill is required to construct a survey, administer it, and correctly interpret the results for valid information. Surveys can be expensive and time-consuming. In addition, even under the best conditions, surveys of the general public must contend with the possibility of irrational behavior patterns. For example, much of the consumer's thoughtful information gathering before purchasing a new car is often undermined by the glitter of a new car showroom or a high-pressure sales pitch. Along the same lines, low response rates to a mail survey should—but often don't—make the results suspect.

If these and similar pitfalls can be avoided, surveys can produce useful information.

Other Approaches

A manager may solicit opinions from a number of other managers and staff people. Occasionally, outside experts are needed to help with a forecast. Advice may be needed on political or economic conditions in the United States or a foreign country, or some other aspect of importance with which an organization lacks familiarity.

Another approach is the **Delphi method.** It involves circulating a series of questionnaires among individuals who possess the knowledge and ability to contribute meaningfully. Responses are kept anonymous, which tends to encourage honest responses and reduces the risk that one person's opinion will prevail. Each new questionnaire is developed using the information extracted from the previous one, thus enlarging the scope of information on which participants can base their judgments. The goal is to achieve a consensus forecast.

Delphi method Managers and staff complete a series of questionnaires, each developed from the previous one, to achieve a consensus forecast.

The Delphi method has been applied to a variety of situations, not all of which involve forecasting. The discussion here is limited to its use as a forecasting tool.

As a forecasting tool, the Delphi method is useful for *technological* forecasting; that is, the technique is a method for assessing changes in technology and their impact on an organization. Often the goal is to predict *when* a certain event will occur. For instance, the goal of a Delphi forecast might be to predict when video telephones might be installed in at least 50 percent of residential homes or when a vaccine for a disease might be developed and ready for mass distribution. For the most part, these are long-term, single-time forecasts, which usually have very little hard information to go by or data that are costly to obtain, so the problem does not lend itself to analytical techniques. Rather, judgments of experts or others who possess sufficient knowledge to make predictions are used.

FORECASTS BASED ON TIME SERIES DATA

time series A time-ordered sequence of observations taken at regular intervals.

A **time series** is a time-ordered sequence of observations taken at regular intervals (e.g., hourly, daily, weekly, monthly, quarterly, annually). The data may be measurements of demand, earnings, profits, shipments, accidents, output, precipitation, productivity, and the consumer price index. Forecasting techniques based on time series data are made on the assumption that future values of the series can be estimated from past values. Although no attempt is made to identify variables that influence the series, these methods are widely used, often with quite satisfactory results.

Analysis of time series data requires the analyst to identify the underlying behavior of the series. This can often be accomplished by merely *plotting the data* and visually examining the plot. One or more patterns might appear: trends, seasonal variations, cycles, or variations around an average. In addition, there will be random and perhaps irregular variations. These behaviors can be described as follows:

trend A long-term upward or downward movement in data.

seasonality Short-term regular variations related to the calendar or time of day.

cycle Wavelike variations lasting more than one year.

irregular variation Caused by unusual circumstances, not reflective of typical behavior.

random variations Residual variations after all other behaviors are accounted for.

1. **Trend** refers to a long-term upward or downward movement in the data. Population shifts, changing incomes, and cultural changes often account for such movements.
2. **Seasonality** refers to short-term, fairly regular variations generally related to factors such as the calendar or time of day. Restaurants, supermarkets, and theaters experience weekly and even daily "seasonal" variations.
3. **Cycles** are wavelike variations of more than one year's duration. These are often related to a variety of economic, political, and even agricultural conditions.
4. **Irregular variations** are due to unusual circumstances such as severe weather conditions, strikes, or a major change in a product or service. They do not reflect typical behavior, and inclusion in the series can distort the overall picture. Whenever possible, these should be identified and removed from the data.
5. **Random variations** are residual variations that remain after all other behaviors have been accounted for.

These behaviors are illustrated in Figure 3.1. The small "bumps" in the plots represent random variability.

The remainder of this section has descriptions of the various approaches to the analysis of time series data. Before turning to those discussions, one point should be emphasized: A demand forecast should be based on a time series of past *demand* rather than unit sales. Sales would not truly reflect demand if one or more *stockouts* occurred.

Naive Methods

naive forecast The forecast for any period equals the previous period's actual value.

A simple, but widely used approach to forecasting is the naive approach. A **naive forecast** uses a single previous value of a time series as the basis of a forecast. The naive approach can be used with a stable series (variations around an average), with seasonal variations, or with trend. With a stable series, the last data point becomes the forecast for the next period. Thus, if demand for a product last week was 20 cases, the forecast for this week is 20 cases. With seasonal variations, the forecast for this "season" is equal to the value of the series last "season." For example, the forecast for demand for turkeys this Thanksgiving season is equal to demand for turkeys last Thanksgiving; the forecast of the number of checks cashed at a bank on

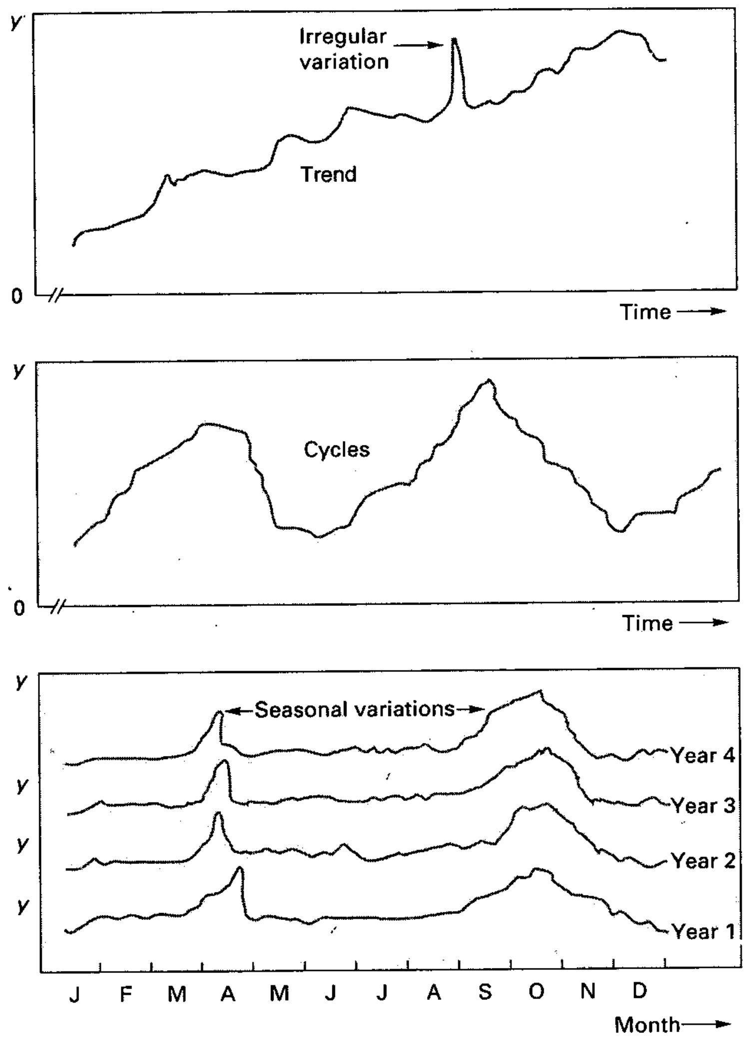


FIGURE 3.1

Trend, seasonal, cyclical, random, and irregular variations

the first day of the month next month is equal to the number of checks cashed on the first day of this month; and the forecast for highway traffic volume this Friday is equal to the highway traffic volume last Friday. For data with trend, the forecast is equal to the last value of the series plus or minus the difference between the last two values of the series. For example, suppose the last two values were 50 and 53. Using *t* to represent the current time period, we have:

Period	Actual	Change from Previous Value	Forecast
(previous) $t-1$	50		
(current) t	53	+3	
(next) $t+1$			53 + +3 = 56

Although at first glance the naive approach may appear *too* simplistic, it is nonetheless a legitimate forecasting tool. Consider the advantages: It has virtually no cost, it is quick and easy to prepare because data analysis is nonexistent, and it is easily understandable. The main objection to this method is its inability to provide highly accurate forecasts. However, if resulting accuracy is acceptable, this approach deserves serious consideration. Moreover, even if other forecasting techniques offer better accuracy, they will almost always involve a greater cost. The accuracy of a naive forecast can serve as a standard of comparison against which to judge the cost and accuracy of other techniques. Thus, managers must answer the question: Is the increased accuracy of another method worth the additional resources required to achieve that accuracy?

Techniques for Averaging

Historical data typically contain a certain amount of random variation, or *white noise,* that tends to obscure systematic movements in the data. This randomness arises from the combined influence of many—perhaps a great many—relatively unimportant factors, and it cannot be reliably predicted. Averaging techniques smooth variations in the data. Ideally, it would be desirable to completely remove any randomness from the data and leave only "real" variations, such as changes in the demand. As a practical matter, however, it is usually impossible to distinguish between these two kinds of variations, so the best one can hope for is that the small variations are random and the large variations are "real."

Averaging techniques smooth fluctuations in a time series because the individual highs and lows in the data offset each other when they are combined into an average. A forecast based on an average thus tends to exhibit less variability than the original data (see Figure 3.2). This can be advantageous because many of these movements merely reflect random variability rather than a true change in the series. Moreover, because responding to changes in expected demand often entails considerable cost (e.g., changes in production rate, changes in the size of a workforce, inventory changes), it is desirable to avoid reacting to minor variations. Thus, minor variations are treated as random variations, whereas larger variations are viewed as more likely to reflect "real" changes, although these, too, are smoothed to a certain degree.

Averaging techniques generate forecasts that reflect recent values of a time series (e.g., the average value over the last several periods). These techniques work best when a series tends to vary around an average, although they also can handle step changes or gradual changes in the level of the series. Three techniques for averaging are described in this section:

1. Moving average
2. Weighted moving average
3. Exponential smoothing

moving average Technique that averages a number of recent actual values, updated as new values become available.

Moving Average One weakness of the naive method is that the forecast just *traces* the actual data, with a lag of one period; it does not smooth at all. But by expanding the amount of historical data a forecast is based on, this difficulty can be overcome. A **moving average** forecast uses a *number* of the most recent actual data values in generating a forecast. The moving average forecast can be computed using the following equation:

$$F_t = MA_n = \frac{\sum_{i=1}^{n} A_{t-i}}{n} \tag{3–1}$$

where

i = An index that corresponds to time periods

n = Number of periods (data points) in the moving average

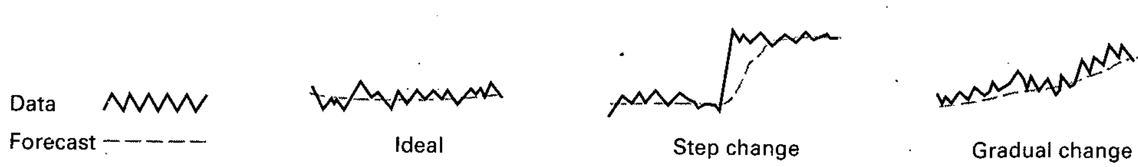
A_i = Actual value in period $t - i$

MA = Moving average

F_t = Forecast for time period t

FIGURE 3.2

Averaging applied to three possible patterns



For example, MA_3 would refer to a three-period moving average forecast, and MA_5 would refer to a five-period moving average forecast.

EXAMPLE 1

Compute a three-period moving average forecast given demand for shopping carts for the last five periods.

Period	Demand	
1	42	
2	40	
3	43	the 3 most recent demands
4	40	
5	41	

SOLUTION

$$F_6 = \frac{43 + 40 + 41}{3} = 41.33$$

If actual demand in period 6 turns out to be 38, the moving average forecast for period 7 would be

$$F_7 = \frac{40 + 41 + 38}{3} = 39.67$$

Note that in a moving average, as each new actual value becomes available, the forecast is updated by adding the newest value and dropping the oldest and then recomputing the average. Consequently, the forecast "moves" by reflecting only the most recent values.

In computing a moving average, including a *moving total* column—which gives the sum of the *n* most current values from which the average will be computed—aids computations. To update the moving total: Subtract the oldest value from the newest value and add that amount to the moving total for each update.

Figure 3.3 illustrates a three-period moving average forecast plotted against actual demand over 31 periods. Note how the moving average forecast *lags* the actual values and how *smooth* the forecasted values are compared with the actual values.

The moving average can incorporate as many data points as desired. In selecting the number of periods to include, the decision maker must take into account that the number of data points in the average determines its sensitivity to each new data point: The fewer the data points in an average, the more sensitive (responsive) the average tends to be. (See Figure 3.4.)

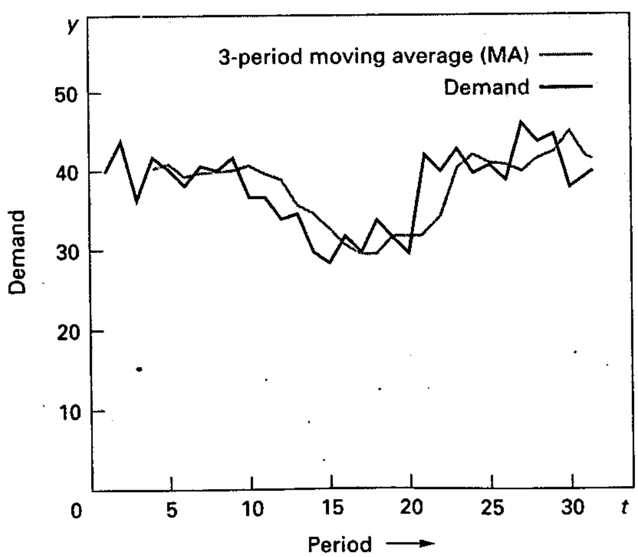
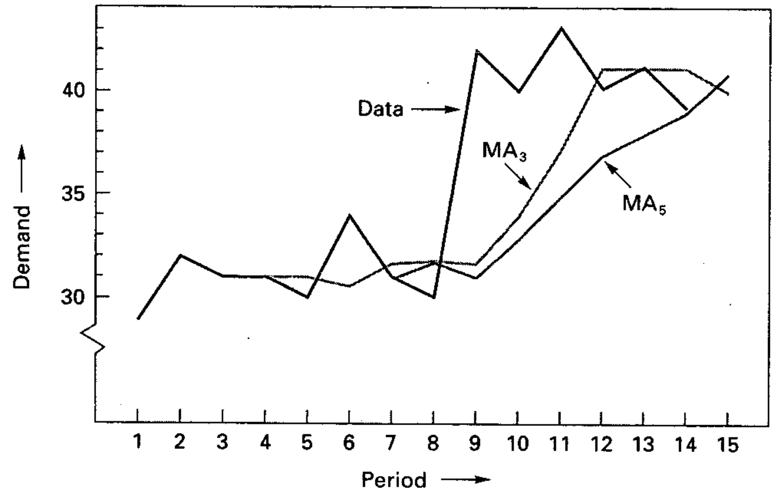


FIGURE 3.3

A moving average forecast tends to smooth and lag changes in the data

FIGURE 3.4

The more periods in a moving average, the greater the forecast will lag changes in the data



If responsiveness is important, a moving average with relatively few data points should be used. This will permit quick adjustment to, say, a step change in the data, but it also will cause the forecast to be somewhat responsive even to random variations. Conversely, moving averages based on more data points will smooth more but be less responsive to "real" changes. Hence, the decision maker must weigh the cost of responding more slowly to changes in the data against the cost of responding to what might simply be random variations. A review of forecast errors can help in this decision.

The advantages of a moving average forecast are that it is easy to compute and easy to understand. A possible disadvantage is that all values in the average are weighted equally. For instance, in a 10-period moving average, each value has a weight of 1/10. Hence, the oldest value has the *same weight* as the most recent value. If a change occurs in the series, a moving average forecast can be slow to react, especially if there are a large number of values in the average. Decreasing the number of values in the average increases the weight of more recent values, but it does so at the expense of losing potential information from less recent values.

weighted average More recent values in a series are given more weight in computing a forecast.

Weighted Moving Average A **weighted average** is similar to a moving average, except that it assigns more weight to the most recent values in a time series. For instance, the most recent value might be assigned a weight of .40, the next most recent value a weight of .30, the next after that a weight of .20, and the next after that a weight of .10. Note that the weights sum to 1.00, and that the heaviest weights are assigned to the most recent values.[1]

EXAMPLE 2

Given the following demand data,

a. Compute a weighted average forecast using a weight of .40 for the most recent period, .30 for the next most recent, .20 for the next, and .10 for the next.

b. If the actual demand for period 6 is 39, forecast demand for period 7 using the same weights as in part *a*.

Period	Demand
1	42
2	40
3	43
4	40
5	41

[1]In general, $F_t = w_n A_{t-n} + w_{n-1} A_{t-(n-1)} + \cdots w_1 A_{t-1}$

SOLUTION

a. $F_6 = .10(40) + .20(43) + .30(40) + .40(41) = 41.0$

b. $F_7 = .10(43) + .20(40) + .30(41) + .40(39) = 40.2$

Note that if four weights are used, only the *four most recent* demands are used to prepare the forecast.

The advantage of a weighted average over a simple moving average is that the weighted average is more reflective of the most recent occurrences. However, the choice of weights is somewhat arbitrary and generally involves the use of trial and error to find a suitable weighting scheme.

exponential smoothing Weighted averaging method based on previous forecast plus a percentage of the forecast error.

IOM

Exponential Smoothing **Exponential smoothing** is a sophisticated weighted averaging method that is still relatively easy to use and understand. Each new forecast is based on the previous forecast plus a percentage of the difference between that forecast and the actual value of the series at that point. That is:

Next forecast = Previous forecast + α(Actual − Previous forecast)

where (Actual − Previous forecast) represents the forecast error and α is a percentage of the error. More concisely,

$$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1}) \quad (3\text{–}2a)$$

where

F_t = Forecast for period t

F_{t-1} = Forecast for the previous period

α = Smoothing constant

A_{t-1} = Actual demand or sales for the previous period

The smoothing constant α represents a percentage of the forecast error. Each new forecast is equal to the previous forecast plus a percentage of the previous error. For example, suppose the previous forecast was 42 units, actual demand was 40 units, and $\alpha = .10$. The new forecast would be computed as follows:

$$F_t = 42 + .10(40 - 42) = 41.8$$

Then, if the actual demand turns out to be 43, the next forecast would be

$$F_t = 41.8 + .10(43 - 41.8) = 41.92$$

An alternate form of formula 3–2a reveals the weighting of the previous forecast and the latest actual demand:

$$F_t = (1 - \alpha)F_{t-1} + \alpha A_{t-1} \quad (3\text{–}2b)$$

For example, if $\alpha = .10$, this would be

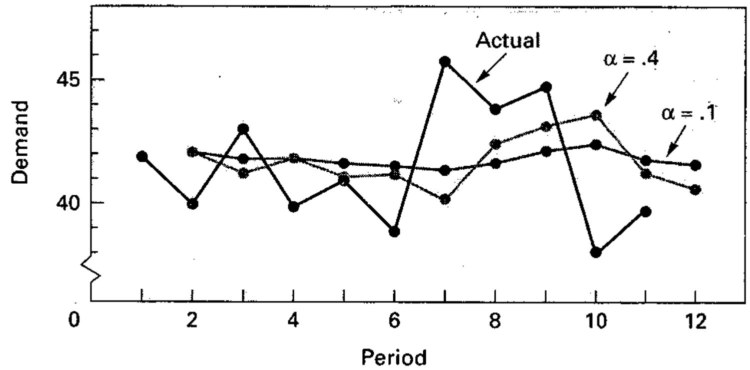
$$F_t = .90F_{t-1} + .10A_{t-1}$$

The quickness of forecast adjustment to error is determined by the smoothing constant, α. The closer its value is to zero, the slower the forecast will be to adjust to forecast errors (i.e., the greater the smoothing). Conversely, the closer the value of α is to 1.00, the greater the responsiveness and the less the smoothing. This is illustrated in Example 3.

EXAMPLE 3

The following table illustrates two series of forecasts for a data set, and the resulting (Actual − Forecast) = Error, for each period. One forecast uses $\alpha = .10$ and one uses $\alpha = .40$. The following figure plots the actual data and both sets of forecasts.

Period (*t*)	Actual Demand	α = .10 Forecast	Error	α = .40 Forecast	Error
1	42	—	—	—	—
2	40	42	−2	42	−2
3	43	41.8	1.2	41.2	1.8
4	40	41.92	−1.92	41.92	−1.92
5	41	41.73	−0.73	41.15	−0.15
6	39	41.66	−2.66	41.09	−2.09
7	46	41.39	4.61	40.25	5.75
8	44	41.85	2.15	42.55	1.45
9	45	42.07	2.93	43.13	1.87
10	38	42.35	−4.35	43.88	−5.88
11	40	41.92	−1.92	41.53	−1.53
12		41.73		40.92	



Selecting a smoothing constant is basically a matter of judgment or trial and error, using forecast errors to guide the decision. The goal is to select a smoothing constant that balances the benefits of smoothing random variations with the benefits of responding to real changes if and when they occur. Commonly used values of α range from .05 to .50. Low values of α are used when the underlying average tends to be stable; higher values are used when the underlying average is susceptible to change.

Some computer packages include a feature that permits automatic modification of the smoothing constant if the forecast errors become unacceptably large.

Exponential smoothing is one of the most widely used techniques in forecasting, partly because of its ease of calculation, and partly because of the ease with which the weighting scheme can be altered—simply by changing the value of α.

Note. A number of different approaches can be used to obtain a *starting forecast,* such as the average of the first several periods, a subjective estimate, or the first actual value as the forecast for period 2 (i.e., the naive approach). For simplicity, the naive approach is used in this book. In practice, using an average of, say, the first three values as a forecast for period 4 would provide a better starting forecast because that would tend to be more representative.

Techniques for Trend

Analysis of trend involves developing an equation that will suitably describe trend (assuming that trend is present in the data). The trend component may be linear, or it may not. Some commonly encountered nonlinear trend types are illustrated in Figure 3.5. A simple plot of the data often can reveal the existence and nature of a trend. The discussion here focuses exclusively on *linear* trends because these are fairly common.

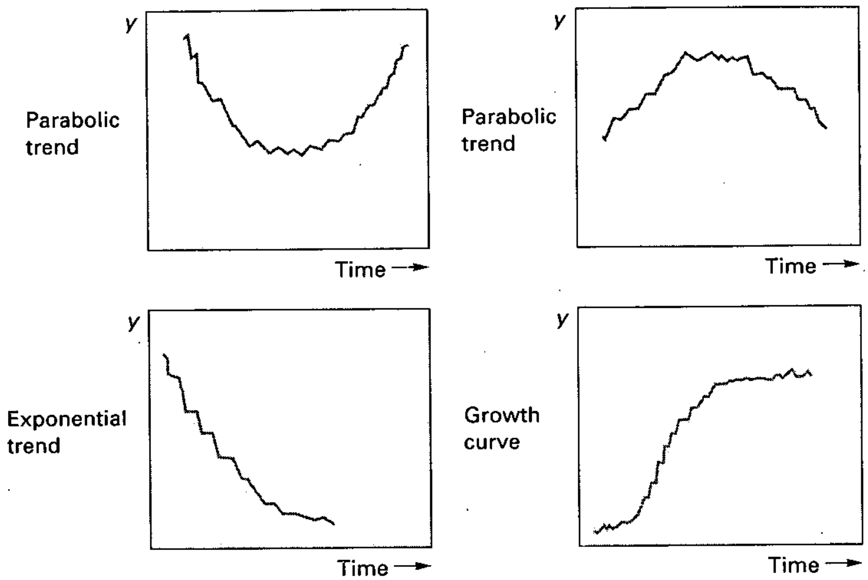


FIGURE 3.5

Graphs of some nonlinear trends

There are two important techniques that can be used to develop forecasts when trend is present. One involves use of a trend equation; the other is an extension of exponential smoothing.

Trend Equation A **linear trend equation** has the form

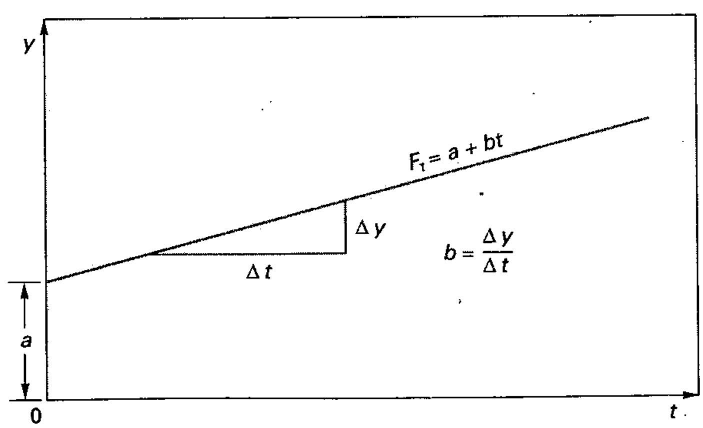
linear trend equation $F_t = a + bt$, used to develop forecasts when trend is present.

IOM

$$F_t = a + bt \tag{3–3}$$

where

t = Specified number of time periods from $t = 0$
F_t = Forecast for period t
a = Value of F_t at $t = 0$
b = Slope of the line



The line intersects the y axis where $y = a$. The slope of the line $= b$.

For example, consider the trend equation $F_t = 45 + 5t$. The value of F_t when $t = 0$ is 45, and the slope of the line is 5, which means that, on the average, the value of F_t will increase by five units for each time period. If $t = 10$, the forecast, F_t, is $45 + 5(10) = 95$ units. The equation can be plotted by finding two points on the line. One can be found by substituting some value of t into the equation (e.g., $t = 10$) and then solving for F_t. The other point is a (i.e., F_t at $t = 0$). Plotting those two points and drawing a line through them yields a graph of the linear trend line.

The coefficients of the line, a and b, can be computed from historical data using these two equations:

$$b = \frac{n\sum ty - \sum t \sum y}{n\sum t^2 - (\sum t)^2} \tag{3–4}$$

$$a = \frac{\sum y - b\sum t}{n} \text{ or } \bar{y} - b\bar{t} \tag{3–5}$$

where

n = Number of periods

y = Value of the time series

Note that these three equations are identical to those used for computing a linear regression line, except that t replaces x in the equations. Manual computation of the coefficients of a trend line can be simplified by use of Table 3.1, which lists values of Σt and Σt^2 for up to 20 periods ($n = 20$). You can also use a template on the CD.

TABLE 3.1
Values of Σt and Σt^2

n	Σt	Σt^2
1 . . .	1	1
2 . . .	3	5
3 . . .	6	14
4 . . .	10	30
5 . . .	15	55
6 . . .	21	91
7 . . .	28	140
8 . . .	36	204
9 . . .	45	285
10 . . .	55	385
11 . . .	66	506
12 . . .	78	650
13 . . .	91	819
14 . . .	105	1,015
15 . . .	120	1,240
16 . . .	136	1,496
17 . . .	153	1,785
18 . . .	171	2,109
19 . . .	190	2,470
20 . . .	210	2,870

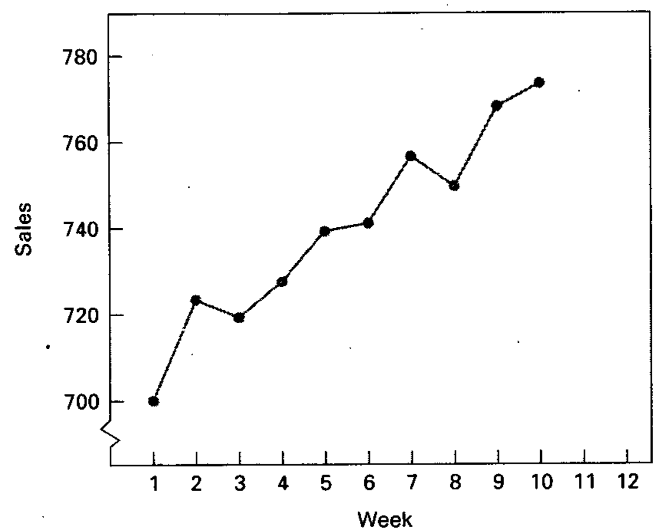
EXAMPLE 4

Cell phone sales for a California-based firm over the last 10 weeks are shown in the table below. Plot the data, and visually check to see if a linear trend line would be appropriate. Then determine the equation of the trend line, and predict sales for weeks 11 and 12.

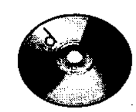
Week	Unit Sales
1	700
2	724
3	720
4	728
5	740
6	742
7	758
8	750
9	770
10	775

SOLUTION

a. A plot suggests that a linear trend line would be appropriate:



b. You can use an Excel template on the DVD or Table 3–1 and Formulas 3–4 and 3–5.



Week (t)	y	ty
1	700	700
2	724	1,448
3	720	2,160
4	728	2,912
5	740	3,700
6	742	4,452
7	758	5,306
8	750	6,000
9	770	6,930
10	775	7,750
	7,407	41,358

From Table 3.1, for $n = 10$, $\Sigma t = 55$ and $\Sigma t^2 = 385$. Using Formulas 3–4 and 3–5, you can compute the coefficients of the trend line:

$$b = \frac{10(41{,}358) - 55(7{,}407)}{10(385) - 55(55)} = \frac{6{,}195}{825} = 7.51$$

$$a = \frac{7{,}407 - 7.51(55)}{10} = 699.40$$

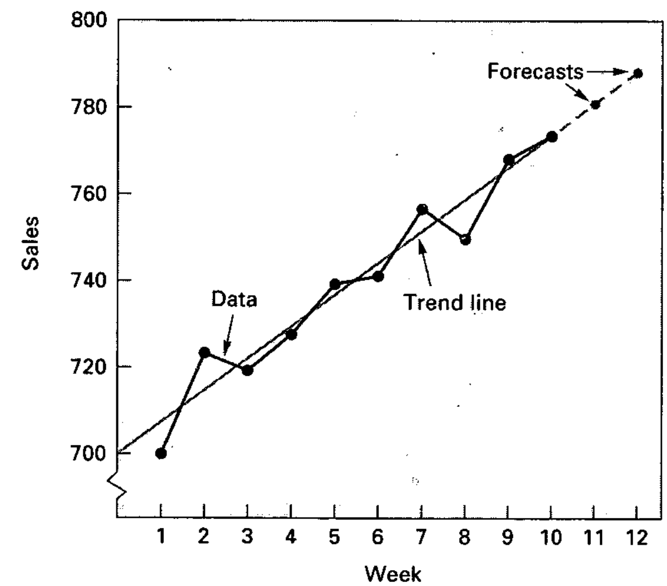
The trend line is $F_t = 699.40 + 7.51t$, where $t = 0$ for period 0.

c. Substituting values of t into this equation, the forecasts for the next two periods (i.e., $t = 11$ and $t = 12$) are:

$$F_{11} = 699.40 + 7.51(11) = 782.01$$

$$F_{12} = 699.40 + 7.51(12) = 789.52$$

d. For purposes of illustration, the original data, the trend line, and the two projections (forecasts) are shown on the following graph:



Trend-Adjusted Exponential Smoothing

trend-adjusted exponential smoothing Variation of exponential smoothing used when a time series exhibits trend.

IOM

A variation of simple exponential smoothing can be used when a time series exhibits a *linear* trend. It is called **trend-adjusted exponential smoothing** or, sometimes, *double smoothing,* to differentiate it from simple exponential smoothing, which is appropriate only when data vary around an average or have step or gradual changes. If a series exhibits trend, and simple smoothing is used on it, the forecasts will all lag the trend: if the data are increasing, each forecast will be too low; if decreasing, each forecast will be too high.

The trend-adjusted forecast (TAF) is composed of two elements: a smoothed error and a trend factor.

$$\text{TAF}_{t+1} = S_t + T_t \quad (3\text{–}6)$$

where

S_t = Previous forecast plus smoothed error

T_t = Current trend estimate

and

$$S_t = \text{TAF}_t + \alpha(A_t - \text{TAF}_t)$$
$$T_t = T_{t-1} + \beta(\text{TAF}_t - \text{TAF}_{t-1} - T_{t-1}) \quad (3\text{–}7)$$

where α and β are smoothing constants. In order to use this method, one must select values of α and β (usually through trial and error) and make a starting forecast and an estimate of trend.

EXAMPLE 5

Using the cell phone data from the previous example (where it was concluded that the data exhibited a linear trend), use trend-adjusted exponential smoothing to obtain forecasts for periods 6 through 11, with $\alpha = .40$ and $\beta = .30$.

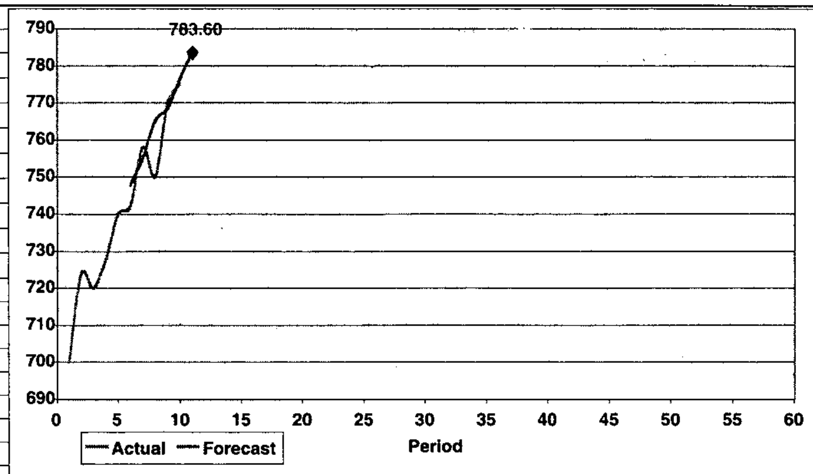
SOLUTION

The initial estimate of trend is based on the net change of 28 for the *three changes* from period 1 to period 4, for an average of 9.33. The Excel spreadsheet is shown in Table 3.2. Notice that an initial estimate of trend is estimated from the first four values, and that the starting forecast (period 5) is developed using the previous (period 4) value of 728 plus the initial trend estimate:

Starting forecast = 728 + 9.33 = 737.33

TABLE 3.2 Using the Excel template for trend-adjusted smoothing

Trend Adjusted Exponential Smoothing			
<Back			Clear
Model Initialization:			
Period =	5		
Forecast =	737.33	α =	0.4
Trend =	9.3	Δα =	0.1
MAD =	5.39	β =	0.3
MSE =	69.41	Δβ =	0.1
Period	**Actual**	**Forecast**	**Error**
1	700		
2	724		
3	720		
4	728		
5	740		
6	742	747.728	−5.728
7	758	755.0872	2.9128
8	750	765.21536	−15.21536
9	770	768.44179	1.558208
10	775	776.55181	−1.551808
11		783.6048	
12			



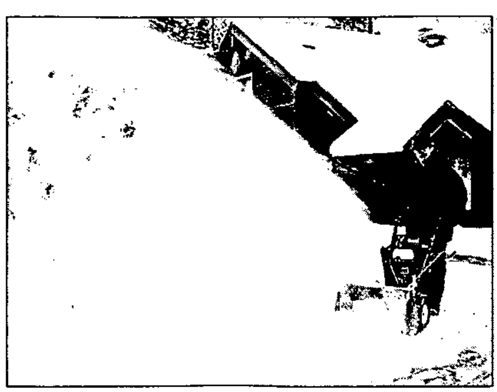
Period: 11 | Actual: | Forecast: 783.60

Unlike a linear trend line, trend-adjusted smoothing has the ability to adjust to *changes* in trend. Of course, trend projections are much simpler with a trend line than with trend-adjusted forecasts, so a manager must decide which benefits are most important when choosing between these two techniques for trend.

Techniques for Seasonality

Seasonal variations in time series data are regularly repeating upward or downward movements in series values that can be tied to recurring events. *Seasonality* may refer to regular annual variations. Familiar examples of seasonality are weather variations (e.g., sales of winter and summer sports equipment) and vacations or holidays (e.g., airline travel, greeting card sales, visitors at tourist and resort centers). The term *seasonal variation* is also applied to daily, weekly, monthly, and other regularly recurring patterns in data. For example, rush hour traffic occurs twice a day—incoming in the morning and outgoing in the late afternoon. Theaters and restaurants often experience weekly demand patterns, with demand higher later in the week. Banks may experience daily seasonal variations (heavier traffic during the noon hour and just before closing), weekly variations (heavier toward the end of the week), and monthly variations (heaviest around the beginning of the month because of social security, payroll, and welfare checks being cashed or deposited). Mail volume; sales of toys, beer, automobiles, and turkeys; highway usage; hotel registrations; and gardening also exhibit seasonal variations.

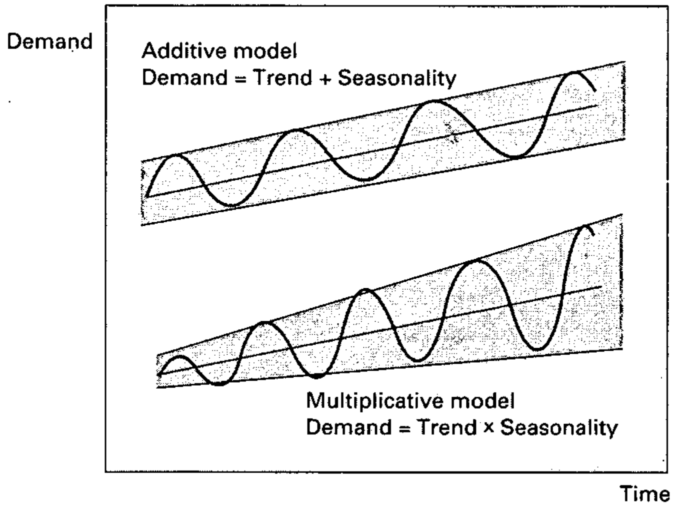
seasonal variations Regularly repeating movements in series values that can be tied to recurring events.



Demand for products such as lawnmowers and snow throwers is subject to seasonal fluctuations. Toro matches these fluctuations by reallocating manufacturing capacity between products.

FIGURE 3.6

Seasonality: the additive and multiplicative models compared using a linear trend



Seasonality in a time series is expressed in terms of the amount that actual values deviate from the *average* value of a series. If the series tends to vary around an average value, then seasonality is expressed in terms of that average (or a moving average); if trend is present, seasonality is expressed in terms of the trend value.

There are two different models of seasonality: additive and multiplicative. In the *additive* model, seasonality is expressed as a *quantity* (e.g., 20 units), which is added to or subtracted from the series average in order to incorporate seasonality. In the *multiplicative* model, seasonality is expressed as a *percentage* of the average (or trend) amount (e.g., 1.10), which is then used to multiply the value of a series to incorporate seasonality. Figure 3.6 illustrates the two models for a linear trend line. In practice, businesses use the multiplicative model much more widely than the additive model, so we shall focus exclusively on the multiplicative model.

seasonal relative Percentage of average or trend.

The seasonal percentages in the multiplicative model are referred to as **seasonal relatives** or *seasonal indexes.* Suppose that the seasonal relative for the quantity of toys sold in May at a store is 1.20. This indicates that toy sales for that month are 20 percent above the monthly average. A seasonal relative of .90 for July indicates that July sales are 90 percent of the monthly average.

Knowledge of seasonal variations is an important factor in retail planning and scheduling. Moreover, seasonality can be an important factor in capacity planning for systems that must be designed to handle peak loads (e.g., public transportation, electric power plants, highways, and bridges). Knowledge of the extent of seasonality in a time series can enable one to *remove* seasonality from the data (i.e., to seasonally adjust data) in order to discern other patterns or the lack of patterns in the series. Thus, one frequently reads or hears about "seasonally adjusted unemployment" and "seasonally adjusted personal income."

The next section briefly describes how seasonal relatives are used, and the following section describes how seasonal relatives are computed.

Using Seasonal Relatives Seasonal relatives are used in two different ways in forecasting. One way is to *deseasonalize data;* the other way is to *incorporate seasonality* in a *forecast.*

To deseasonalize data is to remove the seasonal component from the data in order to get a clearer picture of the nonseasonal (e.g., trend) components. Deseasonalizing data is accomplished by *dividing* each data point by its corresponding seasonal relative (e.g., divide November demand by the November relative, divide December demand by the December relative, and so on).

Incorporating seasonality in a forecast is useful when demand has both trend (or average) and seasonal components. Incorporating seasonality can be accomplished in this way:

1. Obtain trend estimates for desired periods using a trend equation.

2. Add seasonality to the trend estimates by *multiplying* (assuming a multiplicative model is appropriate) these trend estimates by the corresponding seasonal relative (e.g., multiply the November trend estimate by the November seasonal relative, multiply the December trend estimate by the December seasonal relative, and so on).

Example 6 illustrates incorporating seasonality in a forecast.

EXAMPLE 6

A furniture manufacturer wants to predict quarterly demand for a certain loveseat for periods 15 and 16, which happen to be the second and third quarters of a particular year. The series consists of both trend and seasonality. The trend portion of demand is projected using the equation $F_t = 124 + 7.5t$. Quarter relatives are $Q_1 = 1.20$, $Q_2 = 1.10$, $Q_3 = 0.75$, and $Q_4 = 0.95$. Use this information to predict demand for periods 15 and 16.

SOLUTION

The trend values at $t = 15$ and $t = 16$ are:

$$F_{15} = 124 + 7.5(15) = 236.5$$
$$F_{16} = 124 + 7.5(16) = 244.0$$

Multiplying the trend value by the appropriate quarter relative yields a forecast that includes both trend and seasonality. Given that $t = 15$ is a second quarter and $t = 16$ is a third quarter, the forecasts are

Period 15: 236.5(1.10) = 260.15

Period 16: 244.0(0.75) = 183.00

Computing Seasonal Relatives A commonly used method for representing the trend portion of a time series involves a **centered moving average.** Computations and the resulting values are the same as those for a moving average forecast. However, the values are not projected as in a forecast; instead, they are *positioned in the middle* of the periods used to compute the moving average. The implication is that the average is most representative of that point in the series. For example, assume the following time series data:

centered moving average A moving average positioned at the center of the data that were used to compute it.

Period	Demand	Three-Period Centered Average	
1	40		
2	46	42.67	$Average = \frac{40 + 46 + 42}{3} = 42.67$
3	42		

The three-period average is 42.67. As a centered average, it is positioned at period 2; the average is most representative of the series at that point.

The ratio of demand at period 2 to this centered average at period 2 is an estimate of the seasonal relative at that point. Because the ratio is 46/42.67 = 1.08, the series is about 8 percent above average at that point. To achieve a reasonable estimate of seasonality for any season (e.g., Friday attendance at a theater), it is usually necessary to compute seasonal ratios for a number of seasons and then average these ratios. In the case of theater attendance, average the ratios of five or six Fridays for the Friday relative, average five or six Saturdays for the Saturday relative, and so on.

EXAMPLE 7

The manager of a parking lot has computed daily relatives for the number of cars per day in the lot. The computations are repeated here (about three weeks are shown for illustration). A seven-period centered moving average is used because there are seven days (seasons) per week.

Day	Volume	Moving Total	Centered MA_7	Volume/MA
Tues	67			
Wed	75			
Thur	82			
Fri	98		71.86	98/71.86 = 1.36 (Friday)
Sat	90		70.86	90/70.86 = 1.27
Sun	36		70.57	36/70.57 = 0.51
Mon	55	503 ÷ 7 =	71.00	55/71.00 = 0.77
Tues	60	496 ÷ 7 =	71.14	60/71.14 = 0.84 (Tuesday)
Wed	73	494 etc.	70.57	73/70.57 = 1.03
Thur	85	497	71.14	85/71.14 = 1.19
Fri	99	498	70.71	99/70.71 = 1.40 (Friday)
Sat	86	494	71.29	86/71.29 = 1.21
Sun	40	498	71.71	40/71.71 = 0.56
Mon	52	495	72.00	52/72.00 = 0.72
Tues	64	499	71.57	64/71.57 ≐ 0.89 (Tuesday)
Wed	76	502	71.86	76/71.86 = 1.06
Thur	87	504	72.43	87/72.43 = 1.20
Fri	96	501	72.14	96/72.14 = 1.33 (Friday)
Sat	88	503		
Sun	44	507		
Mon	50	505		

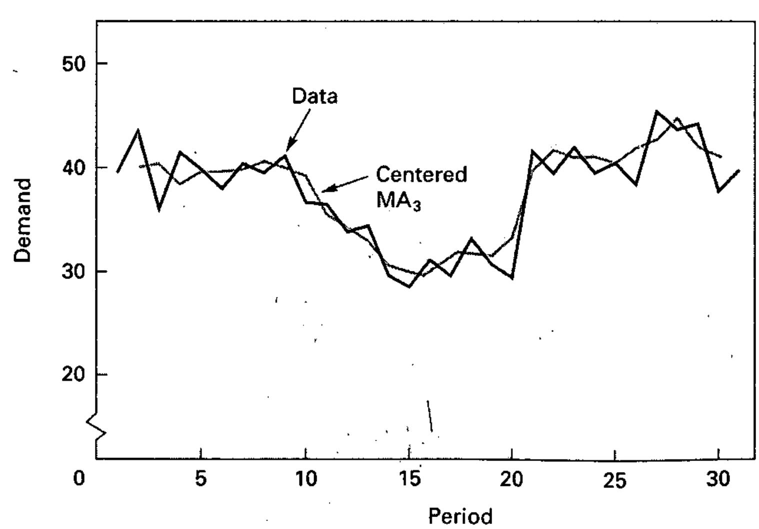
The estimated Friday relative is $(1.36 + 1.40 + 1.33)/3 = 1.36$. Relatives for other days can be computed in a similar manner. For example, the estimated Tuesday relative is $(0.84 + 0.89)/2 = 0.87$.

The number of periods needed in a centered moving average is equal to the number of "seasons" involved. For example, with monthly data, a 12-period moving average is needed. When the number of periods is even, one additional step is needed because the middle of an even set falls between two periods. The additional step requires taking a centered two-period moving average of the even-numbered centered moving average, which results in averages that "line up" with data points and, hence, permit determination of seasonal ratios. (See Solved Problem 4 at the end of this chapter for an example.)

A centered moving average is used to obtain representative values because by virtue of its centered position—it "looks forward" and "looks backward"—it is able to closely follow data movements whether they involve trends, cycles, or random variability alone. Figure 3.7 illustrates how a three-period centered moving average closely tracks the data originally shown in Figure 3.3.

FIGURE 3.7

A centered moving average closely tracks the data



Techniques for Cycles

Cycles are up and down movements similar to seasonal variations but of longer duration—say, two to six years between peaks. When cycles occur in time series data, their frequent irregularity makes it difficult or impossible to project them from past data because turning points are difficult to identify. A short moving average or a naive approach may be of some value, although both will produce forecasts that lag cyclical movements by one or several periods.

The most commonly used approach is explanatory: Search for another variable that relates to, and *leads,* the variable of interest. For example, the number of housing starts (i.e., permits to build houses) in a given month often is an indicator of demand a few months later for products and services directly tied to construction of new homes (landscaping; sales of washers and dryers, carpeting, and furniture; new demands for shopping, transportation, schools). Thus, if an organization is able to establish a high correlation with such a *leading variable* (i.e., changes in the variable precede changes in the variable of interest), it can develop an equation that describes the relationship, enabling forecasts to be made. It is important that a persistent relationship exists between the two variables. Moreover, the higher the correlation, the better the chances that the forecast will be on target.

ASSOCIATIVE FORECASTING TECHNIQUES

Associative techniques rely on identification of related variables that can be used to predict values of the variable of interest. For example, sales of beef may be related to the price per pound charged for beef and the prices of substitutes such as chicken, pork, and lamb; real estate prices are usually related to property location and square footage; and crop yields are related to soil conditions and the amounts and timing of water and fertilizer applications.

The essence of associative techniques is the development of an equation that summarizes the effects of **predictor variables.** The primary method of analysis is known as **regression.** A brief overview of regression should suffice to place this approach into perspective relative to the other forecasting approaches described in this chapter.

predictor variables Variables that can be used to predict values of the variable of interest.

regression Technique for fitting a line to a set of points.

Simple Linear Regression

The simplest and most widely used form of regression involves a linear relationship between two variables. A plot of the values might appear like that in Figure 3.8. The object in linear regression is to obtain an equation of a straight line that minimizes the sum of squared vertical deviations of data points from the line (i.e., the *least squares criterion*). This **least squares line** has the equation

$$y_c = a + bx \tag{3–8}$$

least squares line Minimizes the sum of the squared vertical deviations around the line.

IOM

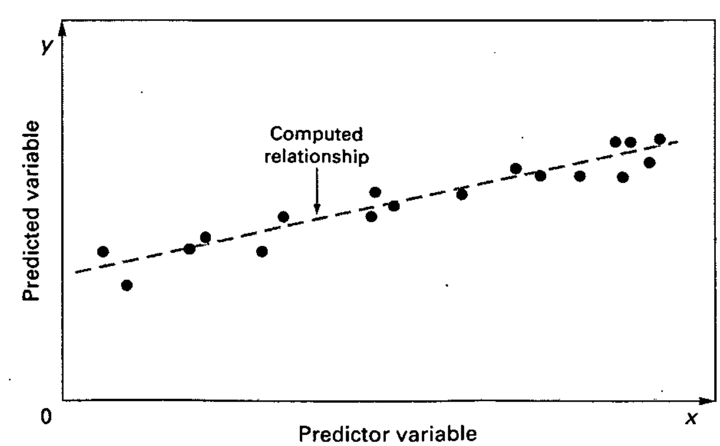
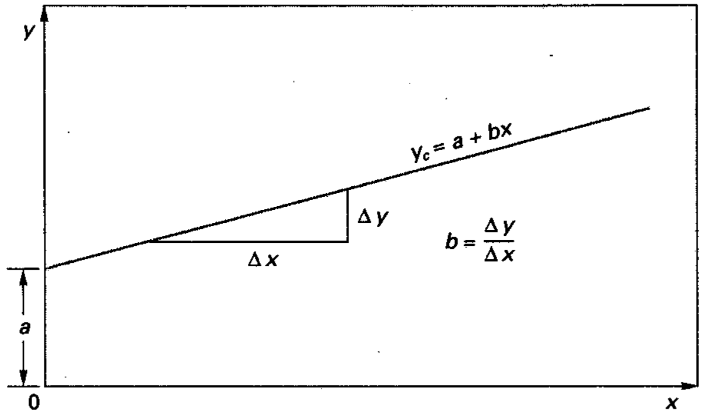


FIGURE 3.8

A straight line is fitted to a set of sample points

FIGURE 3.9
Equation of a straight line



The line intersects the y axis where $y = a$. The slope of the line = b.

where

y_c = Predicted (dependent) variable
x = Predictor (independent) variable
b = Slope of the line
a = Value of y_c when $x = 0$ (i.e., the height of the line at the y intercept)

(Note: It is conventional to represent values of the predicted variable on the y axis and values of the predictor variable on the x axis.) Figure 3.9 is a general graph of a linear regression line.

The coefficients a and b of the line are based on these two equations:

$$b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \tag{3–9}$$

$$a = \frac{\sum y - b\sum x}{n} \text{ or } \bar{y} - b\bar{x} \tag{3–10}$$

where

n = Number of paired observations

EXAMPLE 8

Healthy Hamburgers has a chain of 12 stores in northern Illinois. Sales figures and profits for the stores are given in the following table. Obtain a regression line for the data, and predict profit for a store assuming sales of $10 million.

Unit Sales, x (in $ millions)	Profits, y (in $ millions)
$ 7	$0.15
2	0.10
6	0.13
4	0.15
14	0.25
15	0.27
16	0.24
12	0.20
14	0.27
20	0.44
15	0.34
7	0.17

SOLUTION

First, plot the data and decide if a linear model is reasonable (i.e., do the points seem to scatter around a straight line? Figure 3.10 suggests they do). Next, using the appropriate Excel

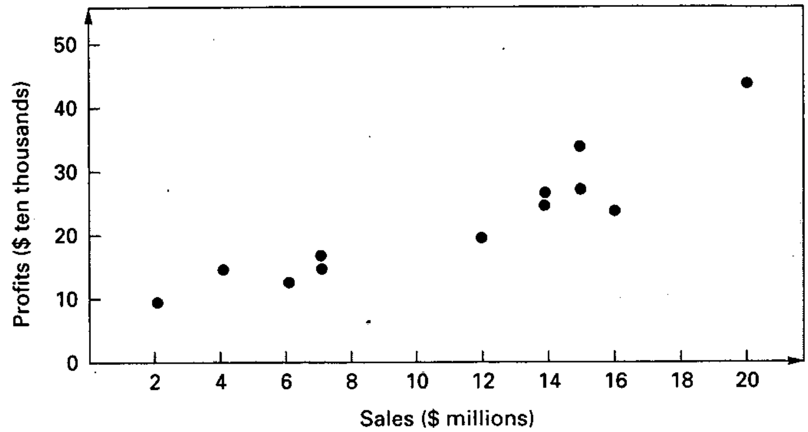
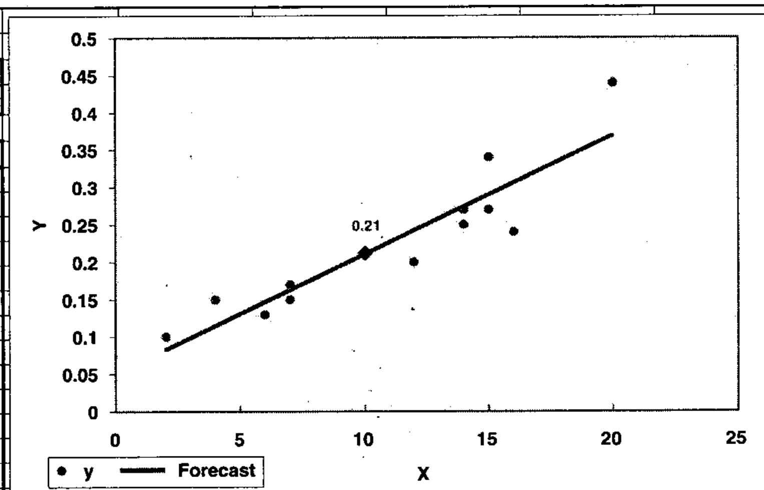


FIGURE 3.10
A linear model seems reasonable

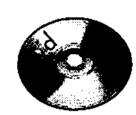
TABLE 3.3 Using the Excel template for linear regression

Simple Linear Regression		Clear	
<Back			
Slope =	0.0159	r =	0.9166657
Intercept =	0.0506008	r^2 =	0.840276
x	y	Forecast	Error
7	0.15	0.1621124	–0.0121124
2	0.1	0.0824612	0.0175388
6	0.13	0.1461822	–0.0161822
4	0.15	0.1143217	0.0356783
14	0.25	0.273624	–0.023624
15	0.27	0.2895543	–0.0195543
16	0.24	0.3054845	–0.0654845
12	0.2	0.2417636	–0.0417636
14	0.27	0.273624	–0.003624
20	0.44	0.3692054	0.0707946
15	0.34	0.2895543	0.0504457
7	0.17	0.1621124	0.0078876



x =	10		
Δx =	1	Forecast:	0.2099031

template on the DVD, obtain the regression equation $y_c = 0.0506 + 0.0159x$ (see Table 3.3). For sales of $x = 10$ (i.e., 10 million), estimated profit is $y_c = 0.0506 + 0.0159(10) = 0.2099$, or $209,900. (It may appear strange that substituting $x = 0$ into the equation produces a predicted profit of $50,600 because it seems to suggest that amount of profit will occur with no sales. However, the value of $x = 0$ is *outside the range of observed values.* The regression line should be used only for the range of values from which it was developed; the relationship may be nonlinear outside that range. The purpose of the a value is simply to establish the height of the line where it crosses the y axis.)



Excel

One application of regression in forecasting relates to the use of indicators. These are uncontrollable variables that tend to lead or precede changes in a variable of interest. For example, changes in the Federal Reserve Board's discount rate may influence certain business activities. Similarly, an increase in energy costs can lead to price increases for a wide range of products and services. Careful identification and analysis of indicators may yield insight into possible future demand in some situations. There are numerous published indexes and websites from which to choose.[2] These include

[2]See, for example, *The National Bureau of Economic Research, The Survey of Current Business, The Monthly Labor Review,* and *Business Conditions Digest.*

Net change in inventories on hand and on order.

Interest rates for commercial loans.

Industrial output.

Consumer price index (CPI).

The wholesale price index.

Stock market prices.

Other potential indicators are population shifts, local political climates, and activities of other firms (e.g., the opening of a shopping center may result in increased sales for nearby businesses). Three conditions are required for an indicator to be valid:

1. The relationship between movements of an indicator and movements of the variable should have a logical explanation.
2. Movements of the indicator must precede movements of the dependent variable by enough time so that the forecast isn't outdated before it can be acted upon.
3. A fairly high correlation should exist between the two variables.

correlation A measure of the strength and direction of relationship between two variables.

Correlation measures the strength and direction of relationship between two variables. Correlation can range from -1.00 to $+1.00$. A correlation of $+1.00$ indicates that changes in one variable are always matched by changes in the other; a correlation of -1.00 indicates that increases in one variable are matched by decreases in the other; and a correlation close to zero indicates little *linear* relationship between two variables. The correlation between two variables can be computed using the equation

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2} \cdot \sqrt{n(\sum y^2) - (\sum y)^2}} \qquad (3\text{–}11)$$

The square of the correlation coefficient, r^2, provides a measure of the percentage of variability in the values of y that is "explained" by the independent variable. The possible values of r^2 range from 0 to 1.00. The closer r^2 is to 1.00, the greater the percentage of explained variation. A high value of r^2, say .80 or more, would indicate that the independent variable is a good predictor of values of the dependent variable. A low value, say .25 or less, would indicate a poor predictor, and a value between .25 and .80 would indicate a moderate predictor.

Comments on the Use of Linear Regression Analysis

Use of simple regression analysis implies that certain assumptions have been satisfied. Basically, these are

1. Variations around the line are random. If they are random, no patterns such as cycles or trends should be apparent when the line and data are plotted.
2. Deviations around the line should be normally distributed. A concentration of values close to the line with a small proportion of larger deviations supports the assumption of normality.
3. Predictions are being made only within the range of observed values.

If the assumptions are satisfied, regression analysis can be a powerful tool. To obtain the best results, observe the following:

1. Always plot the data to verify that a linear relationship is appropriate.
2. The data may be time-dependent. Check this by plotting the dependent variable versus time; if patterns appear, use analysis of time series instead of regression, or use time as an independent variable as part of a *multiple regression analysis.*
3. A small correlation may imply that other variables are important.

In addition, note these weaknesses of regression:

1. Simple linear regression applies only to linear relationships with *one* independent variable.

2. One needs a considerable amount of data to establish the relationship—in practice, 20 or more observations.
3. All observations are weighted equally.

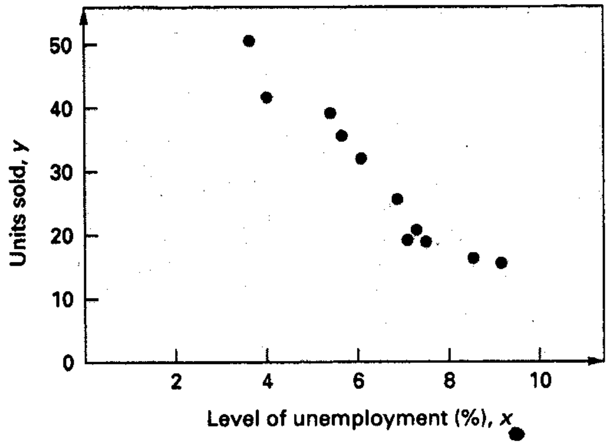
EXAMPLE 9

Sales of 19-inch color television sets and three-month lagged unemployment are shown in the following table. Determine if unemployment levels can be used to predict demand for 19-inch color TVs and, if so, derive a predictive equation.

Period	1	2	3	4	5	6	7	8	9	10	11
Units sold	20	41	17	35	25	31	38	50	15	19	14
Unemployment % (three-month lag)	7.2	4.0	7.3	5.5	6.8	6.0	5.4	3.6	8.4	7.0	9.0

SOLUTION

1. Plot the data to see if a *linear* model seems reasonable. In this case, a linear model seems appropriate *for the range of the data.*



2. Check the correlation coefficient to confirm that it is not close to zero using the DVD template, and then obtain the regression equation:

   $r = -.966$

   This is a fairly high negative correlation. The regression equation is

   $y = 71.85 - 6.91x$

Excel

Note that the equation pertains only to unemployment levels in the range 3.6 to 9.0, because sample observations covered only that range.

Curvilinear and Multiple Regression Analysis

Simple linear regression may prove inadequate to handle certain problems because a linear model is inappropriate or because more than one predictor variable is involved. When nonlinear relationships are present, you should employ curvilinear regression; models that involve more than one predictor require the use of multiple regression analysis. While these analyses are beyond the scope of this text, you should be aware that they are often used. The computations lend themselves more to computers than to hand calculation. Multiple regression forecasting substantially increases data requirements. In each case, it is necessary to weigh the additional cost and effort against potential improvements in accuracy of predictions.

ACCURACY AND CONTROL OF FORECASTS

Accuracy and control of forecasts is a vital aspect of forecasting. The complex nature of most real-world variables makes it almost impossible to correctly predict future values of those variables on a regular basis. Consequently, it is important to include an indication of the extent to which the forecast might deviate from the value of the variable that actually occurs. This will provide the forecast user with a better perspective on how far off a forecast might be.

Moreover, decision makers will want to include accuracy as a factor when choosing among different techniques, along with cost. Accurate forecasts are necessary for the success of daily activities of every business organization. Forecasts are the basis for an organization's schedules, and unless the forecasts are accurate, schedules will be generated that may provide for too few or too many resources, too little or too much output, the wrong output, or the wrong timing of output, all of which can lead to additional costs, dissatisfied customers, and headaches for managers.

Some forecasting applications involve a series of forecasts (e.g., weekly revenues), whereas others involve a single forecast that will be used for a one-time decision (e.g., the size of a power plant). When making periodic forecasts, it is important to monitor forecast errors to determine if the errors are within reasonable bounds. If they are not, it will be necessary to take corrective action.

error Difference between the actual value and the value that was predicted for a given period.

Forecast **error** is the difference between the value that occurs and the value that was predicted for a given time period. Hence, Error = Actual − Forecast:

$$e_t = A_t - F_t \qquad (3\text{–}12)$$

Positive errors result when the forecast is too low, negative errors when the forecast is too high. For example, if actual demand for a week is 100 units and forecast demand was 90 units, the forecast was too low; the error is 100 − 90 = +10.

Forecast errors influence decisions in two somewhat different ways. One is in making a choice between various forecasting alternatives, and the other is in evaluating the success or failure of a technique in use. We shall begin by examining ways to summarize forecast error over time, and see how that information can be applied to compare forecasting alternatives. Then we shall consider methods for controlling forecasts.

High Forecasts Can Be Bad News — NEWSCLIP

Overly optimistic forecasts by retail store buyers can easily lead retailers to overorder, resulting in bloated inventories. When that happens, there is pressure on stores to cut prices in order to move the excess merchandise. Although customers delight in these markdowns, retailer profits generally suffer. Furthermore, retailers will naturally cut back on new orders while they work off their inventories, creating a ripple effect that hits the entire supply chain, from shippers, to producers, to suppliers of raw materials. The message is clear: Overly optimistic forecasts can be bad news.

Source: Based on "Bloated Inventories at Retailers May Mean Trouble for Investors" by Susan Pulliam, *The Wall Street Journal*, May 22, 1997, p. C1.

Summarizing Forecast Accuracy

Forecast accuracy is a significant factor when deciding among forecasting alternatives. Accuracy is based on the historical error performance of a forecast.

mean absolute deviation (MAD) The average absolute forecast error.

mean squared error (MSE) The average of squared forecast errors.

mean absolute percent error (MAPE) The average absolute percent error.

Three commonly used measures for summarizing historical errors are the **mean absolute deviation (MAD)**, the **mean squared error (MSE)**, and the **mean absolute percent error (MAPE).** MAD is the average absolute error, MSE is the average of squared errors, and MAPE is the average absolute percent error. The formulas used to compute MAD,[3] MSE, and MAPE are

$$\text{MAD} = \frac{\sum|\text{Actual}_t - \text{Forecast}_t|}{n} \qquad (3\text{–}13)$$

$$\text{MSE} = \frac{\sum(\text{Actual}_t - \text{Forecast}_t)^2}{n-1} \qquad (3\text{–}14)$$

$$\text{MAPE} = \frac{\sum \frac{|\text{Actual}_t - \text{Forecast}_t|}{\text{Actual}_t} \times 100}{n} \qquad (3\text{–}15)$$

[3]The absolute value, represented by the two vertical lines in formula 3–13, ignores minus signs; all data are treated as positive values. For example, −2 becomes +2.

Example 10 illustrates the computation of MAD, MSE, and MAPE.

EXAMPLE 10

Compute MAD, MSE, and MAPE for the following data.

Period	Actual	Forecast	(A − F) Error	|Error|	Error²	[|Error| ÷ Actual] × 100
1	217	215	2	2	4	.92%
2	213	216	−3	3	9	1.41
3	216	215	1	1	1	.46
4	210	214	−4	4	16	1.90
5	213	211	2	2	4	.94
6	219	214	5	5	25	2.28
7	216	217	−1	1	1	.46
8	212	216	−4	4	16	1.89
			−2	22	76	10.26%

SOLUTION

Using the figures shown in the table,

$$\text{MAD} = \frac{\Sigma|e|}{n} = \frac{22}{8} = 2.75$$

$$\text{MSE} = \frac{\Sigma e^2}{n-1} = \frac{76}{8-1} = 10.86$$

$$\text{MAPE} = \frac{\Sigma\left[\frac{|e|}{\text{Actual}} \times 100\right]}{n} = \frac{10.26\%}{8} = 1.28\%$$

From a computational standpoint, the difference between these measures is that MAD weights all errors evenly, MSE weights errors according to their *squared* values, and MAPE weights according to relative error.

One use for these measures is to compare the accuracy of alternative forecasting methods. For instance, a manager could compare the results of exponential smoothing with values of alpha of .1, .2, and .3, to determine one that yields the *lowest* MAD, MSE, or MAPE for a given set of data.

In some instances, historical error performance is secondary to the ability of a forecast to respond to changes in data patterns. Choice among alternative methods would then focus on the cost of not responding quickly to a change relative to the cost of responding to changes that are not really there (i.e., random fluctuations).

Overall, the operations manager must settle on the relative importance of historical performance versus responsiveness and whether to use MAD, MSE, or MAPE to measure historical performance.

Controlling the Forecast

Many forecasts are made at regular intervals (e.g., weekly, monthly, quarterly). Because forecast errors are the rule rather than the exception, there will be a succession of forecast errors. Tracking the forecast errors and analyzing them can provide useful insight on whether or not forecasts are performing satisfactorily.

There are a variety of possible sources of forecast errors, including the following:

1. The model may be inadequate due to (*a*) the omission of an important variable, (*b*) a change or shift in the variable that the model cannot deal with (e.g., sudden appearance of a trend or cycle), or (*c*) the appearance of a new variable (e.g., new competitor).
2. Irregular variations may occur due to severe weather or other natural phenomena, temporary shortages or breakdowns, catastrophes, or similar events.
3. The forecasting technique may be used incorrectly or the results misinterpreted.

4. There are always random variations in the data. Randomness is the inherent variation that remains in the data after all causes of variation have been accounted for.

A forecast is generally deemed to perform adequately when the errors exhibit only random variations. Hence, the key to judging when to reexamine the validity of a particular forecasting technique is whether forecast errors are random. If they are not random, it is necessary to investigate to determine which of the other sources is present and how to correct the problem.

control chart A visual tool for monitoring forecast errors.

A very useful tool for detecting nonrandomness in errors is a **control chart.** Errors are plotted on a control chart in the order that they occur, such as the one depicted in Figure 3.11. The centerline of the chart represents an error of zero. Note the two other lines, one above and one below the centerline. They are called the upper and lower control limits because they represent the upper and lower ends of the range of acceptable variation for the errors.

In order for the forecast errors to be judged "in control" (i.e., random), two things are necessary. One is that all errors are within the control limits. The other is that no patterns (e.g., trends, cycles, noncentered data) are present. Both can be accomplished by inspection. Figure 3.12 illustrates some examples of nonrandom errors.

Technically speaking, one could determine if any values exceeded either control limit without actually plotting the errors, but the visual detection of patterns generally requires plotting the errors, so it is best to construct a control chart and plot the errors on the chart.

FIGURE 3.11

Conceptual representation of a control chart

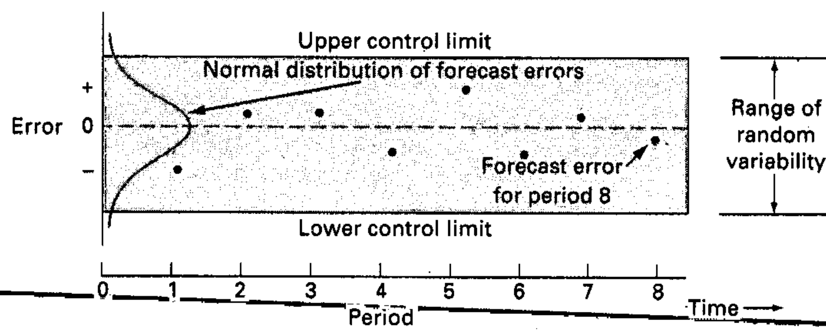
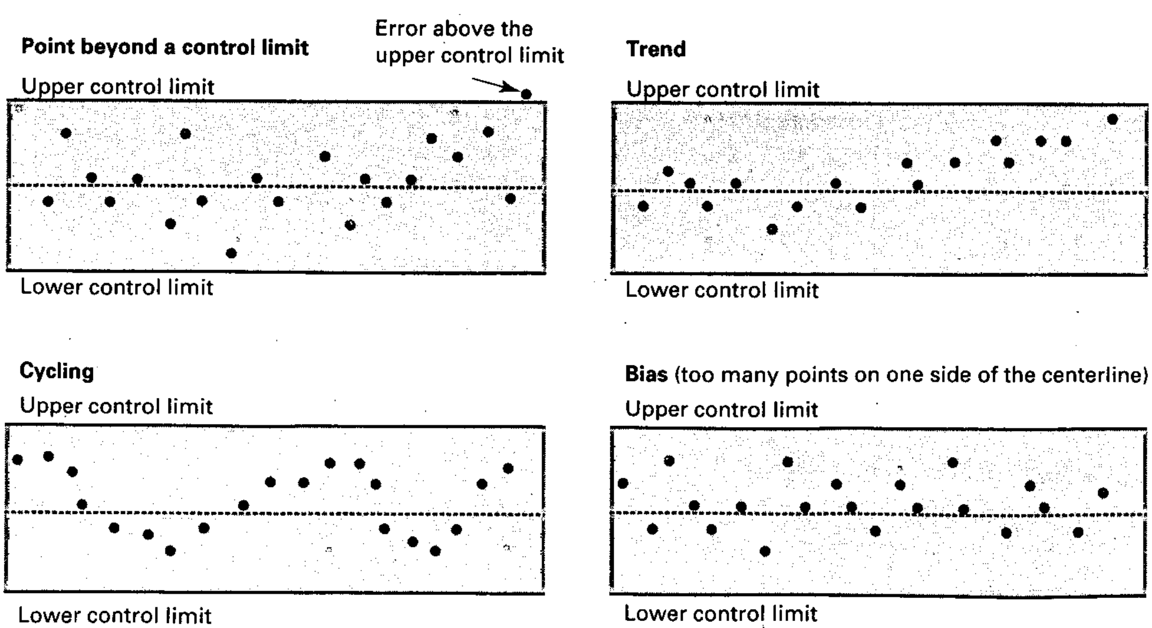


FIGURE 3.12

Examples of nonrandomness



To construct a control chart, first compute the MSE. The square root of MSE is used in practice as an estimate of the standard deviation of the distribution of errors.[4] That is,

$$s = \sqrt{\text{MSE}} \tag{3–16}$$

Control charts are based on the assumption that when errors are random, they will be distributed according to a normal distribution around a mean of zero. Recall that for a normal distribution, approximately 95.5 percent of the values (errors in this case) can be expected to fall within limits of $0 \pm 2s$ (i.e., 0 ± 2 standard deviations), and approximately 99.7 percent of the values can be expected to fall within $\pm 3s$ of zero. With that in mind, the following formulas can be used to obtain the upper control limit (UCL) and the lower control limit (LCL):

$$\text{UCL: } 0 + z\sqrt{\text{MSE}}$$

$$\text{LCL: } 0 - z\sqrt{\text{MSE}}$$

where

z = the number of standard deviations from the mean.

Combining these two formulas, we obtain the following expression for the control limits:

$$\text{Control limits: } 0 \pm z\sqrt{\text{MSE}} \tag{3–17}$$

EXAMPLE 11

Compute $2s$ control limits for forecast errors when the MSE is 2.0

SOLUTION

$s = \sqrt{\text{MSE}} = 1.41$

$\text{UCL} = 0 + 2(1.41) = +2.82$

$\text{LCL} = 0 - 2(1.41) = -2.82$

+2.82 ______________

0 - - - - - - - - - - - - - -

−2.82 ______________

An older, less informative technique that is sometimes employed to monitor forecast errors is the **tracking signal.** It relates the cumulative forecast error to the average absolute error (i.e., MAD). The intent is to detect any **bias** in errors over time (i.e., a tendency for a sequence of errors to be positive or negative). The tracking signal is computed period by period using the formula.

tracking signal The ratio of cumulative forecast error to the corresponding value of MAD, used to monitor a forecast.

bias Persistent tendency for forecasts to be greater or less than the actual values of a time series.

$$\text{Tracking signal}_t = \frac{\Sigma(\text{Actual}_t - \text{Forecast}_t)}{\text{MAD}_t} \tag{3–18}$$

Values can be positive or negative. A value of zero would be ideal; limits of ± 4 or ± 5 are often used for a range of acceptable values of the tracking signal. If a value outside the acceptable range occurs, that would be taken as a signal that there is bias in the forecast, and that corrective action is needed.

After an initial value of MAD had been determined, MAD can be updated using exponential smoothing:

$$\text{MAD}_t = \text{MAD}_{t-1} + \alpha(|\text{Actual} - \text{Forecast}|_t - \text{MAD}_{t-1}) \tag{3–19}$$

EXAMPLE 12

Monthly sales of leather jackets at the Lucky Leather Shoppe for the past 24 months, and forecasts and errors for those months, are shown in the following table. Determine if the forecast is working using these approaches:

1. A tracking signal, beginning with month 10, updating MAD with exponential smoothing. Use limits of ± 4 and $\alpha = .2$.
2. A control chart with $2s$ limits. Use data from the first eight months to develop the control chart, then evaluate the remaining data with the control chart.

[4]The actual value could be computed as $s = \sqrt{\frac{\Sigma(e - \bar{e})^2}{n - 1}}$.

Month	A (Sales)	F (Forecast)	A − F (Error)	|e|	Cumulative |e|
1	47	43	4	4	4
2	51	44	7	7	11
3	54	50	4	4	15
4	55	51	4	4	19
5	49	54	−5	5	24
6	46	48	−2	2	26
7	38	46	−8	8	34
8	32	44	−12	12	46
9	25	35	−10	10	56
10	24	26	−2	2	58
11	30	25	5	5	
12	35	32	3	3	
13	44	34	10	10	
14	57	50	7	7	
15	60	51	9	9	
16	55	54	1	1	
17	51	55	−4	4	
18	48	51	−3	3	
19	42	50	−8	8	
20	30	43	−13	13	
21	28	38	−10	10	
22	25	27	−2	2	
23	35	27	8	8	
24	38	32	6	6	
			−11		

SOLUTION

a. The sum of absolute errors through the 10th month is 58. Hence, the initial MAD is 58/10 = 5.8. The subsequent MADs are updated using the formula $MAD_{new} = MAD_{old} + \alpha(|e| - MAD_{old})$. The results are shown in the following table.

The tracking signal for any month is

$$\frac{\text{Cumulative error at that month}}{\text{Updated MAD at that month}}$$

t (Month)	|e|	$MAD_t = MAD_{t-1} + .2(\|e\| - MAD_{t-1})$	Cumulative Error	Tracking Signal = Cumulative $Error_t \div MAD_t$
10			−20	−20/5.800 = −3.45
11	5	5.640 = 5.8 + .2(5 − 5.8)	−15	−15/5.640 = −2.66
12	3	5.112 = 5.640 + .2(3 − 5.64)	−12	−12/5.112 = −2.35
13	10	6.090 = 5.112 + .2(10 − 5.112)	−2	−2/6.090 = −0.33
14	7	6.272 = 6.090 + .2(7 − 6.090)	5	5/6.272 = 0.80
15	9	6.818 = 6.272 + .2(9 − 6.272)	14	14/6.818 = 2.05
16	1	5.654 = 6.818 + .2(1 − 6.818)	15	15/5.654 = 2.65
17	4	5.323 = 5.654 + .2(4 − 5.654)	11	11/5.323 = 2.07
18	3	4.858 = 5.323 + .2(3 − 5.323)	8	8/4.858 = 1.65
19	8	5.486 = 4.858 + .2(8 − 4.858)	0	0/5.486 = 0.00
20	13	6.989 = 5.486 + .2(13 − 5.486)	−13	−13/6.989 = −1.86
21	10	7.591 = 6.989 + .2(10 − 6.989)	−23	−23/7.591 = −3.03
22	2	6.473 = 7.591 + .2(2 − 7.591)	−25	−25/6.473 = −3.86
23	8	6.778 = 6.473 + .2(8 − 6.473)	−17	−17/6.778 = −2.51
24	6	6.622 = 6.778 + .2(6 − 6.778)	−11	−11/6.622 = −1.66

Because the tracking signal is within ±4 every month, there is no evidence of a problem.

b. (1) Make sure that the average error is approximately zero, because a large average would suggest a biased forecast.

$$\text{Average error} = \frac{\sum \text{errors}}{n} = \frac{-11}{24} = -0.46$$

(2) Compute the standard deviation:

$$s = \sqrt{\text{MSE}} = \sqrt{\frac{\Sigma e^2}{n-1}}$$

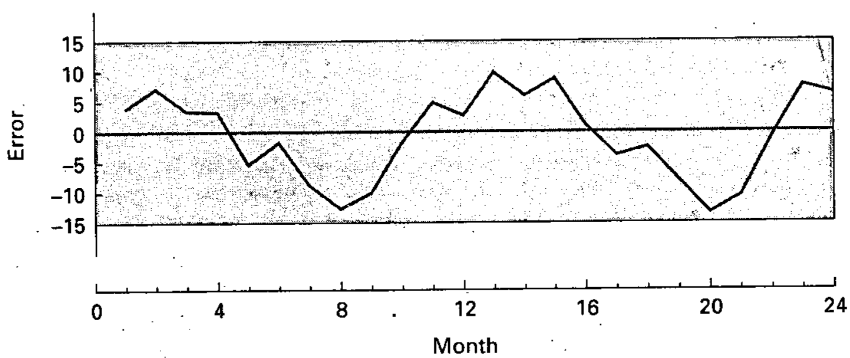
$$= \sqrt{\frac{4^2 + 7^2 + 4^2 + 4^2 + (-5)^2 + (-2)^2 + (-8)^2 + (-12)^2}{8-1}} = 6.91$$

(3) Determine $2s$ control limits:

$$0 \pm 2s = 0 \pm 2(6.91) = -13.82 \text{ to } +13.82$$

(4) i. Check that all errors are within the limits. (They are.)

ii. Plot the data (see the following graph), and check for nonrandom patterns. Note the strings of positive and negative errors. This suggests nonrandomness (and that an improved forecast is possible). The tracking signal did not reveal this.



A plot helps you to visualize the process and enables you to check for possible patterns (i.e., nonrandomness) *within the limits* that suggest an improved forecast is possible.[5]

Like the tracking signal, a control chart focuses attention on deviations that lie outside predetermined limits. With either approach, however, it is desirable to check for possible patterns in the errors, even if all errors are within the limits.

If nonrandomness is found, corrective action is needed. That will result in less variability in forecast errors, and, thus, in narrower control limits. (Revised control limits must be computed using the resulting forecast errors.) Figure 3.13 illustrates the impact on control limits due to decreased error variability.

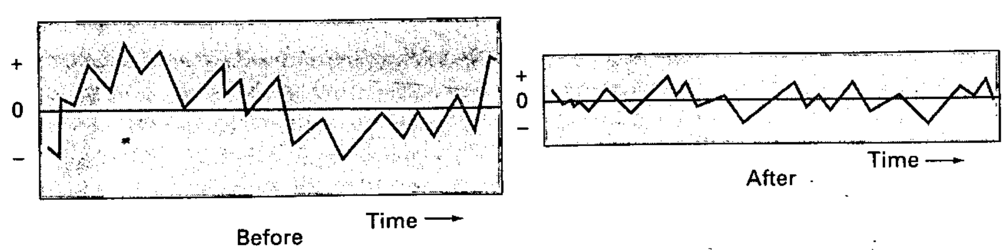


FIGURE 3.13

Removal of a pattern usually results in less variability, and, hence, narrower control limits

[5]The theory and application of control charts and the various methods for detecting patterns in the data are covered in more detail in Chapter 10, on quality control.

Comment. The control chart approach is generally superior to the tracking signal approach. A major weakness of the tracking signal approach is its use of cumulative errors: Individual errors can be obscured so that large positive and negative values cancel each other. Conversely, with control charts, every error is judged individually. Thus, it can be misleading to rely on a tracking signal approach to monitor errors. In fact, the historical roots of the tracking signal approach date from before the first use of computers in business. At that time, it was much more difficult to compute standard deviations than to compute average deviations; for that reason, the concept of a tracking signal was developed. Now computers and calculators can easily provide standard deviations. Nonetheless, the use of tracking signals has persisted, probably because users are unaware of the superiority of the control chart approach.

CHOOSING A FORECASTING TECHNIQUE

Many different kinds of forecasting techniques are available, and no single technique works best in every situation. When selecting a technique for a given situation, the manager or analyst must take a number of factors into consideration.

The two most important factors are *cost* and *accuracy.* How much money is budgeted for generating the forecast? What are the possible costs of errors, and what are the benefits that might accrue from an accurate forecast? Generally speaking, the higher the accuracy, the higher the cost, so it is important to weigh cost–accuracy trade-offs carefully. The best forecast is not necessarily the most accurate or the least costly; rather, it is some combination of accuracy and cost deemed best by management.

Other factors to consider in selecting a forecasting technique include the availability of historical data; the availability of computer software; the ability of decision makers to utilize certain techniques; the time needed to gather and analyze data and to prepare the forecast; and any prior experience with a technique. The forecast horizon is important because some techniques are more suited to long-range forecasts while others work best for the short range. For example, moving averages and exponential smoothing are essentially short-range techniques, since they produce forecasts for the *next* period. Trend equations can be used to project over much longer time periods. When using time series data, *plotting the data* can be very helpful in choosing an appropriate method. Several of the qualitative techniques are well suited to long-range forecasts because they do not require historical data. The Delphi method and executive opinion methods are often used for long-range planning. New products and services lack historical data, so forecasts for them must be based on subjective estimates. In many cases, experience with similar items is relevant. Table 3.4 provides a guide for selecting a forecasting method. Table 3.5 provides additional perspectives on forecasts in terms of the time horizon.

In some instances, a manager might use more than one forecasting technique to obtain independent forecasts. If the different techniques produced approximately the same predictions, that would give increased confidence in the results; disagreement among the forecasts would indicate that additional analysis may be needed.

USING FORECAST INFORMATION

A manager can take a *reactive* or a *proactive* approach to a forecast. A reactive approach views forecasts as probable descriptions of future demand, and a manager reacts to meet that demand (e.g., adjusts production rates, inventories, the workforce). Conversely, a proactive approach seeks to actively influence demand (e.g., by means of advertising, pricing, or product/service changes).

Generally speaking, a proactive approach requires either an explanatory model (e.g., regression) or a subjective assessment of the influence on demand. It is possible that a manager might make two forecasts: one to predict what will happen under the status quo and a second one based on a "what if" approach, if the results of the status quo forecast are unacceptable.

TABLE 3.4 A guide to selecting an appropriate forecasting method

Forecasting Method	Amount of Historical Data	Data Pattern	Forecast Horizon	Preparation Time	Personnel Background
Simple exponential smoothing	5 to 10 observations	Data should be stationary	Short	Short	Little sophistication
Trend-adjusted exponential smoothing	10 to 15 observations	Trend	Short to medium	Short	Moderate sophistication
Trend models	10 to 20; for seasonality at least 5 per season	Trend	Short to medium	Short	Moderate sophistication
Seasonal	Enough to see 2 peaks and troughs	Handles cyclical and seasonal patterns	Short to medium	Short to moderate	Little sophistication
Causal regression models	10 observations per independent variable	Can handle complex patterns	Short, medium, or long	Long development time, short time for implementation	Considerable sophistication

Source: Adapted from J. Holton Wilson and Deborah Allison-Koerber, "Combining Subjective and Objective Forecasts Improves Results," *Journal of Business Forecasting,* Fall 1992, p. 4.

TABLE 3.5
Forecast factors, by range of forecast

Factor	Short Range	Intermediate Range	Long Range
1. Frequency	Often	Occasional	Infrequent
2. Level of aggregation	Item	Product family	Total output Type of product/service
3. Type of model	Smoothing Projection Regression	Projection Seasonal Regression	Managerial judgment
4. Degree of management involvement	Low	Moderate	High
5. Cost per forecast	Low	Moderate	High

COMPUTERS IN FORECASTING

Computers play an important role in preparing forecasts based on quantitative data. Their use allows managers to develop and revise forecasts quickly, and without the burden of manual computations. There is a wide range of software packages available for forecasting. The Excel® templates on your CD-ROM are an example of a spreadsheet approach. There are templates for moving averages, exponential smoothing, linear trend equation, trend-adjusted exponential smoothing, and simple linear regression. Some templates are illustrated in the Solved Problems section at the end of the chapter.

Operations Strategy

Forecasts are the basis for many decisions. Clearly, the more accurate an organization's forecasts, the better prepared it will be to take advantage of future opportunities and reduce potential risks. A worthwhile strategy can be to work to improve short-term forecasts. Better short-term forecasts will not only enhance profits through lower inventory levels, fewer shortages, and improved customer service levels, it also will enhance forecasting *credibility* throughout the organization: If short-term forecasts are inaccurate, why should other areas of the organization put faith in long-term forecasts? Also, the sense of confidence accurate short-term forecasts would generate would allow allocating more resources to strategic and medium- to longer-term planning and less on short-term, tactical activities.

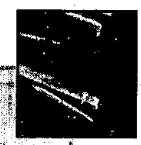
Maintaining accurate, up-to-date information on prices, demand, and other variables can have a significant impact on forecast accuracy. An organization also can do other things to improve forecasts. These do not involve searching for improved techniques but relate to the inverse relation of accuracy to the forecast horizon: Forecasts that cover shorter time frames tend to be more accurate than longer-term forecasts. Recognizing this, management might choose to devote efforts to *shortening the time horizon that forecasts must cover.* Essentially, this means shortening the *lead time* needed to respond to a forecast. This might involve building *flexibility* into operations to permit rapid response to changing demands for products and services, or to changing volumes in quantities demanded; shortening the lead time required to obtain supplies, equipment, and raw materials or the time needed to train or retrain employees; or shortening the time needed to *develop* new products and services.

Sharing forecasts or demand data throughout the supply chain can improve forecast quality in the supply chain, resulting in lower costs and shorter lead times. For example, both Hewlett-Packard and IBM require resellers to include such information in their contracts.

The following reading provides additional insights on forecasting and supply chains.

Gazing at the Crystal Ball

READING



Ram Reddy

Disregarding Demand Forecasting Technologies during Tough Economic Times Can Be a Costly Mistake

It's no secret that the IT sector has felt the brunt of the economic downturn. Caught up in the general disillusionment with IT has been demand forecasting (DF) technologies. Many companies blame DF technologies for supply chain problems such as excess inventory. Pinning the blame on and discontinuing DF technologies is the equivalent of throwing out the baby with the bathwater. The DF misunderstanding stems from the fact that, despite sophisticated mathematical models and underlying technologies, the output from these systems is, at best, an educated guess about the future.

A forecast from these systems is only as good as the assumptions and data used to build the forecast. Even the best forecast fails when an unexpected event—such as a recession—clobbers the underlying assumptions. However, this doesn't imply that DF technologies aren't delivering the goods. But, unfortunately, many DF and supply chain technology implementations have recently fallen victim to this mindset. DF is part science and part art (or intuition)—having the potential to significantly impact a company's bottom line. In this column, you'll find an overview of how DF is supposed to work and contrast that with how most companies actually practice it. I'll conclude with suggestions on how to avoid common mistakes implementing and using this particular class of technologies.

The Need for DF Systems

DF is crucial to minimizing working capital and associated expenses and extracting maximum value from a company's capital investments in property, plant, and equipment (PPE). It takes a manufacturing company a lot of lead time to assemble and stage the raw materials and components to manufacture a given number of products per day. The manufacturing company, in turn, generates its sales forecast numbers using data from a variety of sources such as distribution channels, factory outlets, value-added resellers, historical sales data, and general macroeconomic data. Manufacturing companies can't operate without a demand forecast because they won't know the quantities of finished goods to produce. The manufacturing company wants to make sure all or much of its finished product

(continued)

moves off the store shelves or dealer lots as quickly as possible. Unsold products represent millions of dollars tied up in inventory.

The flip side of this equation is the millions of dollars invested in PPE to manufacture the finished products. The company and its supporting supply chain must utilize as close to 100 percent of its PPE investments. Some manufacturing plants make products in lots of 100 or 1,000. Generally, it's cost prohibitive to have production runs of one unit. So how do you extract maximum value from your investments and avoid having money tied up in unsold inventory?

DF and supply chain management (SCM) technologies try to solve this problem by generating a production plan to meet forecasted demand and extract maximum value from PPE, while reducing the amount of capital tied up in inventory. Usually, the demand forecast is pretty close to the actual outcomes, but there are times when demand forecasts don't match the outcomes. In addition to unforeseen economic events, a new product introduction may be a stellar success or an abysmal failure. In the case of a phenomenal success, the manufacturing plant may not be able to meet demand for its product.

Consider the case of the Chrysler PT Cruiser. It succeeded way beyond the demand forecast's projections. Should it have started with manufacturing capacity to fulfill the runaway demand? Absolutely not. Given the additional millions of dollars of investment in PPE necessary to add that capacity, it would've backfired if the PT Cruiser had been a flop. The value provided by DF and supporting SCM technologies in this instance was the ability to add capacity to meet the amended forecast based on actual events. Demand forecasts can and do frequently miss their targets. The point to underscore here is that the underlying DF and supporting SCM technologies are critical to a company's ability to react and respond in a coordinated manner when market conditions change.

The manufacturing company and its supply chain are able to benefit from sharing information about the changed market conditions and responding to them in a coordinated manner. Despite best practices embedded in DF and SCM technologies to support this manner of collaboration, it plays out differently in the real world.

How It Works in Real Life—Worst Practices

A company prepares its forecast by taking into account data about past sales, feedback from distribution channels, qualitative assessments from field sales managers, and macroeconomic data. DF and SCM technologies take these inputs and add existing capacities within the company and across the supply chain to generate a production plan for optimum financial performance.

There's been incredible pressure on executives of publicly traded companies to keep up stock prices. This pressure, among other reasons, may cause manufacturing company executives to make bold projections to external financial analysts (or Wall Street) about future sales without using the demand forecast generated from the bottom up. When the company realizes this disparity between the initial projection and the forecast, the forecast is changed to reflect the projections made by the company's officers, negating its accuracy.

The company arbitrarily sets sales targets for various regions to meet Wall Street numbers that are totally out of sync with input provided by the regional sales managers for the DF process. Even though the regional sales managers' input may have a qualitative element (art), they tend to be more accurate, given their proximity to the customers in the region. Unfortunately, the arbitrary sales targets make their way back to the supply chain, and the result is often excessive inventory build-up starting at the distribution channels to the upstream suppliers.

Seeing the inventory pile up, the manufacturing company may decide to shut down a production line. This action affects upstream suppliers who had procured raw materials and components to meet the executive-mandated production numbers, which may cause them to treat any future forecasted numbers with suspicion. Most cost efficiencies that could be obtained through planned procurement of raw materials and components go out the window. It's very likely that the companies try to blame DF and SCM technologies for failing to provide a responsive and efficient supply chain, even though the fault may lie in the company's misuse of the technologies and not the technologies themselves.

Guarding against the Extremes

Earlier in this column, I said that DF is part art or intuition and part science. The art/intuition part comes in when subject-matter experts (SMEs) make educated estimates about future sales. These SMEs could range from distribution outlet owners to sales and marketing gurus and economists. Their intuition is typically combined with data (such as historical sales figures) to generate the forecast for the next quarter or year. During a recession, the SMEs tend to get overly pessimistic. The demand forecasts generated from this mindset lead to inventory shortages when the economy recovers. Similarly, during an economic expansion, the SMEs tend to have an overly rosy picture of the future. This optimism leads to inventory gluts when the economy starts to slow down. In both instances, blaming and invalidating DF and SCM technologies is counterproductive in the long run.

It's very rare that a demand forecast and the actual outcome match 100 percent. If it's close enough to avoid lost sales or create an excess inventory situation, it's deemed a success. DF and supporting SCM technologies are supposed to form a closed loop with actual sales at the cash register providing a feedback mechanism. This feedback is especially essential during economic upturns or downturns. It provides the necessary information to a company and its supply chain to react in a coordinated and efficient manner.

(continued)

(concluded)

Don't let the current disillusionment with DF and SCM technologies impede the decision-making process within your company. The intelligent enterprise needs these technologies to effectively utilize its capital resources and efficiently produce to meet its sales forecasts.

Ram Reddy is the author of *Supply Chains to Virtual Integration* (McGraw-Hill, 2001). He is the president of Tactica Consulting Group, a technology and business strategy consulting company.

Source, Ram Reddy, "Gazing at the Crystal Ball," *Intelligent Enterprise,* June 13, 2002.

SUMMARY

Forecasts are vital inputs for the design and the operation of the productive systems because they help managers to anticipate the future.

Forecasting techniques can be classified as qualitative or quantitative. Qualitative techniques rely on judgment, experience, and expertise to formulate forecasts; quantitative techniques rely on the use of historical data or associations among variables to develop forecasts. Some of the techniques are simple and others are complex. Some work better than others, but no technique works all the time. Moreover, all forecasts include a certain degree of inaccuracy, and allowance should be made for this. The techniques generally assume that the same underlying causal system that existed in the past will continue to exist in the future.

The qualitative techniques described in this chapter include consumer surveys, salesforce estimates, executive opinions, and manager and staff opinions. Two major quantitative approaches are described: analysis of time series data and associative techniques. The time series techniques rely strictly on the examination of historical data; predictions are made by projecting past movements of a variable into the future without considering specific factors that might influence the variable. Associative techniques attempt to explicitly identify influencing factors and to incorporate that information into equations that can be used for predictive purposes.

All forecasts tend to be inaccurate; therefore, it is important to provide a measure of accuracy. It is possible to compute several measures of forecast accuracy that help managers to evaluate the performance of a given technique and to choose among alternative forecasting techniques. Control of forecasts involves deciding whether a forecast is performing adequately, typically using a control chart.

TABLE 3.6
Forecasting approaches

	Approaches	Brief Description
Judgment/opinion:	Consumer surveys	Questioning consumers on future plans
	Direct-contact composites	Joint estimates obtained from salespeople or customer service people
	Executive opinion	Finance, marketing, and manufacturing managers join to prepare forecast
	Delphi technique	Series of questionnaires answered anonymously by knowledgeable people; successive questionnaires are based on information obtained from previous surveys
	Outside opinion	Consultants or other outside experts prepare the forecast
Statistical:	Time series:	
	Naive	Next value in a series will equal the previous value in a comparable period
	Moving averages	Forecast is based on an average of recent values
	Exponential smoothing	Sophisticated form of weighted moving average
	Associative models:	
	Simple regression	Values of one variable are used to predict values of a dependent variable
	Multiple regression	Two or more variables are used to predict values of a dependent variable

When selecting a forecasting technique, a manager must choose a technique that will serve the intended purpose at an acceptable level of cost and accuracy.

The various forecasting techniques are summarized in Table 3.6. Table 3.7 lists the formulas used in the forecasting techniques and in the methods of measuring their accuracy. Note that the Excel templates on the CD that accompanies this book are especially useful for tedious calculations.

TABLE 3.7
Summary of formulas

Technique	Formula	Definitions
Moving average forecast	$F = \frac{\sum_{i=1}^{n} A_{t-i}}{n}$	A = Demand in period $t-i$ n = Number of periods
Exponential smoothing forecast	$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1})$	α = Smoothing factor
Linear trend forecast	$F_t = a + bt$ where $b = \frac{n\sum ty - \sum t \sum y}{n\sum t^2 - (\sum t)^2}$ $a = \frac{\sum y - b\sum t}{n}$ or $\bar{y} - b\bar{t}$	a = y intercept b = Slope
Trend-adjusted forecast	$TAF_{t+1} = S_t + T_t$ where $S_t = TAF_t + \alpha(A_t - TAF_t)$ $T_t = T_{t-1} + \beta(TAF_t - TAF_{t-1} - T_{t-1})$	t = Current period TAF_{t+1} = Trend-adjusted forecast for next period S = Previous forecast plus smoothed error T = Trend component
Linear regression forecast	$y_c = a + bx$ where $b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2}$ $a = \frac{\sum y - b\sum x}{n}$ or $\bar{y} - b\bar{x}$	y_c = Computed value of dependent variable x = Predictor (independent) variable b = Slope of the line a = Value of y_c when x = 0
MAD	$MAD = \frac{\sum^{n} \lvert e \rvert}{n}$	MAD = Mean absolute deviation e = Error, $A - F$ n = Number of errors
MSE	$MSE = \frac{\sum^{n} e^2}{n-1}$	MSE = Mean squared error n = Number of errors
MAPE	$MAPE = \frac{\sum^{n}\left[\frac{\lvert e_t \rvert}{\text{Actual}_t} \times 100\right]}{n}$	MAPE = Mean absolute percent error n = Number of errors
Tracking signal	$TS = \frac{\sum^{n} e}{MAD}$	
Control limits	$UCL = 0 + z\sqrt{MSE}$ $LCL = 0 - z\sqrt{MSE}$	$\sqrt{MSE}$ = standard deviation z = Number of standard deviations; 2 and 3 are typical values

KEY TERMS

SOLVED PROBLEMS

Problem 1

Forecasts based on averages. Given the following data:

Period	Number of Complaints
1	60
2	65
3	55
4	58
5	64

Prepare a forecast using each of these approaches:

a. The appropriate naive approach.

b. A three-period moving average.

c. A weighted average using weights of .50 (most recent), .30, and .20.

d. Exponential smoothing with a smoothing constant of .40.

Solution

a. The values are stable (i.e., no trend or cycles). Therefore, the most recent value of the series becomes the next forecast: 64.

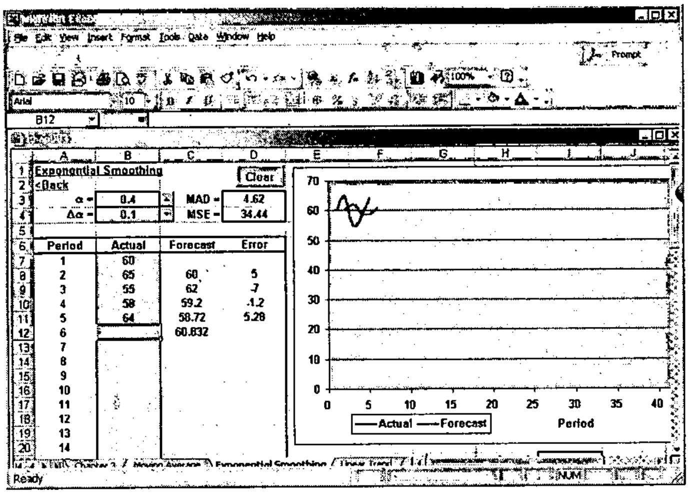
b. $MA_3 = \frac{55 + 58 + 64}{3} = 59$

c. $F = .20(55) + .30(58) + .50(64) = 60.4$

d.

Period	Number of Complaints	Forecast	Calculations
1	60 →		[The previous value of the series is used
2	65	60	as the starting forecast.]
3	55	62	$60 + .40(65 - 60) = 62$
4	58	59.2	$62 + .40(55 - 62) = 59.2$
5	64	58.72	$59.2 + .40(58 - 59.2) = 58.72$
6		60.83	$58.72 + .40(64 - 58.72) = 60.83$

You also can obtain the forecasts and a plot using an Excel template, as shown:



Excel Tutorial

Problem 2

Using seasonal relatives. Apple's Citrus Fruit Farm ships boxed fruit anywhere in the world. Using the following information, a manager wants to forecast shipments for the first four months of next year.

Month	Seasonal Relative	Month	Seasonal Relative
Jan.	1.2	Jul.	0.8
Feb.	1.3	Aug.	0.6
Mar.	1.3	Sep.	0.7
Apr.	1.1	Oct.	1.0
May	0.8	Nov.	1.1
Jun.	0.7	Dec.	1.4

The monthly forecast equation being used is:

$$F_t = 402 + 3t$$

where

t_0 = January of *last* year

F_t = Number of shipments

Solution

a. Determine trend amounts for the first four months of *next* year: January, $t = 24$; February, $t = 25$; etc. Thus,

$$F_{\text{Jan}} = 402 + 3(24) = 474$$

$$F_{\text{Feb}} = 402 + 3(25) = 477$$

$$F_{\text{Mar}} = 402 + 3(26) = 480$$

$$F_{\text{Apr}} = 402 + 3(27) = 483$$

b. Multiply each monthly trend by the corresponding seasonal relative for that month.

Month	Seasonal Relative	Forecast
Jan.	1.2	474(1.2) = 568.8
Feb.	1.3	477(1.3) = 620.1
Mar.	1.3	480(1.3) = 624.0
Apr.	1.1	483(1.1) = 531.3

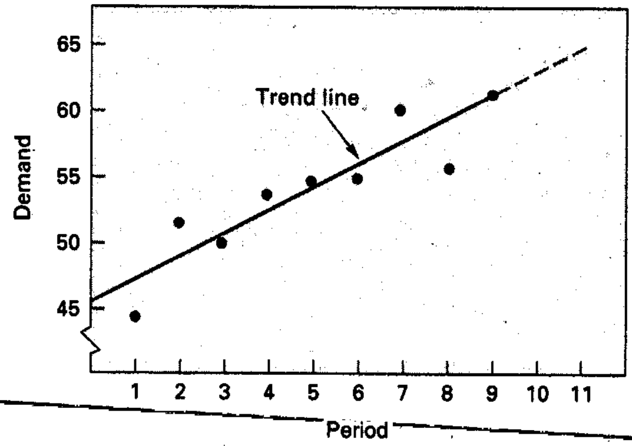
Problem 3

Linear trend line. Plot the data on a graph, and verify visually that a linear trend line is appropriate. Develop a line trend equation for the following data. Then use the equation to predict the next two values of the series.

Solution

Period	Demand
1	44
2	52
3	50
4	54
5	55
6	55
7	60
8	56
9	62

A plot of the data indicates that a linear trend line is appropriate:



Period, t	Demand, y	ty	
1	44	44	From Table 3.1, with $n = 9$,
2	52	104	
3	50	150	$\Sigma t = 45$ and $\Sigma t^2 = 285$
4	54	216	
5	55	275	
6	55	330	
7	60	420	
8	56	448	
9	62	558	
	488	2,545	

$$b = \frac{n\Sigma ty - \Sigma t \Sigma y}{n\Sigma t^2 - (\Sigma t)^2} = \frac{9(2,545) - 45(488)}{9(285) - 45(45)} = 1.75$$

$$a = \frac{\Sigma y - b\Sigma t}{n} = \frac{488 - 1.75(45)}{9} = 45.47$$

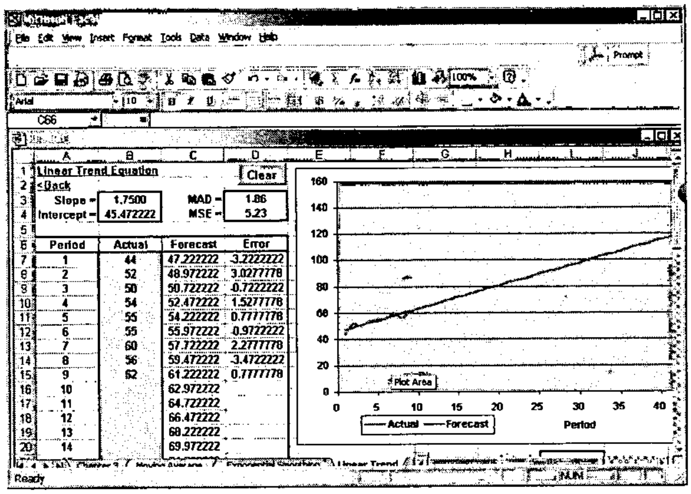
Thus, the trend equation is $F_t = 45.47 + 1.75t$. The next two forecasts are:

$F_{10} = 45.47 + 1.75(10) = 62.97$

$F_{11} = 45.47 + 1.75(11) = 64.72$

You also can use an Excel template to obtain the coefficients and a plot. Simply replace the existing data in the template with your data.

Excel Tutorial



Problem 4

Seasonal relatives. Obtain estimates of quarter relatives for these data:

Year:	1				2				3				4
Quarter:	1	2	3	4	1	2	3	4	1	2	3	4	1
Demand:	14	18	35	46	28	36	60	71	45	54	84	88	58

Solution

Note that each season has an *even* number of data points. When an even-numbered moving average is used (in this case, a four-period moving average), the "centered value" will not correspond to an actual data point; the center of 4 is *between* the second and third data points. To correct for this, a *second* set of moving averages must be computed using the MA_4 values. The MA_2 values are centered between the MA_4 and "line up" with actual data points. For example, the first MA_4 value is 28.25. It is centered between 18 and 35 (i.e., between quarter 2 and quarter 3). When the average of the first two MA_4 values is taken (i.e., MA_2) and centered, it lines up with the 35 and, hence, with quarter 3.

So, whenever an even-numbered moving average is used as a centered moving average (e.g., MA_4, MA_{12}), a second moving average, a two-period moving average, is used to achieve correspondence with periods. This procedure is not needed when the number of periods in the centered moving average is odd. See Example 7 in this chapter for an example with an odd number of periods.

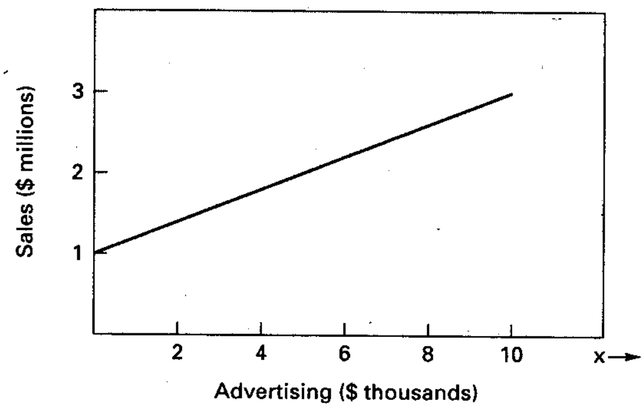
Year	Quarter	Demand	MA_4	MA_2	Demand/MA_2
1........	1	14			
	2	18			
			28.25		
	3	35		30.00	1.17
			31.75		
	4	46		34.00	1.35
			36.25		
2........	1	28		39.38	0.71
			42.50		
	2	36		45.63	0.79
			48.75		
	3	60		50.88	1.18
			53.00		
	4	71		55.25	1.29
			57.50		
3........	1	45		60.50	0.74
			63.50		
	2	54		65.63	0.82
			67.75		
	3	84		69.38	1.21
			71.00		
	4	88			
4........	1	58			

	QUARTER			
	1	2	3	4
	0.71	0.79	1.17	1.35
	0.74	0.82	1.18	1.29
	1.45	1.61	1.21	2.64
			3.56	
Average for the quarter:	0.725	0.805	1.187	1.320

The sum of these relatives is 4.037. Multiplying each by 4.00/4.037 will standardize the relatives, making their total equal 4.00. The resulting relatives are quarter 1, 0.718; quarter 2, 0.798; quarter 3, 1.176; quarter 4, 1.308.

Problem 5

Regression analysis. A large midwestern retailer has developed a graph that summarizes the effect of advertising expenditures on sales volume. Using the graph, determine an equation of the form $y = a + bx$ that describes this relationship.



Solution

The linear equation has the form $y = a + bx$, where a is the value of y when $x = 0$ (i.e., where the line intersects the y axis) and b is the slope of the line (the amount by which y changes for a one-unit change in x).

Accordingly, $a = 1$ and $b = (3 - 1)/(10 - 0) = 0.2$, so $y = a + bx$ becomes $y = 1 + 0.2x$. [*Note:* $(3 - 1)$ is the change in y, and $(10 - 0)$ is the change in x.]

Problem 6

Regression analysis. The owner of a small hardware store has noted a sales pattern for window locks that seems to parallel the number of break-ins reported each week in the newspaper. The data are:

Sales:	46	18	20	22	27	34	14	37	30
Break-ins:	9	3	3	5	4	7	2	6	4

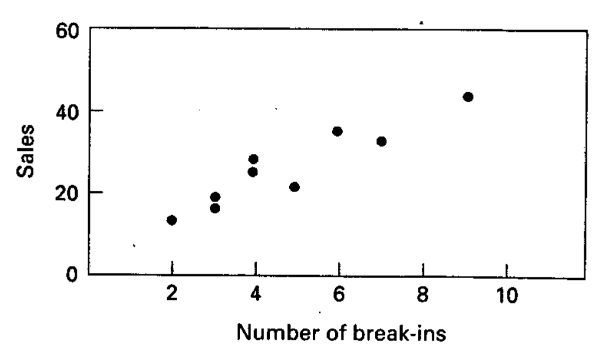
a. Plot the data to determine which type of equation, linear or nonlinear, is appropriate.

b. Obtain a regression equation for the data.

c. Estimate sales when the number of break-ins is five.

Solution

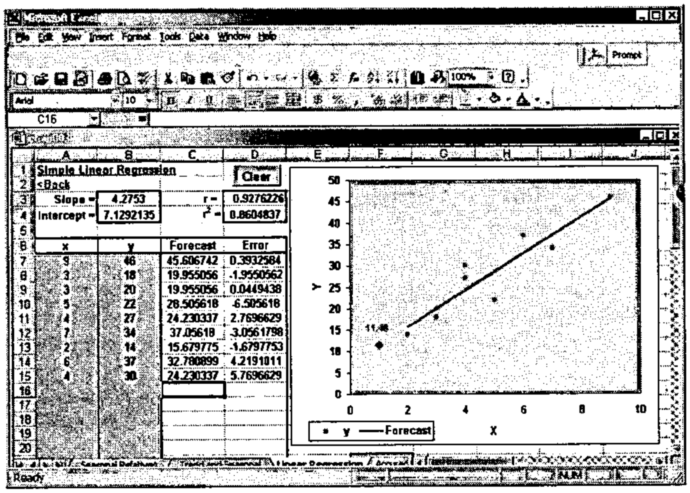
a.



The graph supports a linear relationship.

b. You can obtain the regression coefficients using the appropriate Excel template. Simply replace the existing data for x and y with your data. Note: Be careful to enter the values for the variable you want to predict as y values. In this problem, the objective is to predict sales, so the sales values are entered in the y column. The equation is $y_c = 7.129 = 4.275x$.

Excel



c. For $x = 5, y_c = 7.129 + 4.275(5) = 28.50$.

Problem 7

Accuracy and control of forecasts. The manager of a large manufacturer of industrial pumps must choose between two alternative forecasting techniques. Both techniques have been used to prepare forecasts for a six-month period. Using MAD as a criterion, which technique has the better performance record?

		FORECAST	
Month	**Demand**	**Technique 1**	**Technique 2**
1.........	492	488	495
2.........	470	484	482
3.........	485	480	478
4.........	493	490	488
5.........	498	497	492
6.........	492	493	493

Solution

Check that each forecast has an average error of approximately zero. (See computations that follow.)

Month	Demand	Technique 1	e	|e|	Technique 2	e	|e|
1	492	488	4	4	495	−3	3
2	470	484	−14	14	482	−12	12
3	485	480	5	5	478	7	7
4	493	490	3	3	488	5	5
5	498	497	1	1	492	6	6
6	492	493	−1	1	493	−1	1
			−2	28		+2	34

$$\text{MAD}_1 = \frac{\Sigma|e|}{n} = \frac{28}{6} = 4.67$$

$$\text{MAD}_2 = \frac{\Sigma|e|}{n} = \frac{34}{6} = 5.67$$

Technique 1 is superior in this comparison because its MAD is smaller, although six observations would generally be too few on which to base a realistic comparison.

Problem 8

Control chart. Given the demand data that follow, prepare a naive forecast for periods 2 through 10. Then determine each forecast error, and use those values to obtain $2s$ control limits. If demand in the next two periods turns out to be 125 and 130, can you conclude that the forecasts are in control?

Period:	1	2	3	4	5	6	7	8	9	10
Demand:	118	117	120	119	126	122	117	123	121	124

Solution

For a naive forecast, each period's demand becomes the forecast for the next period. Hence, the forecasts and errors are:

Period	Demand	Forecast	Error	Error^2
1	118	—	—	—
2	117	118	−1	1
3	120	117	3	9
4	119	120	−1	1
5	126	119	7	49
6	122	126	−4	16
7	117	122	−5	25
8	123	117	6	36
9	121	123	−2	4
10	124	121	3	9
			+6	150

$$s = \sqrt{\frac{\Sigma \text{error}^2}{n-1}} = \sqrt{\frac{150}{9-1}} = 4.33 \qquad (n = \text{Number of errors})$$

The control limits are $2(4.33) = \pm 8.66$

The forecast for period 11 was 124. Demand turned out to be 125, for an error of $125 - 124 = +1$. This is within the limits of ± 8.66. If the next demand is 130 and the naive forecast is 125 (based on the period 11 demand of 125), the error is +5. Again, this is within the limits, so you cannot conclude the forecast is not working properly. With more values—at least five or six—you could plot the errors to see whether you could detect any patterns suggesting the presence of nonrandomness.

DISCUSSION AND REVIEW QUESTIONS

1. What are the main advantages that quantitative techniques for forecasting have over qualitative techniques? What limitations do quantitative techniques have?
2. What are some of the consequences of poor forecasts? Explain.
3. List the specific weaknesses of each of these approaches to developing a forecast:
   a. Consumer surveys
   b. Salesforce composite
   c. Committee of managers or executives
4. Briefly describe the Delphi technique. What are its main benefits and weaknesses?
5. What is the purpose of establishing control limits for forecast errors?
6. What factors would you consider in deciding whether to use wide or narrow control limits for a forecast?
7. Contrast the use of MAD and MSE in evaluating forecasts.
8. What advantages as a forecasting tool does exponential smoothing have over moving averages?
9. How does the number of periods in a moving average affect the responsiveness of the forecast?

10. What factors enter into the choice of a value for the smoothing constant in exponential smoothing?
11. How accurate is your local five-day weather forecast? Support your answer with actual data.
12. Explain how using a centered moving average with a length equal to the length of a season eliminates seasonality from a time series.
13. Contrast the terms *sales* and *demand.*
14. Contrast the reactive and proactive approaches to forecasting. Give several examples of types of organizations or situations in which each type is used.
15. Explain how flexibility in production systems relates to the forecast horizon and forecast accuracy.
16. How is forecasting in the context of a supply chain different from forecasting for just a single organization? List possible supply chain benefits and discuss potential difficulties in doing supply chain forecasting.
17. Which type of forecasting approach, qualitative or quantitative, is better?
18. Suppose a software producer is about to release a new version of its popular software. What information do you think it would take into account in forecasting initial sales?
19. Choose the type of forecasting technique (survey, Delphi, averaging, seasonal naive, trend, or associative) that would be most appropriate for predicting
    a. Demand for Mother's Day greeting cards
    b. Popularity of a new television series.
    c. Demand for vacations on the moon.
    d. The impact a price increase of 10 percent would have on sales of orange marmalade.
    e. Demand for toothpaste in a particular supermarket.

TAKING STOCK

1. Explain the trade-off between responsiveness and stability in a forecasting system that uses time series data.
2. Who needs to be involved in preparing forecasts?
3. How has technology had an impact on forecasting?

CRITICAL THINKING EXERCISE

It has been said that forecasting using exponential smoothing is like driving a car by looking in the rear-view mirror. What are the conditions that would have to exist for driving a car that are analogous to the assumptions made when using exponential smoothing?

PROBLEMS

1. A commercial bakery has recorded sales (in dozens) for three products, as shown below:

Day	Blueberry Muffins	Cinnamon Buns	Cupcakes
1	30	18	45
2	34	17	26
3	32	19	27
4	34	19	23
5	35	22	22
6	30	23	48
7	34	23	29
8	36	25	20
9	29	24	14
10	31	26	18
11	35	27	47
12	31	28	26
13	37	29	27
14	34	31	24
15	33	33	22

a. Predict orders for the following day for each of the products using an appropriate naive method. *Hint:* Plot each data set.

b. What should the use of *sales* data instead of *demand* imply?

2. National Mixer, Inc., sells can openers. Monthly sales for a seven-month period were as follows:

Month	Sales (000 units)
Feb.	19
Mar.	18
Apr.	15
May	20
Jun.	18
Jul.	22
Aug.	20

a. Plot the monthly data on a sheet of graph paper.

b. Forecast September sales volume using each of the following:
  (1) A linear trend equation.
  (2) A five-month moving average.
  (3) Exponential smoothing with a smoothing constant equal to .20, assuming a March forecast of 19(000).
  (4) The naive approach.
  (5) A weighted average using .60 for August, .30 for July, and .10 for June.

c. Which method seems least appropriate? Why? (*Hint:* Refer to your plot from part *a.*)

d. What does use of the term *sales* rather than *demand* presume?

3. A dry cleaner uses exponential smoothing to forecast equipment usage at its main plant. August usage was forecast to be 88 percent of capacity; actual usage was 89.6 percent of capacity. A smoothing constant of .1 is used.

a. Prepare a forecast for September.

b. Assuming actual September usage of 92 percent, prepare a forecast for October usage.

4. An electrical contractor's records during the last five weeks indicate the number of job requests:

Week:	1	2	3	4	5
Requests:	20	22	18	21	22

Predict the number of requests for week 6 using each of these methods:

a. Naive.

b. A four-period moving average.

c. Exponential smoothing with $\alpha = .30$. Use 20 for week 2 forecast.

5. A cosmetics manufacturer's marketing department has developed a linear trend equation that can be used to predict annual sales of its popular Hand & Foot Cream.

$$F_t = 80 + 15t$$

where

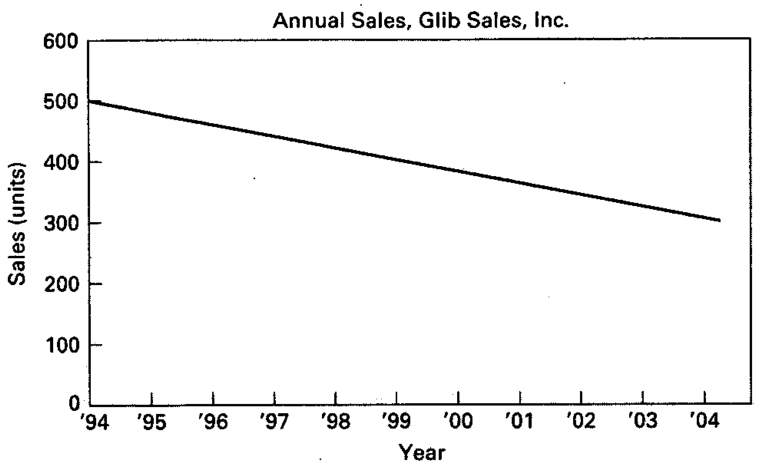
F_t = Annual sales (000 bottles)

t = 0 corresponds to 1990

a. Are annual sales increasing or decreasing? By how much?

b. Predict annual sales for the year 2006 using the equation.

6. From the following graph, determine the linear equation of the trend line using 1994 as the base year for Glib Sales, Inc.



7. Freight car loadings over a 12-year period at a busy port are

Week	Number	Week	Number	Week	Number
1	220	7	350	13	460
2	245	8	360	14	475
3	280	9	400	15	500
4	275	10	380	16	510
5	300	11	420	17	525
6	310	12	450	18	541

a. Determine a linear trend line for freight car loadings.
b. Use the trend equation to predict loadings for weeks 20 and 21.
c. The manager intends to install new equipment when the volume exceeds 800 loadings per week. Assuming the current trend continues, the loading volume will reach that level in approximately what week?

8. *a.* Obtain the linear trend equation for the following data on bread deliveries, and use it to predict deliveries for periods 16 through 19.

Period	Dozen Deliveries	Period	Dozen Deliveries	Period	Dozen Deliveries
1	200	6	232	11	281
2	214	7	248	12	275
3	211	8	250	13	280
4	228	9	253	14	288
5	235	10	267	15	310

b. Use trend-adjusted smoothing with $\alpha = .3$ and $\beta = .2$ to smooth the bread delivery data in part *a*. What is the forecast for Period 16?

9. After plotting demand for four periods, a manager has concluded that a trend-adjusted exponential smoothing model is appropriate to predict future demand. The initial estimate of trend is based on the net change of 30 for the *three* periods from 1 to 4, for an average of +10 units. Use $\alpha = .5$ and $\beta = .4$, and TAF of 250 for period 5. Obtain forecasts for periods 6 through 10.

Period	Actual
1	210
2	224
3	229
4	240
5	255
6	265
7	272
8	285
9	294
10	

10. A manager of a store that sells and installs hot tubs wants to prepare a forecast for January, February, and March of next year. Her forecasts are a combination of trend and seasonality. She uses the following equation to estimate the trend component of monthly demand: $F_t = 70 + 5t$, where $t = 0$ in June of last year. Seasonal relatives are 1.10 for January, 1.02 for February, and .95 for March. What demands should she predict?

11. The following equation summarizes the trend portion of quarterly sales of automatic dishwashers over a long cycle. Sales also exhibit seasonal variations. Using the information given, prepare a forecast of sales for each quarter of 2007, and the first quarter of 2008.

$$F_t = 40 - 6.5t + 2t^2$$

where

F_t = Unit sales

$t = 0$ at the fourth quarter of 2004

Quarter	Relative
1	1.1
2	1.0
3	.6
4	1.3

12. A gift shop in a tourist center is open on weekends (Friday, Saturday, and Sunday). The owner-manager hopes to improve scheduling of part-time employees by determining seasonal relatives for each of these days. Data on recent activity at the store (sales transactions per day) have been tabulated and are shown in the table below.

	WEEK					
	1	2	3	4	5	6
Friday	149	154	152	150	159	163
Saturday	250	255	260	268	273	276
Sunday	166	162	171	173	176	183

a. Develop seasonal relatives for the shop.
b. Use a naive trend approach to predict sales transactions for the following week.

13. The manager of a fashionable restaurant open Wednesday through Saturday says that the restaurant does about 35 percent of its business on Friday night, 30 percent on Saturday night, and 20 percent on Thursday night. What seasonal relatives would describe this situation?

14. Coal shipments from Mountain Coal Company's no. 4 mine for the past 18 weeks are

Week	Tons Shipped	Week	Tons Shipped	Week	Tons Shipped
1	405	8	433	15	466
2	410	9	438	16	474
3	420	10	440	17	476
4	415	11	446	18	482
5	412	12	451		
6	420	13	455		
7	424	14	464		

a. Explain why an averaging technique would not be appropriate for forecasting.
b. Use an appropriate technique to develop a forecast for the next three weeks.

15. Obtain estimates of daily relatives for the number of customers at a restaurant for the evening meal, given the following data. (*Hint:* Use a seven-day moving average.)

Day	Number Served	Day	Number Served
1	80	15	84
2	75	16	77
3	78	17	83
4	95	18	96
5	130	19	135
6	136	20	140
7	40	21	37
8	82	22	87
9	77	23	82
10	80	24	98
11	94	25	103
12	125	26	144
13	135	27	144
14	42	28	48

16. A pharmacist has been monitoring sales of a certain over-the-counter pain reliever. Daily sales during the last 15 days were

Day:	1	2	3	4	5	6	7	8	9
Number sold:	36	38	42	44	48	49	50	49	52
Day:	10	11	12	13	14	15			
Number sold:	48	52	55	54	56	57			

a. Which method would you suggest using to predict future sales—a linear trend equation or trend-adjusted exponential smoothing? Why?
b. If you learn that on some days the store ran out of the specific pain reliever, would that knowledge cause you any concern? Explain.
c. Assume that the data refer to demand rather than sales. Using trend-adjusted smoothing with an initial forecast of 50 for week 8, an initial trend estimate of 2, and $\alpha = \beta = .3$, develop forecasts for days 9 through 16. What is the MSE for the eight forecasts for which there are actual data?

17. New car sales for a dealer in Cook County, Illinois, for the past year are shown in the following table, along with monthly indexes (seasonal relatives), which are supplied to the dealer by the regional distributor.

Month	Units Sold	Index	Month	Units Sold	Index
Jan.	640	0.80	Jul.	765	0.90
Feb.	648	0.80	Aug.	805	1.15
Mar.	630	0.70	Sept.	840	1.20
Apr.	761	0.94	Oct.	828	1.20
May	735	0.89	Nov.	840	1.25
Jun.	850	1.00	Dec.	800	1.25

a. Plot the data. Does there seem to be a trend?
b. Deseasonalize car sales.
c. Plot the deseasonalized data on the same graph as the original data. Comment on the two graphs.

18. The following table shows a tool and die company's quarterly sales for the current year. What sales would you predict for the first quarter of next year? Quarter relatives are $Q_1 = 1.10$, $Q_2 = .99$, $Q_3 = .90$, and $Q_4 = 1.01$.

Quarter	1	2	3	4
Sales	88	99	108	141.4

19. A farming cooperative manager wants to estimate quarterly relatives for grain shipments, based on the data shown (quantities are in metric tons):

	QUARTER			
Year	**1**	**2**	**3**	**4**
1	200	250	210	340
2	210	252	212	360
3	215	260	220	358
4	225	272	233	372
5	232	284	240	381

Determine quarter relatives. (*Hint:* Use a centered four-period moving average initially, and then use a centered two-period moving average of the four-period moving average.)

20. Long-Life Insurance has developed a linear model that it uses to determine the amount of term life insurance a family of four should have, based on the current age of the head of the household. The equation is:

$$y = 150 - .1x$$

where

y = Insurance needed ($000)

x = Current age of head of household

a. Plot the relationship on a graph.
b. Use the equation to determine the amount of term life insurance to recommend for a family of four if the head of the household is 30 years old.

21. Timely Transport provides local delivery service for a number of downtown and suburban businesses. Delivery charges are based on distance and weight involved for each delivery: 10 cents per pound and 15 cents per mile. Also, there is a $10 handling fee per parcel.
a. Develop an expression that summarizes delivery charges.
b. Determine the delivery charge for transporting a 40-pound parcel 26 miles.

22. The manager of a seafood restaurant was asked to establish a pricing policy on lobster dinners. Experimenting with prices produced the following data:

Average Number Sold per Day, *y*	**Price, *x***	**Average Number Sold per Day, *y***	**Price, *x***
200	$6.00	155	$8.25
190	6.50	156	8.50
188	6.75	148	8.75
180	7.00	140	9.00
170	7.25	133	9.25
162	7.50		
160	8.00		

a. Plot the data and a regression line on the same graph.
b. Determine the correlation coefficient and interpret it.

23. The following data were collected during a study of consumer buying patterns.

Observation	x	y	Observation	x	y
1	15	74	8	18	78
2	25	80	9	14	70
3	40	84	10	15	72
4	32	81	11	22	85
5	51	96	12	24	88
6	47	95	13	33	90
7	30	83			

a. Plot the data.
b. Obtain a linear regression line for the data.
c. What percentage of the variation is explained by the regression line?
d. Use the equation determined in part *b* to predict the value of *y* for $x = 41$.

24. Lovely Lawns, Inc., intends to use sales of lawn fertilizer to predict lawn mower sales. The store manager estimates a probable six-week lag between fertilizer sales and mower sales. The pertinent data are:

Period	Fertilizer Sales (tons)	Number of Mowers Sold (six-week lag)	Period	Fertilizer Sales (tons)	Number of Mowers Sold (six-week lag)
1	1.6	10	8	1.3	7
2	1.3	8	9	1.7	10
3	1.8	11	10	1.2	6
4	2.0	12	11	1.9	11
5	2.2	12	12	1.4	8
6	1.6	9	13	1.7	10
7	1.5	8	14	1.6	9

a. Determine the correlation between the two variables. Does it appear that a relationship between these variables will yield good predictions? Explain.
b. Obtain a linear regression line for the data.
c. Predict lawn mower sales for the first week in August, given fertilizer sales six weeks earlier of 2 tons.

25. An analyst must decide between two different forecasting techniques for weekly sales of roller blades: a linear trend equation and the naive approach. The linear trend equation is $F_t = 124 + 2t$, and it was developed using data from periods 1 through 10. Based on data for periods 11 through 20 as shown in the table, which of these two methods has the greater accuracy?

t	Units Sold	*t*	Units Sold
11	147	16	152
12	148	17	155
13	151	18	157
14	145	19	160
15	155	20	165

26. Two different forecasting techniques (F1 and F2) were used to forecast demand for cases of bottled water. Actual demand and the two sets of forecasts are as follows:

		PREDICTED DEMAND	
Period	Demand	F1	F2
1	68	66	66
2	75	68	68
3	70	72	70
4	74	71	72
5	69	72	74
6	72	70	76
7	80	71	78
8	78	74	80

a. Compute MAD for each set of forecasts. Given your results, which forecast appears to be more accurate? Explain.
b. Compute the MSE for each set of forecasts. Given your results, which forecast appears to be more accurate?
c. In practice, *either* MAD *or* MSE would be employed to compute forecast errors. What factors might lead a manager to choose one rather than the other?
d. Compute MAPE for each data set. Which forecast appears to be more accurate?

27. The manager of a travel agency has been using a seasonally adjusted forecast to predict demand for packaged tours. The actual and predicted values are

Period	Demand	Predicted
1	129	124
2	194	200
3	156	150
4	91	94
5	85	80
6	132	140
7	126	128
8	126	124
9	95	100
10	149	150
11	98	94
12	85	80
13	137	140
14	134	128

a. Compute MAD for the fifth period, then update it period by period using exponential smoothing with $\alpha = .3$.
b. Compute a tracking signal for periods 5 through 14 using the initial and updated MADs. If limits of ± 4 are used, what can you conclude?

28. Two independent methods of forecasting based on judgment and experience have been prepared each month for the past 10 months. The forecasts and actual sales are as follows.

Month	Sales	Forecast 1	Forecast 2
1	770	771	769
2	789	785	787
3	794	790	792
4	780	784	798
5	768	770	774
6	772	768	770
7	760	761	759
8	775	771	775
9	786	784	788
10	790	788	788

a. Compute the MSE and MAD for each forecast. Does either forecast seem superior? Explain.
b. Compute MAPE for each forecast.
c. Compute a tracking signal for the 10th month for each forecast using the cumulative error for months 1 to 10. Use action limits of ± 4. Is there bias present? Explain.
d. Compute $2s$ control limits for each forecast.
e. Prepare a naive forecast for periods 2 through 11 using the given sales data. Compute each of the following; (1) MSE, (2) MAD, (3) tracking signal at month 10, and (4) $2s$ control limits. How do the naive results compare with the other two forecasts?

29. The classified department of a monthly magazine has used a combination of quantitative and qualitative methods to forecast sales of advertising space. Results over a 20-month period are as follows:

Month	Error	Month	Error
1	−8	11	1
2	−2	12	6
3	4	13	8
4	7	14	4
5	9	15	1
6	5	16	−2
7	0	17	−4
8	−3	18	−8
9	−9	19	−5
10	−4	20	−1

a. Compute a tracking signal for months 11 through 20. Compute an initial value of MAD for month 11, and then update it for each month using exponential smoothing with $\alpha = .1$. What can you conclude? Assume limits of ± 4.

b. Using the first half of the data, construct a control chart with $2s$ limits. What can you conclude?

c. Plot the last 10 errors on the control chart. Are the errors random? What is the implication of this?

30. A textbook publishing company has compiled data on total annual sales of its business texts for the preceding nine years:

Year:	1	2	3	4	5	6	7	8	9
Sales (000):	40.2	44.5	48.0	52.3	55.8	57.1	62.4	69.0	73.7

a. Using an appropriate model, forecast textbook sales for each of the next five years.

b. Prepare a control chart for the forecast using the original data. Use $2s$ limits.

c. Suppose actual sales for the next five years turn out as follows:

Year:	10	11	12	13	14
Sales (000):	77.2	82.1	87.8	90.6	98.9

Is the forecast performing adequately? Explain.

31. A manager has just received an evaluation from an analyst on two potential forecasting alternatives. The analyst is indifferent between the two alternatives, saying that they should be equally effective.

Period:	1	2	3	4	5	6	7	8	9	10
Data:	37	39	37	39	45	49	47	49	51	54
Alt. 1:	36	38	40	42	46	46	46	48	52	55
Alt. 2:	36	37	38	38	41	52	47	48	52	53

a. What would cause the analyst to reach this conclusion?

b. What information can you add to enhance the analysis?

32. A manager uses this equation to predict demand: $F_t = 10 + 5t$. Over the past eight periods, demand has been as follows.

Period, t:	1	2	3	4	5	6	7	8
Demand:	15	21	23	30	32	38	42	47

Is the forecast performing adequately? Explain.

33. A manager uses a trend equation plus quarterly relatives to predict demand. Quarter relatives are $Q_1 = .90$, $Q_2 = .95$, $Q_3 = 1.05$, and $Q_4 = 1.10$. The trend equation is: $F_t = 10 + 5t$. Over the past nine quarters, demand has been as follows.

Period, t:	1	2	3	4	5	6	7	8	9
Demand:	14	20	24	31	31	37	43	48	52

Is the forecast performing adequately? Explain.

M&L Manufacturing

CASE

M&L Manufacturing makes various components for printers and copiers. In addition to supplying these items to a major manufacturer of printers and copiers, the company distributes these and similar items to office supply stores and computer stores as replacement parts for printers and desktop copiers. In all, the company makes about 20 different items. The two markets (the major manufacturer and the replacement market) require somewhat different handling. For example, replacement products must be packaged individually whereas products are shipped in bulk to the major manufacturer.

The company does not use forecasts for production planning. Instead, the operations manager decides which items to produce, and the batch size, based partly on orders, and the amounts in inventory. The products that have the fewest amounts in inventory get the highest priority. Demand is uneven, and the company has experienced being overstocked on some items and out of others. Being understocked has occasionally created tensions with the managers of retail outlets. Another problem is that prices of raw materials have been creeping up, although the operations manager thinks that this might be a temporary condition.

Because of competitive pressures and falling profits, the manager has decided to undertake a number of changes. One change is to introduce more formal forecasting procedures in order to improve production planning and inventory management.

With that in mind, the manager wants to begin forecasting for two products. These products are important for several reasons. First, they account for a disproportionately large share of the company's profits. Second, the manager believes that one of these products will become increasingly important to future growth plans; and third, the other product has experienced periodic out-of-stock instances.

The manager has compiled data on product demand for the two products from order records for the previous 14 weeks. These are shown in the following table.

Week	Product 1	Product 2
1	50	40
2	54	38
3	57	41
4	60	46
5	64	42
6	67	41
7	90*	41
8	76	47
9	79	42
10	82	43
11	85	42
12	87	49
13	92	43
14	96	44

*Unusual order due to flooding of customer's warehouse.

Questions

1. What are some of the potential benefits of a more formalized approach to forecasting?
2. Prepare a weekly forecast for the next four weeks for each product. Briefly explain why you chose the methods you used. (*Hint:* For product 2, a simple approach, possibly some sort of naive/intuitive approach, would be preferable to a technical approach in view of the manager's disdain of more technical methods.)

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PART THREE

System Design

This part of the book covers product and service design, capacity planning, process selection, facility layout, design of work systems, and location planning and analysis.

Satisfying the customer begins with product and service design. Moreover, decisions made in this area impact on operations and on the organization's overall success.

Similarly, process selection and capacity planning impact on the ability of the production system to perform and to satisfy customers. Flexibility, production time, and cost are key considerations in process design.

Process selection and layout are closely related. Layout decisions involve the arrangement of the workplace, which affects the flow of work through a system and impacts productivity, cost, and flexibility. Layout decisions are influenced by decisions made in product and service design.

Capacity and location decisions influence operating costs and the ability to respond to customer demand. Location decisions also impact transportation costs, labor availability, material costs, and access to markets.

Work design focuses on the human element in production systems. Increasingly, managers are realizing that workers are a valuable asset and can contribute greatly to the organization's success. Strategic planning is beginning to incorporate employee participation to help improve production systems.

Design decisions have strategic significance for business organizations. Many of these decisions are not made by the operations manager. Nonetheless, because of the important links between operations and each strategic area, it is essential to the success of the organization to involve all of the functional areas of the organization in design decisions.

System design encompasses decisions involving:

CHAPTER 4

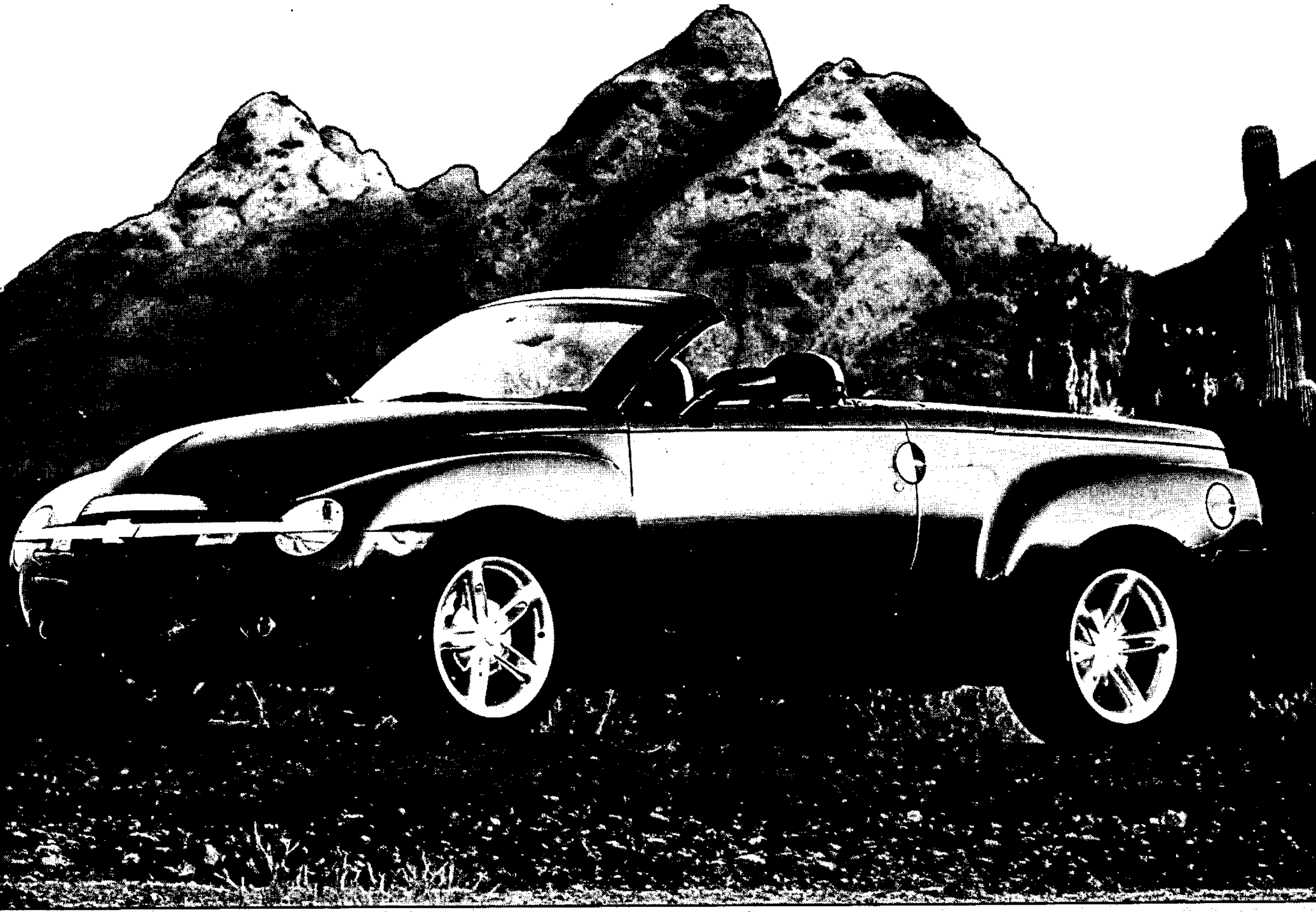
Product and Service Design

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Explain the *strategic* importance of product and service design.
2. List some key reasons for design or redesign.
3. Identify the main objectives of product and service design.
4. Discuss the importance of standardization.
5. Discuss the importance of legal, ethical, and environmental issues in product and service design.
6. Briefly describe the phases in product design and development.
7. Describe some of the main sources of design ideas.
8. Name several key issues in manufacturing design.
9. Name several key issues in service design.
10. Name the phases in service design.
11. List the characteristics of well-designed service systems.
12. Name some of the challenges of service design.

CHAPTER OUTLINE



As more and more women join the workforce and more families rely on two incomes, the spending and eating habits of Americans are changing. Quick meals have replaced leisurely meals. There is an increased awareness of healthy foods. And spicy foods have replaced plain foods. Fast-food chains, food companies, and supermarkets are scrambling to meet the challenge.

Spice giant McCormick is finding that sales of traditional spices are down. To compensate, the company is promoting seasoning mixes that are designed to save time. Salsa is becoming very popular, and Mexican restaurants are springing up all over. Supermarkets are offering a wide array of already prepared foods (see the Wegmans Tour in Chapter 1) as well as recipes for quick meals in their stores and on their web pages.

For these and other companies, from high tech to no tech, product and service design plays an important role in their profitability and their very survival.

The essence of any organization is the products or services it offers. There is an obvious link between the *design* of those products or services and the *success* of the organization. Organizations that have well-designed products or services are more likely to realize their goals than those with poorly designed products or services. Hence, organizations have a vital stake in achieving good product and service design.

In this chapter you will find many interesting insights into product and service design. Among the topics covered are the need for product and service design or redesign; sources of ideas for design or redesign; legal, environmental, and ethical issues; and design elements for both manufacturing and service.

Product and service design—or redesign—should be closely tied to an organization's strategy. It is a major factor in cost, quality, time to market, customer satisfaction, and competitive advantage.

INTRODUCTION

In this section you will learn what product and service designers do, the reasons for design (or redesign), and the objectives of design.

What Does Product and Service Design Do?

A range of activities fall under the heading of product and service design. The activities and responsibilities of product and service design include the following (functional interactions are shown in parentheses):

1. Translate customer wants and needs into product and service requirements. (marketing, operations)
2. Refine existing products and services. (marketing)
3. Develop new products and/or services. (marketing, operations)
4. Formulate quality goals. (marketing, operations)
5. Formulate cost targets. (accounting, finance, operations)
6. Construct and test prototypes. (operations, marketing, engineering)
7. Document specifications.

Product and service design involves or affects nearly every functional area of an organization. However, marketing and operations have major involvement.

Reasons for Product or Service Design or Redesign

Product or service design has typically had *strategic* implications for the success and prosperity of an organization. Furthermore, it has an impact on future activities. Consequently, decisions in this area are some of the most fundamental that managers must make.

Organizations become involved in product or service design or redesign for a variety of reasons. The main forces that initiate design or redesign are market opportunities and threats. The factors that give rise to market opportunities and threats can be one or more *changes:*

Economic (e.g., low demand, excessive warranty claims, the need to reduce costs).

Social and demographic (e.g., aging baby boomers, population shifts).

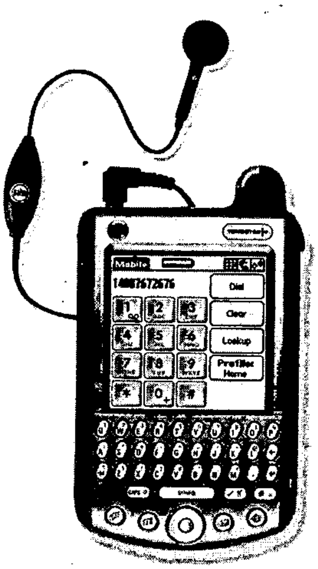
Political, liability, or legal (e.g., government changes, safety issues, new regulations).

Competitive (e.g., new or changed products or services, new advertising/promotions).

Cost or availability (e.g., of raw materials, components, labor).

Technological (e.g., in product components, processes).

When technology affects design, as demonstrated by the Palm Tungsten W handheld, the result can be a "different" type of phone—one that allows the user to talk hands-free, access and send email, and select from thousands of business and personal applications.



While each of these factors may seem obvious, let's reflect a bit on technological changes, which can create a need for product or service design changes in several different ways. An obvious way is new technology that can be used directly in a product or service (e.g., a faster, smaller microprocessor that spawns a new generation of personal digital assistants or cell phones). Technology also can indirectly affect product and service design: Advances in processing technology may require altering an existing design to make it compatible with the new processing technology. Still another way that technology can impact product design is illustrated by new digital recording technology that allows television viewers to skip commercials when they view a recorded program. This means that advertisers (who support a television program) can't get their message to viewers. To overcome this, some advertisers have adopted a strategy of making their products an integral part of a television program, say by having their products prominently displayed and/or mentioned by the actors as a way to call viewers' attention to their products without the need for commercials.

Dutch Boy Brushes up Its Paints

NEWSCLIP

www.sherwin-williams.com

Sherwin-Williams' Dutch Boy Group has put a revolutionary spin on wall/house painting with its new square-shaped Twist & Pour™ paint-delivery container for the Dirt Fighter interior latex paint line. Launched in July 2002, the four-piece square container could be the first major change in how house paint is packaged in decades. Lightweight but sturdy, the Twist & Pour "bucket" is packed with so many conveniences, it's next to impossible to mess up a painting project.

Winning Best of Show in the 2002 AmeriStar packaging competition sponsored by the Institute of Packaging Professionals, the exclusive, all-plastic paint container stands almost 7½ in. tall and holds 126 oz., a bit less than 1 gal. Rust-resistant and moisture-resistant, the plastic bucket gives users a new way to mix, brush, and store paint.

A hollow handle on one side makes it comfortable to pour and [carry]. A convenient, snap-in pour spout neatly pours paint into a tray with no dripping but can be removed if desired, to allow a wide brush to be dipped into the 5¾-in.-dia. mouth. Capping the container is a large, twist-off lid that requires no tools to open or close. Molded with two lugs for a snug-finger-tight closing, the threaded cap provides a tight seal to extend the shelf life of unused paint.

While the lid requires no tools to access, the snap-off carry bail is assembled on the container in a "locked-down position" and can be pulled up after purchase for toting or hanging on a ladder. Large, nearly 4½-in.-tall label panels allow glossy front and back labels printed and UV-coated to wrap around the can's rounded corners, for an impressive display. And there's plenty of graphic real estate to be had with this container. Helpful hints are printed on the back label panel that wraps toward the built-in side handle while the brand, product, and benefits are presented on the main panel

against a blue background. This panel also wraps around toward the side handle.

Jim MacDonald, co-designer of the Twist & Pour and a packaging engineer at Cleveland-based Sherwin-Williams, tells PD that the space-efficient, square shape is easier to ship and for retailers to stack in stores. It can also be nested, courtesy of a recess in the bottom that mates with the lid's top ring. "The new design allows for one additional shelf facing on an eight-foot rack or shelf area."

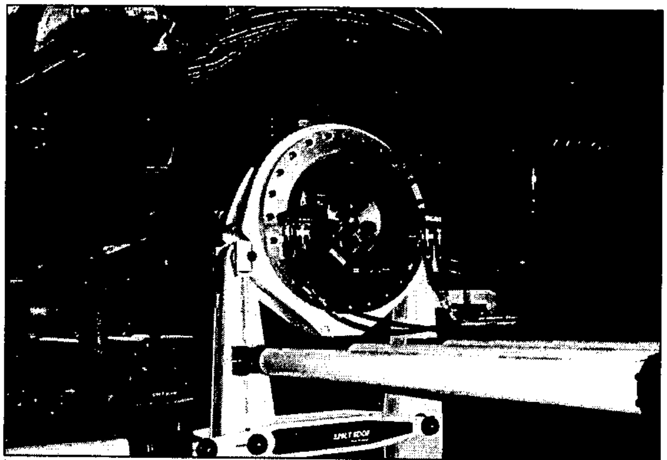
The labels are applied automatically, quite a feat, considering their complexity, size, and the hollow handle they likely encounter during application. MacDonald admits, "Label application was a challenge. We had to modify the bottle several times to accommodate the labeling machinery available."

Source: "Dutch Boy Brushes Up Its Paints," *Packaging Digest*, October 2002.

Objectives of Product and Service Design

The main focus of product and service design is customer satisfaction. Hence, it is essential for designers to *understand what the customer wants* and design with that in mind. Marketing is the primary source of this information.

It is important to note that although profit is generally the overall measure of design effectiveness, because the time interval between the design phase and profit realization is often considerable, more immediate measures come into play. These typically include development time and cost, the product or service cost, and the resulting product or service quality. Quality, of course, is typically high on the list of priorities in product and service design. At one time, having high quality was enough for a product or service to stand out; now it is the norm, and those that fall below this norm are the ones that stand out.



This Degree of Freedom Simulation Test is used in Ford Motor Company labs to simulate proving ground testing in the lab.

www.ford.com

Frontal impact crash test performed for the Honda S2000 by the New Car Assessment Program (NCAP) for the National Highway Safety Administration.

www.hondacars.com

Secondary focuses in product and service design relate to function, cost and potential profit (in for-profit organizations), quality, appearance, forecasted volume, ease of production, ease of assembly, and ease of maintenance or service. It is *crucial* for designers to take into account the operations capabilities of the organization in order to achieve designs that fit with those capabilities. This is sometimes referred to as **designing for operations.** Failure to take this into consideration can result in reduced productivity, reduced quality, and increased costs. For these reasons, it is wise for design to solicit input from operations people throughout the design process to reduce the risk of achieving a design that looks good on paper but doesn't work in the real world.

designing for operations Taking into account the capabilities of the organization in designing goods and services.

In general, design, operations, and marketing must work closely together, keeping each other informed and taking into account the wants and needs of the customer. In addition, legal, environmental, and ethical considerations can influence the design function.

LEGAL, ETHICAL, AND ENVIRONMENTAL ISSUES

Designers must be careful to take into account a wide array of legal and ethical considerations. Moreover, if there is a potential to harm the environment, then those issues also become important. Most organizations have numerous government agencies that regulate them. Among the more familiar federal agencies are the Food and Drug Administration, the Occupational Health and Safety Administration, the Environmental Protection Agency, and various state and local agencies. Bans on cyclamates, red food dye, phosphates, and asbestos have sent designers scurrying back to their drawing boards to find alternative designs that were acceptable to both government regulators and customers. Similarly, automobile pollution standards and safety features, such as seat belts, air bags, safety glass, and energy-absorbing bumpers and frames, have had a substantial impact on automotive design. Much attention also has been directed toward toy design to remove sharp edges, small pieces that can cause choking, and toxic materials. In construction, government regulations require the use of lead-free paint, safety glass in entranceways, access to public buildings for individuals with disabilities, and standards for insulation, electrical wiring, and plumbing.

product liability A manufacturer is liable for any injuries or damages caused by a faulty product.

Product liability can be a strong incentive for design improvements. **Product liability** means that a manufacturer is liable for any injuries or damages caused by a faulty product because of poor workmanship or design. Many business firms have faced lawsuits related to their products, including Firestone Tire & Rubber, Ford and General Motors, tobacco companies, and toy manufacturers. Manufacturers also are faced with the implied warranties created by state laws under the **Uniform Commercial Code,** which says that products carry an implication of *merchantability* and *fitness*; that is, a product must be usable for its intended purposes.

Uniform Commercial Code Products carry an implication of merchantability and fitness.

The suits and potential suits have led to increased legal and insurance costs, expensive settlements with injured parties, and costly recalls. Moreover, increasing customer awareness of product safety can adversely affect product image and subsequent demand for a product.

Thus, it is extremely important to design products that are reasonably free of hazards. When hazards do exist, it is necessary to install safety guards or other devices for reducing accident potential, and to provide adequate warning notices of risks. Consumer groups, business firms, and various government agencies often work together to develop industrywide standards that help avoid some of the hazards.

Ethical issues often arise in the design of products and services; it is important for managers to be aware of these issues and for designers to adhere to ethical standards. Designers are often under pressure to speed up the design process and to cut costs. These pressures often require them to make trade-off decisions, many of which involve ethical considerations. One example of what can happen is "vaporware," when a software company doesn't issue a release of software as scheduled as it struggles with production problems or bugs in the software. The company faces the dilemma of releasing the software right away or waiting until most of the bugs have been removed—knowing that the longer it waits, the longer it will be before it receives revenues and the greater the risk of damage to its reputation.

Organizations generally want designers to adhere to guidelines such as the following:

- Produce designs that are consistent with the goals of the organization. For instance, if the company has a goal of high quality, don't cut corners to save cost, even in areas where it won't be apparent to the customer.
- Give customers the value they expect.
- Make health and safety a primary concern. At risk are employees who will produce goods or deliver services, workers who will transport the products, customers who will use the products or receive the services, and the general public, which might be endangered by the products or services.
- Consider potential to harm the environment.

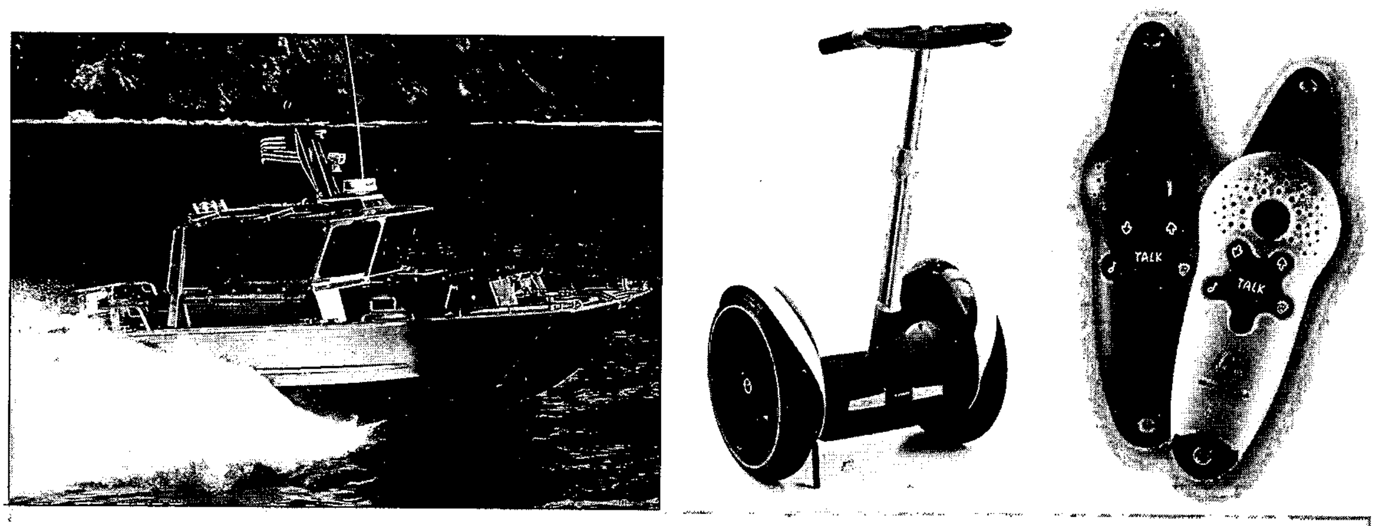
OTHER ISSUES IN PRODUCT AND SERVICE DESIGN

Aside from legal, environmental, and ethical issues, designers must also take into account product or service life cycles, how much standardization to incorporate, product or service reliability, and the range of operating conditions under which a product or service must function. These topics are discussed in this section. We begin with life cycles.

Life Cycles

Many new products and services go through a **life cycle** in terms of demand. When an item is introduced, it may be treated as a curiosity. Demand is generally low because potential buyers are not yet familiar with the item. Many potential buyers recognize that all of the bugs have probably not been worked out and that the price may drop after the introductory period. Capacity and processing are designed for low volume. With the passage of time, design improvements usually create a more reliable and less costly output. Demand then grows for these reasons and because of increasing awareness of the product or service. Higher volume will involve different methods and contribute to lower costs. At the next stage in the life cycle, the product or service reaches maturity: there are few, if any, design changes, and demand levels off. Eventually, the market becomes saturated, which leads to a decline in demand. In the last stage of a life cycle, some firms adopt a defensive research posture whereby they attempt to prolong the useful life of a product or service by improving its reliability, reducing costs of producing it (and, hence, the price), redesigning it, or changing the packaging. In some instances, firms may seek alternative uses of their products (e.g., baking soda, duct tape). Forward-thinking firms begin searching for replacement products during the *maturity* stage. The stages are illustrated in Figure 4.1.

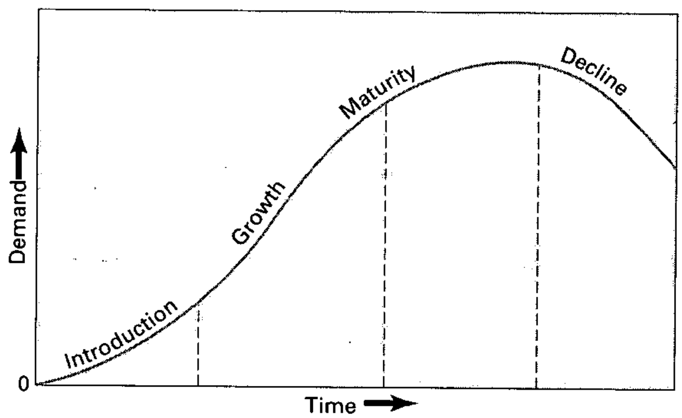
life cycle Incubation, growth, maturity, and decline.



Among the winners of the 2002 Industrial Design Excellence Award sponsored by Business Week: *J3200 Catamaran provides stability and safety in a fast, shallow-draft, rugged boat. The Segway Human Transporter offers personal mobility with less pollution. The Talkabout T4300 Series Two-Way Radio has a two-mile range and 14 channels.*

FIGURE 4.1

Products or services often exhibit life cycles over time



Consider the products in various stages of the life cycle in the music industry: Digital audio tapes are in the introductory stage, compact discs are in the growth stage, cassettes are moving from the maturity-saturation stage into the decline stage.

Some products do not exhibit life cycles: wooden pencils; paper clips; nails; knives, forks, and spoons; drinking glasses; and similar items. However, most new products do.

Some service life cycles are related to the life cycles of products. For example, as older products are phased out, services such as installation and repair of the older products also phase out.

Wide variations exist in the amount of time a particular product or service takes to pass through a given phase of its life cycle: some pass through various stages in a relatively short period; others take considerably longer. Often it is a matter of the basic *need* for the item and the *rate of technological change.* Some toys, novelty items, and style items have a life cycle of less than one year, whereas other, more useful items, such as clothes washers and dryers, may last for many years before yielding to technological change.

standardization Extent to which there is absence of variety in a product, service, or process.

Standardization

An important issue that often arises in both product/service design and process design is the degree of standardization. **Standardization** refers to the extent to which there is absence of variety in a product, service, or process. Standardized products are made in large quantities of identical items; calculators, computers, and 2 percent milk are examples. Standardized service implies that every customer or item processed receives essentially the same service. An automatic car wash is a good example; each car, regardless of how clean or dirty it is, receives the same service. Standardized processes deliver standardized service or produce standardized goods.

Standardization carries a number of important benefits as well as certain disadvantages. Standardized products are immediately available to customers. Standardized products mean *interchangeable parts,* which greatly lower the cost of production while increasing productivity and making replacement or repair relatively easy compared with that of customized parts. Design costs are generally lower. For example, General Motors recently has attempted to standardize key components of its automobiles across product lines; components such as brakes, electrical systems, and other "under-the-skin" parts would be the same for all GM car models. By reducing variety, GM saves time and money while increasing quality and reliability in its products.

www.gm.com

Another benefit of standardization is reduced time and cost to train employees and reduced time to design jobs. Similarly, scheduling of work, inventory handling, and purchasing and accounting activities become much more routine, and quality is more consistent.

Lack of standardization can at times lead to serious difficulties and competitive struggles, particularly when systems running under different conditions are incompatible. Consider a few examples: High-definition television might have been introduced much earlier in the United States, but three competing—and incompatible—systems were proposed, which led to prolonged debate and study before one system could be agreed upon. The lack of standardization in computer software and operating systems in the past has presented users with hard choices because of the difficulty in switching from one system to the other. And the use by U.S. manufacturers of the English system of measurement, while most of the rest of the world's manufacturers use the metric system, has led to problems in selling U.S. goods in foreign countries and in buying foreign machines for use in the United States. This may make it more difficult for U.S. firms to compete in the European Union.

Standardization also has disadvantages. A major one relates to the reduction in variety. This can limit the range of customers to whom a product or service appeals. Customers may reluctantly accept a product only because nothing else suits their needs. But that creates a risk that a competitor will introduce a better product or greater variety (a feature of lean production), and realize a competitive advantage. Another disadvantage is that a manufacturer may freeze (standardize) a design prematurely and, once frozen, it may find compelling reasons to resist modification. A familiar example of this is the keyboard arrangement of computer keyboards. Studies have demonstrated that another arrangement of keys would be more efficient, but the cost of replacing all of the equipment in existence and retraining millions of users would not be worth the benefit.

Obviously, designers must consider important issues related to standardization when making choices. The major advantages and disadvantages of standardization are summarized in Table 4.1.

Designing for Mass Customization

Companies like standardization because it enables them to produce high volumes of relatively low-cost products, albeit products with little variety. Customers, on the other hand, typically prefer more variety, although they like the low cost. The question for producers is how to resolve these issues without (1) losing the benefits of standardization and (2) incurring a host of problems that are often linked to variety. These include increasing the resources needed to achieve design variety; increasing variety in the production process, which would add to the skills necessary to produce products, causing a decrease in productivity; creating an additional inventory burden during and after production, by having to carry replacement parts for the increased variety of parts; and adding to the difficulty of diagnosing and repairing product failures. The answer, at least for some companies, is **mass customization,** a strategy of producing standardized goods or services, but incorporating some degree of customization in the

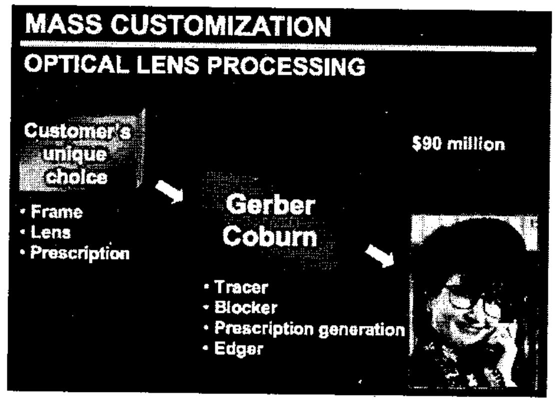
mass customization Producing basically standardized goods, but incorporating some degree of customization.

TABLE 4.1
Advantages and disadvantages of standardization

Advantages	1. Fewer parts to deal with in inventory and in manufacturing. 2. Reduced training costs and time. 3. More routine purchasing, handling, and inspection procedures. 4. Orders fillable from inventory. 5. Opportunities for long production runs and automation. 6. Need for fewer parts justifies increased expenditures on perfecting designs and improving quality control procedures.
Disadvantages	1. Designs may be frozen with too many imperfections remaining. 2. High cost of design changes increases resistance to improvements. 3. Decreased variety results in less consumer appeal.

OPTICAL LENS PROCESSING—
GERBER COBURN

When applied to optical lens processing, this choice involves the desired frame, the lens and finally, the prescription. Gerber's systems enable the necessary lens processing to take place . . . everything from tracing, blocking and prescription generation to edging. The end result is a pair of custom-made glasses. In 1998 alone, more than 70 million pairs of eyeglasses were processed using Gerber Coburn systems. And considering the various prescription and frame combinations available, few, if any, were the same.



www.gerbercoburn.cc

final product or service. Several tactics make this possible. One is *delayed differentiation,* and another is *modular design.*

delayed differentiation Producing, but not quite completing, a product or service until customer preferences are known.

Delayed differentiation is a *postponement* tactic: the process of producing, but not quite completing, a product or service, postponing completion until customer preferences or specifications are known. There are a number of variations of this. In the case of goods, almost-finished units might be held in inventory until customer orders are received, at which time customized features are incorporated, according to customer requests. For example, furniture makers can produce dining room sets, but not apply stain, allowing customers a choice of stains. Once the choice is made, the stain can be applied in a relatively short time, thus eliminating a long wait for customers, giving the seller a competitive advantage. Similarly, various e-mail or Internet services can be delivered to customers as standardized packages, which can then be modified according to the customer's preferences. Hewlett-Packard printers that are made in the United States but intended for foreign markets are mostly completed in domestic assembly plants and then finalized closer to the country of use. The result of delayed differentiation is a product or service with customized features that can be quickly produced, appealing to the customers' desire for variety and speed of delivery, and yet one that for the most part is standardized, enabling the producer to realize the benefits of standardized production. This technique is not new. Manufacturers of men's clothing, for example, produce suits with pants that have legs that are unfinished, allowing customers to tailor choices as to the exact length and whether to have cuffs or no cuffs. What is new is the extent to which business organizations are finding ways to incorporate this concept into a broad range of products and services.

Modular design is a form of standardization. Modules represent groupings of component parts into subassemblies, usually to the point where the individual parts lose their separate identity. One familiar example of modular design is computers, which have modular parts that can be replaced if they become defective. By arranging modules in different configurations, different computer capabilities can be obtained. For mass customization, modular design enables producers to quickly assemble products with modules to achieve a customized configuration for an individual customer, avoiding the long customer wait that would occur if individual parts had to be assembled. Dell Computers has successfully used this concept to become a dominant force in the PC industry by offering consumers the opportunity to configure modules according to their own specifications. Many other computer manufacturers now use a similar approach. Modular design also is found in the construction industry. One firm in Rochester, New York, makes prefabricated motel rooms complete with wiring, plumbing, and even room decorations in its factory and then moves the complete rooms by rail to the construction site, where they are integrated into the structure.

modular design A form of standardization in which component parts are grouped into modules that are easily replaced or interchanged.

One advantage of modular design of equipment compared with nonmodular design is that failures are often easier to diagnose and remedy because there are fewer pieces to investigate. Similar advantages are found in ease of repair and replacement; the faulty module is conveniently removed and replaced with a good one. The manufacture and assembly of modules generally involve simplifications: Fewer parts are involved, so purchasing and inventory control become more routine, fabrication and assembly operations become more standardized, and training costs often are relatively low.

The main disadvantages of modular design stem from the decrease in variety: The number of possible configurations of modules is much less than the number of possible configurations based on individual components. Another disadvantage that is sometimes encountered is the inability to disassemble a module in order to replace a faulty part; the entire module must be scrapped—usually at a higher cost.

Reliability

Reliability is a measure of the ability of a product, a part, a service, or an entire system to perform its intended function under a prescribed set of conditions. The importance of reliability is underscored by its use by prospective buyers in comparing alternatives and by sellers as one determinant of price. Reliability also can have an impact on repeat sales, reflect on the product's image, and, if it is too low, create legal implications.

reliability The ability of a product, part, or system to perform its intended function under a prescribed set of conditions.

The term **failure** is used to describe a situation in which an item does not perform as intended. This includes not only instances in which the item does not function at all, but also instances in which the item's performance is substandard or it functions in a way not intended. For example, a smoke alarm might fail to respond to the presence of smoke (not operate at all), it might sound an alarm that is too faint to provide an adequate warning (substandard performance), or it might sound an alarm even though no smoke is present (unintended response).

failure Situation in which a product, part, or system does not perform as intended.

Reliabilities are always specified with respect to certain conditions, called **normal operating conditions.** These can include load, temperature, and humidity ranges as well as operating procedures and maintenance schedules. Failure of users to heed these conditions often results in premature failure of parts or complete systems. For example, using a passenger car to tow heavy loads will cause excess wear and tear on the drive train; driving over potholes or curbs often results in untimely tire failure; and using a calculator to drive nails might have a marked impact on its usefulness for performing mathematical operations.

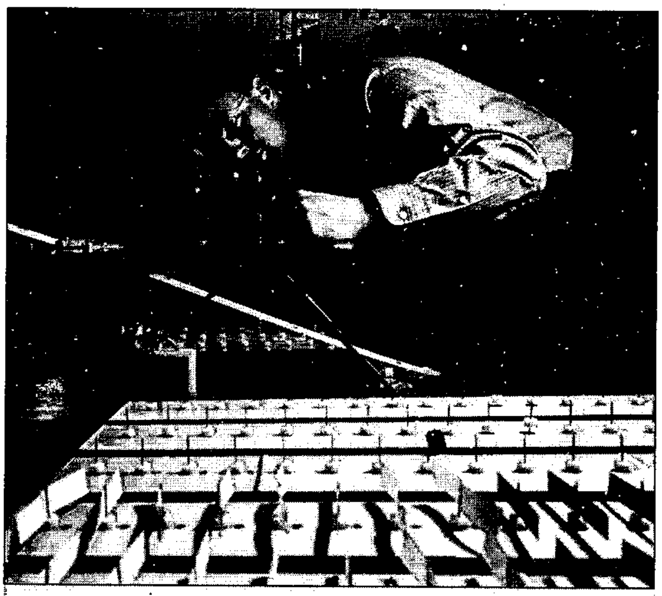
normal operating conditions The set of conditions under which an item's reliability is specified.

Improving Reliability Reliability can be improved in a number of ways, some of which are listed in Table 4.2.

Because overall system reliability is a function of the reliability of individual components, improvements in their reliability can increase system reliability. Unfortunately, inadequate production or assembly procedures can negate even the best of designs, and this is often a source of failures. System reliability can be increased by the use of backup components. Failures in actual use often can be reduced by upgrading user education and refining

TABLE 4.2
Potential ways to improve reliability

1. Improve component design.
2. Improve production and/or assembly techniques.
3. Improve testing.
4. Use backups.
5. Improve preventive maintenance procedures.
6. Improve user education.
7. Improve system design.



Xerox Media Technology Center simulates 'bad hair days' for paper to ensure that it's optimized for digital printing and copying.

www.xerox.com

maintenance recommendations or procedures. Finally, it may be possible to increase the overall reliability of the system by simplifying the system (thereby reducing the number of components that could cause the system to fail) or altering component relationships (e.g., increasing the reliability of interfaces).

A fundamental question concerning improving reliability is: How much reliability is needed? Obviously, the reliability needed for a household light bulb isn't in the same category as the reliability needed for an airplane. So the answer to the question depends on the potential benefits of improvements and on the cost of those improvements. Generally speaking, reliability improvements become increasingly costly. Thus, although benefits initially may increase at a much faster rate than costs, the opposite eventually becomes true. The optimal level of reliability is the point where the incremental benefit received equals the incremental cost of obtaining it. In the short term, this trade-off is made in the context of relatively fixed parameters (e.g., costs). However, in the longer term, efforts to improve reliability and reduce costs can lead to higher optimal levels of reliability.

Robust Design

Some products or services will function as designed only within a narrow range of conditions, while others will perform as designed over a much broader range of conditions. The latter have **robust design.** Consider a pair of fine leather boots—obviously not made for trekking through mud or snow. Now consider a pair of heavy rubber boots—just the thing for mud or snow. The rubber boots have a design that is more *robust* than the fine leather boots.

robust design Design that results in products or services that can function over a broad range of conditions.

The more robust a product or service, the less likely it will fail due to a change in the environment in which it is used or in which it is performed. Hence, the more designers can build robustness into the product or service, the better it should hold up, resulting in a higher level of customer satisfaction.

A similar argument can be made for robust design as it pertains to the production process. Environmental factors can have a negative effect on the quality of a product or service. The more resistant a design is to those influences, the less likely is a negative effect. For example, many products go through a heating process: food products, ceramics, steel, petroleum products, and pharmaceutical products. Furnaces often do not heat uniformly; heat may vary either by position in an oven or over an extended period of production. One approach to this problem might be to develop a superior oven; another might be to design a system that moves the product during heating to achieve uniformity. A robust-design approach would develop a product that is unaffected by minor variations in temperature during processing.

Taguchi's Approach Japanese engineer Genichi Taguchi's approach is based on the robust design. His premise is that it is often easier to design a product that is insensitive to environmental factors, either in manufacturing or in use, than to control the environmental factors.

The central feature of Taguchi's approach—and the feature used most often by U.S. companies—is *parameter design.* This involves determining the specification settings for both the product and the process that will result in robust design in terms of manufacturing variations, product deterioration, and conditions during use.

The Taguchi approach modifies the conventional statistical methods of experimental design. Consider this example. Suppose a company will use 12 chemicals in a new product it intends to produce. There are two suppliers for these chemicals, but the chemical concentrations vary slightly between the two suppliers. Classical design of experiments would require $2^{12} = 4{,}096$ test runs to determine which combination of chemicals would be optimum. Taguchi's approach would involve only testing a portion of the possible combinations. Relying on experts to identify the variables that would be most likely to affect important performance, the number of combinations would be dramatically reduced, perhaps to, say, 32. Identifying the best combination in the smaller sample might be a near-optimal combination instead of the optimal combination. The value of this approach is its ability to achieve major advances in product or process design fairly quickly, using a relatively small number of experiments.

Critics charge that Taguchi's methods are inefficient and incorrect, and often lead to nonoptimal solutions. Nonetheless, his methods are widely used and have been credited with helping to achieve major improvements in U.S. products and manufacturing processes.

Cultural Differences

Product designers in multinational companies also must take into account any cultural differences of different countries or regions related to the product. This can result in different designs for different countries or regions, as illustrated by the following reading.

Do You Want Pickled Beets with That? READING

John Kelly

Since the first McDonald's opened in the United States in 1955, the fast food restaurant has spread around the world.

The company now has locations in 121 countries. In fact, of the 30,000 McDonald's restaurants scattered around the globe, there are more in foreign countries (17,000) than in the good old United States (13,000).

The food you can order at many of these Mickey D's is different from what you'll find at the one down the street. Here's a sample of some of the treats that await you should you pull up to the drive-through window in some faraway places:

India: McAloo Tikki Burger. A totally vegetarian sandwich with regular bun, a crispy, breaded spicy potato and vegetable patty, eggless tomato mayonnaise, two slices of tomatoes and shredded onion.

France: Croque McDo. Cheese and ham between two thin pieces of toasted bread.

Italy: McPink. Two pork patties with a slice of yellow cheese.

New Zealand: Kiwi Burger. A hamburger with a fried egg and a slice of pickled beet.

Turkey: Kofte Burger. A spicy meat patty inside a flavored bun, enriched with a special yogurt mix and spiced tomato sauce.

Philippines: McSpaghetti. Pasta in a red sauce with frankfurter bits.

South Korea: Bulgogi Burger. Pork patty on a bun with lettuce and spicy garlic bulgogi sauce.

China: Hong Dou Pie. A dessert pie filled with red bean paste.

Argentina: McNifica. Hamburger sandwich with cheese, tomato, onion and lettuce.

Egypt: McFalafel. Fried patties of ground beans flavored with spices.

(continued)

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Israel: Seven of the 80 or so McDonald's are kosher, meaning they follow strict Jewish dietary rules so there are no cheeseburgers, milkshakes or sundaes.

United Kingdom: Mega Button Blast. Vanilla ice cream that you eat after breaking through a Cadbury chocolate lid.

Greece: Greek Mac. Pita bread sandwich with two beef patties and some yogurt sauce.

Japan: Teriyaki Burger. Chicken cutlet patty marinated in teriyaki sauce, with sweet mayonnaise and sliced lettuce on a sesame bun.

Germany: Gemuse Mac. A veggie burger with lettuce, tomatoes and special "wurzcreme" sauce.

Questions

1. What effects do cultural differences have on the design of fast food offerings in this reading?
2. What functions in the organization are impacted by the differences in product offerings among different countries?

Source: "Do You Want Pickled Beets with That? John Kelly, December 2002. Copyright ©2002, *The Washington Post*. Reprinted with permission.

TABLE 4.3
Degree of design change and newness to the organization and the market

Type of Design Change	Newness to the Organization	Newness to the Market
Modification	Low	Low
Expansion	Low	Low
Clone	High	Low
New	High	High

The Degree of Newness

Product or service design change can range from the modification of an existing product or service to an entirely new product or service:

1. Modification of an existing product or service.
2. Expansion of an existing product line or service offering.
3. Clone of a competitor's product or service.
4. New product or service.

The degree of change affects the newness to the organization and the newness to the market, as summarized in Table 4.3. For the organization, a low level of newness can mean a fairly quick and easy transition to producing the new product, while a high level of newness would likely mean a slower and more difficult, and therefore more costly, transition. For the market, a low level of newness would mean little difficulty with market acceptance, but possibly low profit potential. Even in instances of low profit potential, organizations might use this strategy to maintain market share. A high level of newness, on the other hand, might mean more difficulty with acceptance, or it might mean a rapid gain in market share with a high potential for profits. Unfortunately, there is no way around these issues. It is important to carefully assess the risks and potential benefits of any design change, taking into account clearly identified customer wants.

PHASES IN PRODUCT DESIGN AND DEVELOPMENT

Product design and development generally proceeds in a series of phases (see Table 4.4):

TABLE 4.4
Phases in the product development process

1. Idea generation	6. Design review
2. Feasibility analysis	7. Market test
3. Product specifications	8. Product introduction
4. Process specifications	9. Follow-up evaluation
5. Prototype development	

Idea generation. Product development begins with idea generation. Ideas can come from a variety of sources. This topic will be discussed in detail following this section.

Feasibility analysis. Feasibility analysis entails market analysis (demand), economic analysis (development cost and production cost, profit potential), and technical analysis (capacity requirements and availability, and the skills needed). Also, it is necessary to answer the question, does it fit with the mission? It requires collaboration among marketing, finance, accounting, engineering, and operations.

Product specification. This involves detailed descriptions of what is needed to meet (or exceed) customer wants, and requires collaboration between legal, marketing, and operations.

Process specifications. Once product specifications have been set, attention turns to specifications for the process that will be needed to produce the product. Alternatives must be weighed in terms of cost, availability of resources, profit potential, and quality. Involves collaboration between accounting and operations.

Prototype development. With product and process specifications complete, one (or a few) units are made to see if there are any problems with the product or process specifications.

Design review. Make any necessary changes, or abandon. Involves collaboration among marketing, finance, engineering, design, and operations.

Market test. A market test is used to determine the extent of consumer acceptance. If unsuccessful, return to the design review phase. (Marketing)

Product introduction. Promote the product. (Marketing)

Follow-up evaluation. Determine if changes are needed, and refine forecasts. (Marketing)

Idea Generation

Ideas can come from a variety of sources. They can be

1. Supply-chain based
2. Competitor based
3. Research based

A supply chain can be a rich source of ideas. Customers, suppliers, distributors, employees, and maintenance and repair personnel can provide valuable insights. Customer input can be obtained from surveys, focus groups, complaints and unsolicited suggestions for improvement. Input from suppliers, distributors, employees, and maintenance or repair personnel might come from interviews, direct or indirect suggestions, or complaints.

One of the strongest motivators for new and improved products or services is competitors' products and services. By studying a competitor's products or services and how the competitor operates (pricing policies, return policies, warranties, location strategies, etc.), an organization can glean many ideas. Beyond that, some companies purchase a competitor's product and then carefully dismantle and inspect it, searching for ways to improve their own product. This is called **reverse engineering.** The Ford Motor Company used this tactic in developing its highly successful Taurus model: It examined competitors' automobiles, searching for best-in-class components (e.g., best hood release, best dashboard display, best door handle). Sometimes reverse engineering can enable a company to "leapfrog" the competition by developing an even better product. Suppliers are still another source of ideas, and with increased emphasis on supply chains and supplier partnerships, suppliers are becoming an important source of ideas.

reverse engineering Dismantling and inspecting a competitor's product to discover product improvements.

Research is another source of ideas for new or improved products or services. **Research and development (R&D)** refers to organized efforts that are directed toward increasing scientific knowledge and product or process innovation. Most of the advances in semiconductors, medicine, communications, and space technology can be attributed to R&D efforts at colleges and universities, research foundations, government agencies, and private enterprises.

research and development (R&D) Organized efforts to increase scientific knowledge or product innovation.

R&D efforts may involve *basic research, applied research,* or *development.*

Basic research has the objective of advancing the state of knowledge about a subject, without any near-term expectation of commercial applications.

Applied research has the objective of achieving commercial applications.

Development converts the results of applied research into useful commercial applications.

Basic research, because it does not lead to near-term commercial applications, is generally underwritten by the government and large corporations. Conversely, applied research and development, because of the potential for commercial applications, appeals to a wide spectrum of business organizations.

The benefits of successful R&D can be tremendous. Some research leads to patents, with the potential of licensing and royalties. However, many discoveries are not patentable, or companies don't wish to divulge details of their ideas so they avoid the patent route. Even so, the first organization to bring a new product or service to the market generally stands to profit from it before the others can catch up. Early products may be priced higher because a temporary monopoly exists until competitors bring their versions out.

The costs of R&D can be high. Kodak, for example, has spent more than $1 million *a day* on R&D. Large companies in the automotive, computer, communications, and pharmaceutical industries spend even more. Even so, critics say that many U.S. companies spend too little on R&D, a factor often cited in the loss of competitive advantage.

www.kodak.com

It is interesting to note that some companies are now shifting from a focus primarily on *products* to a more balanced approach that explores both product and *process* R&D. One reason is that in too many instances, product innovations (e.g., for televisions, VCRs, and microwave ovens) made by U.S. companies have ended up being produced more competitively by foreign companies with better processes.

In certain instances, research may not be the best approach, as explained in the following reading. The second reading illustrates a research success.

Manager's Journal: When Customer Research Is a Lousy Idea

READING

Willard I. Zangwill

www.sony.com

Customer research is often touted as a necessary precursor to product introduction. The problem—especially for innovative products—is that it often proves wrong. For example, hair styling mousse is now a massive hit. Yet in its initial market tests in the U.S., it flopped. "Goopy and gunky" was what people said about it, and they did not like its feel when it "mooshed" through their hair.

Similarly, when the telephone answering machine was consumer tested, it faced an almost universally negative reaction. Back then, most individuals felt that using a mechanical device to answer a phone was rude and disrespectful. Today, of course, many people regard their answering machines as indispensable, and consider scheduling their daily activities without them as impossible. In the same vein, the computer mouse in its initial testing flunked, being evaluated by potential customers as awkward and unnecessary.

Because of these difficulties, some companies have gone so far as to eliminate customer research for their innovative products. According to Sony executive Kozo Ohsone, "When you introduce products that have never been invented before, what good is market research?" The Walkman was launched without the standard customer research, as is typical at Sony.

With customer research not only costly, but often in error, how can a manager determine the innovations customers want? The solution may be design-for-purpose, a new approach in which a firm uses speed and flexibility to gain customer information instead of, or in addition to, standard customer research.

To illustrate, Sony obtains information from the actual sales of various Walkman models and then quickly adjusts its product mix to conform to those sales patterns. Specifically, the process design of each Walkman model is based on a core platform containing the essential technology. But the platform is designed to be flexible, which allows a wide range of models to be easily built on it, such as a beach model, a child's model, one that attaches to the arm, and so on.

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Depending upon which models sell, the models or features are changed, but the platform remains the same. If pink is a hot selling color, they make more pink models. If beach models sell well, they make more of the existing models and also expand the line. This technique is far more accurate than deciding what to make using traditional customer research.

Similarly, without customer research, every season Seiko "throws" into the market several hundred new models of its watches. Those that customers buy, it makes more of; the others, it drops. Capitalizing on the design-for-response strategy, Seiko has a highly flexible design and production process that lets it quickly and inexpensively introduce products. Do they worry if a high percentage of the watches they introduce fail, rejected by the customers? No (unless the failure rate is extremely high), because their fast, flexible product design process has slashed the cost of failure.

When creating a new magazine, Hearst Magazines also follows this approach. Hearst learned that it was almost impossible to customer test the magazine ideas, and that it was better to launch the magazine and see what happens. To do this, Hearst has created a special group of editors with the talent and flexibility to launch almost any new magazine. Based upon the initial sales of the new magazine, they will either revise the content and format or drop the publication. Any new magazine that proves successful is spun off to run independently.

Crucial to this approach, however, is reducing the cost of the failures by keeping expenses down. Hearst accomplishes this by initially hiring one overall editor on a short-time basis, using stringers as writers, and borrowing advertising people. Also, with experience it has discovered the tricks of launching new magazine products inexpensively. For example, it has learned how to test different cover designs efficiently, and how to test sales in different markets, such as newsstands or subscribers.

Many other firms also follow the strategy of using customer research data less and fast-flexible response more, with the food industry in the lead. One of the problems with customer research into foods is that a person's desire for food is powerfully influenced by the ambiance, the dining companions and what foods were eaten recently, all of which confound and confuse the results of the customer research. Even more erratic are the results with children's food, say a new cereal or snack. The responses of kids are strongly swayed by how well they like the people doing the test and the playthings available. Worse, kids quickly change their minds, and in a taste test of several foods a child can judge one food the best but one hour later proclaim the same food as "icky."

Arthur D. Little & Co. discovered that of all new cereals introduced to the market, 92 percent had failed. Since using the full array of customer research techniques produces a success rate of only 8 percent, more and more companies are revising their thinking about doing customer research as usual. Innovative firms such as Keebler and the leading cereal makers are reducing their expenditure for customer research and instead are vigorously cutting the cost of launching new products, including making their manufacturing processes more flexible.

Design-for-response enables firms not only to employ customer research when beneficial but also to respond quickly to what the customers really want, keeping the firm on top of market shifts and surprises.

Note: Mr. Zangwill is a professor at the Graduate School of Business, University of Chicago, and author of *Lightning Strategies for Innovation* (Lexington, 1992).

(See related letter: "Letters to the Editor: Testing the Waters Before the Launch," *WSJ*—April 1, 1993)

Vlasic on a Roll with Huge Pickle Slices

READING

Michele Darnell

www.vlasic.com

Many were skeptical of Frank Meczkowski's plan to develop a pickle so big that a single slice could cover a hamburger.

After all, whoever saw a pickle that big—except maybe in the *Guinness Book of World Records?*

Meczkowski and his team of food researchers at Vlasic Foods International were convinced the project—given the code name Frisbee—could fly.

For about four years, they labored to cultivate a jumbo cucumber with the taste, shape and crunch to be a perfect pickle.

Made only at the company's plant in Millsboro, the monster-sized slices seem to have captured the pickle lover's fancy. They've become one of Vlasic's best-selling products since their introduction in supermarkets. And, the better-than-anticipated sales have helped to reverse a three-year decline in consumption of Vlasic pickles.

Hamburger Stackers are about 10 times bigger than traditional pickle chips and come in dill and bread-and-butter varieties.

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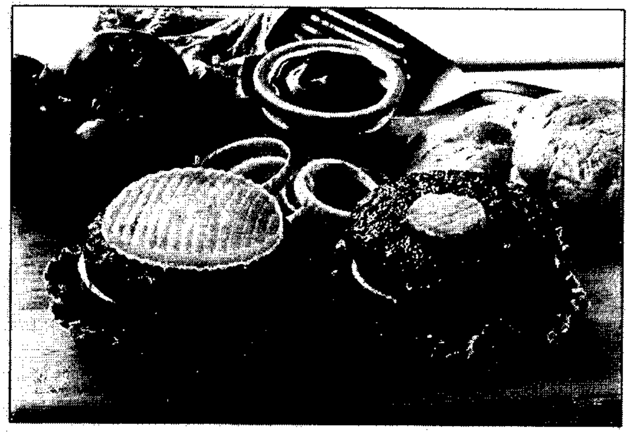

The 'Hamburger Stacker' on the burger at left dwarfs a traditional pickle slice. Stackers are 'genetically designed' using cucumbers that grow to over 3 inches in diameter and weigh five pounds.

"They said it just couldn't be done."

Making a bigger pickle may not sound like that big of a deal. You just grow a bigger cucumber, right?

There is more to it than that. The folks at Vlasic soon learned how tough it was to deal with gigantic cucumbers as they developed the new product and as they retooled the Delaware plant.

Meczkowski came up with the idea for the mammoth pickle slices soon after Vlasic's introduction of its Sandwich Stackers—regular-size pickles sliced lengthwise so they can be draped on sandwiches.

Sandwich Stackers currently account for 20 percent of all Vlasic pickle sales.

Vlasic is the No. 1 seller of pickles in the United States, with a 32 percent share of the $800 million retail pickle market, beating out brands such as Claussen, Heinz and Peter Piper's.

To develop Hamburger Stackers, Meczkowski worked with seed researchers and others to scour the globe looking for oversized varieties of cucumbers. Most weren't in commercial production.

Vlasic's team grew different varieties in greenhouses, looking for one that would get big enough yet still make a good pickle.

It had to taste like a regular cucumber, stay crisp when pickled, have a small seed cavity and be straight enough so that it could be cut mechanically.

"We wanted it to really be a cucumber," said Meczkowski, who has worked as a food researcher for 22 years and is based at Vlasic's headquarters in New Jersey.

He said Vlasic also had to decide just how big Hamburger Stackers should be. At one point, it asked consumers who were participating in focus groups to bring in their own homemade burgers so the company could determine the perfect size for its new pickles.

Eventually, Vlasic officials found what they were looking for—a now-patented cucumber that grows 3.25 inches in diameter, easily reaches 12 to 16 inches in length and weighs about five pounds.

It looks like the watermelon's skinny runt brother.

Once the company settled on a cucumber, it had to work out details of how to get Hamburger Stackers into commercial production. One challenge was to grow the cucumbers in fields, rather than in a greenhouse.

Randy Spence, Vlasic's manager of manufacturing services, said the jumbo cucumbers grew quicker than anyone expected.

"Early on, we expected the bigger ones to grow slower, but that hasn't been the case," he said.

These days, most of the gigantic cucumbers are grown in Florida, where they are handpicked because of their size. Depending on the weather, they take about 54 days from seed to harvest.

Once harvested, they're shipped to Vlasic's plant in Sussex County. The plant employs about 260 workers year-round and 300 to 400 others from April to November.

Steven McNulty, director of plant operations at the nearly 30-year-old Millsboro facility, said the size of the new cucumbers meant they couldn't be handled in the same manner as the smaller versions used to make pickle spears and sweet gherkins.

That became obvious when Vlasic tried to process its first batch of the somewhat fragile, jumbo-sized cucumbers.

Officials didn't end up with the Hamburger Stackers they envisioned. Instead, they ended up with a batch of broken big cucumbers.

"On the first run, we broke every one," Spence said.

But it taught the company a lot about some of the retooling they'd have to do to the plant in Millsboro.

Officials at the plant began making months worth of adjustments so one of the facility's four production lines could handle the jumbo cucumbers.

"We've learned a lot," McNulty said. "And we're still learning."

Making Hamburger Stackers requires a mix of automation and the human touch. The process starts when the big cucumbers arrive by truck and are rushed into a cold-storage facility to preserve their flavor.

Once cooled, the cucumbers can be loaded onto the production line and checked for bad spots and other flaws.

They're washed by machine a couple times and sliced.

Then they're sized. Jiggling along a conveyor belt, slices that are too small are weeded out by a worker and a machine. Those that are too big also are sorted out.

Too big?

Yes, the monster-sized cucumbers can get a little too big to fit in the jar.

The cucumber slices that make the cut are mechanically stacked into jars and then topped off by hand.

Ella Mae Wilkerson, who has worked at the Vlasic plant in Millsboro for 17 years, said it takes some fast hands to make certain that outgoing jars have enough pickles packed in.

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"The bigger the jar, the harder it is," she said as containers of sweet gherkins being jarred on another production line zipped by on a conveyor belt.

After being packed with pickle slices, the jars of Hamburger Stackers are filled with a combination of water, vinegar, salt and other flavorings and colorings. They are capped, vacuum-sealed and pasteurized before being labeled and packed for global distribution.

Some details of how Hamburger Stackers are made are kept secret. McNulty said that is because the company is certain its rivals would love to figure out how to make their own Hamburger Stackers.

Vlasic is the only pickle-making company with such a product on the market. "We think the competition loves the idea," McNulty said.

Apparently, so does the pickle-eating public.

About $13 million worth of Hamburger Stackers were sold in the first five months after they were introduced.

The company is optimistic that the product will continue to grow in popularity with U.S. consumers who eat about 3.5 billion hamburgers at home annually.

Source: *Rochester Democrat and Chronicle,* December 13, 1999.

DESIGNING FOR MANUFACTURING

In this section, you will learn about design techniques that have greater applicability for the design of products than the design of services. Even so, you will see that they do have some relevance for service design. The topics include concurrent engineering, computer-assisted design, designing for assembly and disassembly, and the use of components for similar products.

Concurrent Engineering

To achieve a smoother transition from product design to production, and to decrease product development time, many companies are using *simultaneous development,* or concurrent engineering. In its narrowest sense, **concurrent engineering** means bringing design and manufacturing engineering people together early in the design phase to simultaneously develop the product and the processes for creating the product. More recently, this concept has been enlarged to include manufacturing personnel (e.g., materials specialists) and marketing and purchasing personnel in loosely integrated, cross-functional teams. In addition, the views of suppliers and customers are frequently sought. The purpose, of course, is to achieve product designs that reflect customer wants as well as manufacturing capabilities.

concurrent engineering Bringing engineering design and manufacturing personnel together early in the design phase.

Traditionally, designers developed a new product without any input from manufacturing, and then turned over the design to manufacturing, which would then have to develop a process for making the new product. This "over-the-wall" approach created tremendous challenges for manufacturing, generating numerous conflicts and greatly increasing the time needed to successfully produce a new product. It also contributed to an "us versus them" mentality.

For these and similar reasons, the simultaneous development approach has great appeal. Among the key advantages of this approach are the following:

1. Manufacturing personnel are able to identify production capabilities and capacities. Very often, they have some latitude in design in terms of selecting suitable materials and processes. Knowledge of production capabilities can help in the selection process. In addition, cost and quality considerations can be greatly influenced by design, and conflicts during production can be greatly reduced.
2. Early opportunities for design or procurement of critical tooling, some of which might have long lead times. This can result in a major shortening of the product development process, which could be a key competitive advantage.
3. Early consideration of the technical feasibility of a particular design or a portion of a design. Again, this can avoid serious problems during production.
4. The emphasis can be on *problem* resolution instead of *conflict* resolution.

However, despite the advantages of concurrent engineering, a number of potential difficulties exist in this codevelopment approach. Two key ones are the following:

1. Longstanding existing boundaries between design and manufacturing can be difficult to overcome. Simply bringing a group of people together and thinking that they will be able to work together effectively is probably naive.
2. There must be extra communication and flexibility if the process is to work, and these can be difficult to achieve.

Hence, managers should plan to devote special attention if this approach is to work.

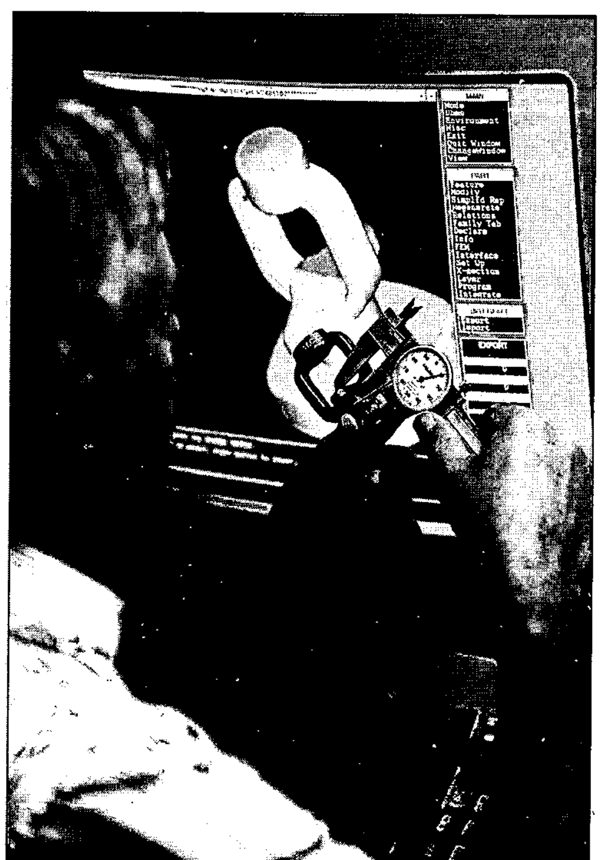
Computer-Aided Design (CAD)

computer-aided design (CAD) Product design using computer graphics.

Computers are increasingly used for product design. **Computer-aided design (CAD)** uses computer graphics for product design. The designer can modify an existing design or create a new one on a CRT by means of a light pen, a keyboard, a joystick, or a similar device. Once the design is entered into the computer, the designer can maneuver it on the screen: It can be rotated to provide the designer with different perspectives, it can be split apart to give the designer a view of the inside, and a portion of it can be enlarged for closer examination. The designer can obtain a printed version of the completed design and file it electronically, making it accessible to people in the firm who need this information (e.g., marketing, operations).

A growing number of products are being designed in this way, including transformers, automobile parts, aircraft parts, integrated circuits, and electric motors.

A major benefit of CAD is the increased productivity of designers. No longer is it necessary to laboriously prepare mechanical drawings of products or parts and revise them repeatedly to correct errors or incorporate revisions. A rough estimate is that CAD increases the productivity of designers from 3 to 10 times. A second major benefit of CAD is the creation of a database for manufacturing that can supply needed information on product geometry and dimensions, tolerances, material specifications, and so on. It should be noted, however, that CAD needs this database to function and that this entails a considerable amount of effort.



Computer-aided design (CAD) is used to design components and products to exact measurement and detail. This firehead sprinkler was designed to exact specifications and then manufactured at the Thompson Factory in Atlanta, Georgia.

Some CAD systems allow the designer to perform engineering and cost analyses on proposed designs. For instance, the computer can determine the weight and volume of a part and do stress analysis as well. When there are a number of alternative designs, the computer can quickly go through the possibilities and identify the best one, given the designer's criteria.

Production Requirements

As noted earlier in the chapter, designers must take into account *production capabilities*. Design needs to clearly understand the capabilities of production (e.g., equipment, skills, types of materials, schedules, technologies, special abilities). This helps in choosing designs that match capabilities. When opportunities and capabilities do not match, management must consider the potential for expanding or changing capabilities to take advantage of those opportunities.

Forecasts of future demand can be very useful, supplying information on the timing and volume of demand, and information on demands for new products and services.

Manufacturability is a key concern for manufactured goods: Ease of fabrication and/or assembly is important for cost, productivity, and quality. With services, ease of providing the service, cost, productivity, and quality are of great concern.

The term **design for manufacturing (DFM)** is used to indicate the designing of products that are compatible with an organization's capabilities. A related concept in manufacturing is **design for assembly (DFA).** A good design must take into account not only how a product will be fabricated, but also how it will be assembled. Design for assembly focuses on reducing the number of parts in an assembly, as well as on the assembly methods and sequence that will be employed. Another, more general term, **manufacturability,** is sometimes used when referring to the ease with which products can be fabricated and/or assembled.

design for manufacturing (DFM) Designers take into account the organization's capabilities when designing a product.

design for assembly (DFA) Design focuses on reducing the number of parts in a product and on assembly methods and sequence.

manufacturability The ease of fabrication and/or assembly.

Recycling

Recycling is sometimes an important consideration for designers. **Recycling** means recovering materials for future use. This applies not only to manufactured parts, but also to materials used during production, such as lubricants and solvents. Reclaimed metal or plastic parts may be melted down and used to make different products.

Companies recycle for a variety of reasons, including

1. Cost savings.
2. Environment concerns.
3. Environmental regulations.

recycling Recovering materials for future use.

An interesting note: Companies that want to do business in the European Union must show that a specified proportion of their products are recyclable.

The pressure to recycle has given rise to the term **design for recycling (DFR),** referring to product design that takes into account the ability to disassemble a used product to recover the recyclable parts.

design for recycling (DFR) Design facilitates the recovery of materials and components in used products for reuse.

More Cars Come with a Shade of Green—Recycled Materials

NEWSCLIP

www.ford.com
www.gm.com
www.chryslercorp.com

Detroit's Big Three automakers, doing their best to build cars that don't fall apart, have a new goal: building cars that are easy to take apart.

The reason: Easy-to-remove parts are easy to recycle.

Car companies are putting the ability to recycle parts on the same level as safety, fuel economy, and costs when they design new vehicles.

For example, the Oldsmobile Aurora . . . uses scrap metal in its radiator mounting, and the bumper beams contain recycled copper and aluminum. Chrysler Corp. uses recycled tires for the splash guards on its midsize sedans.

Car parts have been recycled for years. But the auto industry only recently began to build cars with the idea of using recycled material. About 75 percent of new cars contain recycled material, mostly iron or steel used in the body.

Auto dismantlers usually buy a vehicle and remove all the parts that still work, such as seats, engines and headlights. The vehicle then goes to a shredder where it is reduced to small fragments and a huge magnet separates out the metal parts.

The challenge for auto companies is to find ways to separate the more than 20,000 different grades of plastic found in

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cars. About 24 percent of shredded material, known as "fluff," contains plastic, fluids, rubber, glass and other material. Most "fluff" can't be recycled.

Ford, GM and Chrysler have jointly formed the Vehicle Recycling Partnership in hopes of improving the technology to recover plastics and other material found in "fluff." Suppliers of material and the recycling industry are included in the partnership.

Manufacturers aren't suddenly becoming Friends of the Earth. "All of the recycling programs undertaken by Ford have been cost-effective," says Susan Day, vehicle recycling coordinator.

Source: *Rochester Democrat and Chronicle,* February 20, 1994.

Remanufacturing

remanufacturing Refurbishing used products by replacing wornout or defective components.

An emerging concept in manufacturing is the remanufacturing of products. **Remanufacturing** refers to refurbishing used products by replacing worn-out or defective components, and reselling the products. This can be done by the original manufacturer, or another company. Among the products that have remanufactured components are automobiles, printers, copiers, cameras, computers, and telephones.

There are a number of important reasons for doing this. One is that a remanufactured product can be sold for about 50 percent of the cost of a new product. Another is that the process requires mostly unskilled and semiskilled workers. And in the global market, European lawmakers are increasingly requiring manufacturers to take back used products, because this means fewer products end up in landfills and there is less depletion of natural resources such as raw materials and fuel.

design for disassembly (DFD) Design so that used products can be easily taken apart.

Designing products so that they can be more easily taken apart has given rise to yet another design consideration: **Design for disassembly (DFD)** includes using fewer parts and less material, and using snap-fits where possible instead of screws or nuts and bolts.

The reading "Making It (Almost) New Again" gives examples of what some companies are doing.

Making It (Almost) New Again

READING

Phil Ebersole

www.kodak.com

Tired: *Landfills.*
Wired: *Recycling.*
Inspired: *Remanufacturing.*

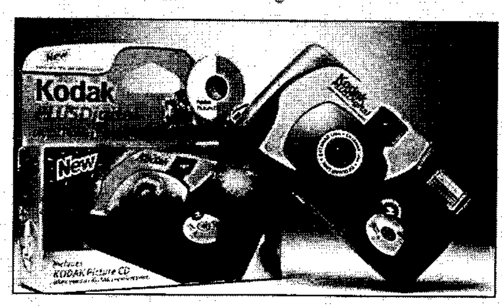
The symbol of 20th century industry was the assembly line. The symbol of 21st century industry may be the disassembly line.

Xerox Corp. and Eastman Kodak Co. design products to make them not only easy to put together, but easy to take apart.

That's because so many parts and components from their old products are refurbished and put into new ones.

Xerox and Kodak, along with Caterpillar Inc., are the leaders in a movement called remanufacturing, said Robert T. Lund, a professor of manufacturing engineering at Boston University and author of a 1996 study of the subject.

"The driving force behind remanufacturing is thrift," Lund said. "A remanufactured product can be sold for 45 to 60 percent of the cost of a new one. You have something enormously more valuable than if you ground it up as raw material."



But in a few years, remanufacturing may be more than just a good idea. European countries are developing rules to make manufacturers take back their products instead of allowing them to wind up in landfills. Europe's rules could set the standard for the world, just as California auto emissions laws set the standard for the U.S. auto industry.

The 15-nation European Union is considering a rule that would require 85 percent of a car by weight to be recycled or remanufactured. This would increase to 95 percent by 2015.

(continued)

This goes beyond what's done now. Currently about 75 percent of the average U.S. car is recycled or remanufactured. About all the metal in a car is reused, but little plastic and other materials.

Fixing up used equipment for resale is nothing new, but Xerox and Kodak take remanufacturing to the point of breaking down the distinction between new and used.

Almost all their new copiers and single-use cameras contain remanufactured parts. Virgin and remanufactured components go through the same production lines and meet the same tests.

If you could find an all-virgin product, they say, you couldn't tell the difference between it and one that was 95 percent remanufactured.

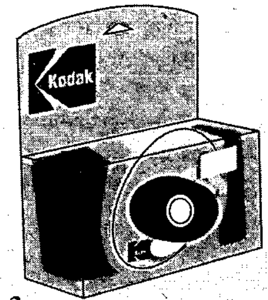
It's a process that goes beyond recycling, because companies conserve not only raw materials, but the energy, labor and ingenuity that went into making the components.

Lund said there are 73,000 companies in 61 industries, ranging from computer chips to locomotives, who do remanufacturing. They have 480,000 employees and do $53 billion worth of business.

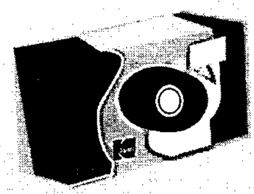
Rochester Institute of Technology is a leader in this movement. It operates a remanufacturing laboratory at its Center for Integrated Manufacturing Studies and publishes a quarterly called *Remanufacturing Today.*

NOT A THROWAWAY

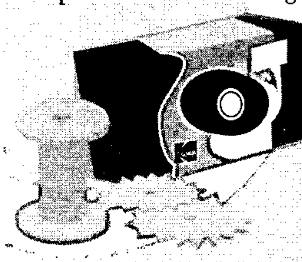
Kodak's Fun Saver shows remanufacturing in action.



Step 1
Buy Kodak Fun Saver Camera loaded with Kodak Gold Film. Take pictures and drop off the entire camera to a photofinisher.



Step 2
Photofinisher ships the used camera back to Kodak's sites at Elmgrove, Guadalajara, Mexico and Chalon, France. Kodak gives incentives and premiums to encourage returns.



Step 3
Kodak and its subcontractors take the camera apart and inspect the parts. Worn out parts are ground up and used as raw material. Usable parts are refurbished for use in new cameras. 86 percent of the cameras by weight are recycled or refurbished.

Step 4
New Kodak Fun Saver cameras are made from virgin and refurbished parts, with new lenses and fresh film.

Remanufacturing isn't easy:

- Although companies ultimately may save money, the initial costs are higher. Remanufacturing is labor-intensive. Each remanufactured component is different, so the process can't be automated.
- Remanufacturers have to overcome a reputation for low quality. "People think remanufacturing is like repair, but it isn't," said Nabil Nasr, an RIT professor of manufacturing engineering.
- Designing products for remanufacturing makes it easier for other companies to refurbish your used products and sell them in competition with you.

For example, Kodak, along with Fuji Photo Film Co. and Konica Corp., battles "reloaders"—companies that sell poorly remade cameras under their own names with cheap Chinese film and used lenses and batteries, said David M. Snook, manager of worldwide recycling for Kodak single-use cameras.

The better Kodak designs its cameras for remanufacturing, the easier Kodak makes it for reloaders.

Remanufacturing is mainly carried on by small and mid-sized companies. Few large U.S. producers remanufacture their own products to the degree Xerox and Kodak do.

Some big companies still try to discourage remanufacturing, Lund said. They regard remanufactured products as competition for their virgin products. Others, like the Big 3 automakers, sanction or subcontract remanufacturing, but do little themselves.

Richard O. Carville, manager of design and manufacturing engineering for Xerox's print cartridge business unit, said he encountered skepticism in 1990 when he proposed remanufacturing print cartridges, the part of the copier that registers and prints the xerographic image.

After the first six months, the unit made a profit. It was able to cut prices as a result of the cost savings it had achieved.

One big challenge has been persuading customers to return the print cartridges, Carville said.

The first leaflets on cartridge return were ineffective. Now, when a customer opens the print engine package, the first thing he or she sees is a prepaid United Parcel Service or Canada Post mailer, shaped like an airplane.

(continued)

(concluded)

"Environmental partnership" cartridges are sold at a discount if the customer promises to return them. "It's not a rebate," Carville said. "It's a prebate."

Xerox has a 60 percent return rate for cartridges. For comparison, Kodak has a 74 percent return rate for its Fun Saver cameras, which, Snook says, compares favorably to recycled aluminum cans.

The print cartridges are sent, at Xerox's expense, to centers in Nogales, Ariz., and Utica, NY, where the cartridges are dismantled, cleaned and inspected. Rejected parts are ground up as raw material. The rest are refurbished and shipped to Webster, NY, for remanufacturing.

All plastics in Xerox copiers are impregnated with a flame-retardant material. Carville's unit worked with Underwriters Laboratories in 1992 and 1993 to get an approval process for remanufactured plastic materials. Currently Xerox plastic is approved for up to five reuses.

Carville said his unit doesn't want to franchise remanufacturers. Xerox wants to control the process so as to guarantee quality.

But from the standpoint of the customer, you can get a remanufactured product quicker and cheaper from an outside company, said James D. Condon, president of Photikon Corp. of Fairport.

His company, originally a broker in copier or printer parts, started making photoreceptor belts in 1989 and now remanufactures entire printer cartridges.

Unlike Xerox, Photikon is a true remanufacturer. Its products are completely remade, not a blend of remade and virgin parts like Xerox's. For this reason, Photikon's products can be made cheaper than Xerox's, Condon said.

Photikon has worked on products remade up to 25 times, although not by Photikon every time.

The demand for remanufactured products is booming, Condon said. Photikon's 19 employees have been working overtime for the past three months, and he expects to hire 10 more in the next year.

Xerox remanufactures about 1 million parts and 150,000 office machines each year. Kodak collects 50 million single-use cameras each year from 20 countries for remanufacturing, as well as reworking products ranging from microfilm machines to photographic film base.

Both companies use subcontractors extensively. Snook said that during the peak season, Outsource Enterprises of Rochester gets as many as 6 million single-use cameras in a week to be inspected, disassembled and sorted.

The most logical company to remanufacture a product is the original manufacturer, said Gordon H. McNeil, president of Magnetic Technologies Corp. of Pittsford, NY, which makes subsystems for Xerox and other companies. And looking at the used parts provides useful information in making new parts, he said.

He said about 35 percent of Magnetic Tech's output is remanufactured products, and this could grow to more than half in a few years.

Source: "Making It New Again and Again," Phil Ebersole, *Rochester Democrat and Chronicle*, July 14, 1997, p. E1. Used with permission.

Component Commonality

Companies often have multiple products or services to offer customers. Often, these products or services have a high degree of similarity of features and components. This is particularly true of *product families*, but it is also true of many services. Companies can realize significant benefits when a part can be used in multiple products. For example, car manufacturers employ this tactic by using internal components such as water pumps, engines, and transmissions on several automobile nameplates. In addition to the savings in design time, companies reap benefits through standard training for assembly and installation, increased opportunities for savings by buying in bulk from suppliers, and commonality of parts for repair, which reduces the inventory dealers and auto parts stores must carry. Similar benefits accrue in services. For example, in automobile repair, component commonality means less training is needed because the variety of jobs is reduced. The same applies to appliance repair, where commonality and *substitutability* of parts are typical. Multiple-use forms in financial and medical services is another example. Computer software often comprises a number of modules that are commonly used for similar applications, thereby saving the time and cost to write the code for major portions of the software. Tool manufacturers use a design that allows tool users to attach different power tools to a common power source. Similarly, Hewlett-Packard has a universal power source that can be used with a variety of computer hardware.

QUALITY FUNCTION DEPLOYMENT

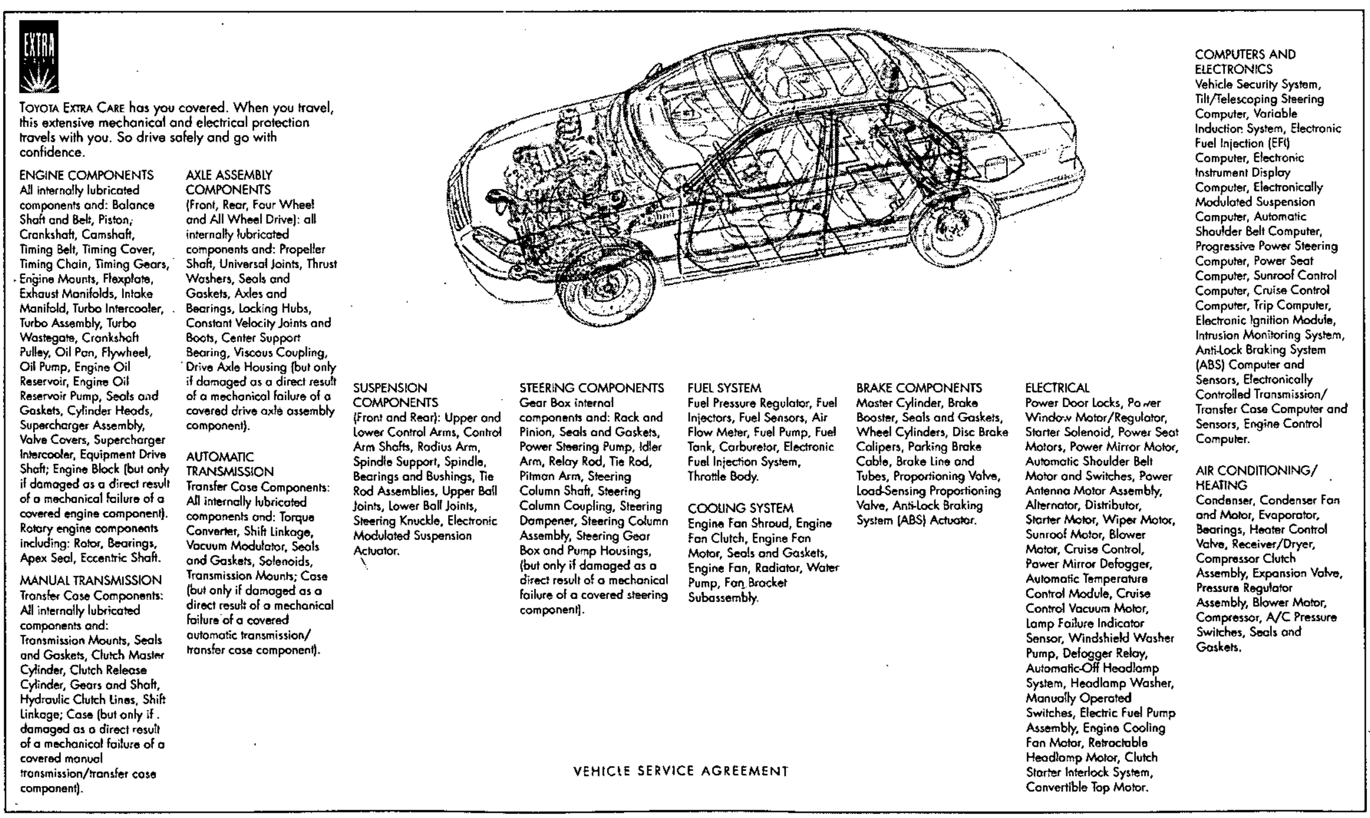
Obtaining input from customers is essential to assure that they will want what is offered for sale. Although obtaining input can be informal through discussions with customers, there is a formal way to document customer wants. **Quality function deployment (QFD)** is a structured approach for integrating the "voice of the customer" into both the product or service development process. The purpose is to ensure that customer requirements are factored into every aspect of the process. Listening to and understanding the customer is the central feature of QFD. Requirements often take the form of a general statement such as, "It should be easy to adjust the cutting height of the lawn mower." Once the requirements are known, they must be translated into technical terms related to the product or service. For example, a statement about changing the height of the lawn mower may relate to the mechanism used to accomplish that, its position, instructions for use, tightness of the spring that controls the mechanism, or materials needed. For manufacturing purposes, these must be related to the materials, dimensions, and equipment used for processing.

quality function deployment (QFD) An approach that integrates the "voice of the customer" into both product and service development.

The structure of QFD is based on a set of matrices. The main matrix relates customer requirements (what) and their corresponding technical requirements (how). This concept is illustrated in Figure 4.2.

Additional features are usually added to the basic matrix to broaden the scope of analysis. Typical additional features include importance weightings and competitive evaluations. A correlational matrix is usually constructed for technical requirements; this can reveal conflicting technical requirements. With these additional features, the set of matrices has the form illustrated in Figure 4.3. It is often referred to as the *house of quality* because of its houselike appearance.

An analysis using this format is shown in Figure 4.4. The data relate to a commercial printer (customer) and the company that supplies the paper. At first glance, the display appears complex. It contains a considerable amount of information for product and process planning. Therefore, let's break it up into separate parts and consider them one at a time. To start, a key part is the list of customer requirements on the left side of the figure. Next, note the technical requirements, listed vertically near the top. The key relationships, and their degree of importance, are shown in the center of the figure. The circle with a dot inside indicates the strongest positive relationship;



Toyota's Extra Care service contract protects the vehicle owner against costly mechanical and electrical repairs. This illustration uses design blueprint information to highlight covered parts and systems. (Not the current version used by Toyota Motor Insurance Services, Inc. © 1995 Toyota Motor Sales, U.S.A., Inc.)

FIGURE 4.2

An example of the house of quality. The main QFD Matrix.

Source: Ernst and Young Consulting Group, *Total Quality* (Homewood, IL: Dow-Jones Irwin, 1991), p. 121. Reprinted by permission.

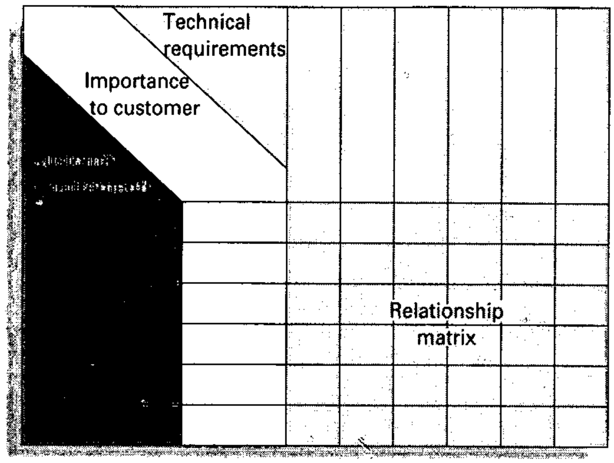
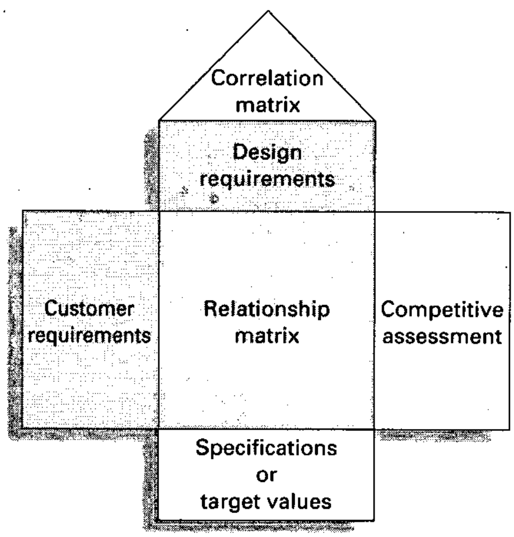


FIGURE 4.3

The house of quality



that is, it denotes the most important technical requirements for satisfying customer requirements. Now look at the "importance to customer" numbers that are shown next to each customer requirement (3 is the most important). Designers will take into account the importance values and the strength of correlation in determining where to focus the greatest effort.

Next, consider the correlation matrix at the top of the "house." Of special interest is the strong negative correlation between "paper thickness" and "roll roundness." Designers will have to find some way to overcome that or make a trade-off decision.

On the right side of the figure is a competitive evaluation comparing the supplier's performance on the customer requirements with each of the two key competitors (A and B). For example, the supplier (X) is worst on the first customer requirement and best on the third customer requirement. The line connects the X performances. Ideally, design will cause all of the Xs to be in the highest positions.

Across the bottom of Figure 4.4 are importance weightings, target values, and technical evaluations. The technical evaluations can be interpreted in a manner similar to that of the competitive evaluations (note the line connecting the Xs). The target values typically contain technical specifications, which we will not discuss. The importance weightings are the sums of values assigned to the relationships (see the lower right-hand key for relationship weights). The 3 in the first column is the product of the importance to the customer, 3, and the small (Δ) weight, 1. The importance weightings and target evaluations help designers focus on desired results. In this example, the first technical requirement has the lowest importance weighting, while the next four technical requirements all have relatively high importance weightings.

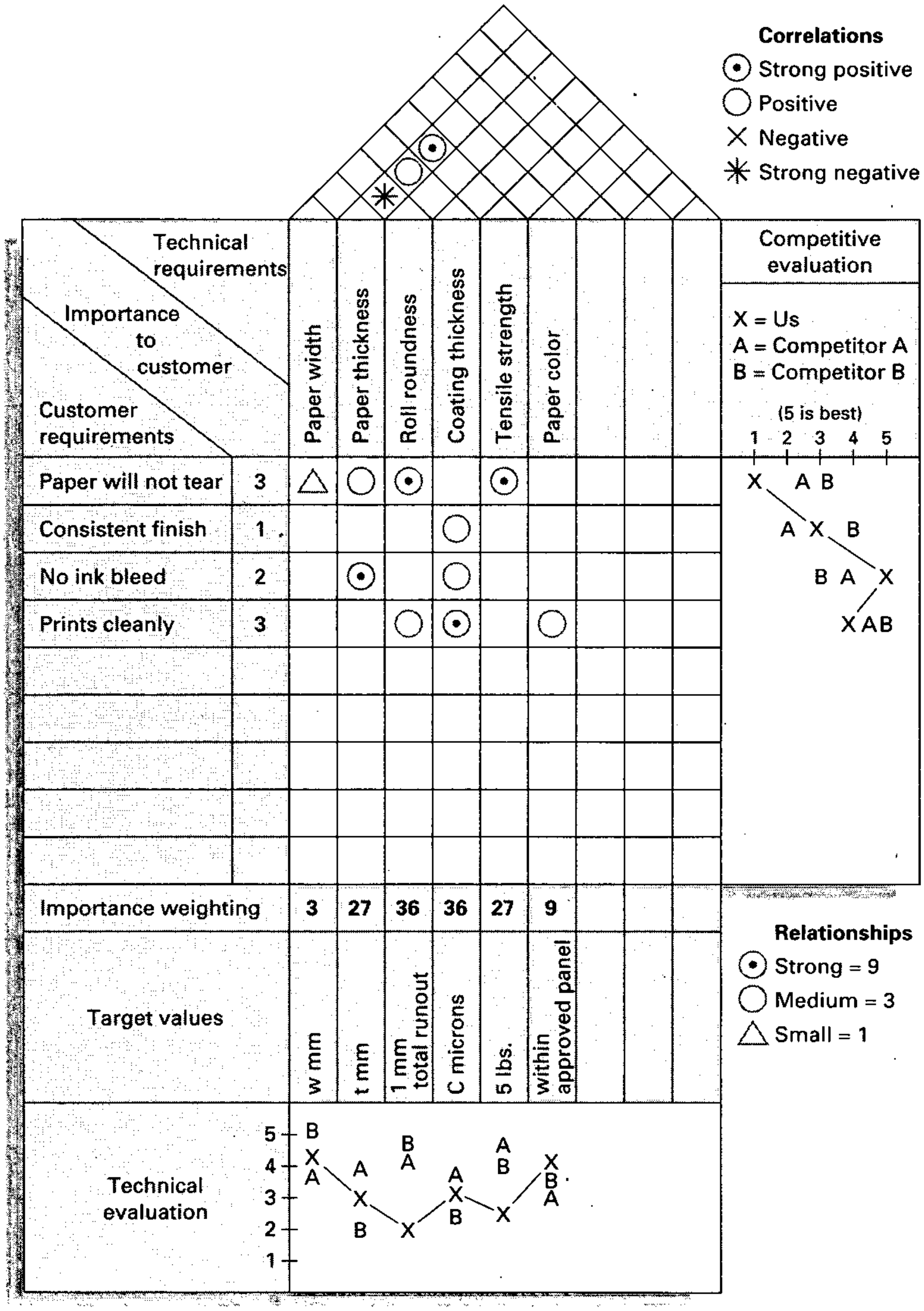


FIGURE 4.4

An example of the house of quality

THE KANO MODEL

The *Kano model* can be an interesting way to conceptualize design characteristics in terms of customer satisfaction. It is illustrated in Figure 4.5. It describes relationships between customer needs and customer satisfaction for three categories of design characteristics: "must have" characteristics, "expected" characteristics, and "excitement" characteristics.

The "must have" characteristics are those that yield a basic level of satisfaction, but do not have the potential for increasing customer satisfaction beyond a certain level. For instance, increasing the length of refrigerator cords beyond a reasonable length will not increase customer satisfaction. Neither will making flour whiter, or producing chewing gum that keeps its flavor (while being chewed) for four weeks. In contrast, the "expected" characteristics in a design will yield a steady increase in customer satisfaction. For example, increasing the life of a tire, or the life of a roof, will yield additional customer satisfaction. And the longer the life of a tire

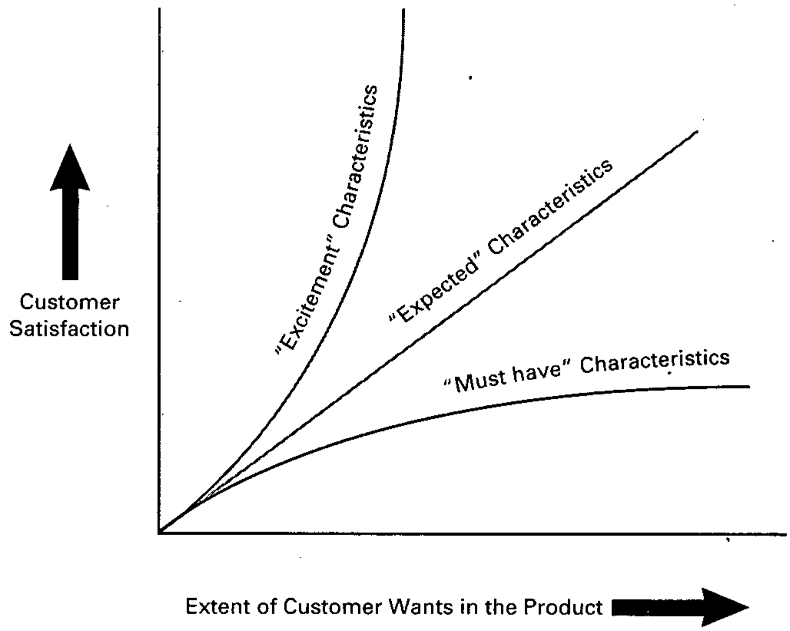


FIGURE 4.5
The Kano Model

or a roof, the higher the level of customer satisfaction. However, the greatest yield comes from "excitement" characteristics, perhaps evoking a "wow" from customers. These characteristics generate a disproportionate increase in customer satisfaction.

A possible design strategy would be to identify the design characteristics in each category for a particular product or service in order to incorporate the "must have" characteristics, and then conduct a cost-benefit analysis of characteristics in the other two categories to achieve desired results. This may not be as easy as it seems, especially in the case of the "excitement" characteristics, because those are often the most difficult to identify. In fact, customers may not be able to articulate them. Consequently, it may be necessary to turn to other alternatives (e.g., trial and error) to attempt to identify them.

SERVICE DESIGN

There are many similarities between product and service design. However, there are some important differences as well, owing to the nature of a service. One major difference is that unlike manufacturing, where production and delivery are usually separated in time, services are usually created and delivered *simultaneously*. Let's begin with some key definitions.

Definitions

service Something that is done to or for a customer.

service delivery system The facilities, processes, and skills needed to provide a service.

product bundle The combination of goods and services provided to a customer.

service package The physical resources needed to perform the service, the accompanying goods, and the explicit and implicit services included.

Service refers to an *act*, something that is done to or for a customer (client, patient, etc.). It is provided by a **service delivery system**, which includes the facilities, processes, and skills needed to provide the service. Many services are not pure services, but part of a **product bundle**—combination of goods and services provided to a customer.

System design involves development or refinement of the overall **service package.**[1]

1. The physical resources needed.
2. The accompanying goods that are purchased or consumed by the customer, or provided with the service.
3. Explicit services (the essential/core features of a service, such as hair styling, lawn mowing).
4. Implicit services (ancillary/extra features, such as friendliness, courtesy).

[1]Adapted from James A. Fitzsimmons and Mona J. Fitzsimmons, *Service Management for Competitive Advantage* (New York: McGraw-Hill, 1994).

Overview of Service Design

Service design begins with the choice of a service strategy, which determines the nature and focus of the service, and the target market. This requires an assessment by top management of the potential market and profitability (or need, in the case of a nonprofit organization) of a particular service, and an assessment of the organization's ability to provide the service. Once decisions on the focus of the service and the target market have been made, the customer requirements and expectations of the target market must be determined.

Two key issues in service design are the degree of variation in service requirements and the degree of customer contact and customer involvement in the delivery system. These have an impact on the degree to which service can be standardized or must be customized. The lower the degree of customer contact and service requirement variability, the more standardized the service can be. Service design with no contact and little or no processing variability is very much like product design. Conversely, high variability and high customer contact generally mean the service must be highly customized. A related consideration in service design is the opportunity for selling: The greater the degree of customer contact, the greater the opportunities for selling.

Differences between Service Design and Product Design

1. Products are generally tangible; services are generally intangible. Consequently, service design often focuses more on intangible factors (e.g., peace of mind, ambiance) than does product design.
2. In many instances services are created and delivered at the same time (e.g., a haircut, a car wash). In such instances there is less latitude in finding and correcting errors *before* the customer has a chance to discover them. Consequently, training, process design, and customer relations are particularly important.
3. Services cannot be inventoried. This poses restrictions on flexibility and makes capacity issues very important.
4. Services are highly visible to consumers and must be designed with that in mind; this adds an extra dimension to process design, one that usually is not present in product design.
5. Some services have low barriers to entry and exit. This places additional pressures on service design to be innovative and cost-effective.
6. Location is often important to service design, with convenience as a major factor. Hence, design of services and choice of location are often closely linked.
7. Service systems range from those with little or no customer contact to those that have a very high degree of customer contact. Here are some examples of those different types:

   Insulated technical core (e.g., software development).

   Production line (e.g., automatic car wash).

   Personalized service (e.g., haircut, medical service).

   Consumer participation (e.g., diet program, dance lessons).

   Self service (e.g., supermarket).

Service design for systems that have little or no customer contact is very much like product design; whereas service design with high customer contact generally requires inclusion of the *service delivery package.*

Phases in the Service Design Process

Table 4.5 lists the phases in the service design process. As you can see, they are quite similar to the phases of product design, except that the delivery system also must be designed.

Service Blueprinting

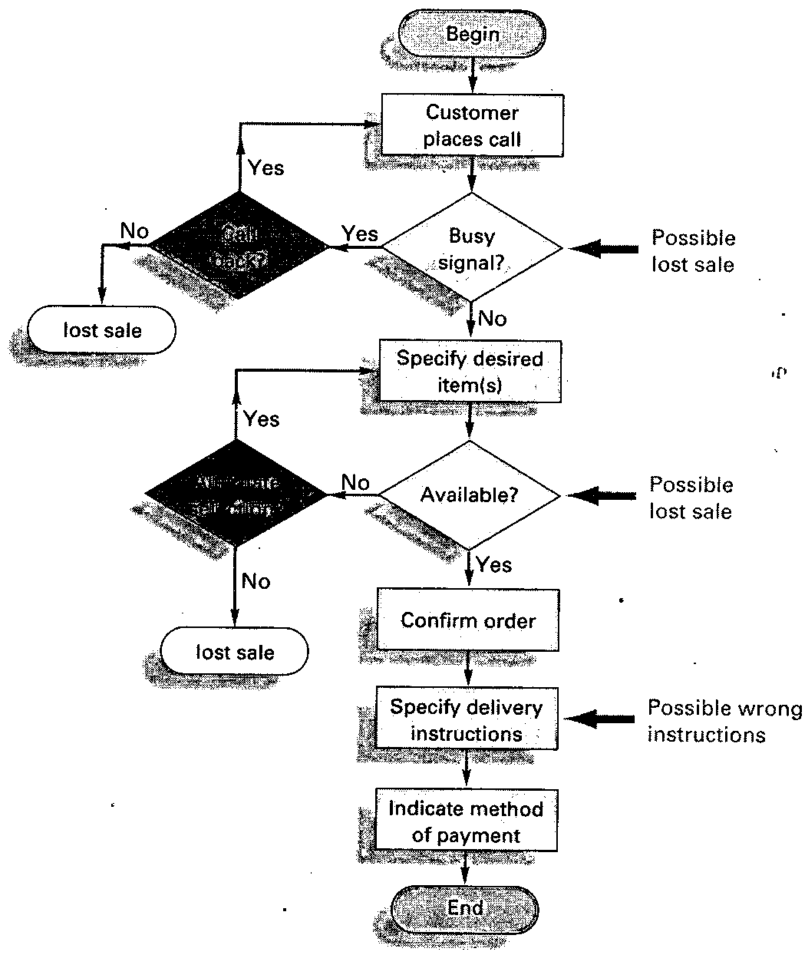
service blueprint A method used in service design to describe and analyze a proposed service.

A useful tool for conceptualizing a service delivery system is the **service blueprint,** which is a method for describing and analyzing a service process. A key aspect of service blueprinting

TABLE 4.5
Phases in service design process

1. Conceptualize
   - Idea generation
   - Assessment of customer wants/needs (marketing)
   - Assessment of demand potential (marketing)
2. Identify service package components needed (operations and marketing)
3. Determine performance specifications (operations and marketing)
4. Translate performance specifications into design specifications
5. Translate design specifications into delivery specifications

FIGURE 4.6
Flowchart of catalog call



is flowcharting the process. Figure 4.6 illustrates a flowchart for catalog telephone orders. Flowcharting a process helps to understand the process, and the resulting flowchart provides a visual model of the process. In Figure 4.6, potential failure points are highlighted.

The major steps in service blueprinting are

1. Establish boundaries for the process and decide on the level of detail that will be needed.
2. Identify the steps involved and describe them. If this is an existing process, get input from those who do it.
3. Prepare a flowchart of major process steps.
4. Identify potential failure points. Incorporate features that minimize the chances of failures.
5. Establish a time frame for service execution and an estimate of variability in processing time requirements. Time is a primary determinant of cost, so establishing a time standard for the service is important. Variability can also impact time, so an estimate of that is also important. Customers regard service time as a key concern—the shorter the service time, the

better. However, there are exceptions, such as a leisurely meal at a fine restaurant and a physician who takes the time to listen to a patient rather than rush to diagnosis or treatment.

6. Analyze profitability. Determine which factors can influence profitability, both positively and negatively, and determine how sensitive profitability is to these factors. For example, processing mistakes are often a key factor. Concentrate design efforts on key factors. Establish design features that protect against negative impacts and maximize positive impacts.

Characteristics of Well-Designed Service Systems

There are a number of characteristics of well-designed service systems. They can serve as guidelines in developing a service system. They include

1. Being consistent with the organization mission.
2. Being user friendly.
3. Being robust if variability is a factor.
4. Being easy to sustain.
5. Being cost-effective.
6. Having value that is obvious to customers.
7. Having effective linkages between back-of-the-house operations (i.e., no contact with the customer) and front-of-the-house operations (i.e., direct contact with customers). Front operations should focus on customer service, while back operations should focus on speed and efficiency.
8. Having a single, unifying theme, such as convenience or speed.
9. Having design features and checks that will ensure service that is reliable and high quality.

Challenges of Service Design

Service design presents some special challenges that are less likely to be encountered in product design, in part because service design also involves design of the delivery system. Among the challenges are the following:

1. There are variable requirements. This creates a need for a robust design that will accommodate a range of inputs and perhaps a range of outputs.
2. Services can be difficult to describe. By their very nature, verbal descriptions can be somewhat imprecise.
3. Customer contact is usually much higher in services.
4. Service design must take into account the service–customer encounter. There can be a relatively large number of variables to deal with in the service–customer encounter.

Operations Strategy

Product and service design is a fertile area for achieving competitive advantage and/or increasing customer satisfaction. Potential sources of such benefits include:

1. Increasing emphasis on component commonality.
2. Packaging products and ancillary services to increase sales. Examples include selling PCs at a reduced cost with a two-year Internet access sign-up agreement, extended warranties on products, companies offering installation and service, and companies offering training with computer software.
3. Using multiple-use platforms. Auto manufacturers use the same platform (basic chassis, say) for several nameplates (e.g., Jaguar S type, Lincoln LS, and Ford Thunderbird have shared the same platform). There are two basic computer platforms, PC and Mac, with many variations of computers using a particular platform.
4. Implementing tactics that will achieve the benefits of high volume while satisfying customer needs for variety, such as mass customization.

5. Continually monitoring products and services for small improvements rather than the "big bang" approach. Often the "little" things can have a positive, long-lasting effect on consumer attitudes and buying behavior.
6. Shortening the time it takes to get new or redesigned goods and services to the market.

A key competitive advantage of some companies is their ability to bring new products to the market more quickly than their competitors. Companies using this "first-to-market" approach are able to enter markets ahead of their competitors, allowing them to set higher selling prices than otherwise due to absence of competition. Such a strategy is also a defense against competition from cheaper "clones" because the competitors always have to play "catch up."

From a design standpoint, reducing the time to market involves

1. Using standardized components to create new but reliable products.
2. Using technology such as CAD (computer-aided design) equipment to rapidly design new or modified products.
3. Concurrent engineering to shorten engineering time.

Time-Based Innovation

READING

George Stalk Jr.

www.mitsubishi.com

A company that can bring out new products three times faster than its competitors enjoys a huge advantage. Today, in one industry after another, Japanese manufacturers are doing just that to their Western competition:

- In projection television, Japanese producers can develop a new television in one-third the time required by U.S. manufacturers.
- In custom plastic injection molds, Japanese companies can develop the molds in one-third the time of U.S. competitors and at one-third the cost.
- In autos, Japanese companies can develop new products in half the time—and with half as many people—as the U.S. and German competition.

To accomplish their fast-paced innovations, leading Japanese manufacturers have introduced a series of organizational techniques that precisely parallel their approach to flexible manufacturing:

- In manufacturing, the Japanese stress short production runs and small lot sizes. In innovation, they favor smaller increments of improvements in new products, but introduce them more often—versus the Western approach of more significant improvements made less often.
- In the organization of product development work, the Japanese use factory cells that are cross-functional teams. Most Western new product development activity is carried out by functional centers.
- In the scheduling of work, Japanese factories stress local responsibility, just as product development scheduling is decentralized. The Western approach to both requires plodding centralized scheduling, plotting, and tracking.

The effects of this time-based advantage are devastating; quite simply, American companies are losing leadership of technology and innovation—supposedly this country's source of long-term advantage. Unless U.S. companies reduce their new product development and introduction cycles from 36–48 months to 12–18 months, Japanese manufacturers will easily out-innovate and out-perform them. Taking the initiative in innovation will require even faster cycle times.

Residential air conditioners illustrate the Japanese ability to introduce more technological innovation in smaller increments—and how in just a few years these improvements add up to remarkably superior products. The Japanese introduce innovations in air conditioners four times faster than their American competitors; in technological sophistication the Japanese products are 7 to 10 years ahead of U.S. products.

Look at the changes in Mitsubishi Electric's three-horsepower heat pump between 1975 and 1985. From 1975 to 1979, the company did nothing to the product except change the sheet metal work, partly to improve efficiency but mostly to reduce materials cost. In 1979, the technological sophistication of the product was roughly equal to that of the U.S. competition. From this point on, the Japanese first established, and then widened the lead.

In 1980, Mitsubishi introduced its first major improvement: a new product that used integrated circuits to control the air-conditioning cycle. One year later, the company replaced the integrated circuits with microprocessors and added two important

(continued)

innovations to increase consumer demand. The first was "quick connect" Freon lines. On the old product (and on the U.S. product), Freon lines were made from copper tubing and cut to length, bent, soldered together, purged, and filled with Freon—an operation requiring great skill to produce a reliable air conditioner. The Japanese substituted quick-connect Freon lines—precharged hoses that simply clicked together. The second innovation was simplified wiring. On the old product (and still today on the U.S. product) the unit had six color-coded wires to connect. The advent of microprocessors made possible a two-wire connection with neutral polarity.

These two changes did not improve the energy-efficiency ratio of the product; nor were they intended to. Rather, the point was to fabricate a unit that would be simpler to install and more reliable, thereby broadening distribution and increasing demand. Because of these innovations, white-goods outlets could sell the new product, and local contractors could easily install it.

In 1982, Mitsubishi introduced a new version of the air conditioner featuring technological advances related to performance. A high-efficiency rotary compressor replaced the outdated reciprocating compressor. The condensing unit had louvered fins and inner fin tubes for better heat transfer. Because the balance of the system changed, all the electronics had to change. As a result, the energy-efficiency ratio improved markedly.

In 1983, Mitsubishi added sensors to the unit and more computing power, expanding the electronic control of the cycle and again improving the energy-efficiency ratio.

In 1984, Mitsubishi came out with another version of the product, this time with an inverter that made possible an even higher energy-efficiency ratio. The inverter, which requires additional electronics for the unit, allows unparalleled control over the speed of the electric motor, dramatically boosting the appliance's efficiency.

Using time-based innovation, Mitsubishi transformed its air conditioner. The changes came incrementally and steadily. Overall they gave Mitsubishi—and other Japanese companies on the same track—the position of technological leadership in the global residential air-conditioning industry.

In 1985, a U.S. air-conditioner manufacturer was just debating whether to use integrated circuits in its residential heat pump. In view of its four-to-five-year product development cycle, it could not have introduced the innovation until 1989 or 1990—putting the American company 10 years behind the Japanese. Faced with this situation, the U.S. air conditioner company followed the example of many U.S. manufacturers that have lost the lead in technology and innovation; it decided to source its air conditioners and components from its Japanese competition.

Consider the remarkable example of Atlas Door, a 10-year-old U.S. company. It has grown at an average annual rate of 15 percent in an industry with an overall annual growth rate of less than 5 percent. In recent years, its pre-tax earnings were 20 percent of sales, about five times the industry average. Atlas is debt free. In its 10th year the company achieved the number one competitive position in its industry.

The company's product: industrial doors. It is a product with almost infinite variety, involving limitless choices of width and height and material. Because of the importance of variety, inventory is almost useless in meeting customer orders; most doors can be manufactured only after the order has been placed.

Historically, the industry had needed almost four months to respond to an order for a door that was out of stock or customized. Atlas's strategic advantage was time; it could respond in weeks to any order. It had structured its order-entry, engineering, manufacturing, and logistics systems to move information and products quickly and reliably.

First, Atlas built just-in-time factories. These are fairly simple in concept. They require extra tooling and machinery to reduce changeover times and a fabrication process organized by product and scheduled to start and complete all of the parts at the same time. But even the performance of the factory—critical to the company's overall responsiveness—still only accounted for 2½ weeks of the completed product delivery cycle.

Second, Atlas compressed time at the front end of the system, where the order first entered and was processed. Traditionally, when customers, distributors, or salespeople called a door manufacturer with a request for price and delivery, they would have to wait more than one week for a response. If the desired door was not in stock, not in the schedule, or not engineered, the supplier's organization would waste even more time, pushing the search for an answer around the system.

Recognizing the opportunity to cut deeply into the time expenditure in this part of the system, Atlas first streamlined, then automated its entire order-entry, engineering, pricing, and scheduling processes. Today Atlas can price and schedule 95 percent of its incoming orders while the callers are still on the telephone. It can quickly engineer new special orders because it has preserved on computer the design and production data of all previous special orders—which drastically reduces the amount of reengineering necessary.

Third, Atlas tightly controlled logistics so that it always shipped only fully complete orders to construction sites. Orders require many components. Gathering all of them at the factory and making sure that they are with the correct order can be a time-consuming task. It is even more time-consuming, however, to get the correct parts to the job site *after* they have missed the initial shipment. Atlas developed a system to track the parts in production and the purchased parts for each order, ensuring arrival of all necessary parts at the shipping dock in time—a just-in-time logistics operation.

When Atlas started operations, distributors were uninterested in its product. The established distributors already carried the door line of a larger competitor; they saw no reason to switch suppliers except, perhaps, for a major price concession. But as a start-up, Atlas was too small to compete on price alone. Instead, it positioned itself as the door supplier of last resort, the company people came to if the established supplier could not deliver or missed a key date.

(continued)

(concluded)

Of course, with industry lead times of almost four months, some calls inevitably came to Atlas. And when it did get a call, Atlas commanded a higher price because of its faster delivery. Atlas not only got a higher price but its time-based processes also yielded lower costs: it thus enjoyed the best of both worlds.

In 10 short years, the company replaced the leading door suppliers in 80 percent of the distributors in the country. With its strategic advantage the company could be selective, becoming the house supplier for only the strongest distributors.

In the wake of this indirect attack, the established competitors have not responded effectively. The conventional view is that Atlas is a "garage shop operator" that cannot sustain its growth: competitors expect the company's performance to degrade to the industry average as it grows larger. But this response—or nonresponse—only reflects a fundamental lack of understanding of time as the source of competitive advantage. The extra delay in responding only adds to the insurmountable lead the indirect time-based attack has created. While the traditional companies track costs and size, the new competitor derives advantage from time, staying on the cutting edge, leaving its rivals behind.

Source: Reprinted by permission of *Harvard Business Review,* "Time—The Next Source of Competitive Advantage," by George Stalk Jr., July–August 1988.

SUMMARY

Product and service design is a key factor in satisfying the customer. To be successful in product and service design, organizations must be continually aware of what customers want, what the competition is doing, what government regulations are, and what new technologies are available.

The design process involves motivation, ideas for improvement, organizational capabilities, and forecasting. In addition to product life cycles, legal, environmental, and ethical considerations influence design choices. What degree of standardization designers should incorporate into designs is also an important consideration. Key objectives for designers are to achieve a product or service design that will meet or exceed customer expectations, that is within cost or budget, and that takes into account the capabilities of operations. Although product design and service design are similar in some respects, a number of key differences exist between products and services that influence the way they are designed.

Successful design often incorporates many of these basic principles: Determine what customers want as a starting point; minimize the number of parts needed to manufacture an item or the number of steps to provide a service; simplify assembly or service, standardize as much as possible; and make the design robust. Trade-off decisions are common in design, and they involve such things as development time and cost, product or service cost, special features/performance, and product or service complexity.

Research and development efforts can play a significant role in product and process innovations, although these are sometimes so costly that only large companies or governments can afford to underwrite them.

Reliability of a product or service is often a key dimension in the eyes of the customer. Measuring and improving reliability are important aspects of product and service design, although other areas of the organization also have an influence on reliability.

Quality function deployment is one approach for getting customer input for product or service design.

KEY TERMS

computer-aided design (CAD), 138
concurrent engineering, 137
delayed differentiation, 128
design for assembly (DFA), 139
design for disassembly (DFD), 140
design for manufacturing (DFM), 139
design for recycling (DFR), 139
designing for operations, 124
failure, 129
life cycle, 125
manufacturability, 139
mass customization, 127
modular design, 129
normal operating conditions, 129
product bundle, 146
product liability, 124
quality function deployment (QFD), 143
recycling, 139
reliability, 129
remanufacturing, 140
research and development (R&D), 133
reverse engineering, 133
robust design, 130
service, 146
service blueprint, 147
service delivery system, 146
service package, 146
standardization, 126
Uniform Commercial Code, 125

DISCUSSION AND REVIEW QUESTIONS

1. What are some of the factors that cause organizations to redesign their products or services?
2. Contrast applied research and basic research.
3. What is CAD? Describe some of the ways a product designer can use it.
4. Name some of the main advantages and disadvantages of standardization.
5. What is modular design? What are its main advantages and disadvantages?
6. Explain the term *design for manufacturing* and briefly explain why it is important.
7. What are some of the competitive advantages of concurrent engineering?
8. Explain the term *remanufacturing.*
9. What is meant by the term *life cycle?* Why would this be a consideration in product or service design?
10. Why is R&D a key factor in productivity improvement? Name some ways R&D contributes to productivity improvements.
11. What is *mass customization?*
12. Name two factors that could make service design much different from product design.
13. Explain the term *robust design.*
14. Explain what *quality function deployment* is and how it can be useful.
15. What is reverse engineering? Do you feel this is unethical?

TAKING STOCK

1. Describe some of the trade-offs that are encountered in product and service design.
2. Who needs to be involved in the design of products and services?
3. How has technology had an impact on product and service design?

CRITICAL THINKING EXERCISE

Think of a new or revised product or service that you would like to see on the market. Discuss the implications of producing that product or service relative to legal, ethical, environmental, profitability, competitive, design, and production issues.

PROBLEMS

1. Prepare a flowchart for each of these banking transactions:
   a. Make a savings deposit using a teller.
   b. Apply for a home equity loan.
2. Prepare a flowchart for each of these post office transactions in the appropriate cell of the table:
   a. Buy stamps from a machine.
   b. Buy stamps from a postal clerk.
3. List the steps involved in getting gasoline into your car for full service and for self service. Assume that paying cash is the only means of payment. For each list, identify the potential trouble points and indicate a likely problem.
4. Construct a list of steps for making a cash withdrawal from an automatic teller machine (ATM). Assume that the process begins at the ATM with your bank card in hand. Then identify the potential failure points (i.e., where problems might arise in the process). For each failure point, state one potential problem.
5. *a.* Refer to Figure 4–5. What two technical requirements have the highest impact on the customer requirement that the paper not tear?
   b. The following table presents technical requirements and customer requirements for the output of a laser printer. First, decide if any of the technical requirements relate to each customer requirement. Decide which technical requirement, if any, has the greatest impact on that customer requirement.

Customer Requirements	Type of Paper (Technical Requirements)	Internal Paper Feed (Technical Requirements)	Print Element (Technical Requirements)
Paper doesn't wrinkle			
Prints clearly			
Easy to use			

6. Prepare a table similar to that shown in Problem 5*b* for cookies sold in a bakery. List what you believe are the three most important customer requirements (not including cost) and the three most relevant technical requirements (not including sanitary conditions). Next, indicate by a checkmark which customer requirements and which technical requirements are related.

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INTERNET SITES

www.onlineethics.org has a long list of codes of ethics for various professional engineering and scientific societies.

Supplement to

CHAPTER 4

Reliability

LEARNING OBJECTIVES

After completing this supplement, you should be able to:

1 Define reliability.

2 Perform simple reliability computations.

3 Explain the purpose of redundancy in a system.

SUPPLEMENT OUTLINE

INTRODUCTION

Reliability is a measure of the ability of a product, service, part, or system to perform its intended function under a prescribed set of conditions. In effect, reliability is a *probability*.

reliability The ability of a product, service, part, or system to perform its intended function under a prescribed set of conditions.

Suppose that an item has a reliability of .90. This means that it has a 90 percent probability of functioning as intended. The probability it will fail is 1 − .90 = .10, or 10 percent. Hence, it is expected that, on the average, 1 of every 10 such items will fail or, equivalently, that the item will fail, on the average, once in every 10 trials. Similarly, a reliability of .985 implies 15 failures per 1,000 parts or trials.

QUANTIFYING RELIABILITY

Engineers and designers have a number of techniques at their disposal for assessing the reliability. A discussion of those techniques is not within the scope of this text. Instead, let us turn to the issue of quantifying overall product or system reliability. Probability is used in two ways.

1. The probability that the product or system will function when activated.
2. The probability that the product or system will function for a given length of time.

The first of these focuses on *one point in time* and is often used when a system must operate for one time or a relatively few number of times. The second of these focuses on the *length of service*. The distinction will become more apparent as each of these approaches is described in more detail.

The probability that a system or a product will operate as planned is an important concept in system and product design. Determining that probability when the product or system consists of a number of *independent* components requires the use of the rules of probability for independent events. **Independent events** have no relation to the occurrence or nonoccurrence

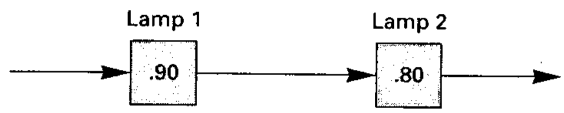
independent events Events whose occurrence or nonoccurrence does not influence each other.

of each other. What follows are three examples illustrating the use of probability rules to determine whether a given system will operate successfully.

Rule 1 If two or more events are independent and "success" is defined as the probability that all of the events occur, then the probability of success is equal to the product of the probabilities of the events.

Example. Suppose a room has two lamps, but to have adequate light both lamps must work (success) when turned on. One lamp has a probability of working of .90, and the other has a probability of working of .80. The probability that both will work is $.90 \times .80 = .72$. Note that the order of multiplication is unimportant: $.80 \times .90 = .72$. Also note that if the room had three lamps, three probabilities would have been multiplied.

This system can be represented by the following diagram:



Even though the individual components of a system might have high reliabilities, the system as a whole can have considerably less reliability because all components that are in series (as are the ones in the preceding example) must function. As the number of components in a series increases, the system reliability decreases. For example, a system that has eight components in a series, each with a reliability of .99, has a reliability of only $.99^8 = .923$.

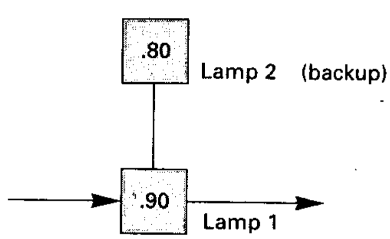
Obviously, many products and systems have a large number of component parts that must all operate, and some way to increase overall reliability is needed. One approach is to use **redundancy** in the design. This involves providing backup parts for some items.

redundancy The use of backup components to increase reliability.

Rule 2 If two events are independent and "success" is defined as the probability that *at least one* of the events will occur, the probability of success is equal to the probability of either one plus 1.00 minus that probability multiplied by the other probability.

Example. There are two lamps in a room. When turned on, one has a probability of working of .90 and the other has a probability of working of .80. Only a single lamp is needed to light for success. If one fails to light when turned on, the other lamp is turned on. Hence, one of the lamps is a backup in case the other one fails. Either lamp can be treated as the backup; the probability of success will be the same. The probability of success is $.90 + (1 - .90) \times .80 = .98$. If the .80 light is first, the computation would be $.80 + (1 - .80) \times .90 = .98$.

This system can be represented by the following diagram.

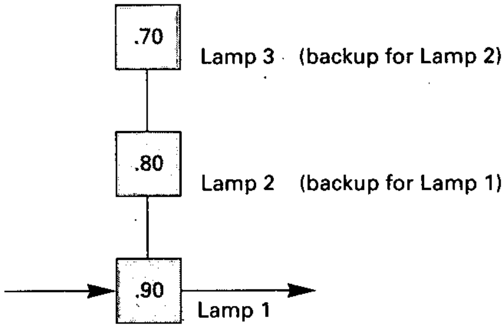


Rule 3 If two or more events are involved and success is defined as the probability that at least one of them occurs, the probability of success is $1 - P$ (all fail).

Example. Three lamps have probabilities of .90, .80, and .70 of lighting when turned on. Only one lighted lamp is needed for success; hence, two of the lamps are considered to be backups. The probability of success is

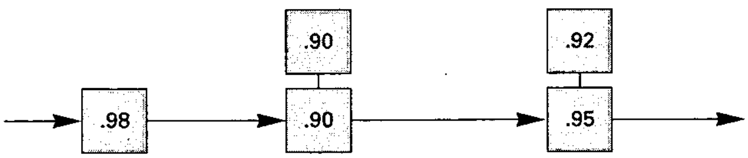
$$1 - [(1 - .90) \times (1 - .80) \times (1 - .70)] = .994$$

This system can be represented by the following diagram:



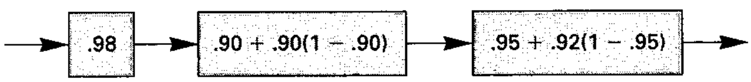
EXAMPLE S-1

Determine the reliability of the system shown below.



SOLUTION

The system can be reduced to a series of three components:



The system reliability is, then, the product of these:

$$.98 \times .99 \times .996 = .966$$

The second way of looking at reliability considers the incorporation of a time dimension: Probabilities are determined relative to a specified length of time. This approach is commonly used in product warranties, which pertain to a given period of time after purchase of a product.

A typical profile of product failure rate over time is illustrated in Figure 4S.1. Because of its shape, it is sometimes referred to as a bathtub curve. Frequently, a number of products fail shortly after they are put into service, not because they wear out, but because they are defective to begin with. The rate of failures decreases rapidly once the truly defective items are weeded out. During the second phase, there are fewer failures because most of the defective items have been eliminated, and it is too soon to encounter items that fail because they have worn out. In some cases, this phase covers a relatively long period of time. In the third phase, failures occur because the products are worn out, and the failure rate increases.

mean time between failures (MTBF) The average length of time between failures of a product or component.

Information on the distribution and length of each phase requires the collection of historical data and analysis of those data. It often turns out that the **mean time between failures (MTBF)**

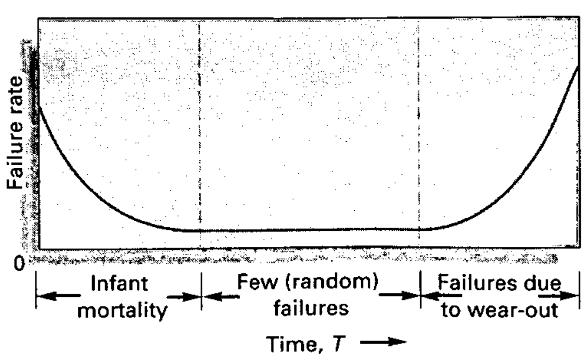
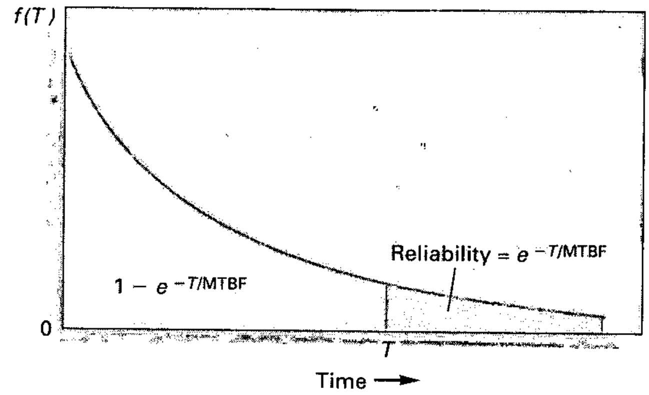


FIGURE 4S.1

Failure rate is a function of time

FIGURE 4S.2

An exponential distribution



in the infant mortality phase can be modeled by a negative exponential distribution, such as that depicted in Figure 4S.2. Equipment failures as well as product failures may occur in this pattern. In such cases, the exponential distribution can be used to determine various probabilities of interest. The probability that equipment or a product put into service at time 0 will fail *before* some specified time, T, is equal to the area under the curve between 0 and T. Reliability is specified as the probability that a product will last *at least until* time T; reliability is equal to the area under the curve *beyond* T. (Note that the total area under the curve in each phase is treated as 100 percent for computational purposes.) Observe that as the specified length of service increases, the area under the curve to the right of that point (i.e., the reliability) decreases.

Determining values for the area under a curve to the right of a given point, T, becomes a relatively simple matter using a table of exponential values. An exponential distribution is completely described using a single parameter, the distribution mean, which reliability engineers often refer to as the mean time between failures. Using the symbol T to represent length of service, the probability that failure will *not* occur before time T (i.e., the area in the right tail) is easily determined:

$$P(\text{no failure before } T) = e^{-T/\text{MTBF}}$$

where

$e = 2.7183 \ldots$

T = Length of service before failure

MTBF = Mean time between failures

The probability that failure will occur before time T is:

$$P(\text{failure before } T) = 1 - e^{-T/\text{MTBF}}$$

Selected values of $e^{-T/\text{MTBF}}$ are listed in Table 4S.1.

EXAMPLE S-2

By means of extensive testing, a manufacturer has determined that its Super Sucker Vacuum Cleaner models have an expected life that is exponential with a mean of four years. Find the probability that one of these cleaners will have a life that ends:

a. After the initial four years of service.

b. Before four years of service are completed.

c. Not before six years of service.

SOLUTION

MTBF = 4 years

a. T = 4 years:

$$T/\text{MTBF} = \frac{4 \text{ years}}{4 \text{ years}} = 1.0$$

TABLE 4S.1
Values of $e^{-T/MTBF}$

T/MTBF	$e^{-T/MTBF}$	T/MTBF	$e^{-T/MTBF}$	T/MTBF	$e^{-T/MTBF}$
0.10	.9048	2.60	.0743	5.10	.0061
0.20	.8187	2.70	.0672	5.20	.0055
0.30	.7408	2.80	.0608	5.30	.0050
0.40	.6703	2.90	.0550	5.40	.0045
0.50	.6065	3.00	.0498	5.50	.0041
0.60	.5488	3.10	.0450	5.60	.0037
0.70	.4966	3.20	.0408	5.70	.0033
0.80	.4493	3.30	.0369	5.80	.0030
0.90	.4066	3.40	.0334	5.90	.0027
1.00	.3679	3.50	.0302	6.00	.0025
1.10	.3329	3.60	.0273	6.10	.0022
1.20	.3012	3.70	.0247	6.20	.0020
1.30	.2725	3.80	.0224	6.30	.0018
1.40	.2466	3.90	.0202	6.40	.0017
1.50	.2231	4.00	.0183	6.50	.0015
1.60	.2019	4.10	.0166	6.60	.0014
1.70	.1827	4.20	.0150	6.70	.0012
1.80	.1653	4.30	.0136	6.80	.0011
1.90	.1496	4.40	.0123	6.90	.0010
2.00	.1353	4.50	.0111	7.00	.0009
2.10	.1255	4.60	.0101		
2.20	.1108	4.70	.0091		
2.30	.1003	4.80	.0082		
2.40	.0907	4.90	.0074		
2.50	.0821	5.00	.0067		

From Table 4S.1, $e^{-1.0} = .3679$.

b. The probability of failure before $T = 4$ years is $1 - e^{-1}$, or $1 - .3679 = .6321$.

c. $T = 6$ years:

$$T/\text{MTBF} = \frac{6 \text{ years}}{4 \text{ years}} = 1.50$$

From Table 4S.1, $e^{-1.5} = .2231$.

Product failure due to wear-out can sometimes be modeled by a normal distribution. Obtaining probabilities involves the use of a table (refer to Appendix Table B). The table provides areas under a normal curve from (essentially) the left end of the curve to a specified point z, where z is a *standardized* value computed using the formula

$$z = \frac{T - \text{Mean wear-out time}}{\text{Standard deviation of wear-out time}}$$

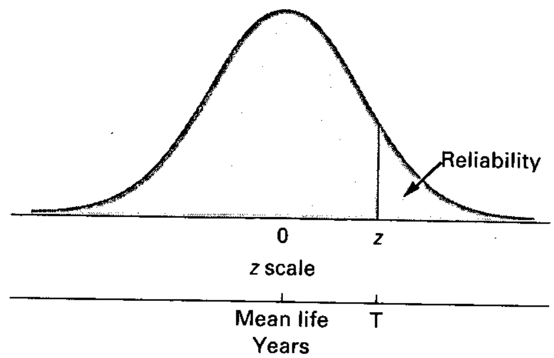
Thus, to work with the normal distribution, it is necessary to know the mean of the distribution and its standard deviation. A normal distribution is illustrated in Figure 4S.3. Appendix Table B contains normal probabilities (i.e., the area that lies to the left of z). To obtain a probability that service life will not exceed some value T, compute z and refer to the table. To find the reliability for time T, subtract this probability from 100 percent. To obtain the value of T that will provide a given probability, locate the nearest probability under the curve *to the left* in Table B. Then use the corresponding z in the preceding formula and solve for T.

EXAMPLE S-3

The mean life of a certain ball bearing can be modeled using a normal distribution with a mean of six years and a standard deviation of one year. Determine each of the following:

FIGURE 4S.3

A normal curve



a. The probability that a ball bearing will wear out *before* seven years of service.

b. The probability that a ball bearing will wear out *after* seven years of service (i.e., find its reliability).

c. The service life that will provide a wear-out probability of 10 percent.

SOLUTION

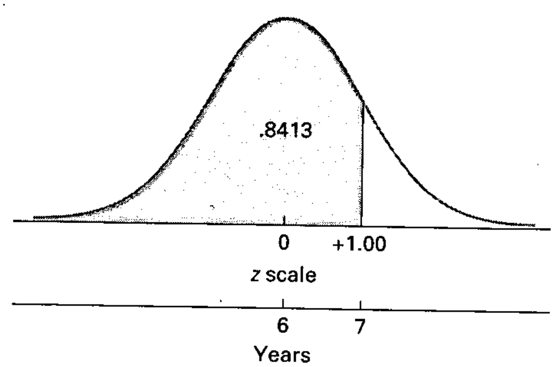
Wear-out life mean = 6 years

Wear-out life standard deviation = 1 year

Wear-out life is normally distributed

a. Compute z and use it to obtain the probability directly from Appendix Table B (see diagram).

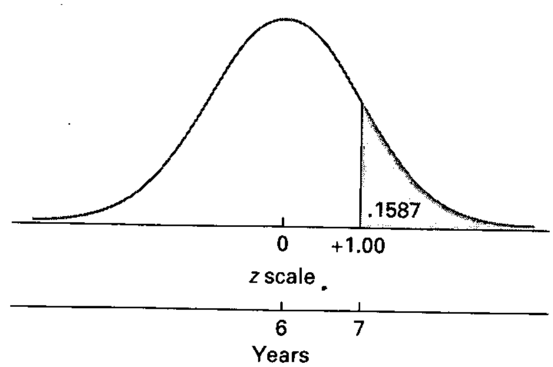
$$z = \frac{7-6}{1} = +1.00$$



Thus, $P(T < 7) = .8413$.

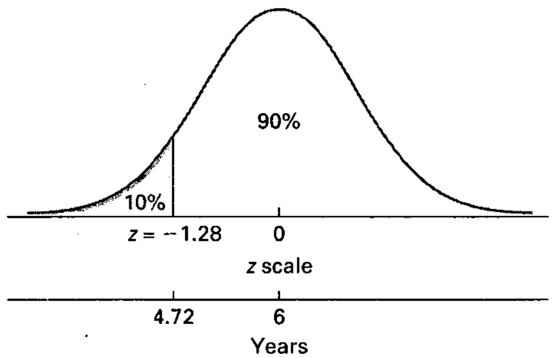
b. Subtract the probability determined in part *a* from 100 percent (see diagram).

$$1.00 - .8413 = .1587$$



c. Use the normal table and find the value of z that corresponds to an area under the curve of 10% (see diagram).

$$z = -1.28 = \frac{T-6}{1}$$



Solving for *T*, we find $T = 4.72$ years.

AVAILABILITY

A related measure of importance to customers, and hence to designers, is **availability.** It measures the fraction of time a piece of equipment is expected to be operational (as opposed to being down for repairs). Availability can range from zero (never available) to 1.00 (always available). Companies that can offer equipment with a high availability factor have a competitive advantage over companies that offer equipment with lower availability values. Availability is a function of both the mean time between failures and the mean time to repair. The availability factor can be computed using the following formula:

availability The fraction of time a piece of equipment is expected to be available for operation.

$$Availability = \frac{MTBF}{MTBF + MTR}$$

where

MTBF = Mean time between failures

MTR = Mean time to repair

EXAMPLE S-4

A copier is able to operate for an average of 200 hours between repairs, and the mean repair time is two hours. Determine the availability of the copier.

SOLUTION

MTBF = 200 hours and MTR = 2 hours

$$Availability = \frac{MTBF}{MTBF + MTR} = \frac{200}{200 + 2} = .99$$

Two implications for design are revealed by the availability formula. One is that availability increases as the mean time between failures increases. The other is that availability also increases as the mean repair time decreases. It would seem obvious that designers would want to design products that have a long time between failures. However, some design options enhance repairability, which can be incorporated into the product. Ink jet printers, for example, are designed with print cartridges that can easily be replaced.

KEY TERMS

SOLVED PROBLEMS

Problem 1

A product design engineer must decide if a redundant component is cost-justified in a certain system. The system in question has a critical component with a probability of .98 of operating. System failure would involve a cost of $20,000. For a cost of $100, a switch could be added that would automatically transfer the system to the backup component in the event of a failure. Should the backup be added if the backup probability is also .98?

Solution

Because no probability is given for the switch, we will assume its probability of operating when needed is 100 percent. The expected cost of failure (i.e., without the backup) is $20,000 × (1 − .98) = $400.

With the backup, the probability of *not* failing would be:

$$.98 + .02(.98) = .9996$$

Hence, the probability of failure would be 1 − .9996 = .0004. The expected cost of failure with the backup would be the added cost of the backup component plus the failure cost:

$$\$100 + \$20{,}000(.0004) = \$108$$

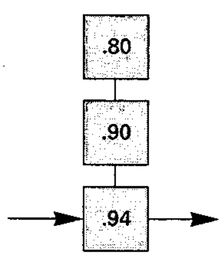
Because this is less than the cost without the backup, it appears that adding the backup is definitely cost justifiable.

Problem 2

Due to the extreme cost of interrupting production, a firm has two standby machines available in case a particular machine breaks down. The machine in use has a reliability of .94, and the backups have reliabilities of .90 and .80. In the event of a failure, either backup can be pressed into service. If one fails, the other backup can be used. Compute the system reliability.

$R_1 = .94, \quad R_2 = .90, \quad \text{and} \quad R_3 = .80$

The system can be depicted in this way:



$$\begin{aligned} R_{\text{system}} &= R_1 + R_2(1 - R_1) + R_3(1 - R_2)(1 - R_1) \\ &= .94 + .90(1 - .94) + .80(1 - .90)(1 - .94) = .9988 \end{aligned}$$

Problem 3

A hospital has three *independent* fire alarm systems, with reliabilities of .95, .97, and .99. In the event of a fire, what is the probability that a warning would be given?

Solution

A warning would *not* be given if all three alarms failed. The probability that at least one alarm would operate is 1 − *P*(none operate):

$$P(\text{none operate}) = (1 - .95)(1 - .97)(1 - .99) = .000015$$

$$P(\text{warning}) = 1 - .000015 = .999985$$

Problem 4

A weather satellite has an expected life of 10 years from the time it is placed into earth orbit. Determine its probability of no wear-out before each of the following lengths of service. Assume the exponential distribution is appropriate.

a. 5 years. *b.* 12 years. *c.* 20 years. *d.* 30 years.

Solution

MTBF = 10 years

Compute the ratio T/MTBF for $T = 5$, 12, 20, and 30, and obtain the values of $e^{-T/\text{MTBF}}$ from Table 4S.1. The solutions are summarized in the following table.

T	MTBF	*T*/MTBF	$e^{-T/\text{MTBF}}$
a. 5	10	0.50	.6065
b. 12	10	1.20	.3012
c. 20	10	2.00	.1353
d. 30	10	3.00	.0498

Problem 5

What is the probability that the satellite described in Solved Problem 4 will fail between 5 and 12 years after being placed into earth orbit?

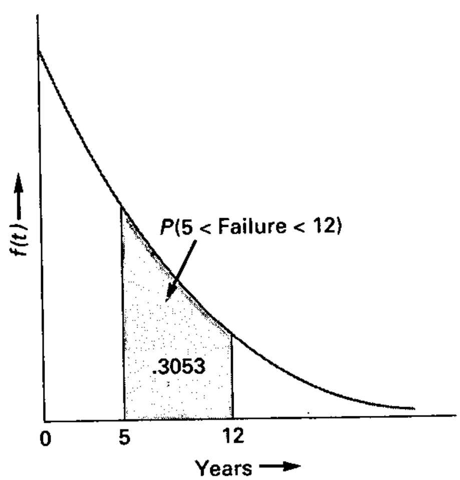
Solution

$$P(5 \text{ years} < \text{failure} < 12 \text{ years}) = P(\text{failure after 5 years}) - P(\text{failure after 12 years})$$

Using the probabilities shown in the previous solution, you obtain:

$$\begin{aligned} P(\text{failure after 5 years}) &= .6065 \\ -\,P(\text{failure after 12 years}) &= \underline{.3012} \\ &\ .3053 \end{aligned}$$

The corresponding area under the curve is illustrated as follows:



Problem 6

One line of radial tires produced by a large company has a wear-out life that can be modeled using a normal distribution with a mean of 25,000 miles and a standard deviation of 2,000 miles. Determine each of the following:

a. The percentage of tires that can be expected to wear out within ± 2,000 miles of the average (i.e., between 23,000 miles and 27,000 miles).

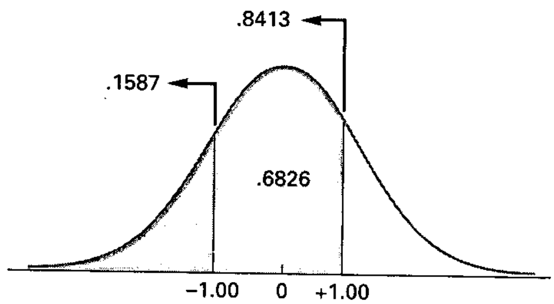
b. The percentage of tires that can be expected to fail between 26,000 miles and 29,000 miles.

Solution

Notes: (1) Miles are analogous to time and are handled in exactly the same way; (2) the term *percentage* refers to a probability.

a. The phrase "within ± 2,000 miles of the average" translates to within one standard deviation of the mean since the standard deviation equals 2,000 miles. Therefore the range of z is $z = -1.00$ to $z = +1.00$, and the area under the curve between those points is found as the difference between $P(z < +1.00)$ and $P(z < -1.00)$, using values obtained from Appendix Table B.

$$\begin{aligned} P(z < +1.00) &= .8413 \\ -\,P(z < -1.00) &= .1587 \\ \hline P(-1.00 < z < +1.00) &= .6826 \end{aligned}$$



b. Wear-out mean = 25,000 miles

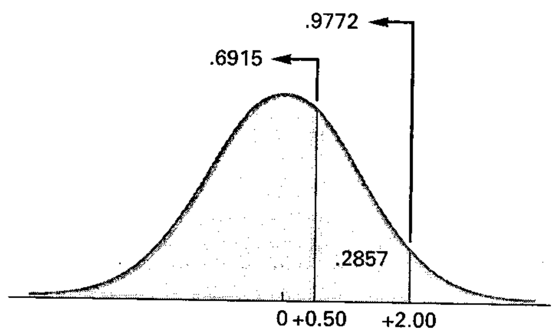
Wear-out standard deviation = 2,000 miles

$P(26{,}000 < \text{Wear-out} < 29{,}000) = P(z < z_{29,000}) - P(z < z_{26,000})$

$z_{29,000} = \dfrac{29{,}000 - 25{,}000}{2{,}000} = +2.00.$ From Appendix Table B $P = .9772$

$z_{26,000} = \dfrac{26{,}000 - 25{,}000}{2{,}000} = +.50.$ From Appendix Table B $P = .6915$

The difference is .9772 − .6915 = .2857, which is the expected percent of tires that will wear out between 26,000 miles and 29,000 miles.

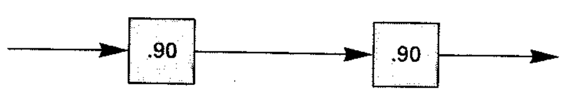


DISCUSSION AND REVIEW QUESTIONS

1. Define the term *reliability.*
2. Explain why a product or system might have an overall reliability that is low even though it is comprised of components that have fairly high reliabilities.
3. What is redundancy and how can it improve product design?

PROBLEMS

1. Consider the following system:



Determine the probability that the system will operate under each of these conditions:
a. The system as shown.
b. Each system component has a backup with a probability of .90 and a switch that is 100 percent reliable.
c. Backups with .90 probability and a switch that is 99 percent reliable.

2. A product is composed of four parts. In order for the product to function properly in a given situation, each of the parts must function. Two of the parts have a .96 probability of functioning, and two have a probability of .99. What is the overall probability that the product will function properly?
3. A system consists of three identical components. In order for the system to perform as intended, all of the components must perform. Each has the same probability of performance. If the system is to

have a .92 probability of performing, what is the minimum probability of performing needed by each of the individual components?

4. A product engineer has developed the following equation for the cost of a system component: $C = (10P)^2$, where C is the cost in dollars and P is the probability that the component will operate as expected. The system is composed of two identical components, both of which must operate for the system to operate. The engineer can spend \$173 for the two components. To the nearest two decimal places, what is the largest component probability that can be achieved?

5. The guidance system of a ship is controlled by a computer that has three major modules. In order for the computer to function properly, all three modules must function. Two of the modules have reliabilities of .97, and the other has a reliability of .99.
   a. What is the reliability of the computer?
   b. A backup computer identical to the one being used will be installed to improve overall reliability. Assuming the new computer automatically functions if the main one fails, determine the resulting reliability.
   c. If the backup computer must be activated by a switch in the event that the first computer fails, and the switch has a reliability of .98, what is the overall reliability of the system? (*Both* the switch and the backup computer must function in order for the backup to take over.)

6. One of the industrial robots designed by a leading producer of servomechanisms has four major components. Components' reliabilities are .98, .95, .94, and .90. All of the components must function in order for the robot to operate effectively.
   a. Compute the reliability of the robot.
   b. Designers want to improve the reliability by adding a backup component. Due to space limitations, only one backup can be added. The backup for any component will have the same reliability as the unit for which it is the backup. Which component should get the backup in order to achieve the highest reliability?
   c. If one backup with a reliability of .92 can be added to any one of the main components, which component should get it to obtain the highest overall reliability?

7. A production line has three machines A, B, and C, with reliabilities of .99, .96, and .93, respectively. The machines are arranged so that if one breaks down, the others must shut down. Engineers are weighing two alternative designs for increasing the line's reliability. Plan 1 involves adding an identical backup *line,* and plan 2 involves providing a backup for each *machine.* In either case, three machines (A, B, and C) would be used with reliabilities equal to the original three.
   a. Which plan will provide the higher reliability?
   b. Explain why the two reliabilities are not the same.
   c. What other factors might enter into the decision of which plan to adopt?

8. Refer to the previous problem.
   a. Assume that the single switch used in plan 1 is 98 percent reliable, while reliabilities of the machines remain the same. Recalculate the reliability of plan 1. Compare the reliability of this plan with the reliability of the plan 1 calculated in solving the original problem. How much did reliability of plan 1 decrease as a result of a 98 percent reliable switch?
   b. Assume that the three switches used in plan 2 are all 98 percent reliable, while reliabilities of the machines remain the same. Recalculate the reliability of plan 2. Compare the reliability of this plan with the reliability of the plan 2 calculated in solving the original problem. How much did reliability of plan 2 decrease?

9. A web server has five major components that must all function in order for it to operate as intended. Assuming that each component of the system has the same reliability, what is the minimum reliability each one must have in order for the overall system to have a reliability of .98?

10. Repeat Problem 9 under the condition that one of the components will have a backup with a reliability equal to that of any one of the other components.

11. Hoping to increase the chances of reaching a performance goal, the director of a research project has assigned three separate research teams the same task. The director estimates that the team probabilities are .9, .8, and .7 for successfully completing the task in the allotted time. Assuming that the teams work independently, what is the probability that the task will not be completed in time?

12. An electronic chess game has a useful life that is exponential with a mean of 30 months. Determine each of the following:
    a. The probability that any given unit will operate for at least: (1) 39 months, (2) 48 months, (3) 60 months.

b. The probability that any given unit will fail sooner than: (1) 33 months, (2) 15 months, (3) 6 months.

c. The length of service time after which the percentage of failed units will approximately equal: (1) 50 percent, (2) 85 percent, (3) 95 percent, (4) 99 percent.

13. A manufacturer of programmable calculators is attempting to determine a reasonable free-service period for a model it will introduce shortly. The manager of product testing has indicated that the calculators have an expected life of 30 months. Assume product life can be described by an exponential distribution.
    a. If service contracts are offered for the expected life of the calculator, what percentage of those sold would be expected to fail during the service period?
    b. What service period would result in a failure rate of approximately 10 percent?
14. Lucky Lumen light bulbs have an expected life that is exponentially distributed with a mean of 5,000 hours. Determine the probability that one of these light bulbs will last
    a. At least 6,000 hours.
    b. No longer than 1,000 hours.
    c. Between 1,000 hours and 6,000 hours.
15. Planetary Communications, Inc., intends to launch a satellite that will enhance reception of television programs in Alaska. According to its designers, the satellite will have an expected life of six years. Assume the exponential distribution applies. Determine the probability that it will function for each of the following time periods:
    a. More than 9 years.
    b. Less than 12 years.
    c. More than 9 years but less than 12 years.
    d. At least 21 years.
16. An office manager has received a report from a consultant that includes a section on equipment replacement. The report indicates that scanners have a service life that is normally distributed with a mean of 41 months and a standard deviation of 4 months. On the basis of this information, determine the percentage of scanners that can be expected to fail in the following time periods:
    a. Before 38 months of service.
    b. Between 40 and 45 months of service.
    c. Within ± 2 months of the mean life.
17. A major television manufacturer has determined that its 19-inch color TV picture tubes have a mean service life that can be modeled by a normal distribution with a mean of six years and a standard deviation of one-half year.
    a. What probability can you assign to service lives of at least: (1) Five years? (2) Six years? (3) Seven and one-half years?
    b. If the manufacturer offers service contracts of four years on these picture tubes, what percentage can be expected to fail from wear-out during the service period?
18. Refer to Problem 17. What service period would achieve an expected wear-out rate of:
    a. 2 percent?
    b. 5 percent?
19. Determine the availability for each of these cases:
    a. MTBF = 40 days, average repair time = 3 days.
    b. MTBF = 300 hours, average repair time = 6 hours.
20. A machine can operate for an average of 10 weeks before it needs to be overhauled, a process which takes two days. The machine is operated five days a week. Compute the availability of this machine. (Hint: all times must be in the same units.)
21. A manager must decide between two machines. The manager will take into account each machine's operating costs and initial costs, and its breakdown and repair times. Machine A has a projected average operating time of 142 hours and a projected average repair time of seven hours. Projected times for machine B are an average operating time of 65 hours and a repair time of two hours. What are the projected availabilities of each machine?
22. A designer estimates that she can (*a*) increase the average time between failures of a part by 5 percent at a cost of $450, or (*b*) reduce the average repair time by 10 percent at a cost of $200. Which option would be more cost-effective? Currently, the average time between failures is 100 hours and the average repair time is four hours.

23. Auto batteries have an average life of 2.7 years. Battery life is normally distributed with a mean of 2.7 years and a standard deviation of .3 year. The batteries are warranted to operate for a minimum of two years. If a battery fails within the warranty period, it will be replaced with a new battery at no charge. The company sells and installs the batteries. Also, the usual $5 installation charge will be waived.
    a. What percentage of batteries would you expect to fail before the warranty period expires?
    b. A competitor is offering a warranty of 30 months on its premium battery. The manager of this company is toying with the idea of using the same battery with a different exterior, labeling it as a premium battery, and offering a 30-month warranty on it. How much more would the company have to charge on its "premium" battery to offset the additional cost of replacing batteries?
    c. What other factors would you take into consideration besides the price of the battery?

CHAPTER 5

Strategic Capacity Planning for Products and Services

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Explain the importance of capacity planning.
2. Discuss ways of defining and measuring capacity.
3. Describe the determinants of effective capacity.
4. Discuss the major considerations related to developing capacity alternatives.
5. Briefly describe approaches that are useful for evaluating capacity alternatives.

CHAPTER OUTLINE

Capacity planning encompasses many basic decisions with long-term consequences for the organization. In this chapter, you will learn about the importance of capacity decisions, the measurement of capacity, how capacity requirements are determined, and the development and evaluation of capacity alternatives.

INTRODUCTION

Capacity issues are important for all organizations, and at all levels of an organization. **Capacity** refers to an upper limit or ceiling on the load that an operating unit can handle. The operating unit might be a plant, department, machine, store, or worker.

capacity The upper limit or ceiling on the load that an operating unit can handle.

The goal of strategic capacity planning is to achieve a match between the long-term supply capabilities of an organization and the predicted level of long-term demand. Organizations become involved in capacity planning for various reasons. Among the chief reasons are changes in demand, changes in technology, changes in the environment, and perceived threats or opportunities. A gap between current and desired capacity will result in capacity that is out of balance. Overcapacity causes operating costs that are too high, while undercapacity causes strained resources and possible loss of customers.

Excess Capacity Can Be Bad News! NEWSCLIP

Today, huge gaps between supply and demand have many companies struggling. Excess capacity abounds in such major industries as telecom, airline, and auto manufacturing. The bad news is that some companies are losing millions of dollars a year because of this. In the telecom industry, the increasing reach of cellular technology and other kinds of wireless access is continuing to create more and more supply, requiring telecom companies to cut prices and offer incentives to increase demand.

In the airline industry, air travel is way down, leaving airline companies awash in capacity. And even much of the currently mothballed aircraft are only in storage. Companies have eliminated flights to save money and cut prices to the bone trying to lure passengers.

The auto producers don't have it quite so bad, but for years they've been offering their customers incentives and interest-free financing—in order to keep their excess plants running.

Some basic questions in capacity planning are the following:

1. What kind of capacity is needed?
2. How much is needed?
3. When is it needed?

The question of what kind of capacity is needed depends on the products and services that management intends to produce or provide. Hence, in a very real sense, capacity planning is governed by those choices.

Forecasts are key inputs used to answer the questions of how much capacity is needed and when is it needed.

In some instances, capacity choices are made very infrequently; in others, they are made regularly, as part of an ongoing process. Generally, the factors that influence this frequency are the stability of demand, the rate of technological change in equipment and product design, and competitive factors. Other factors relate to the type of product or service and whether style changes are important (e.g., automobiles and clothing). In any case, management must review product and service choices periodically to ensure that the company makes capacity changes when they are needed for cost, competitive effectiveness, or other reasons.

CAPACITY DECISIONS ARE STRATEGIC

For a number of reasons, capacity decisions are among the most fundamental of all the design decisions that managers must make. In fact, capacity decisions can be *critical* for an organization:

1. Capacity decisions have a real impact on the ability of the organization to meet future demands for products and services; capacity essentially limits the rate of output possible. Having capacity to satisfy demand can allow a company to take advantage of tremendous opportunities. When the Quigley (www.quigleyco.com) Corporation's zinc gluconate lozenges, sold under the name Cold-Eeze™, attracted the public's interest during the height of the cold and flu season in 1997, drugstores and supermarkets quickly sold out. The product was so popular that the company couldn't keep up with demand. Because of this, the company was unable to take full advantage of the strong demand.
2. Capacity decisions affect operating costs. Ideally, capacity and demand requirements will be matched, which will tend to minimize operating costs. In practice, this is not always achieved because actual demand either differs from expected demand or tends to vary (e.g., cyclically). In such cases, a decision might be made to attempt to balance the costs of over- and undercapacity.
3. Capacity is usually a major determinant of initial cost. Typically, the greater the capacity of a productive unit, the greater its cost. This does not necessarily imply a one-for-one relationship; larger units tend to cost *proportionately* less than smaller units.

4. Capacity decisions often involve long-term commitment of resources and the fact that, once they are implemented, it may be difficult or impossible to modify those decisions without incurring major costs.
5. Capacity decisions can affect competitiveness. If a firm has excess capacity, or can quickly add capacity, that fact may serve as a barrier to entry by other firms. Then too, capacity can affect *delivery speed,* which can be a competitive advantage.
6. Capacity affects the ease of management; having appropriate capacity makes management easier than when capacity is mismatched.
7. Globalization has increased the importance and the complexity of capacity decisions. Far-flung supply chains and distant markets add to the uncertainty about capacity needs.
8. Because capacity decisions often involve substantial financial and other resources, it is necessary to plan for them far in advance. For example, it may take years for a new power generating plant to be constructed and become operational. However, this increases the risk that the designated amount of capacity will not match actual demand when the capacity becomes available.

DEFINING AND MEASURING CAPACITY

Capacity often refers to an upper limit on the *rate* of output. Even though this seems simple enough, there are subtle difficulties in actually measuring capacity in certain cases. These difficulties arise because of different interpretations of the term *capacity* and problems with identifying suitable measures for a specific situation.

In selecting a measure of capacity, it is important to choose one that does not require updating. For example, dollar amounts are often a poor measure of capacity (e.g., capacity of $30 million a year) because price changes necessitate updating of that measure.

Where only one product or service is involved, the capacity of the productive unit may be expressed in terms of that item. However, when multiple products or services are involved, as is often the case, using a simple measure of capacity based on units of output can be misleading. An appliance manufacturer may produce both refrigerators and freezers. If the output rates for these two products are different, it would not make sense to simply state capacity in units without reference to either refrigerators or freezers. The problem is compounded if the firm has other products. One possible solution is to state capacities in terms of each product. Thus, the firm may be able to produce 100 refrigerators per day *or* 80 freezers per day. Sometimes this approach is helpful, sometimes not. For instance, if an organization has many different products or services, it may not be practical to list all of the relevant capacities. This is especially true if there are frequent changes in the mix of output, because this would necessitate a frequently changing composite index of capacity. The preferred alternative in such cases is to use a measure of capacity that refers to *availability of inputs.* Thus, a hospital has a certain number of beds, a factory has a certain number of machine hours available, and a bus has a certain number of seats and a certain amount of standing room.

No single measure of capacity will be appropriate in every situation. Rather, the measure of capacity must be tailored to the situation. Table 5.1 provides some examples of commonly used measures of capacity.

Up to this point, we have been using a general definition of capacity. Although it is functional, it can be refined into two useful definitions of capacity:

1. *Design capacity:* The maximum output rate or service capacity an operation, process, or facility is designed for.
2. *Effective capacity:* Design capacity minus allowances such as personal time, maintenance, and scrap.

Design capacity is the maximum rate of output achieved under ideal conditions. Effective capacity is usually less than design capacity owing to realities of changing product mix, the need for periodic maintenance of equipment, lunch breaks, coffee breaks, problems in scheduling and balancing operations, and similar circumstances. *Actual output* cannot exceed effective capacity

TABLE 5.1
Measures of capacity

Business	Inputs	Outputs
Auto manufacturing	Labor hours, machine hours	Number of cars per shift
Steel mill	Furnace size	Tons of steel per day
Oil refinery	Refinery size	Gallons of fuel per day
Farming	Number of acres, number of cows	Bushels of grain per acre per year, gallons of milk per day
Restaurant	Number of tables, seating capacity	Number of meals served per day
Theater	Number of seats	Number of tickets sold per performance
Retail sales	Square feet of floor space	Revenue generated per day

and is often less because of machine breakdowns, absenteeism, shortages of materials, and quality problems, as well as factors that are outside the control of the operations managers.

These different measures of capacity are useful in defining two measures of system effectiveness: efficiency and utilization. *Efficiency* is the ratio of actual output to effective capacity. *Capacity utilization* is the ratio of actual output to design capacity.

Excel

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}} \tag{5–1}$$

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}} \tag{5–2}$$

Both measures are expressed as percentages.

It is not unusual for managers to focus exclusively on efficiency, but in many instances, this emphasis can be misleading. This happens when effective capacity is low compared to design capacity. In those cases, high efficiency would seem to indicate effective use of resources when it does not. The following example illustrates this point.

EXAMPLE 1

Given the information below, compute the efficiency and the utilization of the vehicle repair department:

$$\begin{aligned} \text{Design capacity} &= 50 \text{ trucks per day} \\ \text{Effective capacity} &= 40 \text{ trucks per day} \\ \text{Actual output} &= 36 \text{ trucks per day} \end{aligned}$$

SOLUTION

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}} = \frac{36 \text{ trucks per day}}{40 \text{ trucks per day}} = 90\%$$

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}} = \frac{36 \text{ trucks per day}}{50 \text{ trucks per day}} = 72\%$$

Compared to the effective capacity of 40 units per day, 36 units per day looks pretty good. However, compared to the design capacity of 50 units per day, 36 units per day is much less impressive although probably more meaningful.

Because effective capacity acts as a lid on actual output, the real key to improving capacity utilization is to increase effective capacity by correcting quality problems, maintaining equipment in good operating condition, fully training employees, and fully utilizing bottleneck equipment.

Hence, increasing utilization depends on being able to increase effective capacity, and this requires a knowledge of what is constraining effective capacity.

The following section explores some of the main determinants of effective capacity. It is important to recognize that the benefits of high utilization are realized only in instances where there is demand for the output. When demand is not there, focusing exclusively on utilization can be counterproductive, because the excess output not only results in additional variable costs, it also generates the costs of having to carry the output as inventory. Another disadvantage of high utilization is that operating costs may increase because of increasing waiting time due to bottleneck conditions.

DETERMINANTS OF EFFECTIVE CAPACITY

Many decisions about system design have an impact on capacity. The same is true for many operating decisions. This section briefly describes some of these factors, which are then elaborated on elsewhere in the book. The main factors relate to facilities, products or services, processes, human considerations, operational factors, the supply chain, and external forces.

Less Trash Leaves Landfills in a Bind

NEWSCLIP

www.gm.com

Not too long ago, dire predictions were made about the lack of landfill capacity to handle the growing amounts of trash companies and residences were generating. Now, some landfills around the country are not getting the trash (and the fees) they need to survive. What was once regarded as undercapacity has now turned into overcapacity.

The reasons for this turnaround can be found in strong efforts by the general public to recycle—stronger than most experts had predicted. Companies, too, are recycling more, a result of government regulations and cost-saving measures. They are also incorporating more recyclable and reusable parts and materials in their products, and they are reducing the amount of materials used to package their products.

But landfills, like many other kinds of operations, are designed to operate at a certain level. It is difficult (and in some states illegal) for them to operate above their design capacity, and it is inefficient to operate at levels much below design capacity. The shortfall that some landfills are experiencing underscores the risks involved in long-term capacity planning and the importance of good forecasts of future demand.

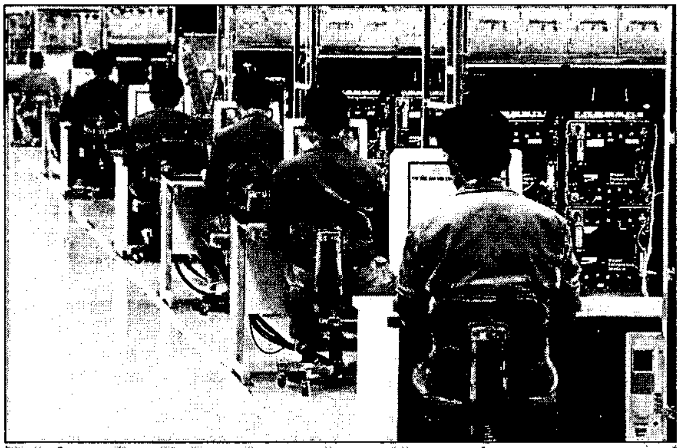
Source: Based on "Riga Landfill Strains to Survive," by Michael Caputo, *Rochester Democrat and Chronicle,* July 28, 1997.

Facilities The design of facilities, including size and provision for expansion, is key. Locational factors, such as transportation costs, distance to market, labor supply, energy sources, and room for expansion, are also important. Likewise, layout of the work area often determines how smoothly work can be performed, and environmental factors such as heating, lighting, and ventilation also play a significant role in determining whether personnel can perform effectively or whether they must struggle to overcome poor design characteristics.

Product and Service Factors Product or service design can have a tremendous influence on capacity. For example, when items are similar, the ability of the system to produce those items is generally much greater than when successive items differ. Thus, a restaurant that offers a limited menu can usually prepare and serve meals at a faster rate than a restaurant with an extensive menu. Generally speaking, the more uniform the output, the more opportunities there are for standardization of methods and materials, which leads to greater capacity. The particular mix of products or services rendered also must be considered since different items will have different rates of output.

Process Factors The quantity capability of a process is an obvious determinant of capacity. A more subtle determinant is the influence of output *quality.* For instance, if quality of output does not meet standards, the rate of output will be slowed by the need for inspection and rework activities.

Human Factors The tasks that make up a job, the variety of activities involved, and the training, skill, and experience required to perform a job all have an impact on the potential and actual output. In addition, employee motivation has a very basic relationship to capacity, as do absenteeism and labor turnover.



A mass producer of large-frame computers, the Sujitsu plant in Numazu, Japan, conducts product testing. Building efficiency into product testing increases their capacity.

Artisans making rugs by hand in a carpet workshop at the Grand Bazaar in Istanbul, Turkey. Capacity is highly limited in production systems such as this, where items are specialized and produced one at a time.

Operational Factors Scheduling problems may occur when an organization has differences in equipment capabilities among alternative pieces of equipment or differences in job requirements. Inventory stocking decisions, late deliveries, purchasing requirements, acceptability of purchased materials and parts, and quality inspection and control procedures also can have an impact on effective capacity.

Inventory shortages of even one component of an assembled item (e.g., computers, refrigerators, automobiles) can cause a temporary halt to assembly operations until the components become available. This can have a major impact on effective capacity. Thus, insufficient capacity in one area can affect overall capacity.

Supply Chain Factors Supply chain factors must be taken into account in capacity planning if substantial capacity changes are involved. Key questions include: What impact will the changes have on suppliers, warehousing, transportation, and distributors? If capacity will be increased, will these elements of the supply chain be able to handle the increase? Conversely, if capacity is to be decreased, what impact will the loss in business have on these elements of the supply chain?

External Factors Product standards, especially minimum quality and performance standards, can restrict management's options for increasing and using capacity. Thus, pollution standards on products and equipment often reduce effective capacity, as does paperwork required by government regulatory agencies by engaging employees in nonproductive activities. A similar effect occurs when a union contract limits the number of hours and type of work an employee may do.

Table 5.2 summarizes these factors. In addition, *inadequate planning* can be a major limiting determinant of effective capacity.

STRATEGY FORMULATION

An organization typically bases its capacity strategy on assumptions and predictions about long-term demand patterns, technological changes, and the behavior of its competitors. These typically involve (1) the growth rate and variability of demand, (2) the costs of building and operating facilities of various sizes, (3) the rate and direction of technological innovation, (4) the likely behavior of competitors, and (5) availability of capital and other inputs.

Key decisions of capacity planning relate to

TABLE 5.2
Factors that determine effective capacity

A. Facilities	5. Compensation
1. Design	6. Learning rates
2. Location	7. Absenteeism and labor turnover
3. Layout	E. Operational
4. Environment	1. Scheduling
B. Product/Service	2. Materials management
1. Design	3. Quality assurance
2. Product or service mix	4. Maintenance policies
C. Process	5. Equipment breakdowns
1. Quantity capabilities	F. External factors
2. Quality capabilities	1. Product standards
D. Human factors	2. Safety regulations
1. Job content	3. Unions
2. Job design	4. Pollution control standards
3. Training and experience	
4. Motivation	

1. The amount of capacity needed.
2. The timing of changes.
3. The need to maintain balance throughout the system.
4. The extent of flexibility of facilities and the workforce.

Deciding on the *amount of capacity* involves consideration of expected demand and capacity costs. In some instances a decision may be made to incorporate a **capacity cushion,** which is an amount of capacity in excess of expected demand when there is some uncertainty about demand. It is expressed as a percentage: Typically, the greater the degree of demand uncertainty, the greater the amount of cushion used. Organizations that have standard products or services generally have smaller capacity cushions. *Timing* relates to availability of capital, lead time needed to make the changes, and expected demand. *Balance* requires proportionate changes in capacity in all related areas of the system. Uncertainty about demand and the degree of variety in work requirements will influence the degree of *system flexibility* needed.

capacity cushion Extra demand intended to offset uncertainty.

Steps in the Capacity Planning Process

1. Estimate future capacity requirements.
2. Evaluate existing capacity and facilities and identify gaps.
3. Identify alternatives for meeting requirements.
4. Conduct financial analyses of each alternative.
5. Assess key qualitative issues for each alternative.
6. Select one alternative to pursue.
7. Implement the selected alternative.
8. Monitor results.

DETERMINING CAPACITY REQUIREMENTS

Capacity planning decisions involve both long-term and short-term considerations. Long-term considerations relate to overall *level* of capacity, such as facility size; short-term considerations relate to probable *variations* in capacity requirements created by such things as seasonal, random, and irregular fluctuations in demand. Because the time intervals covered by each of these categories can vary significantly from industry to industry, it would be misleading to put times on the intervals. However, the distinction will serve as a framework within which to discuss capacity planning.

We determine *long-term* capacity needs by forecasting demand over a time horizon and then converting those forecasts into capacity requirements. Figure 5.1 illustrates some basic demand patterns that might be identified by a forecast. In addition to basic patterns there are more complex patterns, such as a combination of cycles and trends.

When trends are identified, the fundamental issues are (1) how long the trend might persist, because few things last forever, and (2) the slope of the trend. If cycles are identified, interest focuses on (1) the approximate length of the cycles and (2) the amplitude of the cycles (i.e., deviation from average).

Short-term capacity needs are less concerned with cycles or trends than with seasonal variations and other variations from average. These deviations are particularly important because they can place a severe strain on a system's ability to satisfy demand at some times and yet result in idle capacity at other times.

An organization can identify seasonal patterns using standard forecasting techniques. Although commonly thought of as annual fluctuations, seasonal variations are also reflected in monthly, weekly, and even daily capacity requirements. Table 5.3 provides some examples of items that tend to exhibit seasonal demand patterns.

When time intervals are too short to have seasonal variations in demand, the analysis can often describe the variations by probability distributions such as a normal, uniform, or Poisson distribution. For example, we might describe the amount of coffee served during the midday meal at a luncheonette by a normal distribution with a certain mean and standard deviation. The number of customers who enter a bank branch on Monday mornings might be described by a Poisson distribution with a certain mean. It does not follow, however, that *every* instance of random variability will lend itself to description by a standard statistical distribution. Service systems in particular may experience a considerable amount of variability in capacity requirements unless requests for service can be scheduled. Manufacturing systems, because of their typical isolation

FIGURE 5.1
Common demand patterns

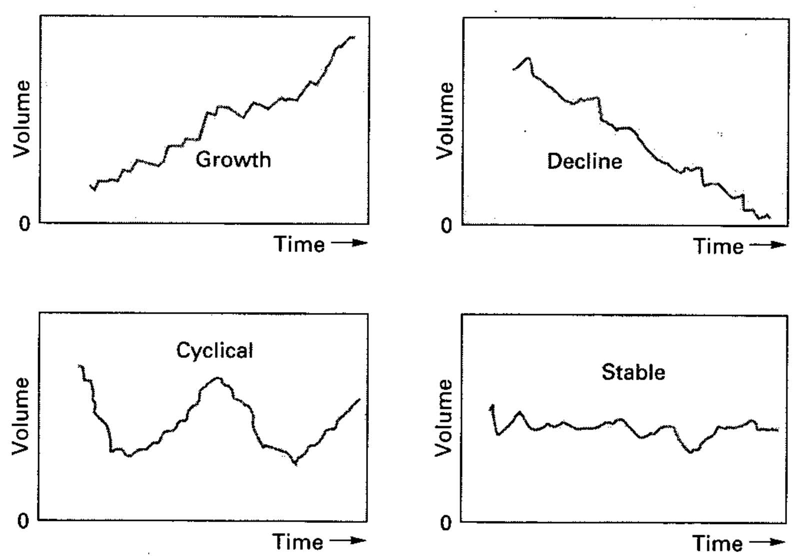


TABLE 5.3
Examples of seasonal demand patterns

Period	Items
Year	Beer sales, toy sales, airline traffic, clothing, vacations, tourism, power usage, gasoline consumption, sports and recreation, education
Month	Welfare and social security checks, bank transactions
Week	Retail sales, restaurant meals, automobile traffic, automotive rentals, hotel registrations
Day	Telephone calls, power usage, automobile traffic, public transportation, classroom utilization, retail sales, restaurant meals

from customers and the more uniform nature of production, are likely to experience less variations. Waiting-line models and simulation models can be useful when analyzing service systems. These models are described in Chapter 18.

Irregular variations are perhaps the most troublesome: They are difficult or impossible to predict. They are created by such diverse forces as major equipment breakdowns, freak storms that disrupt normal routines, foreign political turmoil that causes oil shortages, discovery of health hazards (nuclear accidents, unsafe chemical dumping grounds, carcinogens in food and drink), and so on.

The link between marketing and operations is crucial to realistic determination of capacity requirements. Through customer contracts, demographic analyses, and forecasts, marketing can supply vital information to operations for ascertaining capacity needs for both the long term and the short term.

Calculating Processing Requirements

A necessary piece of information is the capacity requirements of products that will be processed. To get this information, one must have reasonably accurate demand forecasts for each product and know the standard processing time per unit for each product, the number of workdays per year, and the number of shifts that will be used.

EXAMPLE 2

Excel

A department works one eight-hour shift, 250 days a year, and has these figures for usage of a machine that is currently being considered:

Product	Annual Demand	Standard Processing Time per Unit (Hr)	Processing Time Needed (Hr)
#1	400	5.0	2,000
#2	300	8.0	2,400
#3	700	2.0	1,400
			5,800

Working one eight-hour shift, 250 days a year provides an annual capacity of $8 \times 250 = 2{,}000$ hours per year. We can see that three of these machines would be needed to handle the required volume:

$$\frac{5{,}800 \text{ hours}}{2{,}000 \text{ hours/machine}} = 2.90 \text{ machines}$$

The task of determining capacity requirements should not be taken lightly. Substantial losses can occur when there are misjudgments on capacity needs. One key reason for those misjudgments can be overly optimistic projections of demand and growth. Marketing personnel are generally optimistic in their outlook, which isn't necessarily a bad thing. But care must be taken so that that optimism doesn't lead to overcapacity, because the resulting underutilized capacity will create an additional cost burden. Another key reason for misjudgments may be focusing exclusively on sales and revenue potential, and not taking into account the *product mix* that will be needed to generate those sales and revenues. To avoid that, marketing and operations personnel must work closely to determine the optimal product mix needed and the resulting cost and profit.

A reasonable approach to determining capacity requirements is to obtain a forecast of future demand, translate demand into both the *quantity and the timing* of capacity requirements, and then decide what capacity changes (increased, decreased, or no changes) are needed.

Long-term capacity alternatives include expansion or contraction of an existing facility, opening or closing branch facilities, and relocation of existing operations. At this point, a decision must be made on whether to make or buy a good, or provide or buy a service.

MAKE OR BUY

Once capacity requirements have been determined, the organization must decide whether to produce a good or provide a service itself, or to **outsource** (buy) from another organization. Many organizations buy parts or contract out services, for a variety of reasons. Among those factors are

outsource Obtain a good or service from an external provider.

1. *Available capacity.* If an organization has available the equipment, necessary skills, and *time,* it often makes sense to produce an item or perform a service in-house. The additional costs would be relatively small compared with those required to buy items or subcontract services.
2. *Expertise.* If a firm lacks the expertise to do a job satisfactorily, buying might be a reasonable alternative.
3. *Quality considerations.* Firms that specialize can usually offer higher quality than an organization can attain itself. Conversely, unique quality requirements or the desire to closely monitor quality may cause an organization to perform a job itself.
4. *The nature of demand.* When demand for an item is high and steady, the organization is often better off doing the work itself. However, wide fluctuations in demand or small orders are usually better handled by specialists who are able to combine orders from multiple sources, which results in higher volume and tends to offset individual buyer fluctuations.
5. *Cost.* Any cost savings achieved from buying or making must be weighed against the preceding factors. Cost savings might come from the item itself or from transportation cost savings. If there are fixed costs associated with making an item that cannot be reallocated if the item is purchased, that has to be recognized in the analysis.
6. *Risk.* Outsourcing may involve certain risks. One is loss of control over operations. Another is the need to disclose proprietary information.

In some cases, a firm might choose to perform part of the work itself and let others handle the rest in order to maintain flexibility and to hedge against loss of a subcontractor. If part or all of the work will be done "in-house," capacity alternatives will need to be developed.

DEVELOPING CAPACITY ALTERNATIVES

Aside from the general considerations about the development of alternatives (i.e., conduct a reasonable search for possible alternatives, consider doing nothing, take care not to overlook nonquantitative factors), there are other things that can be done to enhance capacity management:

1. **Design flexibility into systems.** The long-term nature of many capacity decisions and the risks inherent in long-term forecasts suggest potential benefits from designing flexible systems. For example, provision for future expansion in the original design of a structure frequently can be obtained at a small price compared to what it would cost to remodel an existing structure that did not have such a provision. Hence, if future expansion of a restaurant seems likely, water lines, power hookups, and waste disposal lines can be put in place initially so that if expansion becomes a reality, modification to the existing structure can be minimized. Similarly, a new golf course may start as a nine-hole operation, but if provision is made for future expansion by obtaining options on adjacent land, it may progress to a larger (18-hole) course. Other considerations in flexible design involve layout of equipment, location, equipment selection, production planning, scheduling, and inventory policies, which will be discussed in later chapters.

Would You Like That Rare, Medium, or Vacuum-Packed?

READING

Yumiko Ono

Let Restaurant-Goers Beware: Prix Fixe May Be Prefab; "Thaw-and-Serve" Mousse

Kirk Berkeland dabs his lips on a cloth napkin and declares himself satiated, having just polished off a plate of herb ravioli stuffed with succulently sweet bits of lobster. The New York banker considers it well worth the $14.50 he is about to be charged at Sfuzzi, an Italian restaurant in downtown Manhattan.

He should think twice, however, before complimenting the chef, for the bulk of his lunch this day actually had been shipped frozen from Denver, where Pastabilities Inc.'s food-preparation

(continued)

factory spits out about one machine-made, lobster-stuffed ravioli per second.

Mr. Berkeland is disheartened by the news: "I would have expected a restaurant like this to make it here."

Tons of Pasta

That is what most full-service restaurants want customers to believe, but increasingly it is no longer the case. Chefs don't advertise that they occasionally use prefabricated food, so it is hard for diners to know. But advertisements by food-processing companies in restaurant-industry magazines suggest that many eateries are serving meals just like mom used to make—when she was in a really big hurry.

"They come up with the concept, we create the item," says William Curtis, president of Pastabilities. He says the company sells tons of ravioli each week to upscale restaurants around the country.

Beany Macgregor, executive chef at Planet Hollywood International Inc., says food companies phone or send him free samples several times a day; he used to hear from them just a few times a month. "It's getting more and more prevalent," he says. He insists that he doesn't fob prefab food off on his customers. Sfuzzi Inc.'s corporate executive chef, John Diana, says lobster ravioli is one of only a few items that his chain buys premade. The herb-flavored dough has to be rolled thin, Mr. Diana explains, so it is hard to be consistent by hand.

Food-preparation companies, striving for a bigger bite of the $100 billion-a-year full-service restaurant industry, offer a diverse menu of elaborate items—from frozen Italian wedding soup to precooked marinated fajita steaks to chicken cacciatore in a vacuum-packed plastic bag.

"A Lot Easier"

Some of the companies' best customers are casual restaurants. Fuddruckers restaurants, known for grinding top-quality hamburger meat in full view of its customers, bake their cookies from the same ready-made, Otis Spunkmeyer Inc. dough that some convenience stores use to sell cheap but freshly baked cookies. The Perkins Family Restaurants chain of Memphis, Tenn., has a long shopping list: The soup comes in a boiling bag from CPC International Inc.; pork chops are butchered by Sara Lee Corp.; and the bread is baked with dough provided by two outside suppliers. A Perkins official says the premade foods help keep the menu prices reasonable and quality consistent, especially at a time when it is getting harder for the company to hire skilled kitchen help.

Even some swank eateries use premade food. Yuca, a Miami-area restaurant where dinner checks average $40 a head, sometimes uses 80%-baked, German-style dough purchased from Euro-Bake, Inc., based in Puerto Rico. "It's a hell of a lot easier," says Guillermo Veloso, Yuca's executive chef.

Mr. Veloso also recently discovered a frozen guacamole so tasty that he occasionally uses it in some recipes when fresh avocados are unavailable, rather than temporarily eighty-six some menu items. "If the quality is there, there's no reason why you can't use it," he says. "I consider our food upscale, but I'm not so close-minded as to not even try it."

Other gourmets disagree. "I still peel my garlic and my carrots," says Mark Strausman, chef at two pricey Italian restaurants in New York, Fred's and Campagna. "When I'm charging what I'm charging, I have a commitment to cook from scratch."

While food companies are happy to talk about their products, most are too discreet to reveal which restaurants they supply. Stockpot Soup Co. of Redwood, Wash., offers 52 varieties in plastic pouches, some of which end up as the soup du jour in upscale restaurants. But Gary Merritt, the company's marketing chief, clams up when asked for restaurant names. "Our product tastes like it's from scratch," he says. "If we were to come in and say it's ours . . ." he sighs, pondering the consequences. Fuddruckers agreed to use Otis Spunkmeyer's cookie dough after confirming that customers didn't have to be told they were buying the convenience-store cookies, says Richard Hendrie, a senior manager at Daka International Inc., Fuddruckers' parent company.

The number of advertisements in restaurant trade magazines indicates the premade-food business is booming. "Hours versus Ours. . . . 'Homemade' is now a matter of heat & serve," declares an ad for frozen mashed potatoes by Lamb Weston Inc., a unit of ConAgra Inc. The Yamazaki Baking Co.'s Vie de France Yamazaki subsidiary calls its "thaw-and-serve" mousse cake a "dessert of pastry-chef quality."

New products also suggest a growing market. Sara Lee late last year teamed up with a Chicago bread company to sell restaurants partially baked focaccia and panini. Land O'Lakes Inc. targets Hispanic kitchen staff with its recently created Queso Sabroso cheese-sauce concentrate for Mexican restaurants, printing the instructions (add water, heat) in English and Spanish.

Restaurants & Institutions magazine has inaugurated a new recipe column on quickie dishes that seem like they were made from scratch. Suggestions from the authors of the "Speed-Scratch" column: beef burgundy pie topped with dehydrated hash browns and bechamel sauce made from canned or frozen cream-of-chicken soup.

Restaurateurs have a powerful incentive to take advantage of such shortcuts—reducing labor costs, which equal about 30% of their revenues. Though the industry was expected to grow a healthy 4.5% in 1996, Americans are demanding more variety at cheaper prices because they are eating out much more frequently. The average check in upscale restaurants was 20% lower in 1995 than in 1985, according to inflation-adjusted figures compiled by consultants at McKinsey & Co.

There can be economic drawbacks to premade food, however. Customers at Bennigan's 200-plus restaurants were less than thrilled with some of the prefab items on its menu, including chicken that had been breaded and frozen by a supplier, according to officials at the chain, a unit of Metromedia Co. in Dallas. So the company started having the help batter the chicken by hand. Kitchen labor costs went up 10%, but guess what? Bennigan's started selling a lot more chicken.

(continued)

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Questions

1. Explain the meaning of the phrase "Hours versus Ours . . . 'Homemade.'"
2. What advantages are there for restaurants to outsource?
3. What are some important disadvantages or limitations of outsourcing for restaurants?
4. Do you consider this practice to be dishonest? Unethical? Explain.

2. **Take stage of life cycle into account.** Capacity requirements are often closely linked to the stage of the life cycle that a product or service is in. At the *introduction phase,* it can be difficult to determine both the size of the market and the organization's eventual share of that market. Therefore, organizations should be cautious in making large and/or inflexible capacity investments.

In the *growth phase* the overall market may experience rapid growth. However, the real issue is the rate at which the *organization's* market share grows, which may be more or less than the market rate, depending on the success of the organization's strategies. Organizations generally regard growth as a good thing. They want growth in the overall market for their products or services, and in their share of the market, because they see this as a way of increasing volume, and thus, increasing profits. However, there can also be a downside to this because increasing output levels will require increasing capacity, and that means increasing investment and increasing complexity. In addition, decision makers should take into account possible similar moves by competitors, which would increase the risk of overcapacity in the market, and result in higher unit costs of the output. Another strategy would be to compete on some nonprice attribute of the product by investing in technology and process improvements to make differentiation a competitive advantage.

In the *maturity phase* the size of market levels off, and organizations tend to have stable market shares. Organizations may still be able to increase profitability by reducing costs and making full use of capacity. However, some organizations may still try to increase profitability by increasing capacity if they believe this stage will be fairly long, or the cost to increase capacity is relatively small.

In the *decline phase* an organization is faced with underutilization of capacity due to declining demand. Organizations may eliminate the excess capacity by selling it, or by introducing new products or services. An option that is sometimes used in manufacturing is to transfer capacity to a location that has lower labor costs, which allows the organization to continue to make a profit on the product for a while longer.

3. **Take a "big picture" approach to capacity changes.** When developing capacity alternatives, it is important to consider how parts of the system interrelate. For example, when making a decision to increase the number of rooms in a motel, one should also take into account probable increased demands for parking, entertainment and food, and housekeeping. This is a "big picture" approach.

4. **Prepare to deal with capacity "chunks."** Capacity increases are often acquired in fairly large chunks rather than smooth increments, making it difficult to achieve a match between desired capacity and feasible capacity. For instance, the desired capacity of a certain operation may be 55 units per hour, but suppose that machines used for this operation are able to produce 40 units per hour each. One machine by itself would cause capacity to be 15 units per hour short of what is needed, but two machines would result in an excess capacity of 25 units per hour. The illustration becomes even more extreme if we shift the topic—to open-hearth furnaces or to the number of airplanes needed to provide a desired level of capacity.

5. **Attempt to smooth out capacity requirements.** Unevenness in capacity requirements also can create certain problems. For instance, during periods of inclement weather, public transportation ridership tends to increase substantially relative to periods of pleasant weather. Consequently, the system tends to alternate between underutilization and overutilization. Increasing the number of buses or subway cars will reduce the burden during periods of heavy

demand, but this will aggravate the problem of overcapacity at other times and certainly add to the cost of operating the system.

We can trace the unevenness in demand for products and services to a variety of sources. The bus ridership problem is weather related to a certain extent, but demand could be considered to be partly random (i.e., varying because of chance factors). Still another source of varying demand is seasonality. Seasonal variations are generally easier to cope with than random variations because they are *predictable.* Consequently, management can make allowances in planning and scheduling activities and inventories. However, seasonal variations can still pose problems because of their uneven demands on the system: At certain times the system will tend to be overloaded, while at other times it will tend to be underloaded. One possible approach to this problem is to identify products or services that have complementary demand patterns, that is, patterns that tend to offset each other. For instance, demand for snow skis and demand for water skis might complement each other: Demand for water skis is greater in the spring and summer months, and demand for snow skis is greater in the fall and winter months. The same might apply to heating and air-conditioning equipment. The ideal case is one in which products or services with complementary demand patterns involve the use of the same resources but at different times, so that overall capacity requirements remain fairly stable. Figure 5.2 illustrates complementary demand patterns.

Vacationers boarding an international flight to Granada. Capacity requirements in services are affected by seasonal variations, such as holidays or summer months when families are more likely to travel.

Variability in demand can pose a problem for managers. Simply adding capacity by increasing the size of the operation (e.g., increasing the size of the facility, the workforce, or the amount of processing equipment) is not always the best approach, because that reduces flexibility and adds to fixed costs. Consequently, managers often choose to respond to higher than normal demand in other ways. One way is through the use of overtime work. Another way is to subcontract some of the work. A third way is to draw down finished goods inventories during periods of high demand and replenish them during periods of slow demand. These options and others are discussed in detail in the chapter on aggregate planning.

6. **Identify the optimal operating level.** Production units typically have an ideal or optimal level of operation in terms of unit cost of output. At the ideal level, cost per unit is the lowest for that production unit. If the output rate is less than the optimal level, increasing the output rate will result in decreasing average unit costs. This is known as **economies of scale.** However, if output is increased beyond the optimal level, average unit costs would become increasingly larger. This is known as **diseconomies of scale.** Figure 5.3 illustrates these concepts.

Reasons for economies of scale include

a. Fixed costs are spread over more units, reducing the fixed cost per unit.
b. Construction costs increase at a decreasing rate with respect to the size of the facility to be built.
c. Processing costs decrease as output rates increase because operations become more standardized, which reduces unit costs.

economies of scale If the output rate is less than the optimal level, increasing the output rate results in decreasing average unit costs.

diseconomies of scale If the output rate is more than the optimal level, increasing the output rate results in increasing average unit costs.

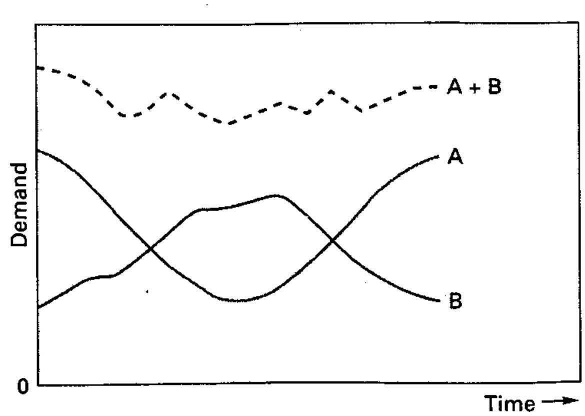


FIGURE 5.2

A and B have complementary demand patterns

FIGURE 5.3

Production units have an optimal rate of output for minimum cost

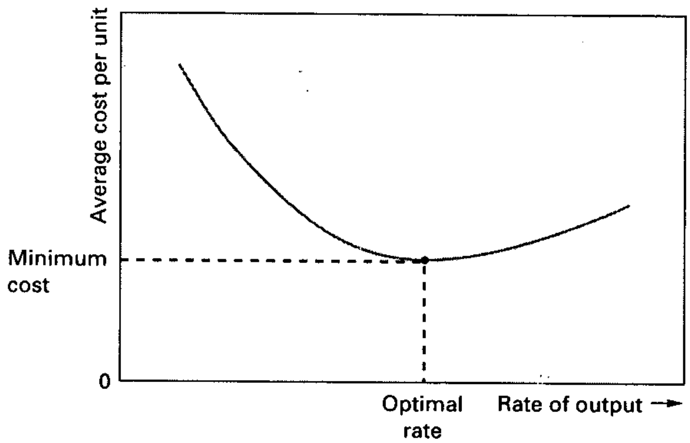
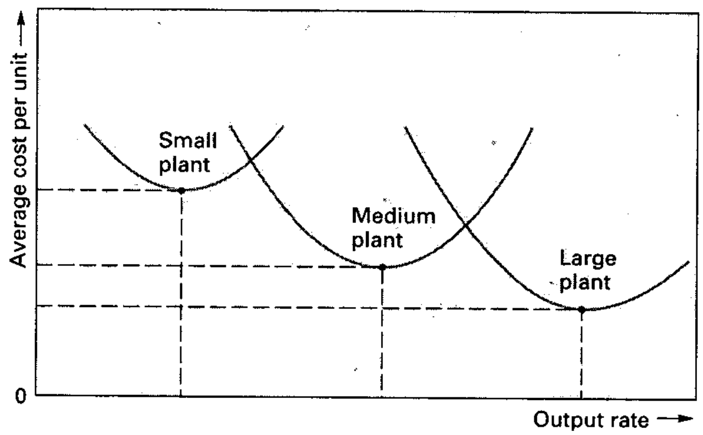


FIGURE 5.4

Minimum cost and optimal operating rate are functions of size of a production unit



Reasons for diseconomies of scale include

a. Distribution costs increase due to traffic congestion and shipping from one large centralized facility instead of several smaller, decentralized facilities.
b. Complexity increases costs; control and communication become more problematic.
c. Inflexibility can be an issue.
d. Additional levels of bureaucracy exist, slowing decision making and approvals for changes.

The explanation for the shape of the cost curve is that at low levels of output, the costs of facilities and equipment must be absorbed (paid for) by very few units. Hence, the cost per unit is high. As output is increased, there are more units to absorb the "fixed" cost of facilities and equipment, so unit costs decrease. However, beyond a certain point, unit costs will start to rise. To be sure, the fixed costs are spread over even more units, so that does not account for the increase, but other factors now become important: worker fatigue; equipment breakdowns; the loss of flexibility, which leaves less of a margin for error; and, generally, greater difficulty in coordinating operations.

Both optimal operating rate and the amount of the minimum cost tend to be a function of the general capacity of the operating unit. For example, as the general capacity of a plant increases, the optimal output rate increases and the minimum cost for the optimal rate decreases. Thus, larger plants tend to have higher optimal output rates and lower minimum costs than smaller plants. Figure 5.4 illustrates these points.

In choosing the capacity of an operating unit, management must take these relationships into account along with the availability of financial and other resources and forecasts of expected demand. To do this, it is necessary to determine enough points for each size facility to be able to make a comparison among different sizes. In some instances, facility sizes are givens, whereas in others, facility size is a continuous variable (i.e., any size can be selected). In the latter case, an ideal facility size can be selected. Usually, management must make a choice from given sizes, and none may have a minimum at the desired rate of output.

THE CHALLENGES OF PLANNING SERVICE CAPACITY

While the foregoing discussion relates generally to capacity planning for both goods and services, it is important to note that capacity planning for services can present special challenges due to the nature of services. Three very important factors in planning service capacity are (1) the need to be near customers, (2) the inability to store services, and (3) the degree of volatility of demand.

Convenience for customers is often an important aspect of service. Generally, a service must be located near customers. For example, hotel rooms must be where customers want to stay; having a vacant room in another city won't help. Thus, capacity and location are closely tied.

Capacity also must be matched with the *timing* of demand. Unlike goods, services cannot be produced in one period and stored for use in a later period. Thus, an unsold seat on an airplane, train, or bus cannot be stored for use on a later trip. Similarly, inventories of goods allow customers to immediately satisfy wants, whereas a customer who wants a service may have to wait. This can result in a variety of negatives for an organization that provides the service. Thus, speed of delivery, or customer waiting time, becomes a major concern in service capacity planning. For example, deciding on the number of police officers and fire trucks to have on duty at any given time affects the speed of response and brings into issue the *cost* of maintaining that capacity. Some of these issues are addressed in the chapter on waiting lines.

Demand volatility presents problems for capacity planners. Demand volatility tends to be higher for services than for goods, not only in timing of demand, but also in the amount of time required to service individual customers. For example, banks tend to experience higher volumes of demand on certain days of the week, and the number and nature of transactions tend to vary substantially for different individuals. Then, too, a wide range of social, cultural, and even weather factors can cause major peaks and valleys in demand. The fact that services can't be stored means service systems cannot turn to inventory to smooth demand requirements on the system the way goods-producing systems are able to. Instead, service planners

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For routine service needs that come frequently and in high volume, employees at a call center may provide customer service most efficiently.

Tax preparation at H&R Block is a specialized service that requires a longer, customized delivery encounter by more expert representatives.

have to devise other methods of coping with demand volatility and cyclical demand. For example, to cope with peak demand periods, planners might consider hiring extra workers, outsourcing some or all of a service, or using pricing and promotion to shift some demand to slower periods.

In some instances, *demand management* is a strategy that can be used to offset capacity limitations. Pricing, promotions, discounts, and similar tactics can help to shift some demand away from peak periods and into slow periods, allowing organizations to achieve a closer match in supply and demand.

EVALUATING ALTERNATIVES

An organization needs to examine alternatives for future capacity from a number of different perspectives. Most obvious are economic considerations: Will an alternative be economically feasible? How much will it cost? How soon can we have it? What will operating and maintenance costs be? What will its useful life be? Will it be compatible with present personnel and present operations?

Less obvious, but nonetheless important, is possible negative public opinion. For instance, the decision to build a new power plant is almost sure to stir up reaction, whether the plant is coal-fired, hydroelectric, or nuclear. Any option that could disrupt lives and property is bound to generate hostile reactions. Construction of new facilities may necessitate moving personnel to a new location. Embracing a new technology may mean retraining some people and terminating some jobs. Relocation can cause unfavorable reactions, particularly if a town is about to lose a major employer. Conversely, community pressure in a new location may arise if the presence of the company is viewed unfavorably (noise, traffic, pollution).

A number of techniques are useful for evaluating capacity alternatives from an economic standpoint. Some of the more common are cost–volume analysis, financial analysis, decision theory, and waiting-line analysis. Cost–volume analysis is described in this section. Financial analysis is mentioned briefly, decision analysis is described in the chapter supplement, and waiting-line analysis is described in Chapter 18.

Cost–Volume Analysis

Cost–volume analysis focuses on relationships between cost, revenue, and volume of output. The purpose of cost–volume analysis is to estimate the income of an organization under different operating conditions. It is particularly useful as a tool for comparing capacity alternatives.

Excel

Use of the technique requires identification of all costs related to the production of a given product. These costs are then designated as fixed costs or variable costs. *Fixed costs* tend to remain constant regardless of volume of output. Examples include rental costs, property taxes, equipment costs, heating and cooling expenses, and certain administrative costs. *Variable costs* vary directly with volume of output. The major components of variable costs are generally materials and labor costs. We will assume that variable cost per unit remains the same regardless of volume of output, and that all output can be sold.

TABLE 5.4
Cost–volume symbols

FC = Fixed cost
VC = Total variable cost
v = Variable cost per unit
TC = Total cost
TR = Total revenue
R = Revenue per unit
Q = Quantity or volume of output
Q_{BEP} = Break-even quantity
P = Profit

Table 5.4 summarizes the symbols used in the cost–volume formulas.

The total cost associated with a given volume of output is equal to the sum of the fixed cost and the variable cost per unit times volume:

$$\text{TC} = \text{FC} + \text{VC} \quad (5\text{–}3)$$

$$\text{VC} = Q \times v \quad (5\text{–}4)$$

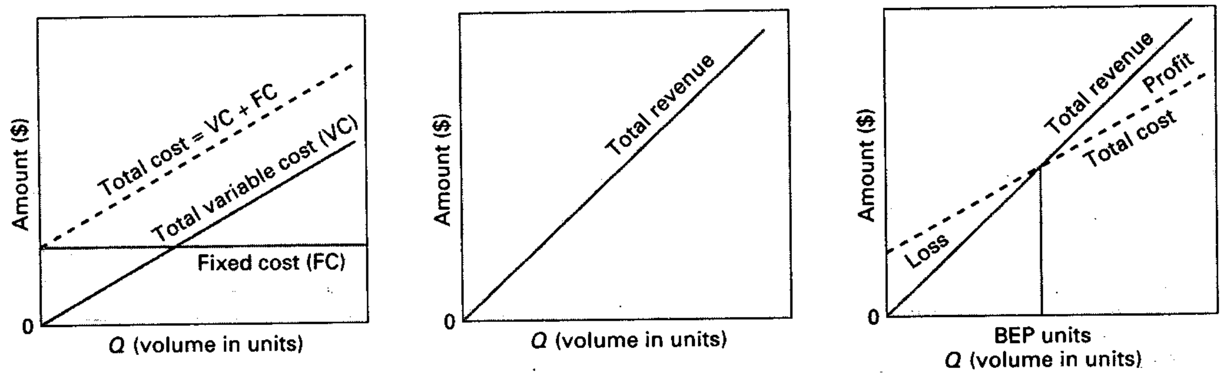
where v = variable cost per unit. Figure 5.5A shows the relationship between volume of output and fixed costs, total variable costs, and total (fixed plus variable) costs.

Revenue per unit, like variable cost per unit, is assumed to be the same regardless of quantity of output. Total revenue will have a linear relationship to output, as illustrated in Figure 5.5B. The total revenue associated with a given quantity of output, Q, is

$$\text{TR} = R \times Q \quad (5\text{–}5)$$

FIGURE 5.5

Cost–volume relationships



A. Fixed, variable, and total costs.

B. Total revenue increases linearly with output.

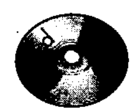
C. Profit = TR – TC.

Figure 5.5C describes the relationship between profit—which is the difference between total revenue and total (i.e., fixed plus variable) cost—and volume of output. The volume at which total cost and total revenue are equal is referred to as the **break-even point (BEP).** When volume is less than the break-even point, there is a loss; when volume is greater than the break-even point, there is a profit. The greater the deviation from this point, the greater the profit or loss. Total profit can be computed using the formula

break-even point (BEP) The volume of output at which total cost and total revenue are equal.

$$P = \text{TR} - \text{TC} = R \times Q - (\text{FC} + v \times Q)$$

IOM



Excel

Rearranging terms, we have

$$P = Q(R - v) - \text{FC} \qquad (5\text{–}6)$$

The required volume, Q, needed to generate a specified profit is

$$Q = \frac{P + \text{FC}}{R - v} \qquad (5\text{–}7)$$

A special case of this is the volume of output needed for total revenue to equal total cost. This is the break-even point, computed using the formula

$$Q_{\text{BEP}} = \frac{\text{FC}}{R - v} \qquad (5\text{–}8)$$

EXAMPLE 3

The owner of Old-Fashioned Berry Pies, S. Simon, is contemplating adding a new line of pies, which will require leasing new equipment for a monthly payment of $6,000. Variable costs would be $2.00 per pie, and pies would retail for $7.00 each.

a. How many pies must be sold in order to break even?

b. What would the profit (loss) be if 1,000 pies are made and sold in a month?

c. How many pies must be sold to realize a profit of $4,000?

d. If 2,000 can be sold, and a profit target is $5,000, what price should be charged per pie?

SOLUTION

$\text{FC} = \$6{,}000, \qquad \text{VC} = \$2 \text{ per pie}, \qquad \text{Rev} = \$7 \text{ per pie}$

a. $Q_{\text{BEP}} = \dfrac{\text{FC}}{\text{Rev} - \text{VC}} = \dfrac{\$6{,}000}{\$7 - \$2} = 1{,}200 \text{ pies/month}$

b. For $Q = 1{,}000$, $P = Q(R - v) - \text{FC} = 1{,}000(\$7 - \$2) - \$6{,}000 = -\$1{,}000$

c. $P = \$4{,}000$; solve for Q using equation 5–7:

$$Q = \frac{\$4{,}000 + \$6{,}000}{\$7 - \$2} = 2{,}000 \text{ pies}$$

d. $\text{Profit} = Q(R - v) - \text{FC}$

$$\$5{,}000 = 2{,}000(R - \$2) - \$6{,}000$$
$$R = \$7.50$$

Capacity alternatives may involve *step costs,* which are costs that increase stepwise as potential volume increases. For example, a firm may have the option of purchasing one, two, or three machines, with each additional machine increasing the fixed cost, although perhaps not linearly. (See Figure 5.6A.) Then fixed costs and potential volume would depend on the number of machines purchased. The implication is that *multiple break-even quantities* may occur, possibly one for each range. Note, however, that the total revenue line might not intersect the fixed-cost line in a particular range, meaning that there would be no break-even point in that range. This possibility is illustrated in Figure 5.6B, where there is no break-even point in the first range. In order to decide how many machines to purchase, a manager must consider projected annual demand (volume) relative to the multiple break-even points and choose the most appropriate number of machines, as Example 4 shows.

EXAMPLE 4

A manager has the option of purchasing one, two, or three machines. Fixed costs and potential volumes are as follows:

Number of Machines	Total Annual Fixed Costs	Corresponding Range of Output
1	$ 9,600	0 to 300
2	15,000	301 to 600
3	$20,000	601 to 900

Variable cost is $10 per unit, and revenue is $40 per unit.

a. Determine the break-even point for each range.

b. If projected annual demand is between 580 and 660 units, how many machines should the manager purchase?

SOLUTION

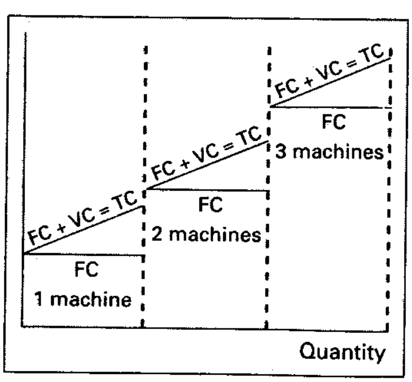
a. Compute the break-even point for each range using the formula $Q_{\text{BEP}} = FC/(R - v)$.

For one machine:

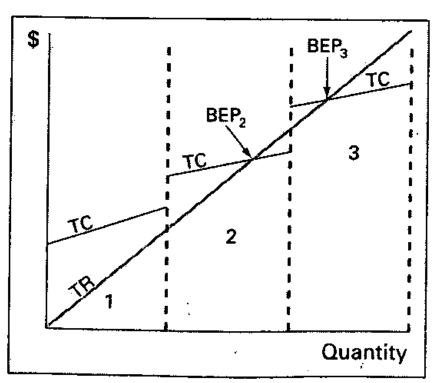
$$Q_{\text{BEP}} = \frac{\$9{,}600}{\$40/\text{unit} - \$10/\text{unit}} = 320 \text{ units [not in range, so there is no BEP]}$$

FIGURE 5.6

Break-even problem with step fixed costs



A. Step fixed costs and variable costs.



B. Multiple break-even points.

$$\text{For two machines: } Q_{BEP} = \frac{\$15{,}000}{\$40/\text{unit} - \$10/\text{unit}} = 500 \text{ units}$$

$$\text{For three machines: } Q_{BEP} = \frac{\$20{,}000}{\$40/\text{unit} - \$10/\text{unit}} = 666.67 \text{ units}$$

b. Comparing the projected range of demand to the two ranges for which a break-even point occurs (see Figure 5.6B), you can see that the break-even point is 500, which is in the range 301 to 600. This means that even if demand is at the low end of the range, it would be above the break-even point and thus yield a profit. That is not true of range 601 to 900. At the top end of projected demand, the volume would still be less than the break-even point for that range, so there would be no profit. Hence, the manager should choose two machines.

Cost–volume analysis can be a valuable tool for comparing capacity alternatives if certain assumptions are satisfied:

1. One product is involved.
2. Everything produced can be sold.
3. The variable cost per unit is the same regardless of the volume.
4. Fixed costs do not change with volume changes, or they are step changes.
5. The revenue per unit is the same regardless of volume.
6. Revenue per unit exceeds variable cost per unit.

As with any quantitative tool, it is important to verify that the assumptions on which the technique is based are reasonably satisfied for a particular situation. For example, revenue per unit or variable cost per unit is not always constant. In addition, fixed costs may not be constant over the range of possible output. If demand is subject to random variations, one must take that into account in the analysis. Also, cost–volume analysis requires that fixed and variable costs can be separated, and this is sometimes exceedingly difficult to accomplish. Cost–volume analysis works best with one product or a few products that have the same cost characteristics.

A notable benefit of cost–volume considerations is the conceptual framework it provides for integrating cost, revenue, and profit estimates into capacity decisions. If a proposal looks attractive using cost–volume analysis, the next step would be to develop cash flow models to see how it fares with the addition of time and more flexible cost functions.

Financial Analysis

A problem that is universally encountered by managers is how to allocate scarce funds. A common approach is to use *financial analysis* to rank investment proposals.

Two important terms in financial analysis are *cash flow* and *present value:*

> **Cash flow** refers to the difference between the cash received from sales (of goods or services) and other sources (e.g., sale of old equipment) and the cash outflow for labor, materials, overhead, and taxes.
>
> **Present value** expresses in current value the sum of all future cash flows of an investment proposal.

cash flow Difference between cash received from sales and other sources, and cash outflow for labor, material, overhead, and taxes.

present value The sum, in current value, of all future cash flows of an investment proposal.

The three most commonly used methods of financial analysis are payback, present value, and internal rate of return.

Payback is a crude but widely used method that focuses on the length of time it will take for an investment to return its original cost. For example, an investment with an original cost of $6,000 and a monthly net cash flow of $1,000 has a payback period of six months. Payback ignores the *time value of money.* Its use is easier to rationalize for short-term than for long-term projects.

The *present value (PV)* method summarizes the initial cost of an investment, its estimated annual cash flows, and any expected salvage value in a single value called the *equivalent current value,* taking into account the time value of money (i.e., interest rates).

The *internal rate of return (IRR)* summarizes the initial cost, expected annual cash flows, and estimated future salvage value of an investment proposal in an *equivalent interest rate.* In other words, this method identifies the rate of return that equates the estimated future returns and the initial cost.

These techniques are appropriate when there is a high degree of *certainty* associated with estimates of future cash flows. In many instances, however, operations managers and other managers must deal with situations better described as risky or uncertain. When conditions of risk or uncertainty are present, decision theory is often applied.

Decision Theory

Decision theory is a helpful tool for financial comparison of alternatives under conditions of risk or uncertainty. It is suited to capacity decisions and to a wide range of other decisions managers must make. Decision theory is described in the supplement to this chapter.

Waiting-Line Analysis

Analysis of lines is often useful for designing or modifying service systems. Waiting lines have a tendency to form in a wide variety of service systems (e.g., airport ticket counters, telephone calls to a cable television company, hospital emergency rooms). The lines are symptoms of bottleneck operations. Analysis is useful in helping managers choose a capacity level that will be cost-effective through balancing the cost of having customers wait with the cost of providing additional capacity. It can aid in the determination of expected costs for various levels of service capacity.

This topic is described in Chapter 18.

Operations Strategy

The strategic implications of capacity decisions can be enormous for an organization, impacting all areas of the organization. From an operations management standpoint, capacity decisions establish a set of conditions within which operations will be required to function. Hence, it is extremely important to include input from operations management people in making capacity decisions.

Flexibility can be a key issue in capacity decisions, although flexibility is not always an option, particularly in capital-intensive industries. However, where possible, flexibility allows an organization to be responsive (agile) to changes in the marketplace. Also, it reduces to a certain extent the dependence on long-range forecasts to accurately predict demand. And flexibility makes it easier for organizations to take advantage of technological and other innovations.

Bottleneck management can be a way to increase effective capacity, by scheduling non–bottleneck operations to achieve maximum utilization of bottleneck operations.

In cases where capacity expansion will be undertaken, there are two strategies for determining the timing and degree of capacity expansion. One is the *expand-early* strategy (i.e., before demand materializes). The intent might be to achieve economies of scale, to expand market share, or to preempt competitors from expanding. The risks of this strategy include an oversupply that would drive prices down, and underutilized equipment that would result in higher unit costs.

The other approach is the *wait-and-see strategy* (i.e., to expand capacity only after demand materializes, perhaps incrementally). Its advantages include a lower chance of oversupply due to more accurate matching of supply and demand, and higher capacity utilization. The key risk is loss of market share.

Some organizations use a strategy of maintaining extra capacity in excess of a capacity cushion, for the purpose of blocking entry into the market by new competitors. The excess capacity enables them to produce at costs lower than what new competitors can. However, such a strategy means higher than necessary unit costs, and it makes it more difficult to cut back if demand slows, or to shift to new product or service offerings.

SUMMARY

Capacity refers to a system's potential for producing goods or delivering services over a specified time interval. Capacity decisions are important because capacity is a ceiling on output and a major determinant of operating costs.

The capacity planning decision is one of the most important decisions that managers make. The capacity decision is strategic and long-term in nature, often involving a significant initial investment of capital. Capacity planning is particularly difficult in cases where returns will accrue over a lengthy period and risk is a major consideration.

A variety of factors can interfere with effective capacity, so effective capacity is usually somewhat less than design capacity. These factors include facilities design and layout, human factors, product/service design, equipment failures, scheduling problems, and quality considerations.

Capacity planning involves long-term and short-term considerations. Long-term considerations relate to the overall level of capacity; short-term considerations relate to variations in capacity requirements due to seasonal, random, and irregular fluctuations in demand. Ideally, capacity will match demand. Thus, there is a close link between forecasting and capacity planning, particularly in the long term. In the short term, emphasis shifts to describing and coping with variations in demand.

Development of capacity alternatives is enhanced by taking a systems approach to planning, by recognizing that capacity increments are often acquired in chunks, by designing flexible systems, and by considering product/service complements as a way of dealing with various patterns of demand.

In evaluating capacity alternatives. a manager must consider both quantitative and qualitative aspects. Quantitative analysis usually reflects economic factors, and qualitative considerations include intangibles such as public opinion and personal preferences of managers. Cost–volume analysis can be useful for analyzing alternatives.

KEY TERMS

break-even point (BEP), 185
capacity, 169
capacity cushion, 175
cash flow, 187
diseconomies of scale, 181
economies of scale, 181
outsource, 177
present value, 187

SOLVED PROBLEMS

Problem 1

A firm's manager must decide whether to make or buy a certain item used in the production of vending machines. Making would involve annual lease costs of $150,000. Cost and volume estimates are as follows:

	Make	Buy
Annual fixed cost	$150,000	None
Variable cost/unit	$60	$80
Annual volume (units)	12,000	12,000

a. Given these numbers, should the firm buy or make this item?

b. There is a possibility that volume could change in the future. At what volume would the manager be indifferent between making and buying?

Solution

a. Determine the annual cost of each alternative:

Total cost = Fixed cost + Volume × Variable cost

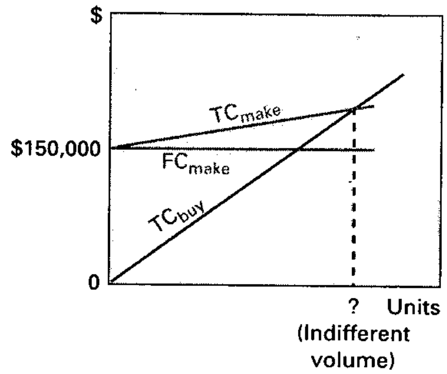
Make: $150,000 + 12,000($60) = $870,000

Buy: 0 + 12,000($80) = $960,000

Because the annual cost of making the item is less than the annual cost of buying it, the manager would reasonably choose to make the item. Note: If the unit cost to buy had been *less than* the *variable cost* to make, there would be no need to even consider fixed costs; it would simply have been better to buy.

b. To determine the volume at which the two choices would be equivalent, set the two total costs equal to each other and solve for volume: $TC_{make} = TC_{buy}$. Thus, $150,000 + Q($60) = 0 + Q($80).

Solving, $Q = 7{,}500$ units. Therefore, at a volume of 7,500 units a year, the manager would be indifferent between making and buying. For lower volumes, the choice would be to buy, and for higher volumes, the choice would be to make.



Problem 2

A small firm produces and sells automotive items in a five-state area. The firm expects to consolidate assembly of its battery chargers line at a single location. Currently, operations are in three widely scattered locations. The leading candidate for location will have a monthly fixed cost of $42,000 and variable costs of $3 per charger. Chargers sell for $7 each. Prepare a table that shows total profits, fixed costs, variable costs, and revenues for monthly volumes of 10,000, 12,000, and 15,000 units. What is the break-even point?

Revenue = $7 per unit

Variable cost = $3 per unit

Fixed cost = $42,000 per month

$\text{Profit} = Q(R - v) - \text{FC}$

$\text{Total cost} = \text{FC} + v \times Q$

Volume	Total Revenue	Total VC	Fixed Cost	Total Cost	Total Profit
10,000	$ 70,000	$30,000	$42,000	$72,000	$(2,000)
12,000	84,000	36,000	42,000	78,000	6,000
15,000	105,000	45,000	42,000	87,000	18,000

$$Q_{\text{BEP}} = \frac{\text{FC}}{R - \text{v}} = \frac{\$42{,}000}{\$7 - \$3} = 10{,}500 \text{ units per month}$$

Problem 3

Refer to Problem 2. Determine profit when volume equals 22,000 units.

Solution

$$\text{Profit} = Q(R - v) - \text{FC} = Q(\$7 - \$3) - \$42{,}000 = \$4Q - \$42{,}000$$

For $Q = 22{,}000$, profit is

$$\$4(22{,}000) - \$42{,}000 = \$46{,}000$$

Problem 4

A manager must decide which type of equipment to buy, Type A or Type B. Type A equipment costs $15,000 each, and Type B costs $11,000 each. The equipment can be operated 8 hours a day, 250 days a year.

Either machine can be used to perform two types of chemical analysis, C1 and C2. Annual service requirements and processing times are shown in the following table. Which type of equipment should be purchased, and how many of that type will be needed? The goal is to minimize total purchase cost.

		Processing Time per Analysis (hr)	
Analysis Type	**Annual Volume**	**A**	**B**
C1	1,200	1	2
C2	900	3	2

Solution

Total processing time (annual volume × processing time per analysis) needed by type of equipment:

Analysis Type	A	B
C1	1,200	2,400
C2	2,700	1,800
Total	3,900	4,200

Total processing time available per piece of equipment is 8 hours/day × 250 days/year = 2,000. Hence, one piece can handle 2,000 hours of analysis, two pieces of equipment can handle 4,000 hours, and so on.

Given the total processing requirements, two of Type A would be needed, for a total cost of 2 × \$15,000 = \$30,000, or three of Type B, for a total cost of 3 × \$11,000 = \$33,000. Thus, two pieces of Type A would have sufficient capacity to handle the load at a lower cost than three of Type B.

DISCUSSION AND REVIEW QUESTIONS

1. Contrast design capacity and effective capacity.
2. List and briefly explain three factors that may inhibit capacity utilization.
3. How do long-term and short-term capacity considerations differ?
4. Give an example of a good and a service that exhibit these seasonal demand patterns:
   a. Annual
   b. Monthly
   c. Weekly
   d. Daily
5. Give some examples of building flexibility into system design.
6. Why is it important to adopt a "big picture" approach to capacity planning?
7. What is meant by "capacity in chunks," and why is that a factor in capacity planning?
8. What kinds of capacity problems do many elementary and secondary schools periodically experience? What are some alternatives to deal with those problems?
9. How can a systems approach to capacity planning be useful?
10. How do capacity decisions influence productivity?
11. Why is it important to match process capabilities with product requirements?
12. Briefly discuss how uncertainty affects capacity decisions.
13. Discuss the importance of capacity planning in deciding on the number of police officers or fire trucks to have on duty at a given time.
14. Why is capacity planning one of the most critical decisions a manager has to make?
15. Why is capacity planning for services more challenging than it is for goods production?

TAKING STOCK

1. What are the major trade-offs in capacity planning?
2. Who needs to be involved in capacity planning?
3. In what ways does technology have an impact on capacity planning?

CRITICAL THINKING EXERCISES

1. A computer repair service has a design capacity of 80 repairs per day. Its effective capacity, however, is 64 repairs per day, and its actual output is 62 repairs per day. The manager would like to increase the number of repairs per day. Which of the following factors would you recommend that the manager investigate: quality problems, absenteeism, or scheduling and balancing? Explain your reasoning.

2. Compared to manufacturing, service requirements tend to be more time dependent, location dependent, and volatile. In addition, service quality is often directly observable by customers. Find a recent article in a business magazine that describes how a service organization is struggling with one or more of these issues and make recommendations on what an organization needs to do to overcome these difficulties.

PROBLEMS

1. Determine the utilization and the efficiency for each of these situations:
   a. A loan processing operation that processes an average of 7 loans per day. The operation has a design capacity of 10 loans per day and an effective capacity of 8 loans per day.
   b. A furnace repair team that services an average of four furnaces a day if the design capacity is six furnaces a day and the effective capacity is five furnaces a day.
   c. Would you say that systems that have higher efficiency ratios than other systems will always have higher utilization ratios than those other systems? Explain.
2. In a job shop, effective capacity is only 50 percent of design capacity, and actual output is 80 percent of effective output. What design capacity would be needed to achieve an actual output of eight jobs per week?
3. A producer of pottery is considering the addition of a new plant to absorb the backlog of demand that now exists. The primary location being considered will have fixed costs of $9,200 per month and variable costs of 70 cents per unit produced. Each item is sold to retailers at a price that averages 90 cents.
   a. What volume per month is required in order to break even?
   b. What profit would be realized on a monthly volume of 61,000 units? 87,000 units?
   c. What volume is needed to obtain a profit of $16,000 per month?
   d. What volume is needed to provide a revenue of $23,000 per month?
   e. Plot the total cost and total revenue lines.
4. A small firm intends to increase the capacity of a bottleneck operation by adding a new machine. Two alternatives, A and B, have been identified, and the associated costs and revenues have been estimated. Annual fixed costs would be $40,000 for A and $30,000 for B; variable costs per unit would be $10 for A and $11 for B; and revenue per unit would be $15.
   a. Determine each alternative's break-even point in units.
   b. At what volume of output would the two alternatives yield the same profit?
   c. If expected annual demand is 12,000 units, which alternative would yield the higher profit?
5. A producer of felt-tip pens has received a forecast of demand of 30,000 pens for the coming month from its marketing department. Fixed costs of $25,000 per month are allocated to the felt-tip operation, and variable costs are 37 cents per pen.
   a. Find the break-even quantity if pens sell for $1 each.
   b. At what price must pens be sold to obtain a monthly profit of $15,000, assuming that estimated demand materializes?
6. A real estate agent is considering changing her cell phone plan. There are three plans to choose from, all of which involve a weekly service charge of $20. Plan A has a cost of $0.45 a minute for daytime calls and $0.20 a minute for evening calls. Plan B has a charge of $0.55 a minute for daytime calls and $0.15 a minute for evening calls. Plan C has a flat rate of $80 with 200 minutes of calls allowed per week and a charge of $0.40 per minute beyond that, day or evening.
   a. Determine the total charge under each plan for this case: 120 minutes of day calls and 40 minutes of evening calls in a week.
   b. Prepare a graph that shows total weekly cost for each plan versus daytime call minutes.
   c. If the agent will use the service for daytime calls, over what range of call minutes will each plan be optimal?
   d. Suppose that the agent expects both daytime and evening calls. At what point (i.e., percentage of call minutes for daytime calls) would she be indifferent between plans A and B?
7. A firm plans to begin production of a new small appliance. The manager must decide whether to purchase the motors for the appliance from a vendor at $7 each or to produce them in-house. Either of two processes could be used for in-house production; one would have an annual fixed cost of $160,000 and a variable cost of $5 per unit, and the other would have an annual fixed cost of $190,000 and a variable cost of $4 per unit. Determine the range of annual volume for which each of the alternatives would be best.

8. A manager is trying to decide whether to purchase a certain part or to have it produced internally. Internal production could use either of two processes. One would entail a variable cost of $17 per unit and an annual fixed cost of $200,000; the other would entail a variable cost of $14 per unit and an annual fixed cost of $240,000. Three vendors are willing to provide the part. Vendor A has a price of $20 per unit for any volume up to 30,000 units. Vendor B has a price of $22 per unit for demand of 1,000 units or less, and $18 per unit for larger quantities. Vendor C offers a price of $21 per unit for the first 1,000 units, and $19 per unit for additional units.
   a. If the manager anticipates an annual volume of 10,000 units, which alternative would be best from a cost standpoint? For 20,000 units, which alternative would be best?
   b. Determine the range for which each alternative is best. Are there any alternatives that are never best? Which?
9. A company manufactures a product using two machine cells. Each cell has a design capacity of 250 units per day and an effective capacity of 230 units per day. At present, actual output averages 200 units per cell, but the manager estimates that productivity improvements soon will increase output to 225 units per day. Annual demand is currently 50,000 units. It is forecasted that within two years, annual demand will triple. How many cells should the company plan to produce to satisfy predicted demand under these conditions? Assume 240 workdays per year.
10. A manager must decide which type of machine to buy, A, B, or C. Machine costs are

Machine	Cost
A	$40,000
B	$30,000
C	$80,000

Product forecasts and processing times on the machines are as follows:

		PROCESSING TIME PER UNIT (MINUTES)		
Product	Annual Demand	A	B	C
1	16,000	3	4	2
2	12,000	4	4	3
3	6,000	5	6	4
4	30,000	2	2	1

   a. Assume that only purchasing costs are being considered. Which machine would have the lowest total cost, and how many of that machine would be needed? Machines operate 10 hours a day, 250 days a year.
   b. Consider this additional information: The machines differ in terms of hourly operating costs: The A machines have an hourly operating cost of $10 each, B machines have an hourly operating cost of $11 each, and C machines have an hourly operating cost of $12 each. Which alternative would be selected, and how many machines, in order to minimize total cost while satisfying capacity processing requirements?
11. A manager must decide how many machines of a certain type to purchase. Each machine can process 100 customers per hour. One machine will result in a fixed cost of $2,000 per day, while two machines will result in a fixed cost of $3,800 per day. Variable costs will be $20 per customer, and revenue will be $45 per customer.
   a. Determine the break-even point for each range.
   b. If estimated demand is 90 to 120 customers per hour, how many machines should be purchased?
12. The manager of a car wash must decide whether to have one or two wash lines. One line will mean a fixed cost of $6,000 a month, and two lines will mean a fixed cost of $10,500 a month. Each line would be able to process 15 cars an hour. Variable costs will be $3 per car, and revenue will be $5.95 per car. The manager projects an average demand of between 14 and 18 cars an hour. Would you recommend one or two lines? The car wash is open 300 hours a month.

High Acres Landfill

OPERATIONS TOUR

The High Acres Landfill is located on a 218-acre site outside Fairport, New York. Opened in 1971, it is licensed to handle residential, commercial, and industrial nonhazardous waste. The landfill has 27 employees, and it receives approximately 3,000 tons of waste per day.

The public often has certain preconceived notions about a landfill, chief among them that landfills are dirty and unpleasant. However, a visit to the landfill dispelled some of those misconceptions. The entrance is nicely landscaped. Most of the site is planted with grass and a few trees. Although unpleasant odors can emanate from arriving trucks or at the dump site, the remainder of the landfill is relatively free of odors.

A major portion of the landfill consists of a large hill within which the waste is buried. Initially, the landfill began not as a hill but as a large hole in the ground. After a number of years of depositing waste, the hole eventually was filled. From that point on, as additional layers were added, the landfill began to take the shape of a flattop hill. Each layer is a little narrower than the preceding one, giving the hill a slope. The sides of the hill are planted with grass. Only the "working face" along the top remains unplanted. When the designated capacity is exhausted (this may take another 10 years), the landfill will be closed to further waste disposal. The site will be converted into a public park with hiking trails and picnic and recreation areas, and given to the town.

The construction and operation of landfills are subject to numerous state and federal regulations. For example, nonpermeable liners must be placed on the bottom and sides of the landfill to prevent leakage of liquids into the groundwater. (Independent firms monitor groundwater to determine if there is any leakage into wells placed around the perimeter of the hill.) Mindful of public opinion, every effort is made to minimize the amount of time that waste is left exposed. At the end of each day, the waste that has been deposited in the landfill is compacted and covered with six inches of soil.

The primary source of income for the landfill is the fees it charges users. The landfill also generates income from methane gas, a by-product of organic waste decomposition, that accumulates within the landfill. A collection system is in place to capture and extract the gas from the landfill, and it is then sold to the local power company. Also, the landfill has a composting operation in which leaves and other yard wastes are converted into mulch.

Part of the liner construction of a new landfill at the High Acres Landfill and Recycling Center in Fairport, New York. The hill in the background is a "closed" landfill, which has been through final cover.

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Supplement to

CHAPTER 5

Decision Theory

LEARNING OBJECTIVES

After completing this supplement, you should be able to:

1. Describe the different environments under which operations decisions are made.
2. Describe and use techniques that apply to decision making under uncertainty.
3. Describe and use the expected-value approach.
4. Construct a decision tree and use it to analyze a problem.
5. Compute the expected value of perfect information.
6. Conduct sensitivity analysis on a simple decision problem.

SUPPLEMENT OUTLINE

INTRODUCTION

Decision theory represents a general approach to decision making. It is suitable for a wide range of operations management decisions. Among them are capacity planning, product and service design, equipment selection, and location planning. Decisions that lend themselves to a decision theory approach tend to be characterized by these elements:

1. A set of possible future conditions that will have a bearing on the results of the decision.
2. A list of alternatives for the manager to choose from.
3. A known payoff for each alternative under each possible future condition.

To use this approach, a decision maker would employ this process:

1. Identify the possible future conditions (e.g., demand will be low, medium, or high; the competitor will or will not introduce a new product). These are called *states of nature.*
2. Develop a list of possible *alternatives,* one of which may be to do nothing.

3. Determine or estimate the *payoff* associated with each alternative for every possible future condition.
4. If possible, estimate the *likelihood* of each possible future condition.
5. Evaluate alternatives according to some *decision criterion* (e.g., maximize expected profit), and select the best alternative.

payoff table Table showing the expected payoffs for each alternative in every possible state of nature.

The information for a decision is often summarized in a **payoff table,** which shows the expected payoffs for each alternative under the various possible states of nature. These tables are helpful in choosing among alternatives because they facilitate comparison of alternatives. Consider the following payoff table, which illustrates a capacity planning problem.

	POSSIBLE FUTURE DEMAND		
Alternatives	**Low**	**Moderate**	**High**
Small facility	$10*	$10	$10
Medium facility	7	12	12
Large facility	(4)	2	16

*Present value in $ millions.

The payoffs are shown in the body of the table. In this instance, the payoffs are in terms of present values, which represent equivalent current dollar values of expected future income less costs. This is a convenient measure because it places all alternatives on a comparable basis. If a small facility is built, the payoff will be the same for all three possible states of nature. For a medium facility, low demand will have a present value of $7 million, whereas both moderate and high demand will have present values of $12 million. A large facility will have a loss of $4 million if demand is low, a present value of $2 million if demand is moderate, and a present value of $16 million if demand is high.

The problem for the decision maker is to select one of the alternatives, taking the present value into account.

Evaluation of the alternatives differs according to the degree of certainty associated with the possible future conditions.

CAUSES OF POOR DECISIONS

Despite the best efforts of a manager, a decision occasionally turns out poorly due to unforeseeable circumstances. Luckily, such occurrences are not common. Often, failures can be traced to a combination of mistakes in the decision process, to *bounded rationality,* or to *suboptimization.*

In many cases, managers fail to appreciate the importance of each step in the decision-making process. They may skip a step or not devote enough effort to completing it before jumping to the next step. Sometimes this happens owing to a manager's style of making quick decisions or a failure to recognize the consequences of a poor decision. The manager's ego can be a factor. This sometimes happens when the manager has experienced a series of successes—important decisions that turned out right. Some managers then get the impression that they can do no wrong. But they soon run into trouble, which is usually enough to bring them back down to earth. Other managers seem oblivious to negative results and continue the process they associate with their previous successes, not recognizing that some of that success may have been due more to luck than to any special abilities of their own. A part of the problem may be the manager's unwillingness to admit a mistake. Yet other managers demonstrate an inability to make a decision; they stall long past the time when the decision should have been rendered.

Of course, not all managers fall into these traps—it seems safe to say that the majority do not. Even so, this does not necessarily mean that every decision works out as expected. Another factor with which managers must contend is **bounded rationality,** or the limits imposed on decision making by costs, human abilities, time, technology, and the availability of information. Because of these limitations, managers cannot always expect to reach decisions that are optimal in the sense of providing the best possible outcome (e.g., highest profit, least cost). Instead, they must often resort to achieving a *satisfactory* solution.

bounded rationality The limitations on decision making caused by costs, human abilities, time, technology, and availability of information.

Still another cause of poor decisions is that organizations typically departmentalize decisions. Naturally, there is a great deal of justification for the use of departments in terms of overcoming span-of-control problems and human limitations. However, **suboptimization** can occur. This is a result of different departments attempting to reach a solution that is optimum for each. Unfortunately, what is optimal for one department may not be optimal for the organization as a whole.

suboptimization The result of different departments each attempting to reach a solution that is optimum for that department.

DECISION ENVIRONMENTS

Operations management decision environments are classified according to the degree of certainty present. There are three basic categories: certainty, risk, and uncertainty.

Certainty means that relevant parameters such as costs, capacity, and demand have known values.

Risk means that certain parameters have probabilistic outcomes.

Uncertainty means that it is impossible to assess the likelihood of various possible future events.

certainty Environment in which relevant parameters have known values.

risk Environment in which certain future events have probable outcomes.

uncertainty Environment in which it is impossible to assess the likelihood of various future events.

Consider these situations:

1. Profit per unit is $5. You have an order for 200 units. How much profit will you make? (This is an example of *certainty* since unit profits and total demand are known.)
2. Profit is $5 per unit. Based on previous experience, there is a 50 percent chance of an order for 100 units and a 50 percent chance of an order for 200 units. What is expected profit? (This is an example of *risk* since demand outcomes are probabilistic.)
3. Profit is $5 per unit. The probabilities of potential demands are unknown. (This is an example of *uncertainty*.)

The importance of these different decision environments is that they require different analysis techniques. Some techniques are better suited for one category than for others.

DECISION MAKING UNDER CERTAINTY

When it is known for certain which of the possible future conditions will actually happen, the decision is usually relatively straightforward: Simply choose the alternative that has the best payoff under that state of nature. Example S–1 illustrates this.

EXAMPLE S-1

Determine the best alternative in the payoff table on pg. 196 for each of the cases: It is known with certainty that demand will be (*a*) low, (*b*) moderate, (*c*) high.

SOLUTION

Choose the alternative with the highest payoff. Thus, if we know demand will be low, we would elect to build the small facility and realize a payoff of $10 million. If we know demand will be moderate, a medium factory would yield the highest payoff ($12 million versus either $10 or $2 million). For high demand, a large facility would provide the highest payoff.

Although complete certainty is rare in such situations, this kind of exercise provides some perspective on the analysis. Moreover, in some instances, there may be an opportunity to consider allocation of funds to research efforts, which may reduce or remove some of the uncertainty surrounding the states of nature, converting uncertainty to risk or to certainty.

DECISION MAKING UNDER UNCERTAINTY

At the opposite extreme is complete uncertainty: no information is available on how likely the various states of nature are. Under those conditions, four possible decision criteria are *maximin, maximax, Laplace,* and *minimax regret.* These approaches can be defined as follows:

maximin Choose the alternative with the best of the worst possible payoffs.

maximax Choose the alternative with the best possible payoff.

Laplace Choose the alternative with the best average payoff of any of the alternatives.

minimax regret Choose the alternative that has the least of the worst regrets.

Maximin—Determine the worst possible payoff for each alternative, and choose the alternative that has the "best worst." The maximin approach is essentially a pessimistic one because it takes into account only the worst possible outcome for each alternative. The actual outcome may not be as bad as that, but this approach establishes a "guaranteed minimum."

Maximax—Determine the best possible payoff, and choose the alternative with that payoff. The maximax approach is an optimistic, "go for it" strategy; it does not take into account any payoff other than the best.

Laplace—Determine the average payoff for each alternative, and choose the alternative with the best average. The Laplace approach treats the states of nature as equally likely.

Minimax regret—Determine the worst *regret* for each alternative, and choose the alternative with the "best worst." This approach seeks to minimize the difference between the payoff that is realized and the best payoff for each state of nature.

The next two examples illustrate these decision criteria.

EXAMPLE S-2

Referring to the payoff table on pg. 196, determine which alternative would be chosen under each of these strategies:

a. Maximin
b. Maximax
c. Laplace

SOLUTION

a. Using maximin, the worst payoffs for the alternatives are

Small facility:	$10 million
Medium facility:	7 million
Large facility:	−4 million

Hence, since $10 million is the best, choose to build the small facility using the maximin strategy.

b. Using maximax, the best payoffs are

Small facility:	$10 million
Medium facility:	12 million
Large facility:	16 million

The best overall payoff is the $16 million in the third row. Hence, the maximax criterion leads to building a large facility.

c. For the Laplace criterion, first find the row totals, and then divide each of those amounts by the number of states of nature (three in this case). Thus, we have

	Row Total (in $ millions)	Row Average (in $ millions)
Small facility	$30	$10.00
Medium facility	31	10.33
Large facility	14	4.67

Because the medium facility has the highest average, it would be chosen under the Laplace criterion.

EXAMPLE S-3

Determine which alternative would be chosen using a minimax regret approach to the capacity planning program.

SOLUTION

The first step in this approach is to prepare a table of **opportunity losses, or regrets.** To do this, subtract every payoff *in each column* from the best payoff in that column. For instance, in the first column, the best payoff is 10, so each of the three numbers in that column must be subtracted from 10. Going down the column, the regrets will be 10 − 10 = 0, 10 − 7 = 3, and 10 − (− 4) = 14. In the second column, the best payoff is 12. Subtracting each payoff from 12 yields 2, 0, and 10. In the third column, 16 is the best payoff. The regrets are 6, 4, and 0. These results are summarized in a regret table:

regret (opportunity loss) The difference between a given payoff and the best payoff for a state of nature.

	REGRETS (IN $ MILLIONS)			
Alternatives	**Low**	**Moderate**	**High**	**Worst**
Small facility	$0	$2	$6	$6
Medium facility	3	0	4	4
Large facility	14	10	0	14

The second step is to identify the worst regret for each alternative. For the first alternative, the worst is 6; for the second, the worst is 4; and for the third, the worst is 14.

The best of these worst regrets would be chosen using minimax regret. The lowest regret is 4, which is for a medium facility. Hence, that alternative would be chosen.

Solved Problem 6 at the end of this supplement illustrates decision making under uncertainty when the payoffs represent costs.

The main weakness of these approaches (except for Laplace) is that they do not take into account *all* of the payoffs. Instead, they focus on the worst or best, and so they lose some information. Still, for a given set of circumstances, each has certain merits that can be helpful to a decision maker.

DECISION MAKING UNDER RISK

Between the two extremes of certainty and uncertainty lies the case of risk: The probability of occurrence for each state of nature is known. (Note that because the states are mutually exclusive and collectively exhaustive, these probabilities must add to 1.00.) A widely used approach under such circumstances is the *expected monetary value criterion.* The expected value is computed for each alternative, and the one with the best expected value is selected. The expected value is the sum of the payoffs for an alternative where each payoff is *weighted* by the probability for the relevant state of nature. Thus, the approach is

> **Expected monetary value (EMV) criterion**—Determine the expected payoff of each alternative, and choose the alternative that has the best expected payoff.

expected monetary value (EMV) criterion The best expected value among the alternatives.

EXAMPLE S-4

Using the expected monetary value criterion, identify the best alternative for the previous payoff table for these probabilities: low = .30, moderate = .50, and high = .20.

SOLUTION

Find the expected value of each alternative by multiplying the probability of occurrence for each state of nature by the payoff for that state of nature and summing them:

$$EV_{small} = .30(\$10) + .50(\$10) + .20(\$10) = \$10$$
$$EV_{medium} = .30(\$7) + .50(\$12) + .20(\$12) = \$10.5$$
$$EV_{large} = .30(-4) + .50(\$2) + .20(\$16) = \$3$$

Hence, choose the medium facility because it has the highest expected value.

The expected monetary value approach is most appropriate when a decision maker is neither risk averse nor risk seeking, but is risk neutral. Typically, well-established organizations with numerous decisions of this nature tend to use expected value because it provides an indication of the long-run, average payoff. That is, the expected-value amount (e.g., \$10.5 million in the last example) is not an actual payoff but an expected or average amount that would be approximated if a large number of identical decisions were to be made. Hence, if a decision maker applies this criterion to a large number of similar decisions, the expected payoff for the total will approximate the sum of the individual expected payoffs.

DECISION TREES

In health care the array of treatment options and medical costs makes tools such as decision trees particularly valuable in diagnosing and prescribing treatment plans. For example, if a 20-year-old and a 50-year-old both are brought into an emergency room complaining of chest pains, the attending physician, after asking each some questions on family history, patient history, general health, and recent events and activities, will use a *decision tree* to sort through the options to arrive at the appropriate decision for each patient.

Decision trees are tools that have many practical applications, not only in health care, but also in legal cases and a wide array of management decision making, including credit card fraud; loan, credit, and insurance risk analysis; decisions on new product or service development; and location analysis.

decision tree A schematic representation of the available alternatives and their possible consequences.

Excel

A **decision tree** is a schematic representation of the alternatives available to a decision maker and their possible consequences. The term gets its name from the treelike appearance of the diagram (see Figure 5S.1). Although tree diagrams can be used in place of a payoff table, they are particularly useful for analyzing situations that involve *sequential* decisions. For instance, a manager may initially decide to build a small facility only to discover that demand is much higher than anticipated. In this case, the manager may then be called upon to make a subsequent decision on whether to expand or build an additional facility.

A decision tree is composed of a number of *nodes* that have *branches* emanating from them (see Figure 5S.1). Square nodes denote decision points, and circular nodes denote chance events. Read the tree from left to right. Branches leaving square nodes represent alternatives; branches leaving circular nodes represent chance events (i.e., the possible states of nature).

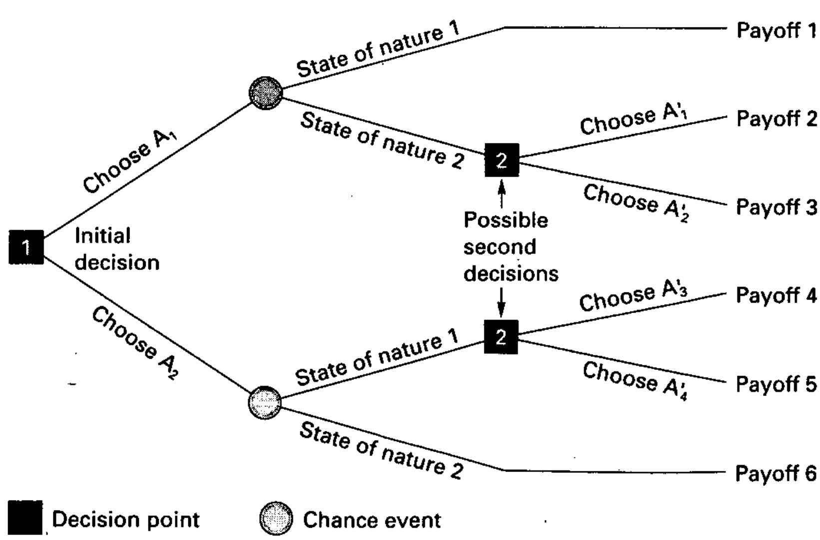
After the tree has been drawn, it is analyzed from *right to left*; that is, starting with the last decision that might be made. For each decision, choose the alternative that will yield the greatest return (or the lowest cost). If chance events follow a decision, choose the alternative that has the highest expected monetary value (or lowest expected cost).

EXAMPLE S-5

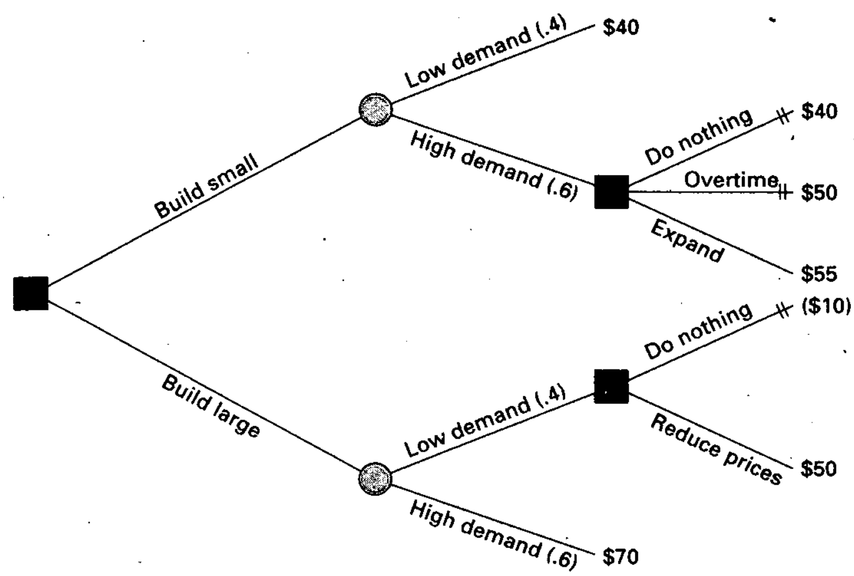
A manager must decide on the size of a video arcade to construct. The manager has narrowed the choices to two: large or small. Information has been collected on payoffs, and a decision tree has

FIGURE 5S.1

Format of a decision tree



been constructed. Analyze the decision tree and determine which initial alternative (build small or build large) should be chosen in order to maximize expected monetary value.



SOLUTION

The dollar amounts at the branch ends indicate the estimated payoffs if the sequence of chance events and decisions that is traced back to the initial decision occurs. For example, if the initial decision is to build a small facility and it turns out that demand is low, the payoff will be $40 (thousand). Similarly, if a small facility is built, demand turns out high, and a later decision is made to expand, the payoff will be $55. The figures in parentheses on branches leaving the chance nodes indicate the probabilities of those states of nature. Hence, the probability of low demand is .4, and the probability of high demand is .6. Payoffs in parentheses indicate losses.

Analyze the decisions from right to left:

1. Determine which alternative would be selected for each possible second decision. For a small facility with high demand, there are three choices: *do nothing, work overtime,* and *expand.* Because *expand* has the highest payoff, you would choose it. Indicate this by placing a double slash through each of the other alternatives. Similarly, for a large facility with low demand, there are two choices: *do nothing* and *reduce prices.* You would choose *reduce prices* because it has the higher expected value, so a double slash is placed on the other branch.
2. Determine the product of the chance probabilities and their respective payoffs for the remaining branches:

   Build small

Low demand	.4($40) = $16
High demand	.6($55) = 33

   Build large

Low demand	.4($50) = 20
High demand	.6($70) = 42

3. Determine the expected value of each initial alternative:

Build small	$16 + $33 = $49
Build large	$20 + $42 = $62

   Hence, the choice should be to build the large facility because it has a larger expected value than the small facility.

EXPECTED VALUE OF PERFECT INFORMATION

In certain situations, it is possible to ascertain which state of nature will actually occur in the future. For instance, the choice of location for a restaurant may weigh heavily on whether a new highway will be constructed or whether a zoning permit will be issued. A decision maker may have probabilities for these states of nature; however, it may be possible to delay a decision until it is clear which state of nature will occur. This might involve taking an option to buy the land. If the state of nature is favorable, the option can be exercised; if it is unfavorable, the option can be allowed to expire. The question to consider is whether the cost of the option will be less than the expected gain due to delaying the decision (i.e., the expected payoff *above* the expected value). The expected gain is the *expected value of perfect information,* or EVPI.

expected value of perfect information (EVPI) The difference between the expected payoff with perfect information and the expected payoff under risk.

Expected value of perfect information (EVPI)—the difference between the expected payoff with perfect information and the expected payoff under risk.

Other possible ways of obtaining perfect information depend somewhat on the nature of the decision being made. Information about consumer preferences might come from market research, additional information about a product could come from product testing, or legal experts might be called on.

There are two ways to determine the EVPI. One is to compute the expected payoff under certainty and subtract the expected payoff under risk. That is,

$$\text{Expected value of perfect information} = \text{Expected payoff under certainty} - \text{Expected payoff under risk} \quad (5S\text{–}1)$$

EXAMPLE S-6

Using the information from Example S–4, determine the expected value of perfect information using Formula 5S–1.

SOLUTION

First, compute the expected payoff under certainty. To do this, identify the best payoff under each state of nature. Then combine these by weighting each payoff by the probability of that state of nature and adding the amounts. Thus, the best payoff under low demand is \$10, the best under moderate demand is \$12, and the best under high demand is \$16. The expected payoff under certainty is, then,

$$.30(\$10) + .50(\$12) + .20(\$16) = \$12.2$$

The expected payoff under risk, as computed in Example 4, is \$10.5. The EVPI is the difference between these:

$$\text{EVPI} = \$12.2 - \$10.5 = \$1.7$$

This figure indicates the upper limit on the amount the decision maker should be willing to spend to obtain perfect information in this case. Thus, if the cost equals or exceeds this amount, the decision maker would be better off not spending additional money and simply going with the alternative that has the highest expected payoff.

A second approach is to use the regret table to compute the EVPI. To do this, find the expected regret for each alternative. The minimum expected regret is equal to the EVPI.

EXAMPLE S-7

Determine the expected value of perfect information for the capacity-planning problem using the expected regret approach.

SOLUTION

Using information from Examples 2, 3, and 4, we can compute the expected regret for each alternative. Thus:

Small facility	.30(0) + .50(2) + .20(6) = 2.2
Medium facility	.30(3) + .50(0) + .20(4) = 1.7 [minimum]
Large facility	.30(14) + .50(10) + .20(0) = 9.2

The lowest expected regret is 1.7, which is associated with the second alternative. Hence, the EVPI is $1.7 million, which agrees with the previous example using the other approach.

SENSITIVITY ANALYSIS

IOM

Excel

Generally speaking, both the payoffs and the probabilities in this kind of a decision problem are estimated values. Consequently, it can be useful for the decision maker to have some indication of how sensitive the choice of an alternative is to changes in one or more of these values. Unfortunately, it is impossible to consider all possible combinations of every variable in a typical problem. Nevertheless, there are certain things a decision maker can do to judge the sensitivity of probability estimates.

Sensitivity analysis provides a range of probability over which the choice of alternatives would remain the same. The approach illustrated here is useful when there are two states of nature. It involves constructing a graph and then using algebra to determine a range of probabilities for which a given solution is best. In effect, the graph provides a visual indication of the range of probability over which the various alternatives are optimal, and the algebra provides exact values of the endpoints of the ranges. Example S–8 illustrates the procedure.

sensitivity analysis Determining the range of probability for which an alternative has the best expected payoff.

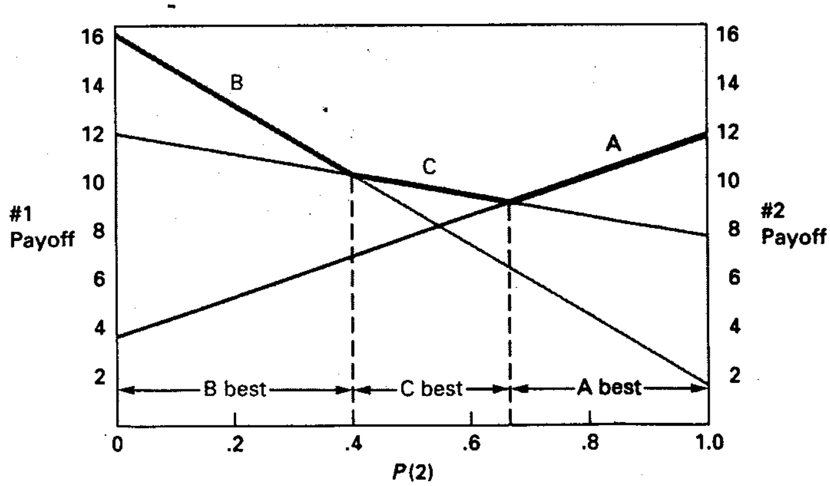
EXAMPLE S-8

Given the following table, determine the range of probability for state of nature #2, that is, $P(2)$, for which each alternative is optimal under the expected-value approach.

		STATE OF NATURE	
		#1	#2
Alternative	A	4	12
	B	16	2
	C	12	8

SOLUTION

First, plot each alternative relative to $P(2)$. To do this, plot the #1 value on the left side of the graph and the #2 value on the right side. For instance, for alternative A, plot 4 on the left side of the graph and 12 on the right side. Then connect these two points with a straight line. The three alternatives are plotted on the graph as shown below.



The graph shows the range of values of $P(2)$ over which each alternative is optimal. Thus, for low values of $P(2)$ [and thus high values of $P(1)$, since $P(1) + P(2) = 1.0$], alternative B will have the highest expected value; for intermediate values of $P(2)$, alternative C is best; and for higher values of $P(2)$, alternative A is best.

To find exact values of the ranges, determine where the upper parts of the lines intersect. Note that at the intersections, the two alternatives represented by the lines would be equivalent in terms of expected value. Hence, the decision maker would be indifferent between the two at that point. To determine the intersections, you must obtain the equation of each line. This is relatively simple to do. Because these are straight lines, they have the form $y = a + bx$, where a is the y-intercept value at the left axis, b is the slope of the line, and x is $P(2)$. Slope is defined as the change in y for a one-unit change in x. In this type of problem, the distance between the two vertical axes is 1.0. Consequently, the slope of each line is equal to the right-hand value minus the left-hand value. The slopes and equations are

	#1	#2	Slope	Equation
A	4	12	12 − 4 = + 8	4 + 8P(2)
B	16	2	2 − 16 = −14	16 − 14P(2)
C	12	8	8 − 12 = − 4	12 − 4P(2)

From the graph, we can see that alternative B is best from $P(2) = 0$ to the point where that straight line intersects the straight line of alternative C, and that begins the region where C is better. To find that point, solve for the value of $P(2)$ at their intersection. This requires setting the two equations equal to each other and solving for $P(2)$. Thus,

$$16 - 14P(2) = 12 - 4P(2)$$

Rearranging terms yields

$$4 = 10P(2)$$

Solving yields $P(2) = .40$. Thus, alternative B is best from $P(2) = 0$ up to $P(2) = .40$. B and C are equivalent at $P(2) = .40$.

Alternative C is best from that point until its line intersects alternative A's line. To find that intersection, set those two equations equal and solve for $P(2)$. Thus,

$$4 + 8P(2) = 12 - 4P(2)$$

Rearranging terms results in

$$12P(2) = 8$$

Solving yields $P(2) = .67$. Thus, alternative C is best from $P(2) > .40$ up to $P(2) = .67$, where A and C are equivalent. For values of $P(2)$ greater than .67 up to $P(2) = 1.0$, A is best.

Note: If a problem calls for ranges with respect to $P(1)$, find the $P(2)$ ranges as above, and then subtract each $P(2)$ from 1.00 (e.g., .40 becomes .60, and .67 becomes .33).

SUMMARY

Decision making is an integral part of operations management.

Decision theory is a general approach to decision making that is useful in many different aspects of operations management. Decision theory provides a framework for the analysis of decisions. It includes a number of techniques that can be classified according to the degree of uncertainty associated with a particular decision problem. Two visual tools useful for analyzing some decision problems are decision trees and graphical sensitivity analysis.

KEY TERMS

bounded rationality, 196
certainty, 197
decision tree, 200
expected monetary value (EMV) criterion, 199
expected value of perfect information (EVPI), 202
Laplace, 198
maximax, 198
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SOLVED PROBLEMS

The following solved problems refer to this payoff table:

		New Bridge Built	No New Bridge
Alternative capacity	A	1	14
for new store	B	2	10
	C	4	6

where A = small, B = medium, and C = large.

Problem 1

Assume the payoffs represent profits. Determine the alternative that would be chosen under each of these decision criteria:

a. Maximin.

b. Maximax.

c. Laplace.

Solution

	New Bridge	No New Bridge	Maximin (worst)	Maximax (best)	Laplace (average)
A	1	14	1	14 [best]	$15 \div 2 = 7.5$ [best]
B	2	10	2	10	$12 \div 2 = 6$
C	4	6	4 [best]	6	$10 \div 2 = 5$

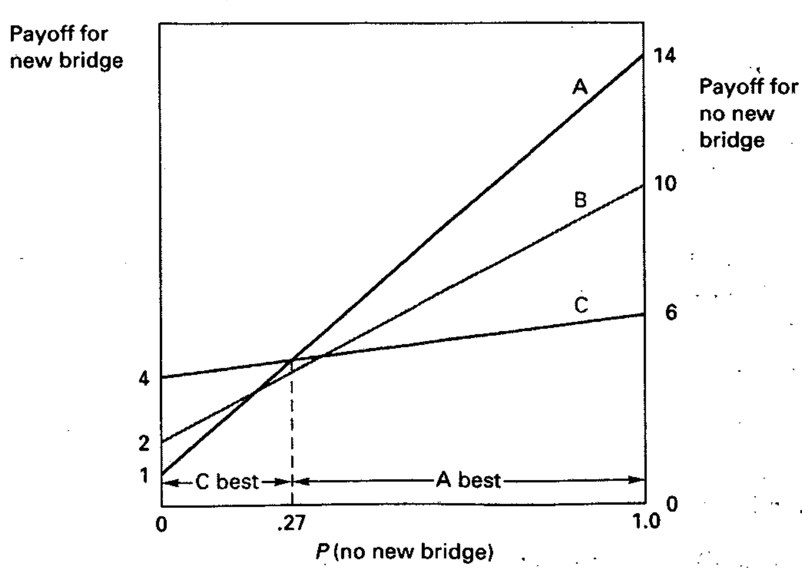
Thus, the alternatives chosen would be C under maximin, A under maximax, and A under Laplace.

Problem 2

Using graphical sensitivity analysis, determine the probability for no new bridge for which each alternative would be optimal.

Solution

Plot a straight line for each alternative. Do this by plotting the payoff for new bridge on the left axis and the payoff for no new bridge on the right axis and then connecting the two points. Each line represents the expected profit for an alternative for the entire range of probability of no new bridge. Because the lines represent expected profit, the line that is highest for a given value of P (no new bridge) is optimal. Thus, from the graph, you can see that for low values of this probability, alternative C is best, and for higher values, alternative A is best (B is never the highest line, so it is never optimal).



The dividing line between the ranges where C and A are optimal occurs where the two lines intersect. To find that probability, first formulate the equation for each line. To do this, let the intersection with the left axis be the *y* intercept; the slope equals the right-side payoff minus the left-side payoff. Thus, for C you have $4 + (6 - 4)P$, which is $4 + 2P$. For A, $1 + (14 - 1)P$, which is $1 + 13P$. Setting these two equal to each other, you can solve for *P*:

$$4 + 2P = 1 + 13P$$

Solving, $P = .27$. Therefore, the ranges for *P*(no new bridge) are

A: $.27 < P \le 1.00$

B: never optimal

C: $0 \le P < .27$

Problem 3

Using the information in the payoff table, develop a table of regrets, and then

a. Determine the alternative that would be chosen under minimax regret.

b. Determine the expected value of perfect information using the regret table, assuming that the probability of a new bridge being built is .60.

Solution

To obtain the regrets, subtract all payoffs in each column from the best payoff in the column. The regrets are

	New Bridge	No New Bridge
A	3	0
B	2	4
C	0	8

a. Minimax regret involves finding the worst regret for each alternative and then choosing the alternative that has the "best" worst. Thus, you would choose A:

	Worst
A	3 [best]
B	4
C	8

b. Once the regret table has been developed, you can compute the EVPI as the *smallest* expected regret. Since the probability of a new bridge is given as .60, we can deduce that the probability of no new bridge is $1.00 - .60 = .40$. The expected regrets are

A: $.60(3) + .40(0) = 1.80$

B: $.60(2) + .40(4) = 2.80$

C: $.60(0) + .40(8) = 3.20$

Hence, the EVPI is 1.80.

Problem 4

Using the probabilities of .60 for a new bridge and .40 for no new bridge, compute the expected value of each alternative in the payoff table, and identify the alternative that would be selected under the expected-value approach.

Solution

A: $.60(1) + .40(14) = 6.20$ [best]

B: $.60(2) + .40(10) = 5.20$

C: $.60(4) + .40(6) = 4.80$

Problem 5

Compute the EVPI using the information from the previous problem.

Solution

Using Formula 5S–1, the EVPI is the expected payoff under certainty minus the maximum expected value. The expected payoff under certainty involves multiplying the best payoff in each column by the column probability and then summing those amounts. The best payoff in the first column is 4, and the best in the second is 14. Thus,

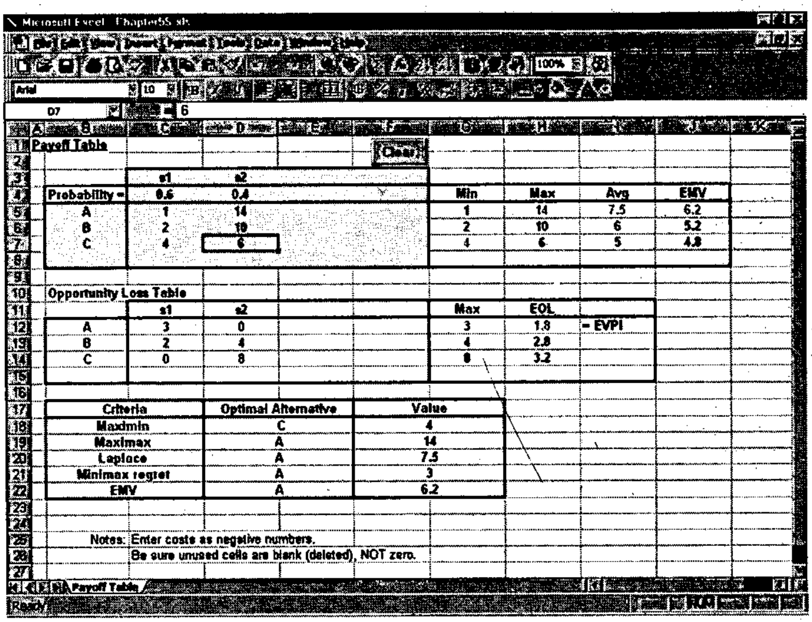
Expected payoff under certainty = .60(4) + .40(14) = 8.00

Then

EVPI = 8.00 − 6.20 = 1.80

(This agrees with the result obtained in Solved Problem 3*b*.)

Excel solution:



Payoff Table

	s1	s2	Min	Max	Avg	EMV
Probability =	0.6	0.4				
A	1	14	1	14	7.5	6.2
B	2	10	2	10	6	5.2
C	4	6	4	6	5	4.8

Opportunity Loss Table

	s1	s2	Max	EOL	
A	3	0	3	1.8	= EVPI
B	2	4	4	2.8	
C	0	8	8	3.2	

Criteria	Optimal Alternative	Value
Maximin	C	4
Maximax	A	14
Laplace	A	7.5
Minimax regret	A	3
EMV	A	6.2

Notes: Enter costs as negative numbers.
Be sure unused cells are blank (deleted), NOT zero.

Placing the problem data in the cell positions shown, the expected monetary value (EMV) for each alternative is shown in column J.

Then, the overall EMV is obtained in column J as the maximum of the values in J5, J6, and J7.

The EVPI is obtained using the Opportunity Loss Table by summing the product of the maximum in column C2 and the probability in C4, and the product of the maximum in column D and the probability in D4.

Problem 6.

Suppose that the values in the payoff table represent *costs* instead of profits.

a. Determine the choice that you would make under each of these strategies: maximin, ***minimin***, and Laplace.*

b. Develop the regret table, and identify the alternative chosen using minimax regret. Then find the EVPI if *P*(new bridge) = .60.

c. Using sensitivity analysis, determine the range of *P*(no new bridge) for which each alternative would be optimal.

d. If *P*(new bridge) = .60 and *P*(no new bridge) = .40, find the alternative chosen to minimize expected cost.

**Solution*Note: Minimin* is the reverse of maximax; for costs minimin identifies the lowest (best) cost.

Solution

a.

	New Bridge	No New Bridge	Maximin (worst)	Minimin (best)	Laplace (average)
A	1	14	14	1 [best]	15 ÷ 2 = 7.5
B	2	10	10	2	12 ÷ 2 = 6
C	4	6	6 [best]	4	10 ÷ 2 = 5 [best]

b. Develop the regret table by subtracting the *lowest cost* in each column from each of the values in the column. (Note that none of the values is negative.)

	New Bridge	No New Bridge	Worst
A	0	8	8
B	1	4	4
C	3	0	3 [best]

EVPI = .60(3) + .40(0) = 1.80

c. The graph is identical to that shown in Solved Problem 2. However, the lines now represent expected *costs,* so the best alternative for a given value of *P*(no new bridge) is the *lowest* line. Hence, for very low values of *P*(no new bridge), A is best; for intermediate values, B is best; and for high values, C is best. You can set the equations of A and B, and B and C, equal to each other in order to determine the values of *P*(no new bridge) at their intersections. Thus,

A = B: $1 + 13P = 2 + 8P$; solving, $P = .20$

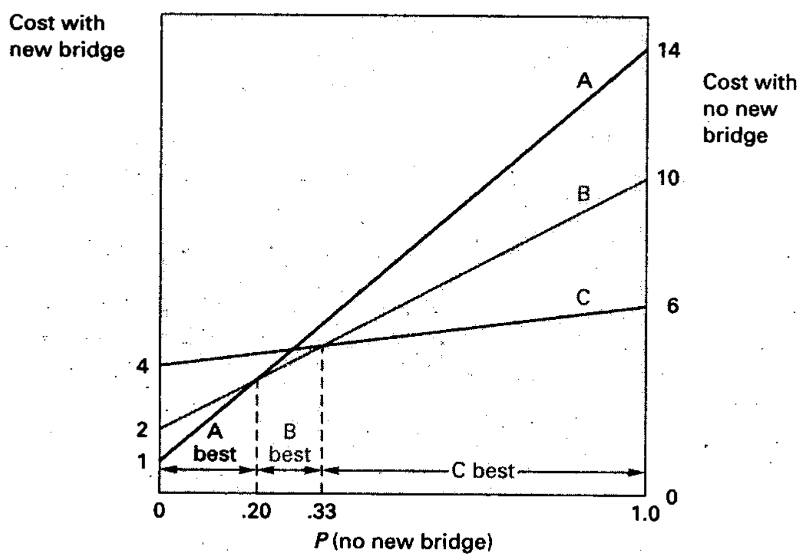
B = C: $2 + 8P = 4 + 2P$; solving, $P = .33$

Hence, the ranges are

A best: $0 \le P < .20$

B best: $.20 < P < .33$

C best: $.33 < P \le 1.00$



d. Expected-value computations are the same whether the values represent costs or profits. Hence, the expected payoffs for costs are the same as the expected payoffs for profits that were computed in Solved Problem 4. However, now you want the alternative that has the *lowest* expected payoff rather than the one with the highest payoff. Consequently, alternative C is the best because its expected payoff is the lowest of the three.

DISCUSSION AND REVIEW QUESTIONS

1. What is the chief role of the operations manager?
2. List the steps in the decision-making process.
3. Explain the term *bounded rationality.*
4. Explain the term *suboptimization.*
5. What are some of the reasons for poor decisions?

6. What information is contained in a payoff table?
7. What is sensitivity analysis, and how can it be useful to a decision maker?
8. Contrast maximax and maximin decision strategies. Under what circumstances is each appropriate?
9. Under what circumstances is expected monetary value appropriate as a decision criterion? When isn't it appropriate?
10. Explain or define each of these terms:
    a. Laplace criterion.
    b. Minimax regret.
    c. Expected value.
    d. Expected value of perfect information.
11. What information does a decision maker need in order to perform an expected-value analysis of a problem? What options are available to the decision maker if the probabilities of the states of nature are unknown? Can you think of a way you might use sensitivity analysis in such a case?
12. Suppose a manager is using maximum EMV as a basis for making a capacity decision and, in the process, obtains a result in which there is a virtual tie between two of the seven alternatives. How is the manager to make a decision?

PROBLEMS

1. A small building contractor has recently experienced two successive years in which work opportunities exceeded the firm's capacity. The contractor must now make a decision on capacity for next year. Estimated profits under each of the two possible states of nature are as shown in the table below. Which alternative should be selected if the decision criterion is
   a. Maximax?
   b. Maximin?
   c. Laplace?
   d. Minimax regret?

	NEXT YEAR'S DEMAND	
Alternative	**Low**	**High**
Do nothing	$50*	$60
Expand	20	80
Subcontract	40	70

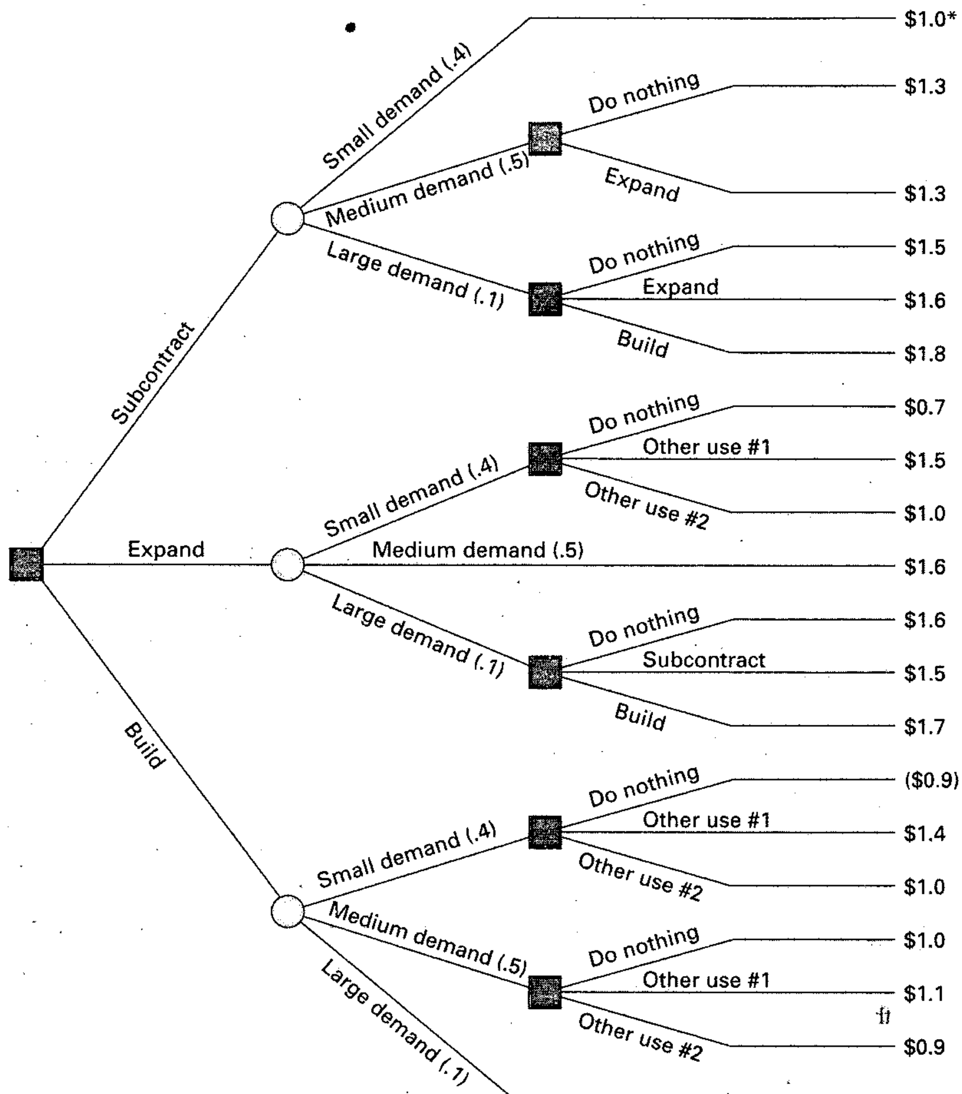
*Profit in $ thousands.

2. Refer to Problem 1. Suppose after a certain amount of discussion, the contractor is able to subjectively assess the probabilities of low and high demand: $P(\text{low}) = .3$ and $P(\text{high}) = .7$.
   a. Determine the expected profit of each alternative. Which alternative is best? Why?
   b. Analyze the problem using a decision tree. Show the expected profit of each alternative on the tree.
   c. Compute the expected value of perfect information. How could the contractor use this knowledge?
3. Refer to Problems 1 and 2. Construct a graph that will enable you to perform sensitivity analysis on the problem. Over what range of $P(\text{high})$ would the alternative of doing nothing be best? Expand? Subcontract?
4. A firm that plans to expand its product line must decide whether to build a small or a large facility to produce the new products. If it builds a small facility and demand is low, the net present value after deducting for building costs will be $400,000. If demand is high, the firm can either maintain the small facility or expand it. Expansion would have a net present value of $450,000, and maintaining the small facility would have a net present value of $50,000.

   If a large facility is built and demand is high, the estimated net present value is $800,000. If demand turns out to be low, the net present value will be −$10,000.

   The probability that demand will be high is estimated to be .60, and the probability of low demand is estimated to be .40.
   a. Analyze using a tree diagram.
   b. Compute the EVPI. How could this information be used?
   c. Determine the range over which each alternative would be best in terms of the value of $P(\text{demand low})$.

5. Determine the course of action that has the highest expected payoff for this decision tree.



* Net present value in millions

6. The lease of Theme Park, Inc., is about to expire. Management must decide whether to renew the lease for another 10 years or to relocate near the site of a proposed motel. The town planning board is currently debating the merits of granting approval to the motel. A consultant has estimated the net present value of Theme Park's two alternatives under each state of nature as shown below. What course of action would you recommend using
   a. Maximax?
   b. Maximin?
   c. Laplace?
   d. Minimax regret?

Options	Motel Approved	Motel Rejected
Renew	$ 500,000	$4,000,000
Relocate	5,000,000	100,000

7. Refer to Problem 6. Suppose that the management of Theme Park, Inc., has decided that there is a .35 probability that the motel's application will be approved.
   a. If management uses maximum expected monetary value as the decision criterion, which alternative should it choose?
   b. Represent this problem in the form of a decision tree.
   c. If management has been offered the option of a temporary lease while the town planning board considers the motel's application, would you advise management to sign the lease? The lease will cost $24,000.
8. Construct a graph that can be used for sensitivity analysis for the preceding problem.
   a. How sensitive is the solution to the problem in terms of the probability estimate of .35?
   b. Suppose that, after consulting with a member of the town planning board, management decides that an estimate of approval is approximately .45. How sensitive is the solution to this revised estimate? Explain.
   c. Suppose the management is confident of all the estimated payoffs except for $4 million. If the probability of approval is .35, for what range of payoff for renew/rejected will the alternative selected using maximum expected value remain the same?
9. A firm must decide whether to construct a small, medium, or large stamping plant. A consultant's report indicates a .20 probability that demand will be low and an .80 probability that demand will be high.

   If the firm builds a small facility and demand turns out to be low, the net present value will be $42 million. If demand turns out to be high, the firm can either subcontract and realize the net present value of $42 million or expand greatly for a net present value of $48 million.

   The firm could build a medium-size facility as a hedge: If demand turns out to be low, its net present value is estimated at $22 million; if demand turns out to be high, the firm could do nothing and realize a net present value of $46 million, or it could expand and realize a net present value of $50 million.

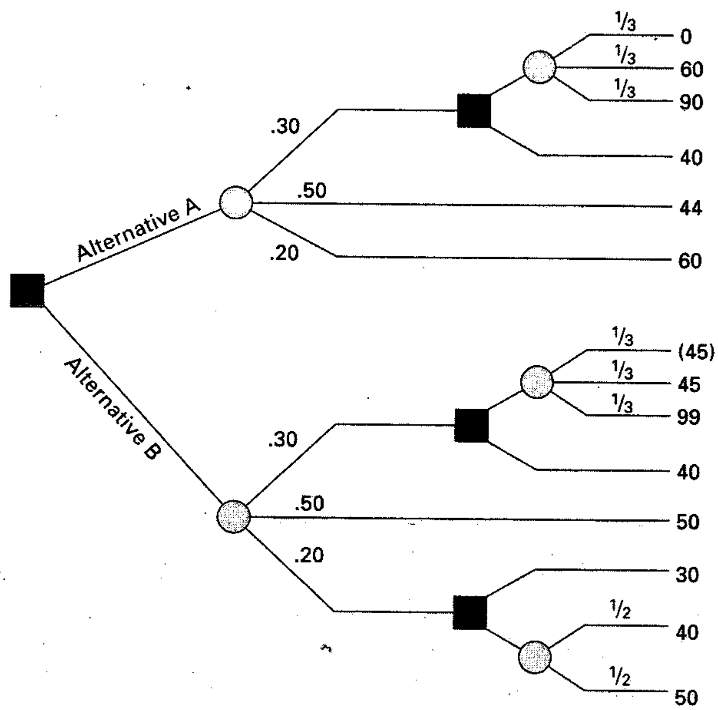
   If the firm builds a large facility and demand is low, the net present value will be −$20 million, whereas high demand will result in a net present value of $72 million.
   a. Analyze this problem using a decision tree.
   b. What is the maximin alternative?
   c. Compute the EVPI and interpret it.
   d. Perform sensitivity analysis on *P*(high).
10. A manager must decide how many machines of a certain type to buy. The machines will be used to manufacture a new gear for which there is increased demand. The manager has narrowed the decision to two alternatives: buy one machine or buy two. If only one machine is purchased and demand is more than it can handle, a second machine can be purchased at a later time. However, the cost per machine would be lower if the two machines were purchased at the same time.

    The estimated probability of low demand is .30, and the estimated probability of high demand is .70.

    The net present value associated with the purchase of two machines initially is $75,000 if demand is low and $130,000 if demand is high.

    The net present value for one machine and low demand is $90,000. If demand is high, there are three options. One option is to do nothing, which would have a net present value of $90,000. A second option is to subcontract; that would have a net present value of $110,000. The third option is to purchase a second machine. This option would have a net present value of $100,000.

    How many machines should the manager purchase initially? Use a decision tree to analyze this problem.
11. Determine the course of action that has the highest EMV for the accompanying tree diagram.



12. A firm that plans to expand its product line must decide whether to build a small or a large facility to produce the new products. If it builds a small facility and demand is low, the net present value after deducting for building costs will be $400,000. If demand is high, the firm can either maintain the small facility or expand it. Expansion would have a net present value of $450,000, and maintaining the small facility would have a net present value of $50,000.

    If a large facility is built and demand is high, the estimated net present value is $800,000. If demand turns out to be low, the net present value will be −$10,000.

    The probability that demand will be high is estimated to be .60, and the probability of low demand is estimated to be .40.

    Analyze using a tree diagram.

13. The director of social services of a county has learned that the state has mandated additional information requirements. This will place an additional burden on the agency. The director has identified three acceptable alternatives to handle the increased workload. One alternative is to reassign present staff members, the second is to hire and train two new workers, and the third is to redesign current practice so that workers can readily collect the information with little additional effort. An unknown factor is the caseload for the coming year when the new data will be collected on a trial basis. The estimated costs for various options and caseloads are shown in the following table:

	CASELOAD		
	Moderate	**High**	**Very High**
Reassign staff	$50*	60	85
New staff	60	60	60
Redesign collection	40	50	90

*Cost in $ thousands.

    Assuming that past experience has shown the probabilities of various caseloads to be unreliable, what decision would be appropriate using each of the following criteria?

    a. Maximin.
    b. Maximax.
    c. Minimax regret.
    d. Laplace.

14. After contemplating the caseload question (see previous problem), the director of social services has decided that reasonable caseload probabilities are .10 for moderate, .30 for high, and .60 for very high.

a. Which alternative will yield the minimum expected cost?
b. Construct a decision tree for this problem. Indicate the expected costs for the three decision branches.
c. Determine the expected value of perfect information using an opportunity loss table.

15. Suppose the director of social services has the option of hiring an additional staff member if one staff member is hired initially and the caseload turns out to be high or very high. Under that plan, the first entry in row 2 of the cost table (see Problem 13) will be 40 instead of 60, the second entry will be 75, and the last entry will be 80. Assume the caseload probabilities are as noted in Problem 14. Construct a decision tree that shows the sequential nature of this decision, and determine which alternative will minimize expected cost.

16. A manager has compiled estimated profits for various capacity alternatives but is reluctant to assign probabilities to the states of nature. The payoff table is

		STATE OF NATURE	
		#1	#2
	A	$ 20*	140
Alternative	B	120	80
	C	100	40

*Cost in $ thousands.

a. Plot the expected-value lines on a graph.
b. Is there any alternative that would never be appropriate in terms of maximizing expected profit? Explain on the basis of your graph.
c. For what range of $P(2)$ would alternative A be the best choice if the goal is to maximize expected profit?
d. For what range of $P(1)$ would alternative A be the best choice if the goal is to maximize expected profit?

17. Repeat all parts of Problem 16, assuming the values in the payoff table are estimated *costs* and the goal is to minimize expected costs.

18. The research staff of a marketing agency has assembled the following payoff table of estimated profits:

		Receive Contract	Not Receive Contract
	#1	$10*	−2
Proposal	#2	8	3
	#3	5	5
	#4	0	7

*Cost in $ thousands.

Relative to the probability of not receiving the contract, determine the range of probability for which each of the proposals would maximize expected profit.

19. Given this payoff table:

		STATE OF NATURE	
		#1	#2
	A	$120*	20
Alternative	B	60	40
	C	10	110
	D	90	90

*Cost in $ thousands.

a. Determine the range of $P(1)$ for which each alternative would be best, treating the payoffs as profits.
b. Answer part *a* treating the payoffs as costs.

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CHAPTER 6

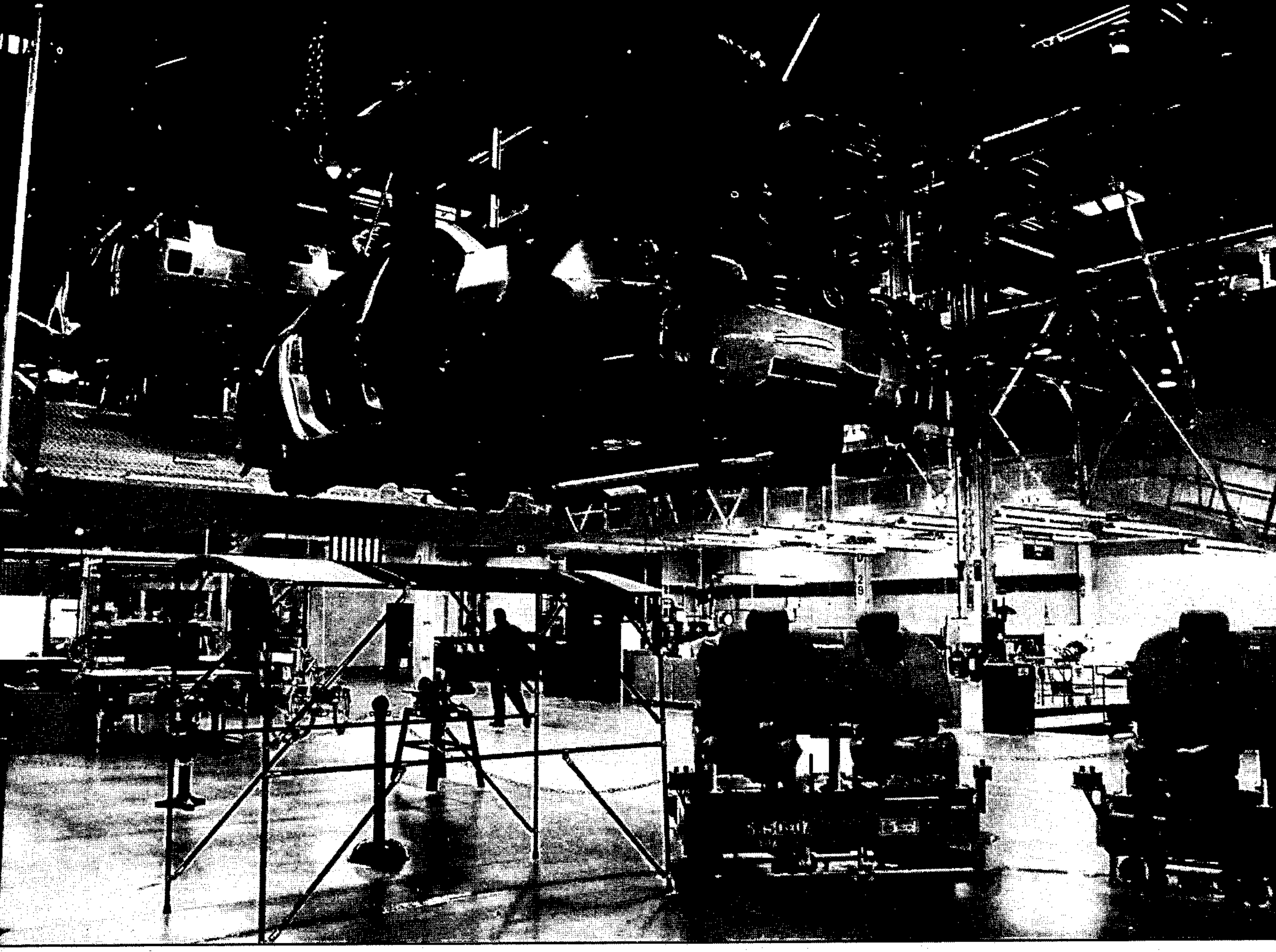
Process Selection and Facility Layout

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1 Explain the strategic importance of process selection.
2 Explain the influence that process selection has on an organization.
3 Describe the basic processing types.
4 Discuss automated approaches to processing.
5 Explain the need for management of technology.
6 List some reasons for redesign of layouts.
7 Describe the basic layout types.
8 List the main advantages and disadvantages of product layouts and process layouts.
9 Solve simple line-balancing problems.
10 Develop simple process layouts.

CHAPTER OUTLINE



Product and service choices, capacity planning, process selection, and layout of facilities are among the most basic decisions managers make because they have long-term consequences for business organizations.

This chapter is about process selection and facility layout. Processes convert inputs into outputs; they are at the core of operations management. But the impact of process selection goes beyond operations management: It affects the entire organization and its ability to achieve its mission, and it affects the organization's supply chain. So process selection choices very often have strategic significance. This chapter will explain why—and how—process selection has such influence.

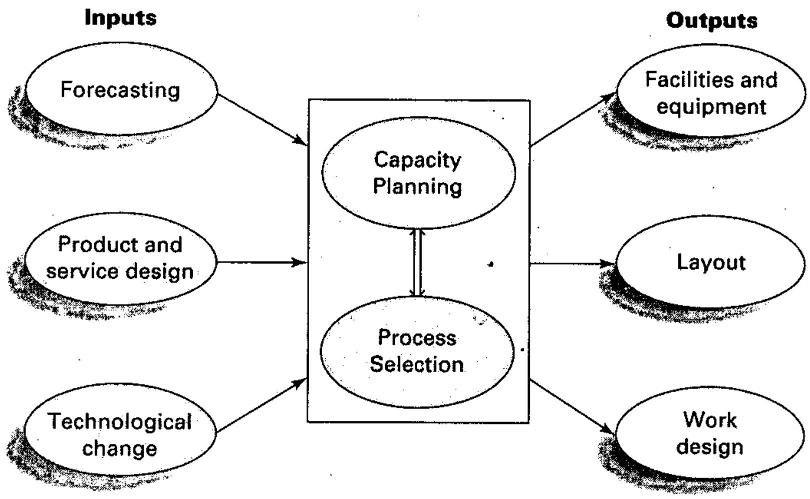
Process selection and facility layout (i.e., the arrangement of the workplace) are closely tied, and for that reason, these two topics are presented in a single chapter. The first part of the chapter covers the basic options for processing work. This is followed by a discussion of how processes and layout are linked. The remainder of the chapter is devoted to layout design.

INTRODUCTION

Process selection refers to deciding on the way production of goods or services will be organized. It has major implications for capacity planning, layout of facilities, equipment, and design of work systems. Process selection occurs as a matter of course when new products or services are being planned. However, it also occurs periodically due to technological changes in products or equipment, as well as competitive pressures. Figure 6.1 provides an overview of where process selection and capacity planning fit into system design.

FIGURE 6.1

Process selection and capacity planning influence system design



How an organization approaches process selection is determined by the organization's *process strategy.* Key aspects include

- Capital intensity: The mix of equipment and labor that will be used by the organization.
- Process flexibility: The degree to which the system can be adjusted to changes in processing requirements due to such factors as changes in product or service design, changes in volume processed, and changes in technology.

PROCESS SELECTION

Three primary questions bear on process selection:

1. How much *variety* in products or services will the system need to handle?
2. What degree of equipment *flexibility* will be needed?
3. What is the expected *volume* of output?

Answers to these questions will serve as a guide to selecting an appropriate process.

Process Types

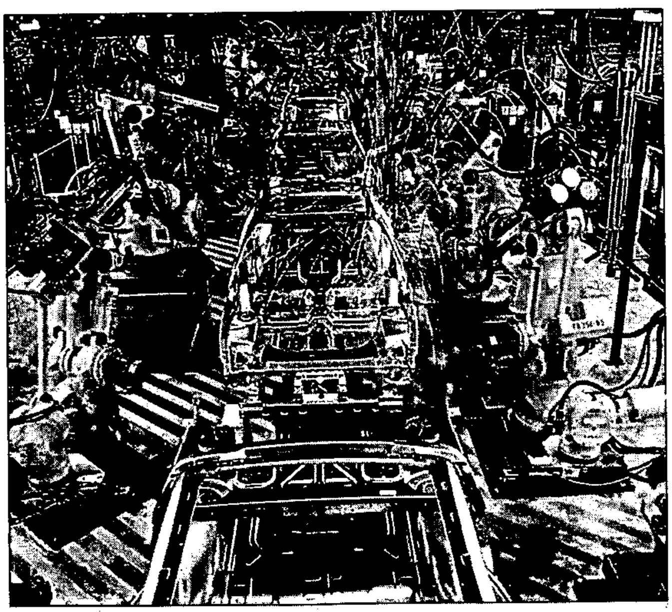
There are five basic process types: job shop, batch, repetitive, continuous, and project. The first four types can be described as follows:

Job shop. A job shop usually operates on a relatively small scale. It is used when a low volume of high-variety goods or services will be needed. Processing is *intermittent;* work includes small jobs, each with somewhat different processing requirements. High flexibility using general-purpose equipment and skilled workers are important characteristics of a job shop. A manufacturing example of a job shop is a tool and die shop that is able to produce one-of-a-kind tools. A service example is a veterinarian's office, which is able to process a variety of animals and a variety of injuries and diseases.

Batch. Batch processing is used when a moderate volume of goods or services is desired, and it can handle a moderate variety in products or services. The equipment need not be as flexible as in a job shop, but processing is still intermittent. The skill level of workers doesn't need to be as high as in a job shop because there is less variety in the jobs being processed. Examples of batch systems include bakeries, which make bread, cakes, or cookies in batches; movie theaters, which show movies to groups (batches) of people; and airlines, which carry planeloads (batches) of people from airport to airport. Other examples of products that lend themselves to batch production are paint, ice cream, soft drinks, beer, magazines, and books. Other examples of services

A job shop process: A Midwestern hospital medical team performs a diagnostic procedure involving a cardiac catheterization.

A batch process. Food preparation, one menu item at a time, in the kitchen of the Spago Restaurant in the Forum at Caesar's Palace, Las Vegas, Nevada.



A repetitive process. Robots join and weld Saturns on an automated assembly line.

A continuous flow process: Pepsi-Cola is bottled in a flow system at GEMEX in Mexico, Pepsi's largest non-U.S. bottler.

include plays, concerts, music videos, radio and television programs, and public address announcements.

Repetitive. When higher volumes of more standardized goods or services are needed, repetitive processing is used. The standardized output means only slight flexibility of equipment is needed. Skill of workers is generally low. Examples of this type of system include production lines and assembly lines. In fact, this type of process is sometimes referred to as *assembly.* Familiar products made by these systems include automobiles, television sets, pencils, and computers. An example of a service system is an automatic

TABLE 6.1
Types of processing

	Job Shop	Batch	Repetitive/ Assembly	Continuous
Description	Customized goods or services	Semi-standardized goods or services	Standardized goods or services	Highly standardized goods or services
Advantages	Able to handle a wide variety of work	Flexibility	Low unit cost, high volume, efficient	Very efficient, very high volume
Disadvantages	Slow, high cost per unit, complex planning and scheduling	Moderate cost per unit, moderate scheduling complexity	Low flexibility, high cost of downtime	Very rigid, lack of variety, costly to change, very high cost of downtime

carwash. Other examples of service include cafeteria lines and ticket collectors at sports events and concerts.

Continuous. When a very high volume of nondiscrete, highly standardized output is desired, a continuous system is used. These systems have almost no variety in output and, hence, no need for equipment flexibility. Workers' skill requirements can range from low to high, depending on the complexity of the system and the expertise workers need. Generally, if equipment is highly specialized, worker skills can be lower. Examples of nondiscrete products made in continuous systems include petroleum products, steel, sugar, flour, and salt. Continuous services include air monitoring, supplying electricity to homes and businesses, and the Internet.

These process types are found in a wide range of manufacturing and service settings. The ideal is to have process capabilities match product or service requirements. Failure to do so can result in inefficiencies and higher costs than are necessary, perhaps creating a competitive disadvantage.

Table 6.1 provides a brief description of each process type along with advantages and disadvantages of each. Figure 6.2 provides an overview of the four process types in the form of a *product-process matrix,* with a product and a service example for each process type. Just below the matrix is a comparison of the process types on four key dimensions: job variety, process flexibility, unit cost, and output volume. Note that job variety, process flexibility, and unit cost are highest for a job shop and get progressively lower moving from job shop to continuous processing. Conversely, volume of output is lowest for a job shop and gets progressively higher moving from job shop to continuous processing.

Note that the examples fall along the diagonal. The implication is that the diagonal represents the ideal choice of processing system for a given set of circumstances. For example, if the goal is to be able to process a small volume of jobs that will involve high variety, job shop processing is most appropriate. For less variety and a higher volume, a batch system would be most appropriate, and so on. Note that combinations far from the diagonal would not even be considered, such as using a job shop for high-volume, low-variety jobs, or continuous processing for low-volume, high-variety jobs.

Another consideration is that products and services often go through *life cycles* that begin with low volume, which increases as products or services become better known. When that happens, a manager must know when to shift from one type of process (e.g., job shop) to the next (e.g., batch). Of course, some operations remain at a certain level (e.g., magazine publishing), while others increase (or decrease as markets become saturated) over time. Again, it is important for a manager to assess his or her products and services and make a judgment on whether to plan for changes in processing over time.

FIGURE 6.2

Process Type	Job Shop	Batch	Repetitive	Continuous
Job shop	Appliance repair Emergency room			Not feasible
Batch		Commercial bakery Classroom lecture		
Repetitive			Automobile assembly Automatic carwash	
Continuous (flow)	Not feasible			Oil refinery Water purification
Dimension				
Job variety	Very high	Moderate	Low	Very low
Process flexibility	Very high	Moderate	Low	Very low
Unit cost	Very high	Moderate	Low	Very low
Volume of output	Very low	Low	High	Very high

All of these process types (job shop, batch, repetitive, and continuous) are typically ongoing operations. However, there are situations that are not ongoing but instead are of limited durations. In such instances, the work is often organized as a *project.*

A **project** is used for work that is nonroutine, with a unique set of objectives to be accomplished in a limited time frame. Examples range from simple to complicated, including such things as putting on a play, consulting, making a motion picture, launching a new product or service, publishing a book, building a dam, and building a bridge. Equipment flexibility and worker skills can range from low to high.

project A nonrepetitive set of activities directed toward a unique goal within a limited time frame.

The type of process or processes used by an organization influences a great many activities of the organization. Table 6.2 briefly describes some of those influences.

The processes discussed do not always exist in their "pure" forms. It is not unusual to find hybrid processes—processes that have elements of other process types embedded in them. For instance, companies that operate primarily in a repetitive mode, or a continuous mode, will often have repair shops (i.e., job shops) to fix or make new parts for equipment that fails. Also, if volume increases for some items, an operation that began, say, in a job shop or as a batch mode may evolve into a batch or repetitive operation. This may result in having some operations in a job shop or batch mode, and others in a repetitive mode.

Automation

A key question in process design is whether to automate. **Automation** is machinery that has sensing and control devices that enable it to operate automatically. If a company decides to automate, the next question is how much. Automation can range from factories that are completely automated to a single automated operation.

automation Machinery that has sensing and control devices that enable it to operate automatically.

Automated services are also an option. Although not as plentiful as in manufacturing, automated services are becoming increasingly important. Examples range from ATM machines to automated heating and air conditioning, and include automated inspection, automated storage and retrieval systems, package sorting, mail processing, e-mail, on-line banking, and E-Z pass.

Automation offers a number of advantages over human labor. It has low variability, whereas it is difficult for a human to perform a task in exactly the same way, in the same amount of time,

TABLE 6.2 Process choice affects numerous activities/functions

Activity/ Function	Job Shop	Batch	Repetitive	Continuous	Projects
Cost estimation	Difficult	Somewhat routine	Routine	Routine	Simple to complex
Cost per unit	High	Moderate	Low	Low	Very high
Equipment used	General purpose	General purpose	Special purpose	Special purpose	Varied
Fixed costs	Low	Moderate	High	Very high	Varied
Variable costs	High	Moderate	Low	Very low	High
Labor skills	High	Moderate	Low	Low to high	Low to high
Marketing	Promote capabilities	Promote capabilities; semi-standard goods and services	Promote standardized goods/services	Promote standardized goods/services	Promote capabilities
Scheduling	Complex	Moderately complex	Routine	Routine	Complex, subject to change
Work-in-process inventory	High	High	Low	Low	Varied

and on a repetitive basis. In a production setting, variability is detrimental to quality and to meeting schedules. Moreover, machines do not get bored or distracted, nor do they go out on strike, ask for higher wages, or file labor grievances. Still another advantage of automation is reduction of variable costs. In order for automated processing to be an option, job-processing requirements must be *standardized* (i.e., have very little or no variety).

Automation is frequently touted as a strategy necessary for competitiveness. However, automation also has certain disadvantages and limitations compared to human labor. To begin with, it can be costly. Technology is expensive; usually it requires high volumes of output to offset high costs. In addition, automation is much less flexible than human labor. Once a process has been automated, there is substantial reason for not changing it. Moreover, workers sometimes fear automation because it might cause them to lose their jobs. That can have an adverse effect on morale and productivity.

Decision makers must carefully examine the issue of whether to automate or the degree in which to automate, so that they clearly understand all the ramifications. Also, much thought and careful planning are necessary to successfully *integrate* automation into a production system. Otherwise, it can lead to major problems. (GM invested heavily in automation in the 1980s only to find its costs increasing while flexibility and productivity took a nosedive. Its market had shrunk while GM was increasing its capacity!) Automation has important implications not only for cost and flexibility, but also for the fit with overall strategic priorities.

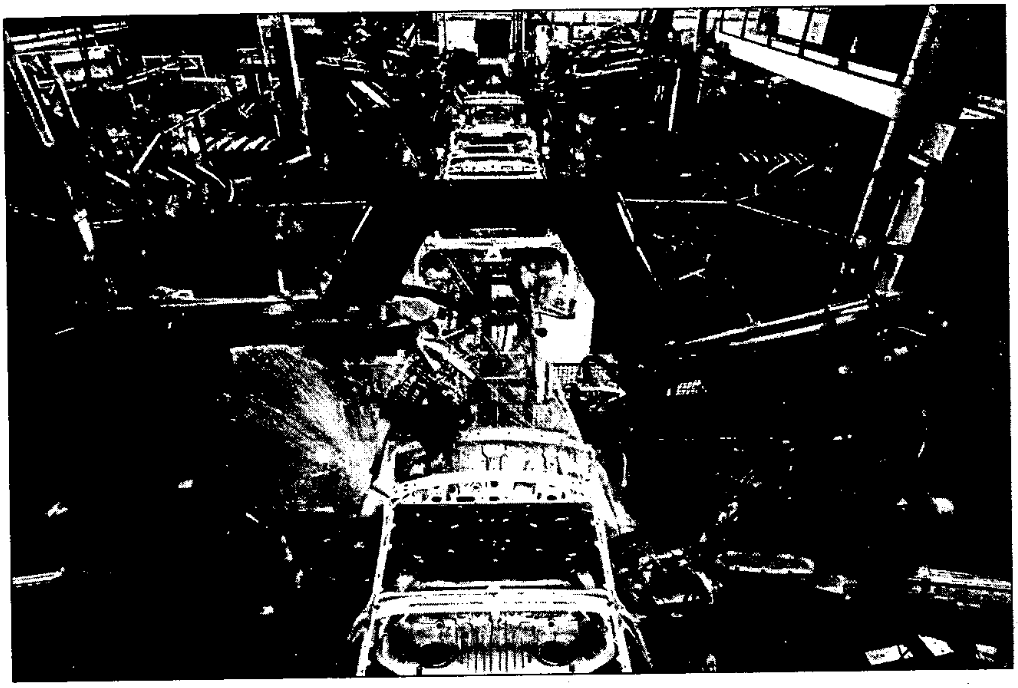
Generally speaking, there are three kinds of automation: fixed, programmable, and flexible. *Fixed automation* is the most rigid of the three types. Sometimes referred to as Detroit-type automation, it uses high-cost, specialized equipment for a fixed sequence of operations. Low cost and high volume are its primary advantages; minimal variety and the high cost of making major changes in either product or process are its primary limitations.

Programmable automation is at the opposite end of the spectrum. It involves the use of high-cost, general-purpose equipment controlled by a computer program that provides both the sequence of operations and specific details about each operation. This type of automation has the capability of economically producing a fairly wide variety of low-volume products in small batches. Numerically controlled (N/C) machines and some robots are applications of programmable automation.

computer-aided manufacturing (CAM) The use of computers in process control.

numerically controlled (N/C) machines Machines that perform operations by following mathematical processing instructions.

Computer-aided manufacturing (CAM) refers to the use of computers in process control, ranging from robots to automated quality control. **Numerically controlled (N/C) machines** are programmed to follow a set of processing instructions based on mathematical relationships



Robots are used to build BMW automobile bodies at the BMW manufacturing plant in Muenchen, Germany.

www.bmwusfactory.com

that tell the machine the details of the operations to be performed. The instructions are stored on a device such as a floppy disk, magnetic tape, or microprocessor. Although N/C machines have been used for many years, they are an important part of new approaches to manufacturing. Individual machines may have their own computer; this is referred to as *computerized numerical control (CNC)*. Or one computer may control a number of N/C machines, which is referred to as *direct numerical control (DNC)*.

N/C machines are best used in cases where parts are processed frequently and in small batches, where part geometry is complex, close tolerances are required, mistakes are costly, and there is the possibility of frequent changes in design. The main limitations of N/C machines are the higher skill levels needed to program the machines and their inability to detect tool wear and material variation.

The use of robots in manufacturing is sometimes an option. A **robot** consists of three parts: a mechanical arm, a power supply, and a controller. Unlike movie versions of robots, which vaguely resemble human beings, industrial robots are much less glamorous and much less mobile; most robots are stationary except for their movable arms.

robot A machine consisting of a mechanical arm, a power supply, and a controller.

Robots can handle a wide variety of tasks, including welding, assembly, loading and unloading of machines, painting, and testing. They relieve humans from heavy or dirty work and often eliminate drudgery tasks.

Some uses of robots are fairly simple, others are much more complex. At the lowest level are robots that follow a fixed set of instructions. Next are programmable robots, which can repeat a set of movements after being led through the sequence. These robots "play back" a mechanical sequence much as a video recorder plays back a visual sequence. At the next level up are robots that follow instructions from a computer. At the top are robots that can recognize objects and make certain simple decisions.

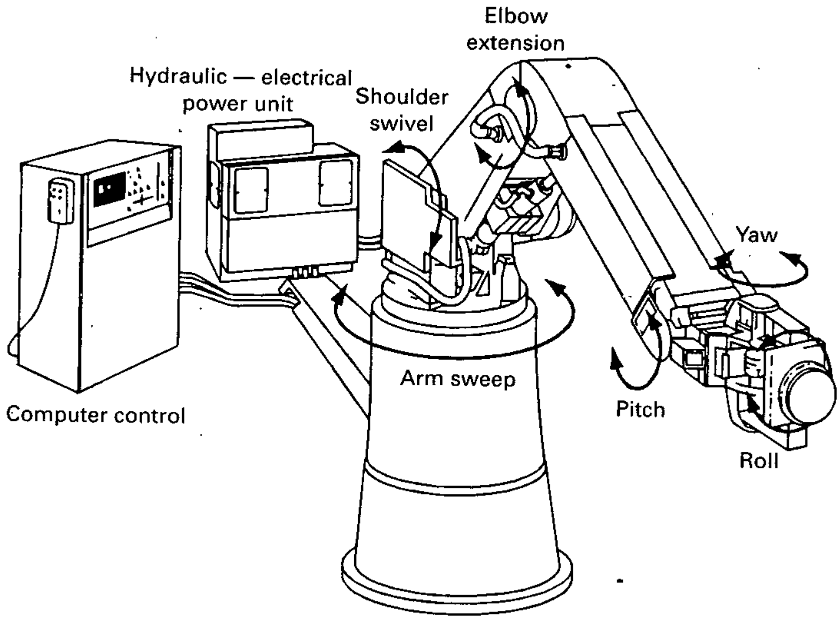
"If you think robots are mainly the stuff of space movies, think again. Right now, all over the world, robots are on the move. They are painting cars at Ford plants, assembling Milano cookies for Pepperidge Farms, walking into live volcanoes, driving trains in Paris, and defusing bombs in Northern Ireland. As they grow tougher, nimbler, and smarter, today's robots are doing more and more things humans can't—or don't want to—do."

Source: www.thetech.org/robotics.

FIGURE 6.3

Industrial robot

Source: Morris A. Cohen and Uday M. Apte, *Manufacturing Automation* (Burr Ridge, IL: Irwin/McGraw-Hill, 1997), p. 138.



Cincinnati Milacron robot system

Figure 6.3 illustrates a robot.

Flexible automation evolved from programmable automation. It uses equipment that is more customized than that of programmable automation. A key difference between the two is that flexible automation requires significantly less changeover time. This permits almost continuous operation of equipment *and* product variety without the need to produce in batches.

In practice, flexible automation is used in several different formats.

manufacturing cell A group of workstations dedicated to production of a limited number of similar parts.

A **manufacturing cell** consists of a group of closely located workstations dedicated to the production of a limited number of part families, thereby requiring a narrow range of operations. In practice, manufacturing cell activities range from primarily manual to a small number of computer-controlled machines that produce a family of similar parts. The machines may be linked with automatic material handing devices.

Tour de Force

READING

Gerald Scott

www.chryslercorp.com

DaimlerChrysler's plant that builds Viper and Prowler is the Motor City's "hottest ticket."

The Viper-Prowler plant is not your typical Detroit assembly operation. Instead of mass production techniques using robots, it's "craftsman-style" production for hand-building Vipers and Prowlers. With mass production, DaimlerChrysler can produce up to 75 cars per hour. With late shifts DaimlerChrysler's nearby Jefferson North Assembly Plant can crank out 1,114 Jeep Grand Cherokees in a 24-hour workday. By comparison, the Viper plant produces 13 Vipers a day and has a capacity for 20 Prowlers.

At 392,000 square feet, the Viper plant is a boutique compared to most massive auto plants, such as Saturn Corp.'s Spring Hill, Tenn., manufacturing complex, which is 5 million square feet. The Jefferson North plant has 2.4 million square feet.

"We're not the biggest plant in the area, but we've got the best work force and build the most exciting products—the Plymouth Prowler and Dodge Viper," said Hinckley, who has spent 33 years working in various Detroit auto plants for General Motors and Chrysler and is known for building and driving "kit car"

(continued)

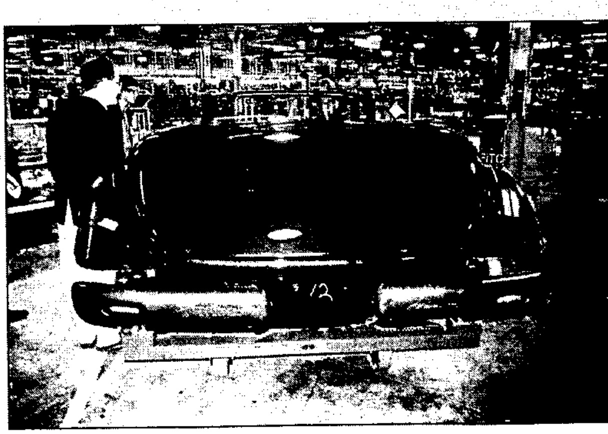
In DaimlerChrysler's Conner Avenue plant, the Dodge Viper and Plymouth Prowler are built individually by hand.

racers. "We're expanding our plant, too. We also are part of the revitalization of Detroit.

"Our plant was about 380,000 square feet and we've just added another 10,000 square feet to improve our process flow and improve our quality. And it provides a little more space since we added the Prowler.

"It will allow us to do a better job of reaching the Prowler's ultimate capacity. It's about a $1 million expansion—for other large plants, that's nothing but for a facility this size it's a lot of money.

"For me it's a dream job. I've been a 'hot rodder' all my life and build race cars and racing engines, and how many hot rodders get to lead the team that runs the only hot-rod plant in the world?"



When each workstation completes its task, the entire line advances to the next station.

Conner Avenue is a throwback to early 20th Century, pre-mass assembly techniques. Vipers and Prowlers are built on parallel 720-foot assembly lines, each with a dozen or so workstations, where the cars are hand-assembled. In a rarity, there are no robots in this plant.

When each workstation completes its task, the entire line advances to the next station. So in those 45-minute stops, the employees are relatively free to grab a cup of coffee or talk to tour groups, something they could never do in a plant cranking out 73 units per hour.

The automaker's flexible labor agreement with UAW Local 212 means everybody working in the plant is a "craftsman" and can solve any problem anywhere on the line—in most plants, job categories are sharply defined and protected.

Most large auto assembly plants still require 2,000 or more workers, while the Viper plant needs only 260.

"We do everything from forklift driving to mopping and sweeping, we do it all," says Andrew Stokes, a UAW craftsman who works in underbody and heavy repair.

"I'm one of the first 12 to work on the Prowler," he added. "The Prowler is a little easier to assemble but a little harder to repair. The Viper seems to be a lot more open than the Prowler is—the car seems to be built around the engine and trans and that makes it a little harder to work on."

Thanks to such an interest from car buyers in this plant, DaimlerChrysler allows Viper customers to pick up their car as it comes out of final assembly, to meet the employees who built it and to drive it home from the plant instead of from the dealership.

(continued)

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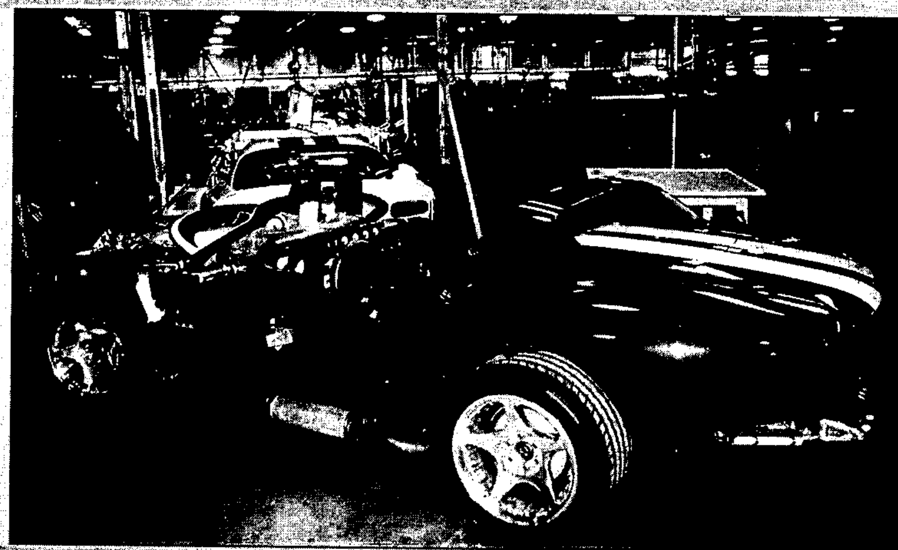
The Viper is built around its engine and transmission, which according to employees, makes it a little harder to work on.



Questions

1. What is different about this assembly plant compared to more typical auto assembly plants?
2. Why do you suppose there are no robots or other automation?

Source: Excerpts from "Tour de Force" by Gerald Scott, *Chicago Tribune*. © 1998 Gerald Scott. Used with permission.

flexible manufacturing system (FMS) A group of machines designed to handle intermittent processing requirements and produce a variety of similar products.

A **flexible manufacturing system (FMS)** is a group of machines that include supervisory computer control, automatic material handling, and robots or other automated processing equipment. Reprogrammable controllers enable these systems to produce a variety of *similar* products. Systems may range from three or four machines to more than a dozen. They are designed to handle intermittent processing requirements with some of the benefits of automation and some of the flexibility of individual, or stand-alone, machines (e.g., N/C machines). Flexible manufacturing systems offer reduced labor costs and more consistent quality compared with more traditional manufacturing methods, lower capital investment and higher flexibility than "hard" automation, and relatively quick changeover time. Flexible manufacturing systems often appeal to managers who hope to achieve both the flexibility of job shop processing and the productivity of repetitive processing systems.

Although these are important benefits, an FMS also has certain limitations. One is that this type of system can handle a relatively narrow range of part variety, so it must be used for a family of similar parts, which all require similar machining. Also, an FMS requires longer planning and development times than more conventional processing equipment because of its increased complexity and cost. Furthermore, companies sometimes prefer a gradual approach to automation, and FMS represents a sizable chunk of technology.

computer-integrated manufacturing (CIM) A system for linking a broad range of manufacturing activities through an integrating computer system.

Computer-integrated manufacturing (CIM) is a system that uses an integrating computer system to link a broad range of manufacturing activities, including engineering design, flexible manufacturing systems, purchasing, order processing, and production planning and control. Not all elements are absolutely necessary. For instance, CIM might be as simple as linking two or more FMSs by a host computer. More encompassing systems can link scheduling, purchasing, inventory control, shop control, and distribution. In effect, a CIM system integrates information from other areas of an organization with manufacturing.

The overall goal of using CIM is to link various parts of an organization to achieve rapid response to customer orders and/or product changes, to allow rapid production, and to reduce *indirect* labor costs.

A shining example of how process choices can lead to competitive advantages can be found at Allen-Bradley's computer-integrated manufacturing process in Milwaukee, Wisconsin. The company converted a portion of its factory to a fully automated "factory within a factory" to assemble contactors and relays for electrical motors. A handful of humans operate the factory, although once an order has been entered into the system, the machines do virtually all the work, including packaging and shipping, and quality control. Any defective items are removed from the line, and replacement parts are automatically ordered and scheduled to compensate for the defective items. The humans program the machines and monitor operations, and attend to any problems signaled by a system of warning lights.

As orders come into the plant, computers determine production requirements and schedules and order the necessary parts. Bar-coded labels that contain processing instructions are automatically placed on individual parts. As the parts approach a machine, a sensing device reads the bar code and communicates the processing instructions to the machine. The factory can produce 600 units an hour.

The company has realized substantial competitive advantages from the system. Orders can be completed and shipped within 24 hours of entry into the system, indirect labor costs and inventory costs have been greatly reduced, and quality is very high.

Operations Strategy

Throughout this book, the importance of *flexibility* as a competitive strategy is stressed. However, flexibility does not always offer the best choice in processing decisions. Flexible systems or equipment is often more expensive and not as efficient as less flexible alternatives. In certain instances, flexibility is unnecessary because products are in mature stages, requiring few design changes, and there is a steady volume of output. Ordinarily, this type of situation calls for specialized processing equipment, with no need for flexibility. The implication is clear: Flexibility should be adopted with great care; its applications should be matched with situations in which a *need* for flexibility clearly exists.

In practice, decision makers choose flexible systems for either of two reasons: Demands are varied or uncertainty exists about demand. The second reason can be overcome through improved forecasting.

FACILITIES LAYOUT

Layout refers to the configuration of departments, work centers, and equipment, with particular emphasis on movement of work (customers or materials) through the system. This section describes the main types of layout designs and the models used to evaluate design alternatives.

As in other areas of system design, layout decisions are important for three basic reasons: (1) they require substantial investments of money and effort; (2) they involve long-term commitments, which makes mistakes difficult to overcome; and (3) they have a significant impact on the cost and efficiency of operations.

The need for layout planning arises both in the process of designing new facilities and in redesigning existing facilities. The most common reasons for redesign of layouts include inefficient operations (e.g., high cost, bottlenecks), accidents or safety hazards, changes in the design of products or services, introduction of new products or services, changes in the volume of output or mix of outputs, changes in methods or equipment, changes in environmental or other legal requirements, and morale problems (e.g., lack of face-to-face contact).

Poor layout design can adversely affect system performance. For example, a change in the layout at the Minneapolis-St. Paul International Airport not long ago solved a problem that had plagued travelers. In the former layout, security checkpoints were located in the boarding area. That meant that arriving passengers who were simply changing planes had to pass through a security checkpoint before being able to board their connecting flight, along with other passengers whose journeys were originating at Minneapolis-St. Paul. This created excessive waiting times for both sets of passengers. The new layout relocated the security checkpoints, moving them from the boarding area to a position close to the ticket counters. Thus, the need for passengers who were making connecting flights to pass through security was eliminated, and in the process, the waiting time for passengers departing from Minneapolis-St. Paul was considerably reduced.[1]

The three basic types of layout are product, process, and fixed-position. *Product layouts* are most conducive to repetitive processing, *process layouts* are used for intermittent processing, and *fixed-position layouts* are used when projects require layouts. The characteristics, advantages, and disadvantages of each layout type are described in this section, along with hybrid layouts, which are combinations of these pure types.

Repetitive Processing: Product Layouts

product layout Layout that uses standardized processing operations to achieve smooth, rapid, high-volume flow.

production line Standardized layout arranged according to a fixed sequence of production tasks.

assembly line Standardized layout arranged according to a fixed sequence of assembly tasks.

Product layouts are used to achieve a smooth and rapid flow of large volumes of goods or customers through a system. This is made possible by highly standardized goods or services that allow highly standardized, repetitive processing. The work is divided into a series of standardized tasks, permitting specialization of equipment and division of labor. The large volumes handled by these systems usually make it economical to invest substantial sums of money in equipment and job design. Because only one or a few very similar items are involved, it is feasible to arrange an entire layout to correspond to the technological processing requirements of the product or service. For instance, if a portion of a manufacturing operation required the sequence of cutting, sanding, and painting, the appropriate pieces of equipment would be arranged in that same sequence. And because each item follows the same sequence of operations, it is often possible to utilize fixed-path material-handling equipment such as conveyors to transport items between operations. The resulting arrangement forms a line like the one depicted in Figure 6.4. In manufacturing environments, the lines are referred to as **production lines** or **assembly lines,** depending on the type of activity involved. In service processes, the term *line* may or may not be used. It is common to refer to a cafeteria line as such but not a car wash, although from a conceptual standpoint the two are nearly identical. Figure 6.5 illustrates the layout of a typical cafeteria serving line. Examples of this type of layout are less plentiful in service environments because processing requirements usually exhibit too much variability to make standardization feasible. Without high standardization, many of the benefits of repetitive processing are lost. When lines are used, certain compromises may be made. For instance, an automatic car wash provides equal treatment to all cars—the same amount of soap, water, and scrubbing—even though cars may differ considerably in cleaning needs. As a result, very dirty

FIGURE 6.4

A flow line for production or service

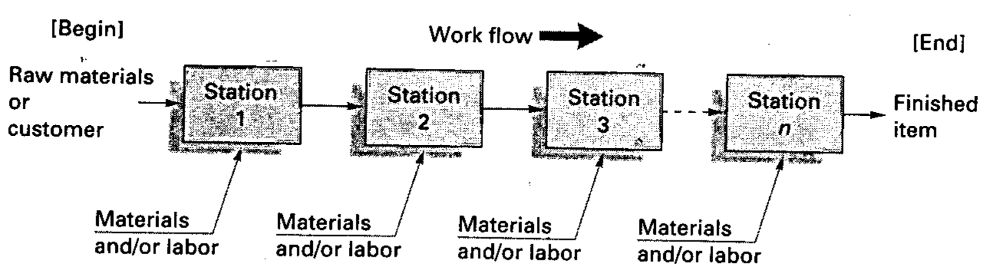
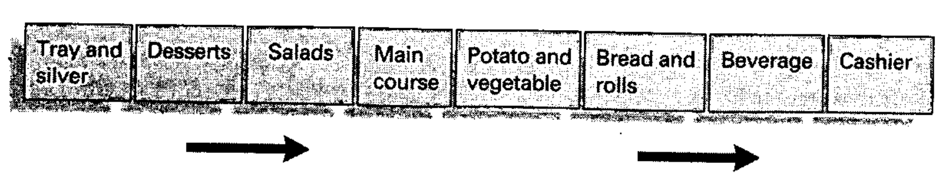


FIGURE 6.5

Cafeteria line



[1]Based on "Airport Checkpoints Moved to Help Speed Travelers on Their Way," *Minneapolis-St. Paul Star Tribune,* January 13, 1995, p. 1B.

Assembly line for manufacturing washing machines at the GE factory in Louisville, Kentucky.

www.ge.com

cars may not come out completely clean, and relatively clean cars go through the same system with considerable waste of soap, water, and energy.

Product layouts achieve a high degree of labor and equipment utilization, which tends to offset their high equipment costs. Because items move quickly from operation to operation, the amount of work-in-process is often minimal. Consequently, operations are so closely tied to each other that the entire system is highly vulnerable to being shut down because of mechanical failure or high absenteeism. Maintenance procedures are geared to this. *Preventive maintenance*—periodic inspection and replacement of worn parts or those with high failure rates—reduces the probability of breakdowns during the operations. Of course, no amount of preventive activity can completely eliminate failures, so management must take measures to provide quick repair. These include maintaining an inventory of spare parts and having repair personnel available to quickly restore equipment to normal operation. These procedures are fairly expensive; because of the specialized nature of equipment, problems become more difficult to diagnose and resolve, and spare-part inventories can be extensive.

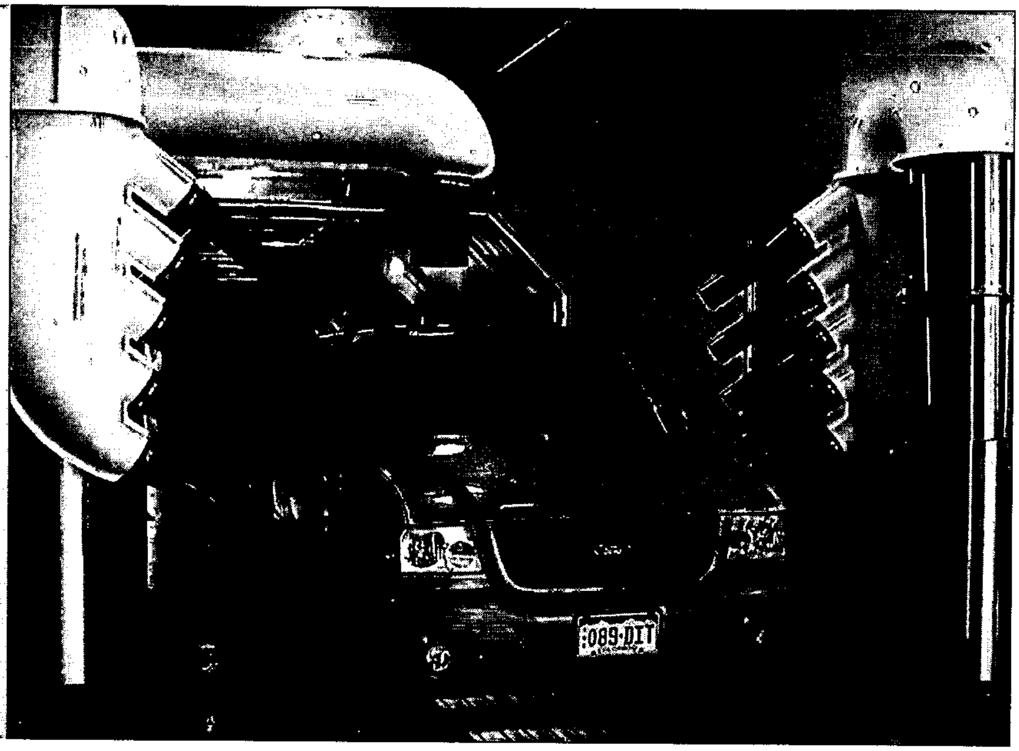
The main advantages of product layouts are

1. A high rate of output.
2. Low unit cost due to high volume; the high cost of specialized equipment is spread over many units.
3. Labor specialization reduces training costs and time, and results in a wide span of supervision.
4. Low material-handling cost per unit; material handling is simplified because units follow the same sequence of operations. Material handling is often automated.
5. A high utilization of labor and equipment.
6. Routing and scheduling are established in the initial design of the system; they do not require much attention once the system is operating.
7. Accounting, purchasing, and inventory control are fairly routine.

The primary disadvantages of product layouts include

1. The intensive division of labor usually creates dull, repetitive jobs that provide little opportunity for advancement and may lead to morale problems and to repetitive stress injuries.

A car wash is a service assembly line with various cleaning and drying tasks being performed in a specific order. Some facilities allow customer options such as undercarriage washing, application of a protective coating, or hand cleaning of floor mats and tires.



2. Poorly skilled workers may exhibit little interest in maintaining equipment or in the quality of output.
3. The system is fairly inflexible in response to changes in the volume of output or changes in product or process design.
4. The system is highly susceptible to shutdowns caused by equipment breakdowns or excessive absenteeism because workstations are highly interdependent.
5. Preventive maintenance, the capacity for quick repairs, and spare-parts inventories are necessary expenses.
6. Incentive plans tied to individual output are impractical since they would cause variations among outputs of individual workers, which would adversely affect the smooth flow of work through the system.

U-Shaped Layouts Although a straight production line may have intuitive appeal, a U-shaped line (see Figure 6.6) has a number of advantages that make it worthy of consideration. One disadvantage of a long, straight line is that it interferes with cross-travel of workers and vehicles. A U-shaped line is more compact; it often requires approximately half the length of a straight production line. In addition, a U-shaped line permits increased communication among workers on the line because workers are clustered, thus facilitating teamwork. Flexibility in work assignments is increased because workers can handle not only adjacent stations but also

FIGURE 6.6

A U-shaped production line

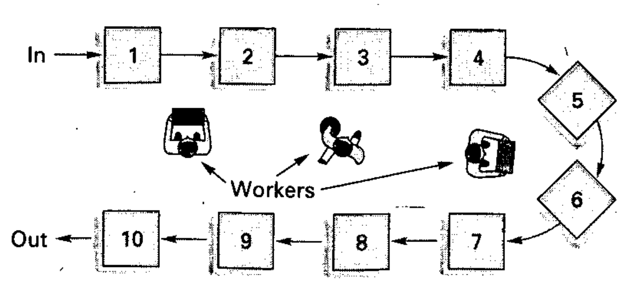
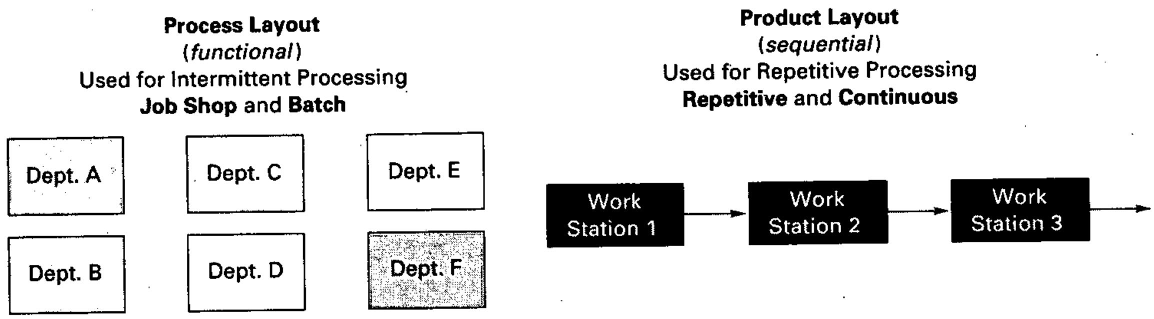


FIGURE 6.7

Comparison of process and product layouts



stations on opposite sides of the line. Moreover, if materials enter the plant at the same point that finished products leave it, a U-shaped line minimizes material handling.

Of course, not all situations lend themselves to U-shaped layouts: On highly automated lines there is less need for teamwork and communication. And entry and exit points may be on opposite sides of the building. Also, operations may need to be separated because of noise or contamination factors.

Nonrepetitive Processing: Process Layouts

process layouts Layouts that can handle varied processing requirements.

Process layouts are designed to process items or provide services that involve a variety of processing requirements. The variety of jobs that are processed requires frequent adjustments to equipment. This causes a discontinuous work flow, which is referred to as *intermittent processing.* The layouts feature departments or other *functional* groupings in which similar kinds of activities are performed. A manufacturing example of a process layout is the *machine shop,* which has separate departments for milling, grinding, drilling, and so on. Items that require those operations are frequently moved in lots or batches to the departments in a sequence that varies from job to job. Consequently, variable-path material-handling equipment (forklift trucks, jeeps, tote boxes) is needed to handle the variety of routes and items. The use of *general-purpose equipment* provides the flexibility necessary to handle a wide range of processing requirements. Workers who operate the equipment are usually skilled or semiskilled. Figure 6.7 illustrates the departmental arrangement typical of a process layout.

Process layouts are quite common in service environments. Examples include hospitals, colleges and universities, banks, auto repair shops, airlines, and public libraries. For instance, hospitals have departments or other units that specifically handle surgery, maternity, pediatrics, psychiatric, emergency, and geriatric care. And universities have separate schools or departments that concentrate on one area of study such as business, engineering, science, or math.

Because equipment in a process layout is arranged by type rather than by processing sequence, the system is much less vulnerable to shutdown caused by mechanical failure or absenteeism. In manufacturing systems especially, idle equipment is usually available to replace machines that are temporarily out of service. Moreover, because items are often processed in lots (batches), there is considerably less interdependence between successive operations than with a product layout. Maintenance costs tend to be lower because the equipment is less specialized than that of product layouts, and the grouping of machinery permits repair personnel to become skilled in handling that type of equipment. Machine similarity reduces the necessary investment in spare parts. On the negative side, routing and scheduling must be done on a continual basis to accommodate the variety of processing demands typically imposed on these systems. Material handling is inefficient, and unit handling costs are generally much higher than in product layouts. In-process inventories can be substantial due to batch processing. Furthermore, it is not uncommon for such systems to have equipment utilization rates under 50 percent because of routing and scheduling complexities related to the variety of processing demands being handled.

In sum, process layouts have both advantages and disadvantages. The advantages of process layouts include

1. Systems can handle a variety of processing requirements.
2. Systems are not particularly vulnerable to equipment failures.
3. General-purpose equipment is often less costly than the specialized equipment used in product layouts and is easier and less costly to maintain.
4. It is possible to use individual incentive systems.

The disadvantages of process layouts include

1. In-process inventory costs can be high if batch processing is used in manufacturing systems.
2. Routing and scheduling pose continual challenges.
3. Equipment utilization rates are low.
4. Material handling is slow and inefficient, and more costly per unit than in product layouts.
5. Job complexities often reduce the span of supervision and result in higher supervisory costs than with product layouts.
6. Special attention necessary for each product or customer (e.g., routing, scheduling, machine setups) and low volumes result in higher unit costs than with product layouts.
7. Accounting, inventory control, and purchasing are much more involved than with product layouts.

Fixed-Position Layouts

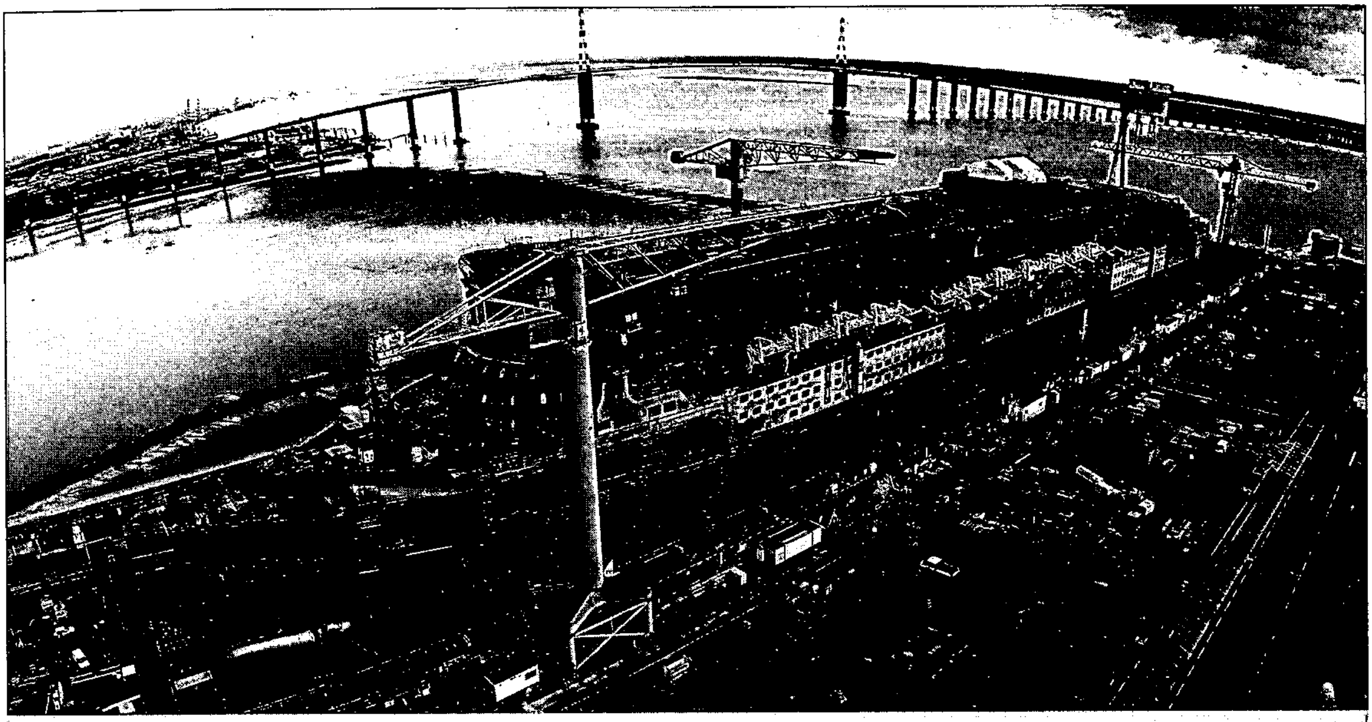
fixed-position layout Layout in which the product or project remains stationary, and workers, materials, and equipment are moved as needed.

In **fixed-position layouts,** the item being worked on remains stationary, and workers, materials, and equipment are moved about as needed. This is in marked contrast to product and process layouts. Almost always, the nature of the product dictates this kind of arrangement: Weight, size, bulk, or some other factor makes it undesirable or extremely difficult to move the product. Fixed-position layouts are used in large construction projects (buildings, power plants, dams), shipbuilding, and production of large aircraft and space mission rockets. In those instances, attention is focused on timing of material and equipment deliveries so as not to clog up the work site and to avoid having to relocate materials and equipment around the work site. Lack of storage space can present significant problems, for example, at construction sites in crowded urban locations. Because of the many diverse activities carried out on large projects and because of the wide range of skills required, special efforts are needed to coordinate the activities, and the span of control can be quite narrow. For these reasons, the administrative burden is often much higher than it would be under either of the other layout types. Material handling may or may not be a factor; in many cases, there is no tangible product involved (e.g., designing a computerized inventory system). When goods and materials are involved, material handling often resembles process-type, variable-path, general-purpose equipment. Projects might require use of earth-moving equipment and trucks to haul materials to, from, and around the work site, for example.

Fixed-position layouts are widely used in farming, firefighting, road building, home building, remodeling and repair, and drilling for oil. In each case, compelling reasons bring workers, materials, and equipment to the "product's" location instead of the other way around.

Combination Layouts

The three basic layout types are ideal models, which may be altered to satisfy the needs of a particular situation. It is not hard to find layouts that represent some combination of these pure types. For instance, supermarket layouts are essentially process layouts, and yet we find most use fixed-path material-handling devices such as roller-type conveyors in the stockroom and belt-type conveyors at the cash registers. Hospitals also use the basic process arrangement, although frequently patient care involves more of a fixed-position approach, in which nurses, doctors, medicines, and special equipment are brought to the patient. By the same token,



Queen Mary 2 under construction at the Chantiers de l'Atlantique shipyard in St. Nazaire, France. When a large project must remain stationary, workers and equipment come to the site. The QM2 *weighs 150,000 tons, is 1,132 feet long, and 147.6 feet wide. Its capacity will be 3,090 passengers and 1,253 officers and crew.*

faulty parts made in a product layout may require off-line reworking, which involves customized processing. Moreover, conveyors are frequently observed in both farming and construction activities.

Process layouts and product layouts represent two ends of a continuum from small jobs to continuous production. Process layouts are conducive to the production of a wider range of products or services than product layouts, which is desirable from a customer standpoint where customized products are often in demand. However, process layouts tend to be less efficient and have higher unit production costs than product layouts. Some manufacturers are moving away from process layouts in an effort to capture some of the benefits of product layouts. Ideally, a system is flexible and yet efficient, with low unit production costs. Cellular manufacturing, group technology, and flexible manufacturing systems represent efforts to move toward this ideal.

Cellular Layouts

Cellular Production **Cellular production** is a type of layout in which workstations are grouped into what is referred to as a *cell.* Groupings are determined by the operations needed to perform work for a set of similar items, or *part families,* that require similar processing. The cells become, in effect, miniature versions of product layouts. The cells may have no conveyorized movement of parts between machines, or may have a flow line connected by a conveyor (automatic transfer). In the cellular layout, machines are arranged to handle all of the operations necessary for a group (family) of similar parts. Thus, all parts follow the same route although minor variations (e.g., skipping an operation) are possible. In contrast, the functional layout involves multiple paths for parts. Moreover, there is little effort or need to identify part families.

cellular production Layout in which workstations are grouped into a cell that can process items that have similar processing requirements.

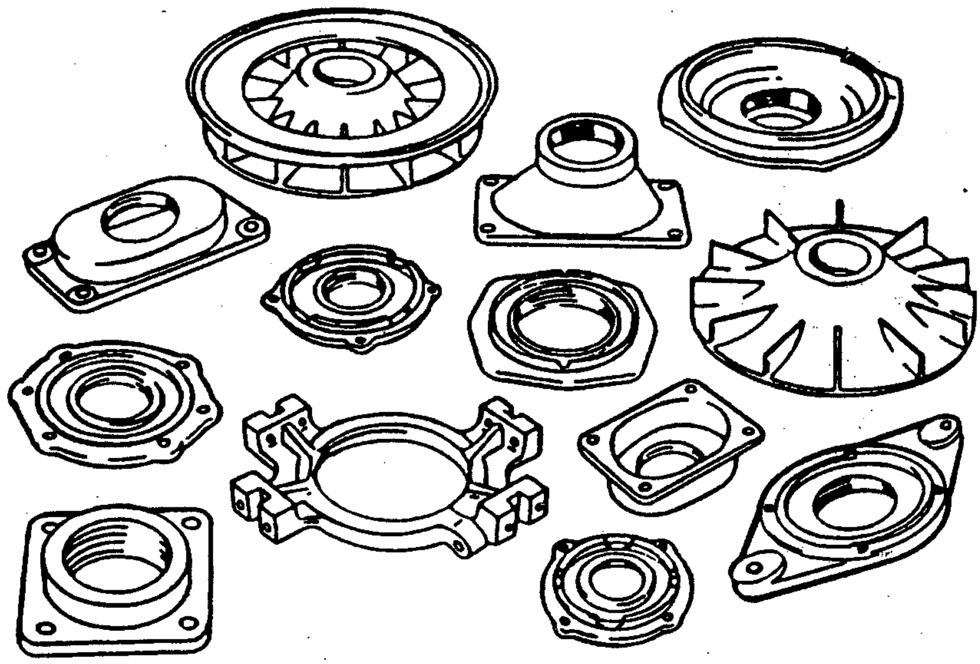
Table 6.3 lists the benefits of cellular layouts compared to functional layouts.

Group Technology Effective cellular manufacturing must have groups of identified items with similar processing characteristics. This strategy for product and process design is known

TABLE 6.3
A comparison of functional (process) layouts and cellular layouts

Dimension	Functional	Cellular
Number of moves between departments	Many	Few
Travel distances	Longer	Shorter
Travel paths	Variable	Fixed
Job waiting time	Greater	Shorter
Throughput time	Higher	Lower
Amount of work in process	Higher	Lower
Supervision difficulty	Higher	Lower
Scheduling complexity	Higher	Lower
Equipment utilization	Lower	Higher

FIGURE 6.8



A group of parts with similar manufacturing process requirements but different design attributes

Source: Mikell P. Groover, *Automation, Production Systems, and Computer-Aided Manufacturing* © 1980, p. 540. Reprinted by permission of Pearson Educations Inc., Upper Saddle River, N.J.

group technology The grouping into part families of items with similar design or manufacturing characteristics.

as **group technology** and involves identifying items with similarities in either *design characteristics* or *manufacturing characteristics,* and grouping them into *part families.* Design characteristics include size, shape, and function; manufacturing or processing characteristics involve the type and sequence of operations required. In many cases, design and processing characteristics are correlated, although this is not always the case. Thus, design families may be different from processing families. Figure 6.8 illustrates a group of parts with similar processing characteristics but different design characteristics.

Once similar items have been identified, items can be classified according to their families; then a system can be developed that facilitates retrieval from a database for purposes of design and manufacturing. For instance, a designer can use the system to determine if there is an existing part similar or identical to one that needs to be designed. It may happen that an existing part, with some modification, is satisfactory. This greatly enhances the productivity of design. Similarly, planning the manufacturing of a new part can include matching it with one of the part families in existence, thereby alleviating much of the burden of specific processing details.

The conversion to group technology and cellular production requires a systematic analysis of parts to identify the part families. This is often a major undertaking; it is a time-consuming job that involves the analysis of a considerable amount of data. Three primary methods for accomplishing this are visual inspection, examination of design and production data, and production flow analysis.

Visual inspection is the least accurate of the three but also the least costly and the simplest to perform. Examination of design and production data is more accurate but much more time-consuming; it is perhaps the most commonly used method of analysis. Production flow analysis has a manufacturing perspective and not a design perspective, because it examines operations sequences and machine routings to uncover similarities. Moreover, the operation sequences and routings are taken as givens; in reality the existing procedures may be far from optimal.

Conversion to cellular production can involve costly realignment of equipment. Consequently, a manager must weigh the benefits of a switch from a process layout to a cellular one against the cost of moving equipment as well as the cost and time needed for grouping parts.

Flexible manufacturing systems (FMSs), discussed earlier in the chapter, are more fully automated versions of cellular manufacturing.

Other Service Layouts

In addition to the layouts already described, there are other layouts found in service environments, such as warehouse, retail, and office layouts.

Warehouse and Storage Layouts The design of storage facilities presents a different set of factors than the design of factory layouts. Frequency of order is an important consideration; items that are ordered frequently should be placed near the entrance to the facility, and those ordered infrequently should be placed toward the rear of the facility. Any correlations between items are also significant (i.e., item A is usually ordered with item B), suggesting that placing those two items close together would reduce the cost and time of *picking* (retrieving) those items. Other considerations include the number and widths of aisles, the height of storage racks, rail and/or truck loading and unloading, and the need to periodically make a physical count of stored items.

S

Retail Layouts The objectives that guide design of manufacturing layouts often pertain to cost minimization and product flow. However, with retail layouts such as department stores, supermarkets, and specialty stores, designers must take into account the presence of customers and the opportunity to influence sales volume and customer attitudes through carefully designed layouts. Traffic patterns and traffic flow are important factors to consider. Some large retail chains use standard layouts for all or most of their stores. This has several advantages. Most obvious is the ability to save time and money by using one layout instead of custom designing one for each store. Another advantage is to avoid confusing consumers who visit more than one store. In the case of service retail outlets, especially small ones such as dry cleaners, shoe repair, and auto service centers, layout design is much simpler.

Office Layouts Office layouts are undergoing transformations as the flow of paperwork is replaced with the increasing use of electronic communications. That means there is less need to place office workers in a layout that optimizes the physical transfer of information or paperwork. Another trend is to create an image of openness; office walls are giving way to low-rise partitions.

Designing Supermarkets

READING

David Schardt

The produce is over here, the dairy's over there. The soft drink specials are at the end of the aisles, the candy's at the checkout. Always.

A visit to your local supermarket isn't as haphazard as it seems. It's been laid out so that you spend as much as possible on what the store wants you to buy. And that's often more than you came in for, as we learned when we spoke to supermarket industry insiders.

Here's how a typical supermarket is designed to maximize sales.

On the Edge

The more time you spend shopping along the sides and back of the supermarket, the more money the store makes. About half its profits come from perimeter items like fruits and veggies, milk and cheese, and meat, poultry, and fish. That's also where you'll

(continued)

(concluded)

find the bakery, the salad bar, and the deli. If a store wants to distinguish itself from its competitors, it's got to be here.

Space Eaters

Some foods are so profitable that they command their own aisles. Breakfast cereals bring in more dollars per foot of shelf space than any other product in the interior of the store. So most supermarkets give cereals plenty of space.

Soft drinks aren't as profitable . . . at least not on paper. But beverage manufacturers sweeten the pot with so much free merchandise and cash rebates that carbonated soft drinks end up being one of the biggest moneymakers in a typical store.

The Meating Place

Why are the meat, poultry, and seafood displays almost always along the back of the supermarket? So that you'll see them every time you emerge from an aisle. Not a bad place to put the most profitable sections of the store.

Going to the Dairy

Why are the dairy products usually as far away from the entrance as possible? Most everybody buys milk when they shop. To reach it, they've got to walk through a good chunk of the supermarket, often along the perimeter. That's right where the store wants shoppers.

Also, stores like to "anchor" a display by putting popular items at each end. That's why milk, for example, is often at one end of the dairy case and margarine and butter at the other. You've got to run the gauntlet of cheese, yogurts, dips, etc. to get what you came for.

Paying for Space

Every year, grocery chains are offered more than 15,000 new products, nearly all of which will fail. How do stores decide which ones to stock?

Moolah, in some cases. Large supermarkets often require manufacturers to pay for shelf space. "Slotting fees," as they're called, can range from $5,000 to $25,000 per supermarket chain for each new food. The small local tofu cheese plant seldom has that kind of money to throw around.

In "Prison"

Some supermarket insiders call the aisles of the store the "prison." Once you're in one, you're stuck until you come out the other end. The "prison" is where most of the less-profitable (for the store) national and regional name brands are, so the more time you spend there, the less time you'll spend along the perimeter . . . buying higher-profit items.

Productive Produce

Think it's a coincidence that you almost always have to walk through the produce department when you enter a supermarket? The look of those shiny, neatly stacked fruits and vegetables is *the* most important influence on where people decide to shop.

It also doesn't hurt that produce is the second most profitable section (meat is first). While it occupies a little over 10 percent of the typical supermarket, it brings in close to 20 percent of the store's profits.

DESIGNING PRODUCT LAYOUTS: LINE BALANCING

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Assembly lines range from fairly short, with just a few operations, to long lines that have a large number of operations. Automobile assembly lines are examples of long lines. At the assembly line for Ford Mustangs in Dearborn, Michigan, a Mustang travels about nine miles from start to finish!

Figure 6.9 illustrates the major steps involved in assembling an automobile.

Many of the benefits of a product layout relate to the ability to divide required work into a series of elemental tasks (e.g., "assemble parts *C* and *D*") that can be performed quickly and routinely by low-skilled workers or specialized equipment. The durations of these elemental tasks typically range from a few seconds to 15 minutes or more. Most time requirements are so brief that it would be impractical to assign only one task to each worker. For one thing, most workers would quickly become bored by the limited job scope. For another, the number of workers required to complete even a simple product or service would be enormous. Instead, tasks are usually grouped into manageable bundles and assigned to workstations staffed by one or two operators.

line balancing The process of assigning tasks to workstations in such a way that the workstations have approximately equal time requirements.

The process of deciding how to assign tasks to workstations is referred to as **line balancing.** The goal of line balancing is to obtain task groupings that represent approximately equal time requirements. This minimizes the idle time along the line and results in a high utilization of labor and equipment. Idle time occurs if task times are not equal among workstations; some stations

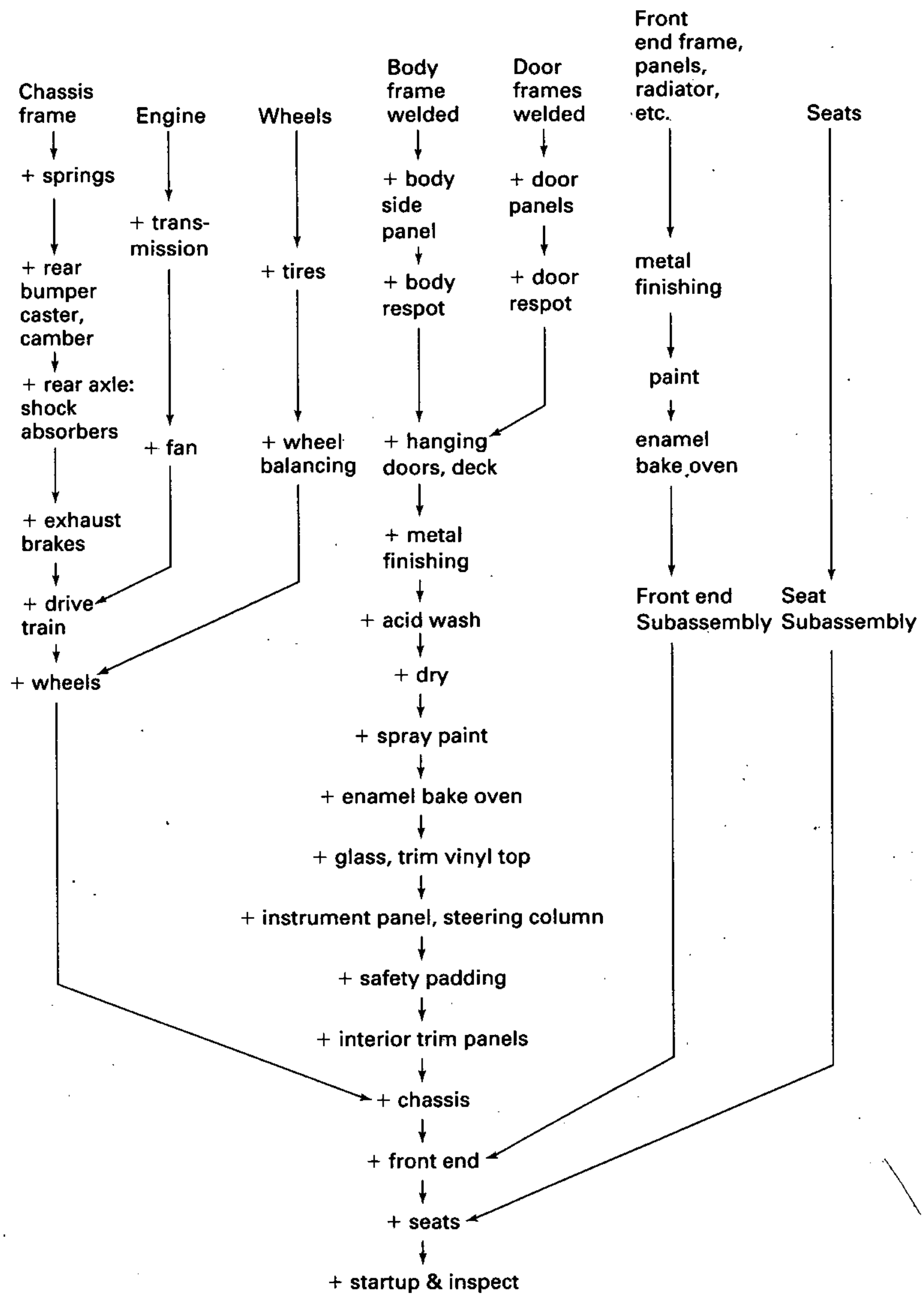

FIGURE 6.9

Auto assembly

Source: "Computer Integrated Manufacturing," Vol. 1 in Revolution in Progress series, Chapman and Hall, London, 1990. Adapted from R. U. Ayres, Morris A. Cohen, and Uday M. Apte. *Manufacturing Automation*. p. 175. McGraw-Hill, Companies, Inc. Used with permission.

are capable of producing at higher rates than others. These "fast" stations will experience periodic waits for the output from slower stations or else be forced into idleness to avoid buildups of work between stations. Unbalanced lines are undesirable in terms of inefficient utilization of labor and equipment and because they may create morale problems at the slower stations for workers who must work continuously.

Lines that are perfectly balanced will have a smooth flow of work as activities along the line are synchronized to achieve maximum utilization of labor and equipment. The major obstacle to attaining a perfectly balanced line is the difficulty of forming task bundles that have the same duration. One cause of this is that it may not be feasible to combine certain activities into the same bundle, either because of differences in equipment requirements or because the activities are not compatible (e.g., risk of contamination of paint from sanding). Another cause of difficulty is that differences among elemental task lengths cannot always be overcome by grouping tasks. A third cause of an inability to perfectly balance a line is that a required technological sequence may prohibit otherwise desirable task combinations. Consider a series of three operations that have durations of two minutes, four minutes, and two minutes, as shown in the following diagram. Ideally, the first and third operations could be combined at one workstation and have a total time equal to that of the second operation. However, it may not be possible to combine the first and third operations. In the case of an automatic car wash, scrubbing and drying operations could not realistically be combined at the same workstation due to the need to rinse cars between the two operations.

Scrubbing 2 minutes → Rinsing 4 minutes → Drying 2 minutes

Line balancing involves assigning tasks to workstations. Usually, each workstation has one worker who handles all of the tasks at that station, although an option is to have several workers at a single workstation. For purposes of illustration, however, all of the examples and problems in this chapter have workstations with one worker. A manager could decide to use anywhere from one to five workstations to handle five tasks. With one workstation, all tasks would be done at that station; with five stations, one task would be assigned to each station. If two, three, or four workstations are used, some or all of the stations will have multiple tasks assigned to them. How does a manager decide how many stations to use?

cycle time The maximum time allowed at each workstation to complete its set of tasks on a unit.

The primary determinant is what the line's **cycle time** will be. The cycle time is the *maximum* time allowed at each workstation to perform assigned tasks before the work moves on. The cycle time also establishes the output rate of a line. For instance, if the cycle time is two minutes, units will come off the end of the line at the rate of one every two minutes.

We can gain some insight into task groupings and cycle time by considering a simple example.

Suppose that the work required to fabricate a certain product can be divided up into five elemental tasks, with the task times and precedence relationships as shown in the following diagram.

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→ 0.1 min. → 0.7 min. → 1.0 min. → 0.5 min. → 0.2 min. →

The task times govern the range of possible cycle times. The *minimum* cycle time is equal to the *longest* task time (1.0 minute), and the *maximum* cycle time is equal to the sum of the task times ($0.1 + 0.7 + 1.0 + 0.5 + 0.2 = 2.5$ minutes). The minimum cycle time would apply if there were five workstations. The maximum cycle time would apply if all tasks were performed at a single workstation. The minimum and maximum cycle times are important because they establish the potential range of output for the line, which we can compute using the following formula:

$$\text{Output capacity} = \frac{\text{OT}}{\text{CT}} \qquad (6\text{–}1)$$

where

OT = Operating time per day

CT = Cycle time

Assume that the line will operate for eight hours per day (480 minutes). With a cycle time of 1.0 minute, output would be

$$\frac{\text{480 minutes per day}}{\text{1.0 minute per unit}} = \text{480 units per day}$$

With a cycle time of 2.5 minutes, the output would be

$$\frac{\text{480 minutes per day}}{\text{2.5 minutes per unit}} = \text{192 units per day}$$

Assuming that no parallel activities are to be employed (e.g., two lines), the output selected for the line must fall in the range of 192 units per day to 480 units per day.

As a general rule, the cycle time is determined by the desired output; that is, a desired output level is selected, and the cycle time is computed. If the cycle time does not fall between the maximum and minimum bounds, the desired output rate must be revised. We can compute the cycle time using this formula:

$$CT = \frac{OT}{D} \quad (6\text{–}2)$$

where

D = Desired output rate

For example, suppose that the desired output rate is 480 units. Using Formula 6–2, the necessary cycle time is

$$\frac{480 \text{ minutes per day}}{480 \text{ units per day}} = 1.0 \text{ minute per unit}$$

The number of workstations that will be needed is a function of both the desired output rate and our ability to combine elemental tasks into workstations. We can determine the *theoretical minimum* number of stations necessary to provide a specified rate of output as follows:

$$N_{min} = \frac{\Sigma t}{CT} \quad (6\text{–}3)$$

where

N_{min} = Theoretical minimum number of stations

Σt = Sum of task times

Suppose the desired rate of output is the maximum of 480 units per day.[2] (This will require a cycle time of 1.0 minute.) The minimum number of stations required to achieve this goal is:

$$N_{min} = \frac{2.5 \text{ minutes per unit}}{1 \text{ minute per unit per station}} = 2.5 \text{ stations}$$

Because 2.5 stations is not feasible, it is necessary to *round up* (because 2.5 is the minimum) to three stations. Thus, the actual number of stations used will equal or exceed three, depending on how successfully the tasks can be grouped into work stations.

A very useful tool in line balancing is a **precedence diagram.** Figure 6.10 illustrates a simple precedence diagram. It visually portrays the tasks that are to be performed along with the *sequential* requirements, that is, the *order* in which tasks must be performed. The diagram is read from left to right, so the initial task(s) are on the left and the final task is on the right. In terms of precedence requirements, we can see from the diagram, for example, that the only requirement to begin task *b* is that task *a* must be finished. However, in order to begin task *d,* tasks *b* and *c* must *both* be finished. Note that the elemental tasks are the same ones that we have been using.

precedence diagram A diagram that shows elemental tasks and their precedence requirements.

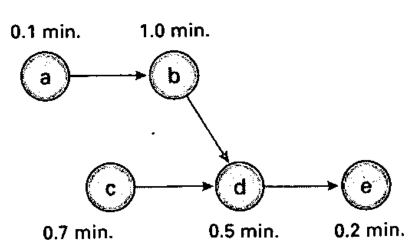


FIGURE 6.10

A simple precedence diagram

[2]At first glance, it might seem that the desired output would logically be the maximum possible output. However, you will see why that is not always the best alternative.

Now let's see how a line is balanced. This involves assigning tasks to workstations. Generally, no techniques are available that guarantee an optimal set of assignments. Instead, managers employ *heuristic (intuitive) rules,* which provide good and sometimes optimal sets of assignments. A number of line-balancing heuristics are in use, two of which are described here for purposes of illustration:

1. Assign tasks in order of most following tasks.
2. Assign tasks in order of greatest positional weight. Positional weight is the sum of each task's time and the times of all following tasks.

The general procedure used in line balancing is described in Table 6.4.

TABLE 6.4
Line balancing procedure

1. Determine the cycle time and the minimum number of workstations.
2. Make assignments to workstations in order, beginning with Station 1. Tasks are assigned to workstations moving from left to right through the precedence diagram.
3. Before each assignment, use the following criteria to determine which tasks are *eligible* to be assigned to a workstation:
   a. All preceding tasks in the sequence have been assigned.
   b. The task time does not exceed the time remaining at the workstation.
   If no tasks are eligible, move on to the next workstation.
4. After each task assignment, determine the time remaining at the current workstation by subtracting the sum of times for tasks already assigned to it from the cycle time.
5. Break ties that occur using one of these rules:
   a. Assign the task with the longest task time.
   b. Assign the task with the greatest number of followers.
   If there is still a tie, choose one task arbitrarily.
6. Continue until all tasks have been assigned to workstations.
7. Compute appropriate measures (e.g., percent idle time, efficiency) for the set of assignments.

EXAMPLE 1

Arrange the tasks shown in Figure 6.10 into three workstations. Use a cycle time of 1.0 minute. Assign tasks in order of the most number of followers.

SOLUTION

Workstation	Time Remaining	Eligible	Assign Task	Revised Time Remaining	Station Idle Time
1	1.0	a, c	a	0.9	
	0.9	c	c	0.2	
	0.2	none	—		0.2
2	1.0	b	b	0.0	0.0
3	1.0	d	d	0.5	
	0.5	e	e	0.3	
	0.3	—	—		0.3
					0.5

Comment: The initial "time remaining" for each workstation is equal to the cycle time. For a task to be eligible, tasks preceding it must have been assigned, and the task's time must not exceed the station's remaining time.

Example 1 is purposely simple; it is designed to illustrate the basic procedure. Later examples will illustrate tiebreaking, constructing precedence diagrams, and the positional weight method. Before considering those examples, let us first consider some measures of effectiveness that can be used for evaluating a given set of assignments.

Two widely used measures of effectiveness are

1. The *percentage of idle time* of the line. This is sometimes referred to as the **balance delay.** It can be computed as follows:

balance delay Percentage of idle time of a line.

$$\text{Percentage of idle time} = \frac{\text{Idle time per cycle}}{N_{\text{actual}} \times \text{cycle time}} \times 100 \qquad (6\text{–}4)$$

where

N_{actual} = Actual number of stations.

For the preceding example, the value is

$$\text{Percentage of idle time} = \frac{.5}{3 \times 1.0} \times 100 = 16.7\%$$

In effect, this is the average idle time divided by the cycle time, multiplied by 100. Note that cycle time refers to the actual cycle time that is achieved.

2. The *efficiency* of the line. This is computed as follows:

$$\text{Efficiency} = 100\% - \text{percent idle time} \qquad (6\text{–}5)$$

Here efficiency = 100% − 16.7% = 83.3%

Now let's consider the question of whether the selected level of output should equal the maximum output possible. The minimum number of workstations needed is a function of the desired output rate and, therefore, the cycle time. Thus, a lower rate of output (hence, a longer cycle time) may result in a need for fewer stations. Hence, the manager must consider whether the potential savings realized by having fewer workstations would be greater than the decrease in profit resulting from producing fewer units.

The preceding examples serve to illustrate some of the fundamental concepts of line balancing. They are rather simple; in most real-life situations, the number of branches and tasks is often much greater. Consequently, the job of line balancing can be a good deal more complex. In many instances, the number of alternatives for grouping tasks is so great that it is virtually impossible to conduct an exhaustive review of all possibilities. For this reason, many real-life problems of any magnitude are solved using heuristic approaches. The purpose of a heuristic approach is to reduce the number of alternatives that must be considered, but it does not guarantee an optimal solution.

Some Guidelines for Line Balancing

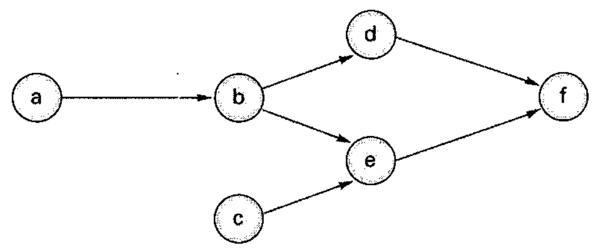
In balancing an assembly line, tasks are assigned *one at a time* to the line, starting at the first workstation. At each step, the unassigned tasks are checked to determine which are eligible for assignment. Next, the eligible tasks are checked to see which of them will fit in the workstation being loaded. A heuristic is used to select one of the tasks that will fit, and the task is assigned. This process is repeated until there are no eligible tasks that will fit. Then the next workstation can be loaded. This continues until all tasks are assigned. The objective is to minimize the idle time for the line subject to technological and output constraints.

Technological constraints tell us which elemental tasks are *eligible* to be assigned at a particular position on the line. Technological constraints can result from the precedence or ordering relationships among the tasks. The precedence relationships require that certain tasks must be performed before others (and so, must be assigned to workstations before others). Thus, in a car wash, the rinsing operation must be performed before the drying operation. The drying operation is not eligible for assignment until the rinsing operation has been assigned. Technological constraints may also result from two tasks being "incompatible" (e.g., space restrictions or the nature of the operations may prevent their being placed in the same work center). For example, sanding and painting operations would not be assigned to the same work center because dust particles from the sanding operation could contaminate the paint.

Output constraints, on the other hand, determine the maximum amount of work that a manager can assign to each workstation, and this determines whether an eligible task *will fit* at a workstation. The desired output rate determines the cycle time, and the sum of the task times assigned to any workstation must not exceed the cycle time. If a task can be assigned to a workstation without exceeding the cycle time, then the task will fit.

Once it is known which tasks are *eligible* and *will fit,* the manager can select the task to be assigned (if there is more than one to choose from). This is where the heuristic rules help us decide which task to assign from among those that are eligible and will fit.

To clarify the terminology, *following tasks* are all tasks that you would encounter by following all paths from the task in question through the precedence diagram. *Preceding tasks* are all tasks you would encounter by tracing all paths *backward* from the task in question. In the precedence diagram below, tasks *b, d, e,* and *f* are followers of task *a*. Tasks *a, b,* and *c* are preceding tasks for *e*.



The *positional weight* for a task is the sum of the task times for itself and all its following tasks.

Neither of the heuristics *guarantees* the *best* solution, or even a good solution to the line-balancing problem, but they do provide guidelines for developing a solution. It may be useful to apply several different heuristics to the same problem and pick the best (least idle time) solution out of those developed.

EXAMPLE 2

Using the information contained in the table shown, do each of the following:

1. Draw a precedence diagram.
2. Assuming an eight-hour workday, compute the cycle time needed to obtain an output of 400 units per day.
3. Determine the minimum number of workstations required.
4. Assign tasks to workstations using this rule: Assign tasks according to greatest number of following tasks. In case of a tie, use the tiebreaker of assigning the task with the longest processing time first.

Task	Immediate Follower	Task Time (in minutes)
a	b	0.2
b	e	0.2
c	d	0.8
d	f	0.6
e	f	0.3
f	g	1.0
g	h	0.4
h	end	0.3
		$\Sigma t = 3.8$

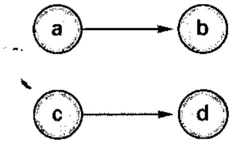
5. Compute the resulting efficiency of the system.

SOLUTION

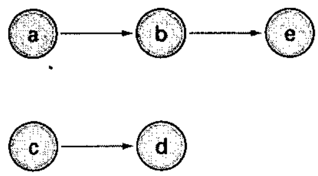
1. Drawing a precedence diagram is a relatively straightforward task. Begin with activities with no predecessors. We see from the list of Immediate Followers that tasks *a* and *c* do not appear. Hence, they have no immediate predecessors. We build from here.

Step 1:

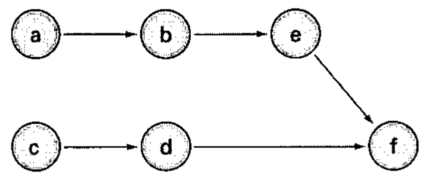
Step 2: Task *b* follows *a*, and *d* follows *c*.



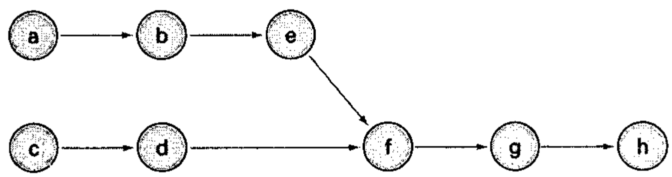
Step 3: Task *e* follows *b*.



Step 4: Task *f* follows *e* and *d*.



Step 5: Task *g* follows *f*, and *h* follows *g*.



2. $\text{CT} = \dfrac{\text{OT}}{D} = \dfrac{480 \text{ minutes per day}}{400 \text{ units per day}} = 1.2 \text{ minutes per cycle}$

3. $N_{min} = \dfrac{\Sigma t}{\text{CT}} = \dfrac{3.8 \text{ minutes per unit}}{1.2 \text{ minutes per cycle per station}} = 3.17 \text{ stations (round to 4)}$

4. Beginning with station 1, make assignments following this procedure: Determine from the precedence diagram which tasks are eligible for assignment. Then determine which of the eligible tasks will fit the time remaining for the station. Use the tiebreaker if necessary. Once a task has been assigned, remove it from consideration. When a station cannot take any more assignments, go on to the next station. Continue until all tasks have been assigned.

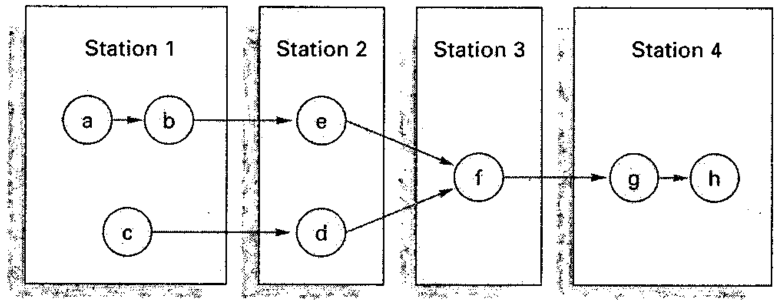
Station	Time Remaining	Eligible	Will Fit	Assign (task time)	Revised Time Remaining	Idle
1	1.2	a, c*	a, c*	a (0.2)	1.0	
	1.0	c, b**	c, b**	c (0.8)	0.2	
	0.2	b, d	b	b (0.2)	0.0	
	0	e, d	None	—		0.0
2	1.2	e, d	e, d	d (0.6)	0.6	
	0.6	e	e	e (0.3)	0.3	
	0.3***	f	None	—		0.3
3	1.2	f	f	f (1.0)	0.2	
	0.2	g	None	—		0.2
4	1.2	g	g	g (0.4)	0.8	
	0.8	h	h	h (0.3)	0.5	
	0.5	—	—	—		0.5
						1.0 min.

*Neither *a* nor *c* has any predecessors, so both are eligible. Task *a* was assigned since it has more followers.

**Once *a* is assigned, *b* and *c* are now eligible. Both will fit in the time remaining of 1.0 minute. The tie cannot be broken by the "most followers" rule, so the longer task is assigned.

***Although *f* is eligible, this task will not fit, so station 2 is left with 0.3 minute of idle time per 1.2-minute cycle.

These assignments are shown in the following diagram. Note: One should not expect that heuristic approaches will always produce optimal solutions; they merely provide a practical way to deal with complex problems that may not lend themselves to optimizing techniques. Moreover, different heuristics often yield different answers.



5. $\text{Efficiency} = 100\% - \dfrac{1.0 \text{ min.}}{4 \times 1.2 \text{ min.}} \times 100 = 79.17\%.$

Other Factors

The preceding discussion on line balancing presents a relatively straightforward approach to approximating a balanced line. In practice, the ability to do this usually involves additional considerations, some of which are technical.

Technical considerations include skill requirements of different tasks. If skill requirements of tasks are quite different, it may not be feasible to place the tasks in the same workstation. Similarly, if the tasks themselves are incompatible (e.g., the use of fire and flammable liquids), it may not be feasible even to place them in stations that are near to each other.

Developing a workable plan for balancing a line may also require consideration of human factors as well as equipment and space limitations.

Although it is convenient to treat assembly operations as if they occur at the same rate time after time, it is more realistic to assume that whenever humans are involved, task completion times will be variable. The reasons for the variations are numerous, including fatigue, boredom, and failure to concentrate on the task at hand. Absenteeism also can affect line balance. Minor variability can be dealt with by allowing some slack along the line. However, if more variability is inherent in even a few tasks, that will severely impact the ability to achieve a balanced line.

For these reasons, lines that involve human tasks are more of an ideal than a reality. In practice, lines are rarely perfectly balanced. However, this is not entirely bad, because some unbalance means that slack exists at points along the line, which can reduce the impact of brief stoppages at some workstations. Also, workstations that have slack can be used for new workers who may not be "up to speed."

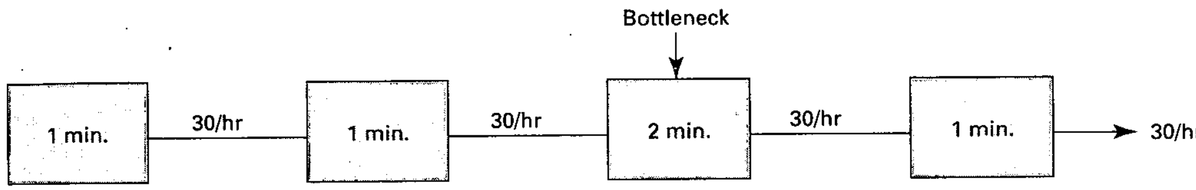
Other Approaches

There are a number of other approaches companies use to achieve a smooth flow of production. One approach is to use *parallel workstations.* These are beneficial for bottleneck operations which would otherwise disrupt the flow of product as it moves down the line. The bottlenecks may be the result of difficult or very long tasks. Parallel workstations increase the work flow and provide flexibility.

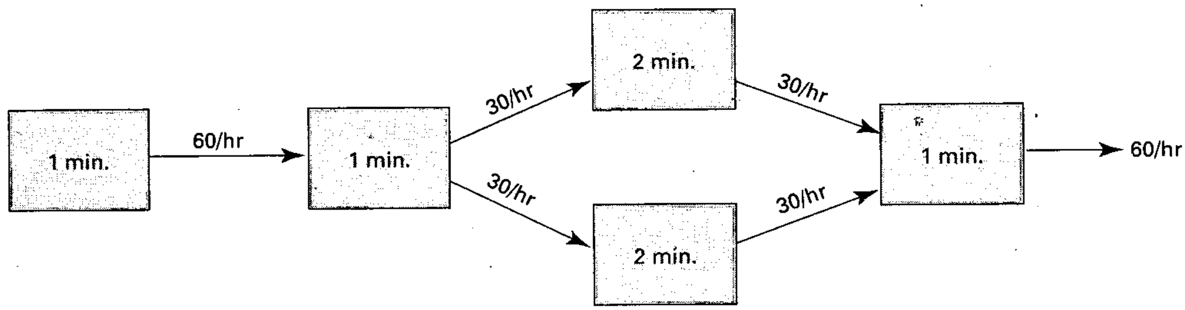
Consider this example.[3] A job has four tasks; task times are 1 minute, 1 minute, 2 minutes, and 1 minute. The cycle time for the line would be 2 minutes, and the output rate would be 30 units per hour:

$$\frac{60 \text{ minutes per hour}}{2 \text{ minutes per unit}} = 30 \text{ units per hour}$$

[3]Adapted from Mikell P. Groover, *Automation, Production Systems, and Computer-Aided Manufacturing,* 2nd ed. © 1987. Reprinted by permission of Pearson Educations, Inc. Upper Saddle River, N.J.



Using parallel stations for the third task would result in a cycle time of 1 minute because the output rate at the parallel stations would be equal to that of a single station and allow an output rate for the line of 60 units per hour:

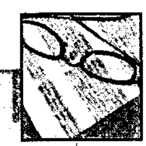


Another approach to achieving a balanced line is to *cross-train* workers so that they are able to perform more than one task. Then, when bottlenecks occur, the workers with temporarily increased idle time can assist other workers who are temporarily overburdened, thereby maintaining an even flow of work along the line. This is sometimes referred to as *dynamic line balancing,* and it is used most often in lean production systems.

Still another approach is to design a line to handle more than one product on the same line. This is referred to as a *mixed model line.* Naturally, the products have to be fairly similar, so that the tasks involved are pretty much the same for all products. This approach offers great flexibility in varying the amount of output of the products. The following newsclip describes one such line.

Toyota Mixes and Matches

NEWSCLIP



www.toyota.com

Toyota, long famous for producing quality cars and light trucks, decided to produce minivans in the U.S. Wanting to get into production quickly, Toyota took an ambitious step at its Georgetown, Kentucky, manufacturing plant, deciding to produce Sienna minivans at the same time—and at the same workstations—that produce Camry automobiles.

"Although Camry and Sienna are built from the same basic chassis, and share 50 percent of their parts, there are key differences. Sienna is five inches longer, three inches wider and a foot taller than Camry. Each Sienna takes up more space on the assembly line and requires more and bigger parts.

"Another automaker might shut down a plant for months to make the changes. But Toyota needed to move quickly. Delay could jeopardize booming sales of Camry.

"Out of 300 stations on the assembly line, Sienna needs different parts at 26. But only seven new production steps are needed. . . . To save time, Toyota decided not to add workstations. Instead, it selected two teams of workers, one for each shift, that are responsible for attaching Sienna-only parts. Meanwhile, engineers, working with Toyota workers, designed equipment intended to make those duties easy to perform."

As soon as a Sienna approaches one of the seven spots on the assembly line, a member of the Sienna team is there to take over. Some team members climb inside, where they scoot around on wheeled carts that look like NASA's Sojourner Mars explorer. Others attach roof racks by standing on platforms that put the van's top waist high, eliminating the need to reach.

Toyota may have shortened the time needed to start production by three years by using this innovative approach to the assembly line.

Source: Based on "Camry Assembly Line Delivers New Minivan," p. B3. Copyright 1997, *USA TODAY.* Adapted with permission.

FIGURE 6.11

Work centers must be assigned to locations

Locations

A	B	C
D	E	F

Work centers to be assigned

1
2
3
4
5
6

DESIGNING PROCESS LAYOUTS

The main issue in designing process layouts concerns the relative positioning of the departments involved. As illustrated in Figure 6.11, departments must be assigned to locations. The problem is to develop a reasonably good layout; some combinations will be more desirable than others. For example, some departments may benefit from adjacent locations whereas others should be separated. A lab with delicate equipment would not be located near a department that had equipment with strong vibrations. Conversely, two departments that share some of the same equipment would benefit from being close together.

Layouts can also be influenced by external factors such as the location of entrances, loading docks, elevators, windows, and areas of reinforced flooring. Also important are noise levels, safety, and the size and locations of restrooms.

www.mcdonalds.com

In some instances (e.g., the layouts of supermarkets, gas stations, and fast-food chains), a sufficient number of installations having similar characteristics justify the development of standardized layouts. For example, the use of the same basic patterns in McDonald's fast-food locations facilitates construction of new structures and employee training. Food preparation, order taking, and customer service follow the same pattern throughout the chain. Installation and service of equipment are also standardized. This same concept has been successfully employed in computer software products such as Microsoft Windows® and the Macintosh® Operating System. Different applications are designed with certain basic features in common, so that a user familiar with one application can readily use other applications without having to start from scratch with each new application.

The majority of layout problems involve single rather than multiple locations, and they present unique combinations of factors that do not lend themselves to a standardized approach. Consequently, these layouts require customized designs.

A major obstacle to finding the most efficient layout of departments is the large number of possible assignments. For example, there are more than 87 billion different ways that 14 departments can be assigned to 14 locations if the locations form a single line. Different location configurations (e.g., 14 departments in a two-by-seven grid) often reduce the number of possibilities, as do special requirements (e.g., the stamping department may have to be assigned to a location with reinforced flooring). Still, the remaining number of layout possibilities is quite large. Unfortunately, no algorithms exist to identify the best layout arrangement under all circumstances. Often planners must rely on heuristic rules to guide trial-and-error efforts for a satisfactory solution to each problem.

Measures of Effectiveness

One advantage of process layouts is their ability to satisfy a variety of processing requirements. Customers or materials in these systems require different operations and different sequences of operations, which causes them to follow different paths through the system. Material-oriented systems necessitate the use of variable-path material-handling equipment to move materials from work center to work center. In customer-oriented systems, people must travel or be transported from work center to work center. In both cases, transportation costs or time can be significant. Because of this factor, one of the major objectives in process layout is to minimize transportation cost, distance, or time. This is usually accomplished by locating departments with relatively high interdepartmental work flow as close together as possible.

The profitable produce section of a grocery store is prominently located along the store's perimeter.

The aisle locations contain the less profitable store and name brands, including canned goods and packaged items.

Other concerns in choosing among alternative layouts include initial costs in setting up the layout, expected operating costs, the amount of effective capacity created, and the ease of modifying the system.

In situations that call for improvement of an existing layout, costs of relocating any work center must be weighed against the potential benefits of the move.

Information Requirements

The design of process layouts requires the following information:

1. A list of departments or work centers to be arranged, their approximate dimensions, and the dimensions of the building or buildings that will house the departments.
2. A projection of future work flows between the various work centers.
3. The distance between locations and the cost per unit of distance to move loads between locations.
4. The amount of money to be invested in the layout.
5. A list of any special considerations (e.g., operations that must be close to each other or operations that must be separated).
6. The location of key utilities, access and exit points, loading docks, and so on, in existing buildings.

The ideal situation is to first develop a layout and then design the physical structure around it, thus permitting maximum flexibility in design. This procedure is commonly followed when new facilities are constructed. Nonetheless, many layouts must be developed in existing structures where floor space, the dimensions of the building, location of entrances and elevators, and other similar factors must be carefully weighed in designing the layout. Note that multilevel structures pose special problems for layout planners.

Minimizing Transportation Costs or Distances

The most common goals in designing process layouts are minimization of transportation costs or distances traveled. In such cases, it can be very helpful to summarize the necessary data in *from-to charts* like those illustrated in Tables 6.5 and 6.6. Table 6.5 indicates the distance between each of the locations, and Table 6.6 indicates actual or projected work flow between each pair. For instance, the distance chart reveals that a trip from location A to location B will involve a distance of 20 meters. (Distances are often measured between department centers.) Oddly enough, the length of a trip between locations A and B may differ depending on the *direction* of the trip, due to one-way routes, elevators, or other factors. To simplify the

TABLE 6.5
Distance between locations (meters)

From \ To	A	B	C
A		20	40
B			30
C			

TABLE 6.6
Interdepartmental work flow (loads per day)

		DEPARTMENT 1	2	3
Dept.	1		30	170
	2			100
	3			

discussion, assume a constant distance between any two locations regardless of direction. However, it is not realistic to assume that interdepartmental work flows are equal—there is no reason to suspect that department 1 will send as much work to department 2 as department 2 sends to 1. For example, several departments may send goods to packaging, but packaging may send only to the shipping department.

Transportation costs can also be summarized in from-to charts, but we shall avoid that complexity, assuming instead that costs are a direct, linear function of distance.

EXAMPLE 3

Assign the three departments shown in Table 6.6 to locations A, B, and C, which are separated by the distances shown in Table 6.5, in such a way that transportation cost is minimized. Note that Table 6.6 summarizes the flows in both directions. Use this heuristic: Assign departments with the greatest interdepartmental work flow first to locations that are closest to each other.

SOLUTION

Ranking departments according to highest work flow and locations according to highest interlocation distances helps in making assignments.

Trip	Distance (meters)	Department Pair	Work Flow
A–B	20	1–3	170
B–C	30	2–3	100
A–C	40	1–2	30

From these listings, you can see that departments 1 and 3 have the highest interdepartmental work flow, and that locations A and B are the closest. Thus, it seems reasonable to consider assigning 1 and 3 to locations A and B, although it is not yet obvious which department should be assigned to which location. Further inspection of the work flow list reveals that 2 and 3 have higher work flow than 1 and 2, so 2 and 3 should probably be located more closely than 1 and 2. Hence, it would seem reasonable to place 3 between 1 and 2, or at least centralize that department with respect to the other two. The resulting assignments might appear as illustrated in Figure 6.12.

If the cost per meter to move any load is \$1, you can compute the total daily transportation cost for this assignment by multiplying each department's number of loads by the trip distance, and summing those quantities:

Department	Number of Loads between	Location	Distance to:	Loads × Distance
1	2: 30	A	C: 40	30 × 40 = 1,200
	3: 170		B: 20	170 × 20 = 3,400
2	3: 100			
3		B	C: 30	100 × 30 = 3,000
				7,600

At \$1 per load meter, the cost for this plan is \$7,600 per day. Even though it might appear that this arrangement yields the lowest transportation cost, you cannot be absolutely positive of that without actually computing the total cost for every alternative and comparing it to this one.

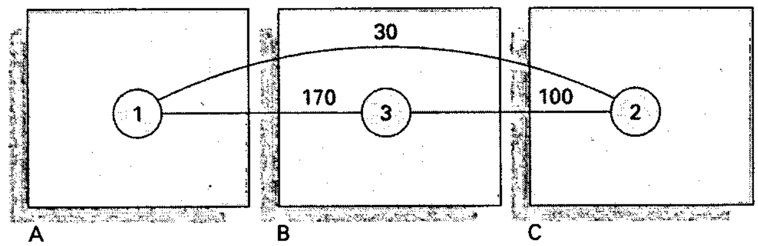


FIGURE 6.12

Interdepartmental work flows for assigned departments

Instead, rely on the choice of reasonable heuristic rules such as those demonstrated above to arrive at a satisfactory, if not optimal, solution.

Closeness Ratings

Although the preceding approach is widely used, it suffers from the limitation of focusing on only one objective, and many situations involve multiple criteria. Richard Muther developed a more general approach to the problem, which allows for subjective input from analysis or managers to indicate the relative importance of each combination of department pairs.[4] That information is then summarized in a grid like that shown in Figure 6.13. Read the grid in the same way as you would read a mileage chart on a road map, except that letters rather than distances appear at the intersections. The letters represent the importance of closeness for each department pair, with A being the most important and X being an undesirable pairing. Thus, in the grid it is "absolutely necessary" to locate 1 and 2 close to each other because there is an A at the intersection of those departments on the grid. On the other hand, 1 and 4 should not be close together because their intersection has an X. In practice, the letters on the grid are often accompanied by numbers that indicate the reason for each assignment: they are omitted here to simplify the illustration. Muther suggests the following list:

1. Use same equipment or facilities.
2. Share the same personnel or records.
3. Sequence of work flow.
4. Ease of communication.
5. Unsafe or unpleasant conditions.
6. Similar work performed.

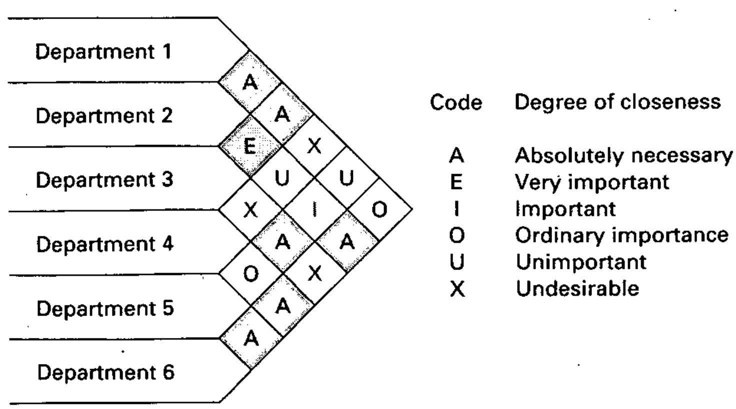


FIGURE 6.13

A Muther grid

EXAMPLE 4

Assign the six departments in Figure 6.12 to a 2 × 3 set of locations using the heuristic rule: Assign critical departments first, because they are the most important.

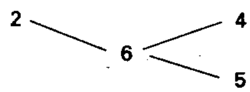
[4]Richard Muther and John Wheeler, "Simplified Systematic Layout Planning," *Factory*, Vol. 120, nos. 8, 9, and 10 (August, September, October 1962), pp. 68–77, 111–119, 101–113, respectively.

SOLUTION

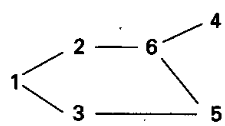
Critical pairs of departments are those with A or X ratings. Prepare a list of those by referring to the grid:

As	Xs
1–2	1–4
1–3	3–6
2–6	3–4
3–5	
4–6	
5–6	

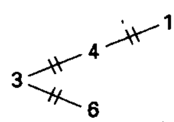
Next, form a cluster of A links, beginning with the department that appears most frequently in the A list (in this case, 6). For instance:



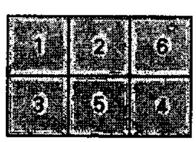
Take the remaining As in order, and add them to this main cluster where possible, rearranging the cluster as necessary. Form separate clusters for departments that do not link with the main cluster. In this case, all link with the main cluster.



Next, graphically portray the Xs:



Observe that, as it stands, the cluster of As also satisfies the X separations. It is a fairly simple exercise to fit the cluster into a 2 × 3 arrangement:



Note that the lower-level ratings have also been satisfied with this arrangement, even though no attempt was made to explicitly consider the E and I ratings. Naturally, not every problem will yield the same results, so it may be necessary to do some additional adjusting to see if improvements can be made, keeping in mind that the A and X assignments deserve the greatest consideration.

Note that departments are considered close not only when they touch side to side, but also when they touch corner to corner.

The value of this rating approach is that it permits the use of multiple objectives and subjective inputs. Its limitations relate to the use of subjective inputs in general: They are imprecise and unreliable.

Computer Analysis

The size and complexity of process layout problems have led to the development of a number of computerized packages. The obvious advantage of computerized analyses of layout problems is the ability to handle large problems and to consider many different layout alternatives. Even so, in some instances, the results of computer analysis require additional manual adjustments before they can be used. The CD that accompanies this book has templates that allow easy solution of the problems at the end of the chapter.

SUMMARY

Process selection choices often have strategic implications for organizations. They can affect cost, quality, productivity, customer satisfaction, and competitive advantage. Process types include job shop, batch processing, repetitive processing, continuous processing, and projects. Process type determines how work is organized, and it has implications for the entire organization and its supply chain. Process type and layout are closely related.

Layout decisions are an important aspect of the design of operations systems, affecting operating costs and efficiency. Layout decisions are often closely related to process selection decisions.

Product layouts are geared to high-volume output of standardized items. Workers and equipment are arranged according to the technological sequence required by the product or service involved. Emphasis in design is on work flow through the system, and specialized processing and handling equipment is often used. Product layouts are highly vulnerable to breakdowns. Preventive maintenance is used to reduce the occurrence of breakdowns.

Process layouts group similar activities into departments or other work centers. These systems can handle a wide range of processing requirements and are less susceptible to breakdowns. However, the variety of processing requirements necessitates continual routing and scheduling and the use of variable-path material-handling equipment. The rate of output is generally much lower than that of product layouts.

Fixed-position layouts are used when size, fragility, cost, or other factors make it undesirable or impractical to move a product through a system. Instead, workers, equipment, and materials are brought to the product.

The main design efforts in product layout development focus on dividing up the work required to produce a product or service into a series of tasks that are as nearly equal as possible. The goal is to achieve a high degree of utilization of labor and equipment. In process layout, design efforts often focus on the relative positioning of departments to minimize transportation costs or to meet other requirements concerning the proximity of certain department pairs.

The large number of possible alternatives to layout problems prevents an examination of each one. Instead, heuristic rules guide discovery of alternatives. The solutions thus obtained are usually satisfactory although not necessarily optimal. Computer packages are available to reduce the effort required to obtain solutions to layout problems, but these too rely largely on heuristic methods.

KEY TERMS

assembly line, 228
automation, 221
balance delay, 241
cellular production, 233
computer-aided manufacturing (CAM), 222
computer-integrated manufacturing (CIM), 226
cycle time, 238
fixed-position layout, 232
flexible manufacturing system (FMS), 226
group technology, 234
line balancing, 236
manufacturing cell, 224
numerically controlled (N/C) machines, 222
precedence diagram, 239
process layout, 231
product layout, 228
production line, 228
project, 221
robot, 223

SOLVED PROBLEMS

Problem 1

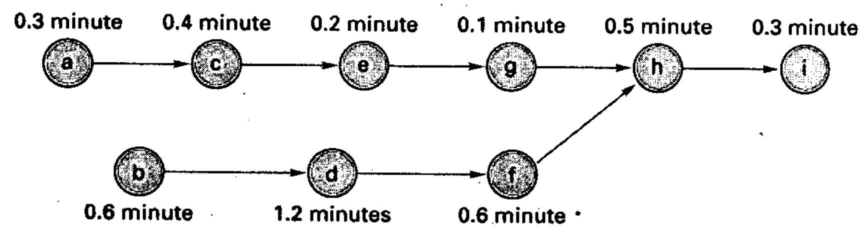
The tasks shown in the following precedence diagram are to be assigned to workstations with the intent of minimizing idle time. Management has designed an output rate of 275 units per day. Assume 440 minutes are available per day.

a. Determine the appropriate cycle time.

b. What is the minimum number of stations possible?

c. Assign tasks using the "positional weight" rule: Assign tasks with highest following times (including a task's own time) first. Break ties using greatest number of following tasks.

d. Compute efficiency.

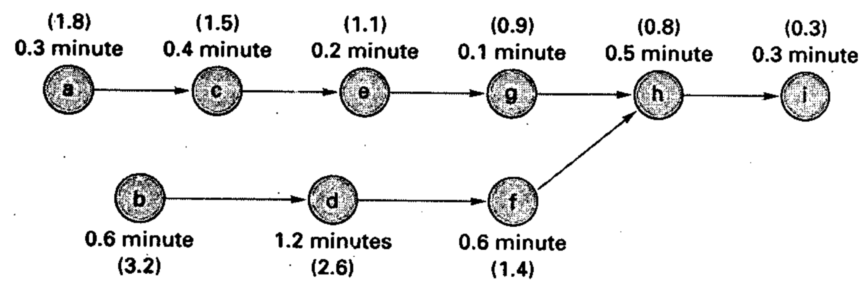


Solution

a. $\text{CT} = \dfrac{\text{Operating time}}{\text{Desired output}} = \dfrac{440 \text{ minutes per day}}{275 \text{ units per day}} = 1.6 \text{ minutes}$

b. $N = \dfrac{\Sigma t}{\text{Cycle time}} = \dfrac{4.2}{1.6 \text{ minutes}} = 2.625 \text{ (round to 3)}$

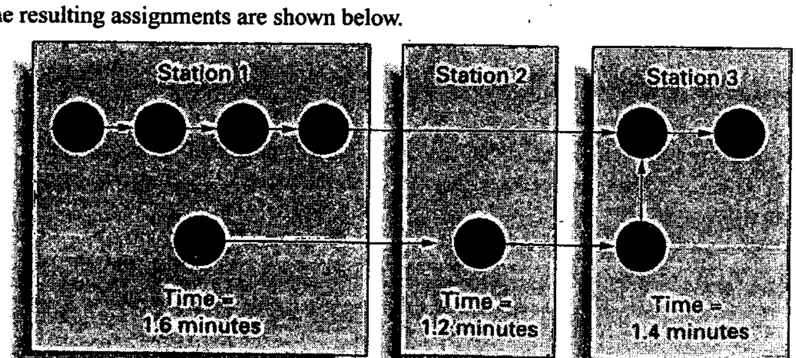
c. Add positional weights (task time plus the sum of all following times) to the diagram. Start at the right end and work backwards:



Station	Time Remaining*	Eligible	Will Fit	Assign Task/Time	Station Idle Time
1	1.6	a, b	a, b	b/0.6	
	1.0	a, d	a	a/0.3	
	0.7	c, d	c	c/0.4	
	0.3	e, d	e	e/0.2	
	0.1	g, d	g	g/0.1	
	0	—	—	—	0
2	1.6	d	d	d/1.2	
	0.4	f	none	none	0.4
3	1.6	f	f	f/0.6	
	1.0	h	h	h/0.5	
	0.5	i	i	i/0.3	
	0.2	—	—	—	0.2
					0.6

*The initial time for each station is the cycle time computed in part *a.*

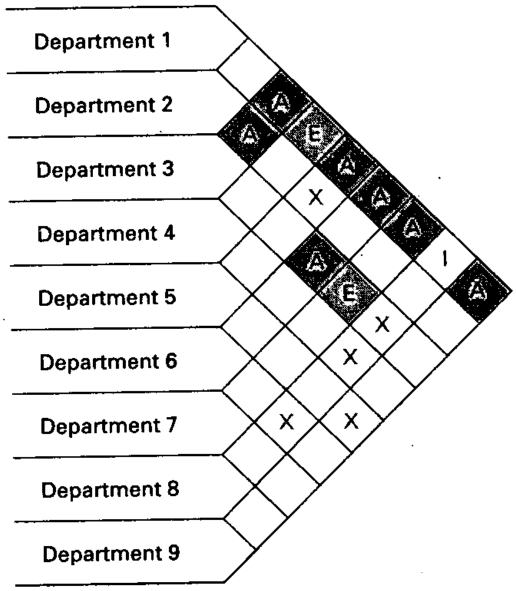
The resulting assignments are shown below.



d. Efficiency = 100% − percent idle time = $100\% - \frac{0.6 \text{ min.}}{3 \times 1.6 \text{ min.}} 100 = 87.5\%$.

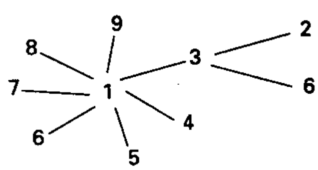
Problem 2

Assign nine automobile service departments to bays in a 3 × 3 grid so that the closeness ratings in the following matrix are satisfied. (The unimportant and ordinary-importance ratings have been omitted to simplify the example.) The location of department 4 must be in the upper right-hand corner of the grid to satisfy a town ordinance.

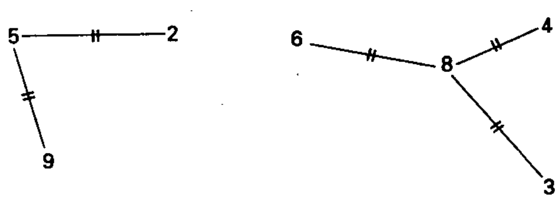


Solution

Note that department 1 has many A ratings, making it a strong candidate for the center position in the grid. We can form a cluster of departments that should be close together:



Next, we can identify departmental pairings that should be avoided:



These departments should be spaced around the perimeter of the grid. After a bit of trial and error, the final grid shown below emerged. Check it against the rating matrix to see if it satisfies the ratings.

2	3	4
9	1	6
8	7	5

Problem 3

Five departments are to be assigned to locations B–F in the grid. (For technical reasons, department 6 must be assigned to location A.) Transportation cost is $2 per foot. The objective is to minimize total transportation cost. Information on interdepartmental work flows and distances between locations is shown in the following tables. Assign departments with the greatest interdepartmental work flow first.

From	To	DISTANCE BETWEEN LOCATIONS (FEET)					
		A	B	C	D	E	F
A		—	50	100	50	80	130
B			—	50	90	40	70
C				—	140	60	50
D					—	50	120
E						—	50
F							—

From	To	NUMBER OF TRIPS PER DAY BETWEEN CENTERS					
		1	2	3	4	5	6
1		—	125	62	64	25	50
2			—	10	17	26	54
3				—	2	0	20
4					—	13	2
5						—	5
6							—

A Dept. 6	B	C
D	E	F

Solution

First either rank or arrange the workflow from high to low. Here they have been arranged from high to low.

Dept.	Workflow
1–2	125
1–4	64
1–3	62
2–6	54
1–6	50
2–5	26
1–5	25
3–6	20
2–4	17
4–5	13
2–3	10
5–6	5
3–4	2
4–6	2
3–5	0

From this, we can see that departments 1 and 2 have the greatest interdepartmental work flow, so they should be close, perhaps at B and E. Next, work flows for 1–3 and 1–4 are high. Note, though, that the work flow for 3–4 is low, suggesting that they need not be close. Instead, we would place them on either side of department 1. Note also that 3–4 is only 2, 3–5 is 0, while 3–6 is 20 and 4–5 is 13. Hence, place department 3 at location D, department 4 at location F, and department 5 at location C.

A Dept. 6	B Dept. 2	C Dept. 5
D Dept. 3	E Dept. 1	F Dept. 4

Total cost:

Trip	b Distance		c Frequency	(b × c × $2) Cost
1–2	(B–E)	40	125	$10,000
1–3	(D–E)	50	62	6,200
1–4	(F–E)	50	64	6,400
1–5	(E–C)	60	25	3,000
1–6	(A–E)	80	50	8,000
2–3	(B–D)	90	10	1,800
2–4	(B–F)	70	17	2,380
2–5	(B–C)	50	26	2,600
2–6	(A–B)	50	54	5,400
3–4	(F–D)	120	2	480
3–5	(D–C)	140	0	0
3–6	(A–D)	50	20	2,000
4–5	(C–F)	50	13	1,300
4–6	(A–F)	130	2	520
5–6	(A–C)	100	5	1,000
				$51,080

DISCUSSION AND REVIEW QUESTIONS

1. Explain the importance of process selection in system design.
2. Briefly describe the five process types, and indicate the kinds of situations in which each would be used.
3. Briefly discuss the advantages and disadvantages of automation.
4. Briefly describe computer-assisted approaches to production.
5. What is a flexible manufacturing system, and under what set of circumstances is it most appropriate?
6. Why is management of technology important?
7. Why might the choice of equipment that provides flexibility sometimes be viewed as a management copout?
8. What are the trade-offs that occur when a process layout is used? What are the trade-offs that occur when a product layout is used?
9. List some common reasons for redesigning layouts.
10. Briefly describe the two main layout types.
11. What are the main advantages of a product layout? The main disadvantages?
12. What are the main advantages of a process layout? The main disadvantages?
13. What is the goal of line balancing? What happens if a line is unbalanced?
14. Why are routing and scheduling continual problems in process layouts?
15. Compare equipment maintenance strategies in product and process layouts.
16. Briefly outline the impact that job sequence has on each of the layout types.
17. The City Transportation Planning Committee must decide whether to begin a long-term project to build a subway system or to upgrade the present bus service. Suppose you are an expert in fixed-path and variable-path material-handling equipment, and the committee seeks your counsel on this matter. What are the advantages and limitations of the subway and bus systems?

18. Identify the fixed-path and variable-path material-handling equipment commonly found in supermarkets.
19. What are heuristic approaches, and why are they used in designing layouts?
20. Why are product layouts atypical in service environments?
21. According to a study by the Alliance of American Insurers, it costs more than three times the original purchase price in parts and labor to reconstruct a wrecked Chevrolet. Explain the reasons for this large discrepancy in terms of the processes used to assemble the original car and those required to reconstruct the wrecked car.
22. Name some ways that a layout can help or hinder productivity.
23. What is cellular manufacturing? What are its main benefits and limitations?
24. What is group technology?
25. Explain the consequences of task time variability on line balancing.

TAKING STOCK

1. Name three major trade-offs in process selection.
2. What trade-offs are involved when deciding how often to rebalance an assembly line?
3. Who needs to be involved in process selection?
4. Who needs to be involved in layout design?
5. In what ways does technology have an impact on process selection? How can technology impact layout decisions?

CRITICAL THINKING EXERCISES

1. There are several factors that must exist in order to make automation feasible. Name the two or three most important factors and briefly explain their importance.
2. Layout decisions affect a wide range of facilities, from factories, supermarkets, offices, department stores, and warehouses, to malls, parking lots and garages, and kitchens. Layout is also important in the design of some products such as the interiors of automobiles and the arrangement of components inside computers and other electronic devices. Select three different items from this list, or other similar items, and explain for each what the four or five key considerations for layout design are.

PROBLEMS

a. Min = 2.4 min.; max = 18 min.
b. 25 to 187.5 units
c. 8 stations
d. 3.6 min/cycle
e. (1) 50 units
(2) 30 units

1. An assembly line with 17 tasks is to be balanced. The longest task is 2.4 minutes, and the total time for all tasks is 18 minutes. The line will operate for 450 minutes per day.
   a. What are the minimum and maximum cycle times?
   b. What range of output is theoretically possible for the line?
   c. What is the minimum number of workstations needed if the maximum output rate is to be sought?
   d. What cycle time will provide an output rate of 125 units per day?
   e. What output potential will result if the cycle time is (1) 9 minutes? (2) 15 minutes?

a.

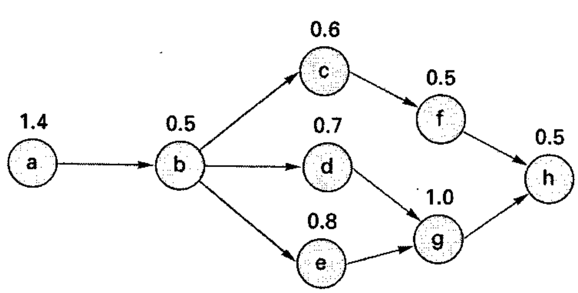
Station	Tasks
1	a
2	b, e
3	d, c, f
4	g, h

b.

Station	Tasks
1	a
2	b, e
3	d, c, f
4	g, h

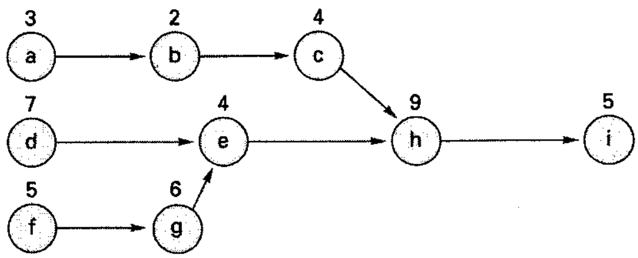
c. a and b are both 83.33%

2. A manager wants to assign tasks to workstations as efficiently as possible, and achieve an hourly output of 33⅓ units. Assume the shop works a 60-minute hour. Assign the tasks shown in the accompanying precedence diagram (times are in minutes) to workstations using the following rules:
   a. In order of most following tasks. Tiebreaker: greatest positional weight.
   b. In order of greatest positional weight.
   c. What is the efficiency?



3. A manager wants to assign tasks to workstations as efficiently as possible, and achieve an hourly output of 4 units. The department uses a working time of 56 minutes per hour. Assign the tasks shown in the accompanying precedence diagram (times are in minutes) to workstations using the following rules:

a. In order of most following tasks. Tiebreaker: greatest positional weight.
b. In order of greatest positional weight.
c. What is the efficiency?



4. A large manufacturer of pencil sharpeners is planning to add a new line of sharpeners, and you have been asked to balance the process, given the following task times and precedence relationships. Assume that cycle time is to be the minimum possible.

Task	Length (minutes)	Immediate Follower
a	0.2	b
b	0.4	d
c	0.3	d
d	1.3	g
e	0.1	f
f	0.8	g
g	0.3	h
h	1.2	end

a. Do each of the following:
(1) Draw the precedence diagram.
(2) Assign tasks to stations in order of greatest number of following tasks.
(3) Determine the percentage of idle time.
(4) Compute the rate of output that could be expected for this line assuming a 420-minute working day.

b. Answer these questions:
(1) What is the shortest cycle time that will permit use of only two workstations? Is this cycle time feasible? Identify the tasks you would assign to each station.
(2) Determine the percentage of idle time that would result if two stations were used.
(3) What is the daily output under this arrangement?
(4) Determine the output rate that would be associated with the maximum cycle time.

5. As part of a major plant renovation project, the industrial engineering department has been asked to balance a revised assembly operation to achieve an output of 240 units per eight-hour day. Task times and precedence relationships are is follows:

Task	Duration (minutes)	Precedes Task
a	0.2	b
b	0.4	c
c	0.2	f
d	0.4	e
e	1.2	g
f	1.2	g
g	1.0	end

Do each of the following:
a. Draw the precedence diagram.
b. Determine the minimum cycle time, the maximum cycle time, and the calculated cycle time.

c. Determine the minimum number of stations needed.
d. Assign tasks to workstations on the basis of greatest number of following tasks. Use longest processing time as a tiebreaker. If ties still exist, assume indifference in choice.
e. Compute the percentage of idle time for the assignment in part *d.*

6. Twelve tasks, with times and precedence requirements as shown in the following table, are to be assigned to workstations using a cycle time of 1.5 minutes. Two heuristic rules will be tried: (1) greatest positional weight, and (2) greatest number of following tasks.
   In each case, the tiebreaker will be shortest task time.

Task	Length (minutes)	Follows Task
a	0.1	—
b	0.2	a
c	0.9	b
d	0.6	c
e	0.1	—
f	0.2	d, e
g	0.4	f
h	0.1	g
i	0.2	h
j	0.7	i
k	0.3	j
l	0.2	k

a. Draw the precedence diagram for this line.
b. Assign tasks to stations under each of the two rules.
c. Compute the percentage of idle time for each rule.

7. For the set of tasks given below, do the following:
   a. Develop the precedence diagram.
   b. Determine the minimum and maximum cycle times in seconds for a desired output of 500 units in a 7-hour day. Why might a manager use a cycle time of 50 seconds?
   c. Determine the minimum number of workstations for output of 500 units per day.
   d. Balance the line using the *largest positional weight* heuristic. Break ties with the *most following tasks* heuristic. Use a cycle time of 50 seconds.
   e. Calculate the percentage idle time for the line.

Task	Task Time (seconds)	Immediate Predecessors
A	45	—
B	11	A
C	9	B
D	50	—
E	26	D
F	11	E
G	12	C
H	10	C
I	9	F, G, H
J	10	I
	193	

a. See IM.
b. $CT = \frac{OT}{D} = \frac{7(60)}{500}$
$= .84$ min.
c. $n = \frac{(D)(\Sigma t)}{OT} = \frac{(500)(193)}{(420)(60)}$
$= 3.83$ or 4 stations
d. See IM.
e. Percentage of idle time $=$
$\frac{\text{Total idle time}}{N \times CT} = \frac{57}{5(50)} =$
.228 or 22.8%

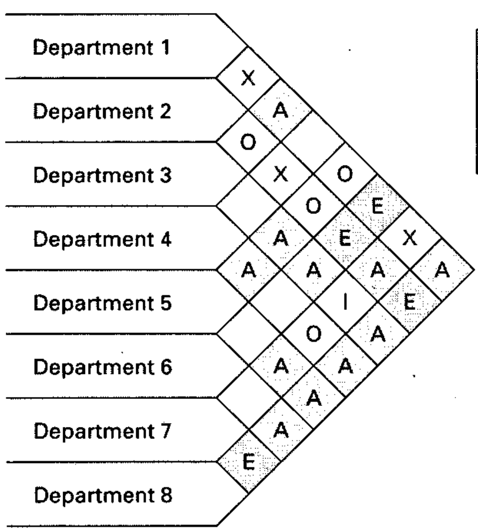
8. A shop works a 400-minute day. The manager of the shop wants an output of 200 units per day for the assembly line that has the elemental tasks shown in the table. Do the following:
   a. Construct the precedence diagram.
   b. Assign tasks according to the *most following tasks* rule.
   c. Assign tasks according to the *greatest positional weight* rule.
   d. Compute the balance delay for each rule. Which one yields the better set of assignments in this instance?

a. See IM
b.

Station	Tasks
1	a, b
2	c, d
3	f, e, i
4	j, g, h
5	k, m

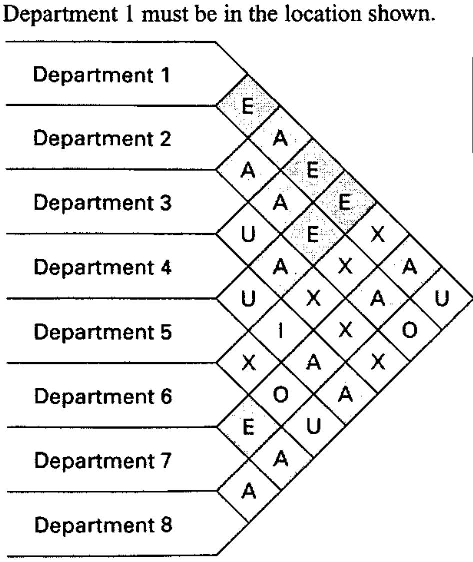
Task	Immediately Precedes Task(s)	Task Time
a	b, c, d	0.5
b	e	1.4
c	e	1.2
d	f	0.7
e	g, j	0.5
f	i	1.0
g	h	0.4
h	k	0.3
i	j	0.5
j	k	0.8
k	m	0.9
m	end	0.3

9. Arrange six departments into a 2 × 3 grid so that these conditions are satisfied: 1 close to 2, 5 close to 2 and 6, 2 close to 5, and 3 not close to 1 or 2.
10. Using the information given in the preceding problem, develop a Muther-type grid using the letters A, O, and X. Assume that any pair of combinations not mentioned have an O rating.
11. Using the information in the following grid, determine if the department locations shown are appropriate. If not, modify the assignments so that the conditions are satisfied.



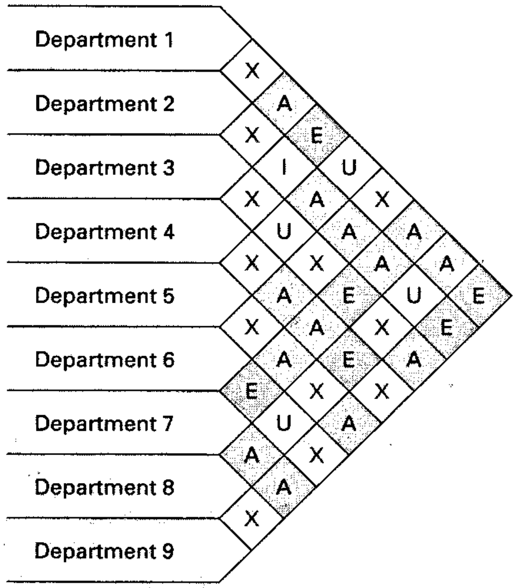
2	5	4
1	8	6
7	3	

12. Arrange the eight departments shown in the accompanying Muther grid into a 2 × 4 format. *Note:* Department 1 must be in the location shown.

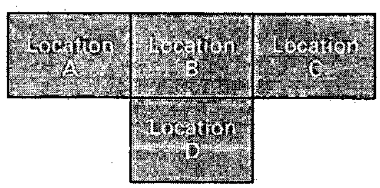


	1		

13. Arrange the departments so they satisfy the conditions shown in the following rating grid into a 3 × 3 format. Place department 5 in the lower left corner of the 3 × 3 grid.



14. Determine the placement of departments for a newly designed facility that will minimize total transportation costs using the data in the following tables. Assume that reverse distances are the same. The locations are shown in the grid. Use a cost of $1 per trip yard.



DISTANCE BETWEEN LOCATIONS (YARDS)

From \ To	A	B	C	D
A	—	40	80	70
B		—	40	50
C			—	60
D				—

NUMBER OF TRIPS PER DAY BETWEEN DEPARTMENTS

From \ To	1	2	3	4
1	—	10	20	80
2		—	40	90
3			—	55
4				—

15. Eight work centers must be arranged in an L-shaped building. The locations of centers 1 and 3 are assigned as shown in the accompanying diagram. Assuming transportation costs are $1 per load per meter, develop a suitable layout that minimizes transportation costs using the given information. Compute the total cost. (Assume the reverse distances are the same.)

DISTANCE (METERS)

From \ To	A	B	C	D	E	F	G	H
A	—	40	40	60	120	80	100	110
B		—	60	40	60	140	120	130
C			—	45	85	40	70	90
D				—	40	50	40	45
E					—	90	50	40
F						—	40	60
G							—	40
H								—

From \ To	1	2	3	4	5	6	7	8
				LOADS PER DAY				
1	—	10	5	90	370	135	125	0
2		—	360	120	40	115	45	120
3			—	350	110	40	20	200
4				—	190	70	50	190
5					—	10	40	10
6						—	50	20
7							—	20
8								—

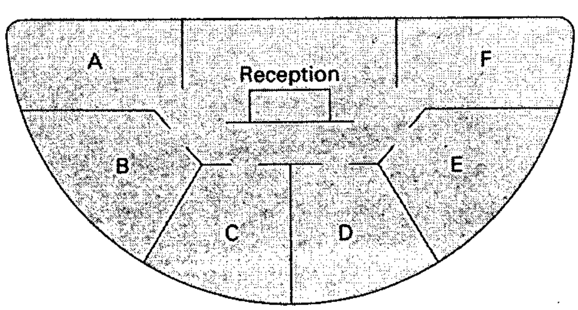
16. Develop a process layout that will minimize the total distance traveled by patients at a medical clinic, using the following information on projected departmental visits by patients and distance between locations. Assume a distance of 35 feet between the reception area and each potential location. Use the format shown.

DISTANCE BETWEEN LOCATIONS (FEET)

From \ To	A	B	C	D	E	F
A	—	40	80	100	120	160
B		—	40	60	80	120
C			—	20	40	80
D				—	20	40
E					—	40
F						—

TRIPS BETWEEN DEPARTMENTS (PER DAY)

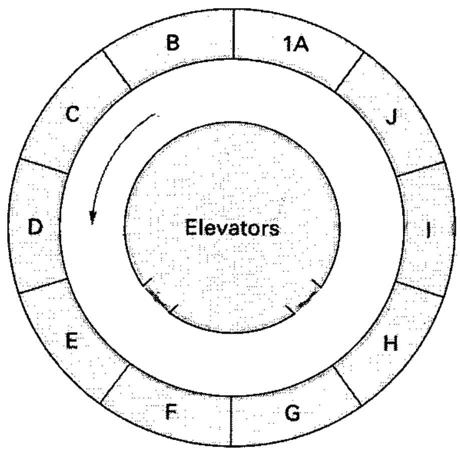
From \ To	Reception	1	2	3	4	5	6
Reception	—	20	50	210	20	10	130
1	10	—	0	40	110	80	50
2	40		—	0	50	40	120
3	10		0	—	10	250	10
4	0				—	40	90
5	10					—	20
6	30						—



17. Ten labs will be assigned to the circular layout shown. Recalling a similar layout's congestion in the halls, the new lab manager has requested an assignment that will minimize traffic between offices. In addition, movement in the halls is restricted to a counterclockwise route. Develop a suitable layout using the following information.

NUMBER OF TRIPS PER DAY BETWEEN DEPARTMENTS

From \ To	1	2	3	4	5	6	7	8	9	10
1	—	40	51	26	23	9	20	12	11	35
2		—	37	16	27	15	18	18	18	36
3			—	18	20	14	50	18	25	36
4				—	35	14	14	22	23	31
5					—	24	14	13	21	25
6						—	17	44	42	25
7							—	14	33	40
8								—	43	35
9									—	47
10										—



18. Rebalance the assembly line in Problem 7. This time, use the *longest operation time* heuristic. Break ties with the *most following tasks* heuristic. What is the percentage idle time for your line?

Morton Salt

OPERATIONS TOUR

www.mortonintl.com

Introduction

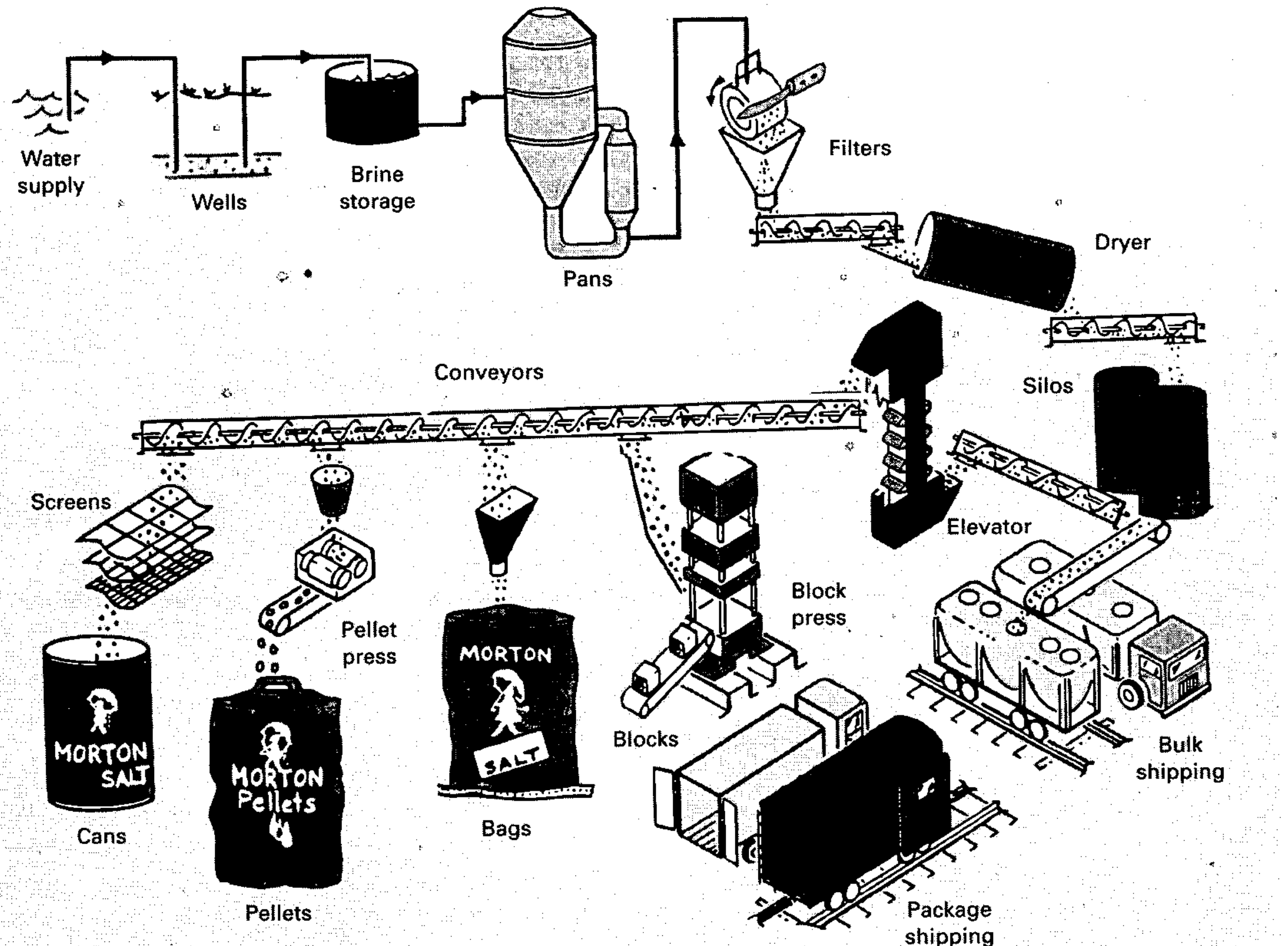
Morton Salt is a subsidiary of Morton International, a manufacturer of specialty chemicals, air bags, and salt products. The Morton salt-processing facility in Silver Springs, New York, between Buffalo and Rochester, is one of six similar Morton salt-processing facilities in the United States. The Silver Springs plant employs about 200 people, ranging from unskilled to skilled. It produces salt products for water conditioning, grocery, industrial, and agricultural markets. The grocery business consists of 26 oz. round cans of iodized salt. Although the grocery business represents a relatively small portion of the total output (approximately 15 percent), it is the most profitable.

Salt Production

The basic raw material, salt, is obtained by injecting water into salt caverns that are located some 2,400 feet below the surface. There, the salt deposits dissolve in the water. The resulting brine is pumped to the surface where it is converted into salt crystals. The brine is boiled, and much of the liquid evaporates, leaving salt crystals and some residual moisture, which is removed in a drying process. This process is run continuously for about six weeks at a time. Initially, salt is produced at the rate of 45 tons per hour. But the rate of output decreases due to scale build up, so that by the sixth week, output is only 75 percent of the initial rate. At that point, the process is halted to perform maintenance on the equipment and remove the scale, after which, salt production resumes.

The salt is stored in silos until it is needed for production, or it is shipped in bulk to industrial customers. Conveyors move

(continued)



the salt to each of the four dedicated production areas, one of which is round can production. (See diagram.) The discussion here focuses exclusively on round can production.

Round Can Production

Annual round can production averages roughly 3.8 million cans. Approximately 70 percent of the output is for the Morton label, and the rest is for private label. There are two parallel, high-speed production lines. The two lines share common processes at the beginning of the lines, and then branch out into two identical lines. Each line is capable of producing 9,600 cans per hour (160 cans per minute). The equipment is not flexible, so the production rate is fixed. The operations are completely standardized; the only variable is the brand label that is applied. One line requires 12 production workers, while both lines together can be operated by 18 workers because of the common processes. Workers on the line perform low-skilled, repetitive tasks.

The plant produces both the salt and the cans the salt is packaged in. The cans are essentially a cylinder with a top and a bottom; they are made of cardboard, except for a plastic pour spout in the top. The cylinder portion is formed from two sheets of chip board that are glued together and then rolled into a continuous tube. The glue not only binds the material, it also provides a moisture barrier. The tube is cut in a two-step process: it is first cut into long sections, and those sections are then cut into can-size pieces. The top and bottom pieces for the cans are punched from a continuous strip of cardboard. The separate pieces move along conveyor belts to the lines where the components are assembled into cans and glued. The cans are then filled with salt and the pour spout is added. Finally, the cans are loaded onto pallets and placed into inventory, ready to be shipped to distributors.

Quality

Quality is checked at several points in the production process. Initially, the salt is checked for purity when it is obtained from the wells. Iodine and an anti-caking compound are added to the salt, and their levels are verified using chemical analysis. Crystal size is important. In order to achieve the desired size and to remove lumps, the salt is forced through a scraping screen, which can cause very fine pieces of metal to mix with the salt. However, these pieces are effectively removed by magnets that are placed at appropriate points in the process. If, for any reason, the salt is judged to be contaminated, it is diverted to a nonfood product.

(continued)

(concluded)

Checking the quality of the cans is done primarily by visual inspection, including verifying the assembly operation is correct, checking filled cans for correct weight, inspecting cans to see that labels are properly aligned, and checking to see that metal pour spouts are correctly attached.

The equipment on the production line is sensitive to misshapen or damaged cans, and frequently jams, causing production delays. This greatly reduces the chance of a defective can getting through the process, but it reduces productivity, and the salt in the defective cans must be scrapped. The cost of quality is fairly high, owing to the amount of product that is scrapped, the large number of inspectors, and the extensive laboratory testing that is needed.

Production Planning and Inventory

The plant can sell all of the salt it produces. The job of the production scheduler is to distribute the salt that is stored in the silos to the various production areas, taking into account production capacities in each area and available inventory levels of those products. A key consideration is to make sure there is sufficient storage capacity in the silos to handle the incoming salt from brine production.

Equipment Maintenance and Repair

The equipment is 1950s vintage, and it requires a fair amount of maintenance to keep it in good working order. Even so, breakdowns occur as parts wear out. The plant has its own tool shop where skilled workers repair parts or make new parts because replacement parts are no longer available for the old equipment.

Questions

1. Briefly describe salt production, from brine production to finished round cans.
2. Briefly describe quality assurance efforts in round can production.
3. What are some of the possible reasons why the company continues to use the old processing equipment instead of buying new, more modern equipment?
4. Where would you place salt production in the product–process spectrum?
5. Determine the approximate number of tons of salt produced annually. Hints: one ton = 2,000 pounds, and one pound = 16 ounces.
6. What improvements can you suggest for the plant?

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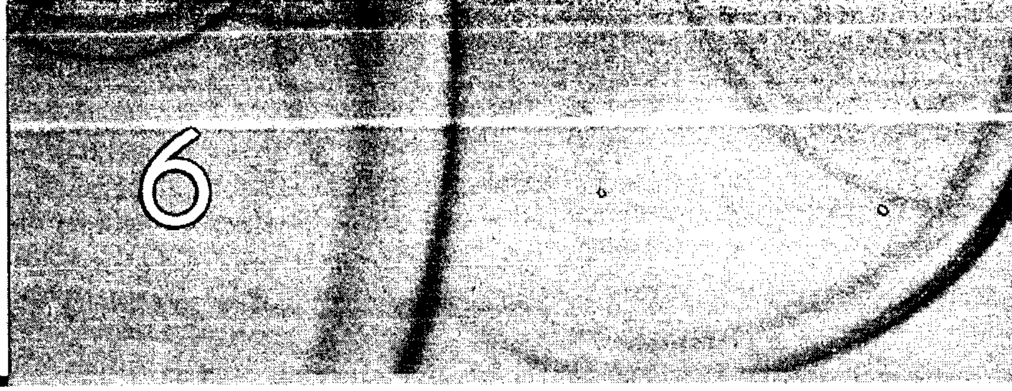
Supplement to

CHAPTER 6



Linear Programming

LEARNING OBJECTIVES

After completing this supplement, you should be able to:

1. Describe the type of problem that would lend itself to solution using linear programming.
2. Formulate a linear programming model from a description of a problem.
3. Solve simple linear programming problems using the graphical method.
4. Interpret computer solutions of linear programming problems.
5. Do sensitivity analysis on the solution of a linear programming problem.

SUPPLEMENT OUTLINE

Linear programming is a powerful quantitative tool used by operations managers and other managers to obtain optimal solutions to problems that involve restrictions or limitations, such as budgets and available materials, labor, and machine time. These problems are referred to as *constrained optimization* problems. There are numerous examples of linear programming applications to such problems, including

- Establishing locations for emergency equipment and personnel that will minimize response time.
- Determining optimal schedules for airlines for planes, pilots, and ground personnel.
- Developing financial plans.
- Determining optimal blends of animal feed mixes.
- Determining optimal diet plans.
- Identifying the best set of worker–job assignments.

- Developing optimal production schedules.
- Developing shipping plans that will minimize shipping costs.
- Identifying the optimal mix of products in a factory.
- Performing production and service planning.

INTRODUCTION

Linear programming (LP) techniques consist of a sequence of steps that will lead to an optimal solution to linear-constrained problems, if an optimum exists. There are a number of different linear programming techniques; some are special-purpose (i.e., used to find solutions for specific types of problems) and others are more general in scope. This supplement covers the two general-purpose solution techniques: graphical linear programming and computer solutions. Graphical linear programming provides a visual portrayal of many of the important concepts of linear programming. However, it is limited to problems with only two variables. In practice, computers are used to obtain solutions for problems, some of which involve a large number of variables.

LINEAR PROGRAMMING MODELS

Tutorial

Linear programming models are mathematical representations of constrained optimization problems. These models have certain characteristics in common. Knowledge of these characteristics enables us to recognize problems that can be solved using linear programming. In addition, it also can help us formulate LP models. The characteristics can be grouped into two categories: components and assumptions. First, let's consider the components.

Four components provide the structure of a linear programming model:

1. Objective function.
2. Decision variables.
3. Constraints.
4. Parameters.

Linear programming algorithms require that a single goal or *objective,* such as the maximization of profits, be specified. The two general types of objectives are maximization and minimization. A maximization objective might involve profits, revenues, efficiency, or rate of return. Conversely, a minimization objective might involve cost, time, distance traveled, or scrap. The **objective function** is a mathematical expression that can be used to determine the total profit (or cost, etc., depending on the objective) for a given solution.

objective function Mathematical statement of profit (or cost, etc.) for a given solution.

Decision variables represent choices available to the decision maker in terms of amounts of either inputs or outputs. For example, some problems require choosing a combination of inputs to minimize total costs, while others require selecting a combination of outputs to maximize profits or revenues.

decision variables Amounts of either inputs or outputs.

Constraints are limitations that restrict the alternatives available to decision makers. The three types of constraints are less than or equal to ($\leq$), greater than or equal to ($\geq$), and simply equal to ($=$). A $\leq$ constraint implies an upper limit on the amount of some scarce resource (e.g., machine hours, labor hours, materials) available for use. A $\geq$ constraint specifies a minimum that must be achieved in the final solution (e.g., must contain at least 10 percent real fruit juice, must get at least 30 MPG on the highway). The $=$ constraint is more restrictive in the sense that it specifies *exactly* what a decision variable should equal (e.g., make 200 units of product A). A linear programming model can consist of one or more constraints. The constraints of a given problem define the set of all feasible combinations of decision variables; this set is referred to as the **feasible solution space.** Linear programming algorithms are designed to search the feasible solution space for the combination of decision variables that will yield an optimum in terms of the objective function.

constraints Limitations that restrict the available alternatives.

feasible solution space The set of all feasible combinations of decision variables as defined by the constraints.

An LP model consists of a mathematical statement of the objective and a mathematical statement of each constraint. These statements consist of symbols (e.g., x_1, x_2) that represent the decision variables and numerical values, called **parameters.** The parameters are fixed values; the model is solved *given* those values.

parameters Numerical constants.

Example S–1 illustrates an LP model.

EXAMPLE S-1

Here is an LP model of a situation that involves the production of three possible products, each of which will yield a certain profit per unit, and each requires a certain use of two resources that are in limited supply: labor and materials. The objective is to determine how much of each product to make to achieve the greatest possible profit while satisfying all constraints.

Decision variables
x_1 = Quantity of product 1 to produce
x_2 = Quantity of product 2 to produce
x_3 = Quantity of product 3 to produce

Maximize	$5x_1 + 8x_2 + 4x_3$ (profit)	(Objective function)
Subject to		
Labor	$2x_1 + 4x_2 + 8x_3 \leq 250$ hours	
Material	$7x_1 + 6x_2 + 5x_3 \leq 100$ pounds	(Constraints)
Product 1	$x_1 \geq 10$ units	
	$x_1, x_2, x_3 \geq 0$	(Nonnegativity constraints)

First, the model lists and defines the decision variables. These typically represent *quantities.* In this case, they are quantities of three different products that might be produced.

Next, the model states the objective function. It includes every decision variable in the model and the contribution (profit per unit) of each decision variable. Thus, product x_1 has a profit of $5 per unit. The profit from product x_1 for a given solution will be 5 times the value of x_1 specified by the solution; the total profit from all products will be the sum of the individual product profits. Thus, if $x_1 = 10, x_2 = 0$, and $x_3 = 6$, the value of the objective function would be

$$5(10) + 8(0) + 4(6) = 74$$

The objective function is followed by a list (in no particular order) of three constraints. Each constraint has a right-side numerical value (e.g., the labor constraint has a right-side value of 250) that indicates the amount of the constraint and a relation sign that indicates whether that amount is a maximum ($\leq$), a minimum ($\geq$), or an equality ($=$). The left side of each constraint consists of the variables subject to that particular constraint and a coefficient for each variable that indicates how much of the right-side quantity *one unit* of the decision variable represents. For instance, for the labor constraint, one unit of x_1 will require two hours of labor. The sum of the values on the left side of each constraint represents the amount of that constraint used by a solution. Thus, if $x_1 = 10, x_2 = 0$, and $x_3 = 6$, the amount of labor used would be

$$2(10) + 4(0) + 8(6) = 68 \text{ hours}$$

Because this amount does not exceed the quantity on the right-hand side of the constraint, it is said to be *feasible.*

Note that the third constraint refers to only a single variable; x_1 must be at least 10 units. Its implied coefficient is 1, although that is not shown.

Finally, there are the nonnegativity constraints. These are listed on a single line; they reflect the condition that no decision variable is allowed to have a negative value.

In order for linear-programming models to be used effectively, certain *assumptions* must be satisfied. These are

1. *Linearity:* the impact of decision variables is linear in constraints and the objective function.
2. *Divisibility:* noninteger values of decision variables are acceptable.

3. *Certainty:* values of parameters are known and constant.
4. *Nonnegativity:* negative values of decision variables are unacceptable.

Model Formulation

An understanding of the components of linear programming models is necessary for model formulation. This helps provide organization to the process of assembling information about a problem into a model.

Naturally, it is important to obtain valid information on what constraints are appropriate, as well as on what values of the parameters are appropriate. If this is not done, the usefulness of the model will be questionable. Consequently, in some instances, considerable effort must be expended to obtain that information.

In formulating a model, use the format illustrated in Example 1. Begin by identifying the decision variables. Very often, decision variables are "the quantity of" something, such as x_1 = the quantity of product 1. Generally, decision variables have profits, costs, times, or a similar measure of value associated with them. Knowing this can help you identify the decision variables in a problem.

Constraints are restrictions or requirements on one or more decision variables, and they refer to available amounts of resources such as labor, material, or machine time, or to minimal requirements, such as "make at least 10 units of product 1." It can be helpful to give a name to each constraint, such as "labor" or "material 1." Let's consider some of the different kinds of constraints you will encounter.

1. A constraint that refers to one or more decision variables. This is the most common kind of constraint. The constraints in Example 1 are of this type.

2. A constraint that specifies a ratio. For example, "the ratio of x_1 to x_2 must be at least 3 to 2." To formulate this, begin by setting up the ratio:

$$\frac{x_1}{x_2} \geq \frac{3}{2}$$

Then, cross multiply, obtaining

$$2x_1 \geq 3x_2$$

This is not yet in a suitable form because all variables in a constraint must be on the left side of the inequality (or equality) sign, leaving only a constant on the right side. To achieve this, we must subtract the variable amount that is on the right side from both sides. That yields

$$2x_1 - 3x_2 \geq 0$$

[Note that the direction of the inequality remains the same.]

3. A constraint that specifies a percentage for one or more variables relative to one or more other variables. For example, "x_1 cannot be more than 20 percent of the mix." Suppose that the mix consists of variables x_1, x_2, and x_3. In mathematical terms, this would be

$$x_1 \leq .20(x_1 + x_2 + x_3)$$

As always, all variables must appear on the left side of the relationship. To accomplish that, we can expand the right side, and then subtract the result from both sides. Expanding yields,

$$x_1 \leq .20x_1 + .20x_2 + .20x_3$$

Subtracting yields

$$.80x_1 - .20x_2 - .20x_3 \leq 0$$

Once you have formulated a model, the next task is to solve it. The following sections describe two approaches to problem solution: graphical solutions and computer solutions.

graphical linear programming Graphical method for finding optimal solutions to two-variable problems.

GRAPHICAL LINEAR PROGRAMMING

Graphical linear programming is a method for finding optimal solutions to two-variable problems. This section describes that approach.

IOM

Outline of Graphical Procedure

The graphical method of linear programming plots the constraints on a graph and identifies an area that satisfies all of the constraints. The area is referred to as the *feasible solution space.* Next, the objective function is plotted and used to identify the optimal point in the feasible solution space. The coordinates of the point can sometimes be read directly from the graph, although generally an algebraic determination of the coordinates of the point is necessary.

The general procedure followed in the graphical approach is

1. Set up the objective function and the constraints in mathematical format.
2. Plot the constraints.
3. Identify the feasible solution space.
4. Plot the objective function.
5. Determine the optimum solution.

The technique can best be illustrated through solution of a typical problem. Consider the problem described in Example S–2.

EXAMPLE S-2

General description: A firm that assembles computers and computer equipment is about to start production of two new types of microcomputers. Each type will require assembly time, inspection time, and storage space. The amounts of each of these resources that can be devoted to the production of the microcomputers is limited. The manager of the firm would like to determine the quantity of each microcomputer to produce in order to maximize the profit generated by sales of these microcomputers.

Additional information: In order to develop a suitable model of the problem, the manager has met with design and production personnel. As a result of those meetings, the manager has obtained the following information:

	Type 1	Type 2
Profit per unit	$60	$50
Assembly time per unit	4 hours	10 hours
Inspection time per unit	2 hours	1 hour
Storage space per unit	3 cubic feet	3 cubic feet

The manager also has acquired information on the availability of company resources. These (daily) amounts are

Resource	Amount Available
Assembly time	100 hours
Inspection time	22 hours
Storage space	39 cubic feet

The manager met with the firm's marketing manager and learned that demand for the microcomputers was such that whatever combination of these two types of microcomputers is produced, all of the output can be sold.

In terms of meeting the assumptions, it would appear that the relationships are *linear:* The contribution to profit per unit of each type of computer and the time and storage space per unit of each type of computer are the same regardless of the quantity produced. Therefore, the total impact of each type of computer on the profit and each constraint is a linear function of the quantity of that variable. There may be a question of *divisibility* because, presumably, only whole units of computers will be sold. However, because this is a recurring process (i.e., the computers will be produced daily, a noninteger solution such as 3.5 computers per day will result in 7 computers every other day), this does not seem to pose a problem. The question of *certainty* cannot be explored here; in practice, the manager could be questioned to determine if there are any other possible constraints and whether the values shown for assembly times, and so forth, are known with certainty. For the purposes of discussion, we will assume certainty. Last, the assumption of *nonnegativity* seems justified; negative values for production quantities would not make sense.

Because we have concluded that linear programming is appropriate, let us now turn our attention to constructing a model of the microcomputer problem. First, we must define the decision variables. Based on the statement, "The manager . . . would like to determine the quantity of each microcomputer to produce," the decision variables are the quantities of each type of computer. Thus,

x_1 = quantity of type 1 to produce
x_2 = quantity of type 2 to produce

Next, we can formulate the objective function. The profit per unit of type 1 is listed as \$60, and the profit per unit of type 2 is listed as \$50, so the appropriate objective function is

$$\text{Maximize } Z = 60x_1 + 50x_2$$

where Z is the value of the objective function, given values of x_1 and x_2. Theoretically, a mathematical function requires such a variable for completeness. However, in practice, the objective function often is written without the Z, as sort of a shorthand version. (That approach is underscored by the fact that computer input does not call for Z: It is understood. The output of a computerized model does include a Z, though.)

Now for the constraints. There are three resources with limited availability: assembly time, inspection time, and storage space. The fact that availability is limited means that these constraints will all be $\leq$ constraints. Suppose we begin with the assembly constraint. The type 1 microcomputer requires 4 hours of assembly time per unit, whereas the type 2 microcomputer requires 10 hours of assembly time per unit. Therefore, with a limit of 100 hours available, the assembly constraint is

$$4x_1 + 10x_2 \leq 100 \text{ hours}$$

Similarly, each unit of type 1 requires 2 hours of inspection time, and each unit of type 2 requires 1 hour of inspection time. With 22 hours available, the inspection constraint is

$$2x_1 + 1x_2 \leq 22$$

(Note: The coefficient of 1 for x_2 need not be shown. Thus, an alternative form for this constraint is $2x_1 + x_2 \leq 22$.) The storage constraint is determined in a similar manner:

$$3x_1 + 3x_2 \leq 39$$

There are no other system or individual constraints. The nonnegativity constraints are

$$x_1, x_2 \geq 0$$

In summary, the mathematical model of the microcomputer problem is

x_1 = quantity of type 1 to produce
x_2 = quantity of type 2 to produce

Maximize	$60x_1 + 50x_2$
Subject to	
Assembly	$4x_1 + 10x_2 \leq 100$ hours
Inspection	$2x_1 + 1x_2 \leq 22$ hours
Storage	$3x_1 + 3x_2 \leq 39$ cubic feet
	$x_1, x_2 \geq 0$

The next step is to plot the constraints.

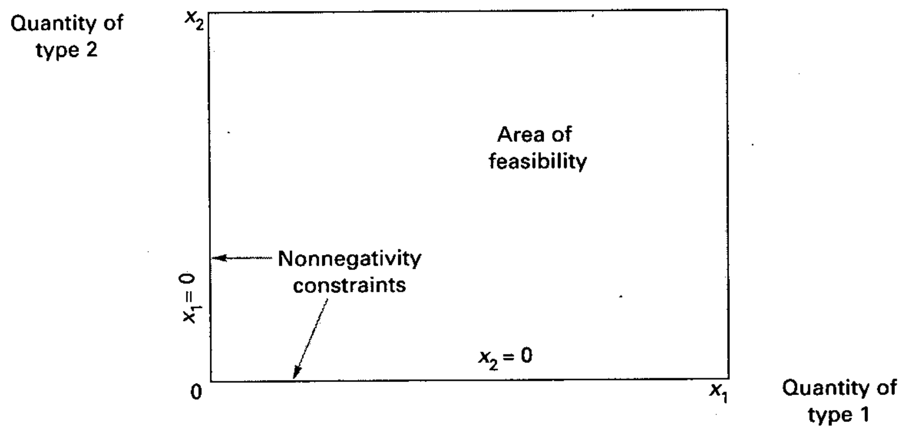


FIGURE 6S.1

Graph showing the nonnegativity constraints

Plotting Constraints

Begin by placing the nonnegativity constraints on a graph, as in Figure 6S.1. The procedure for plotting the other constraints is simple:

1. Replace the inequality sign with an equal sign. This transforms the constraint into an *equation of a straight line.*
2. Determine where the line intersects each axis.
   a. To find where it crosses the x_2 axis, set x_1 equal to zero and solve the equation for the value of x_2.
   b. To find where it crosses the x_1 axis, set x_2 equal to zero and solve the equation for the value of x_1.
3. Mark these intersections on the axes, and connect them with a straight line. (Note: If a constraint has only one variable, it will be a vertical line on a graph if the variable is x_1, or a horizontal line if the variable is x_2.)
4. Indicate by shading (or by arrows at the ends of the constraint line) whether the inequality is greater than or less than. (A general rule to determine which side of the line satisfies the inequality is to pick a point that is not on the line, such as 0,0, solve the equation using these values, and see whether it is greater than or less than the constraint amount.)
5. Repeat steps 1–4 for each constraint.

Consider the assembly time constraint:

$$4x_1 + 10x_2 \leq 100$$

Removing the inequality portion of the constraint produces this straight line:

$$4x_1 + 10x_2 = 100$$

Next, identify the points where the line intersects each axis, as step 2 describes. Thus with $x_2 = 0$, we find

$$4x_1 + 10(0) = 100$$

Solving, we find that $4x_1 = 100$, so $x_1 = 25$ when $x_2 = 0$. Similarly, we can solve the equation for x_2 when $x_1 = 0$:

$$4(0) + 10x_2 = 100$$

Solving for x_2, we find $x_2 = 10$ when $x_1 = 0$.

Thus, we have two points: $x_1 = 0, x_2 = 10$, and $x_1 = 25, x_2 = 0$. We can now add this line to our graph of the nonnegativity constraints by connecting these two points (see Figure 6S.2).

Next we must determine which side of the line represents points that are less than 100. To do this, we can select a test point that is not on the line, and we can substitute the x_1 and x_2 values of

FIGURE 6S.2

Plot of the first constraint (assembly time)

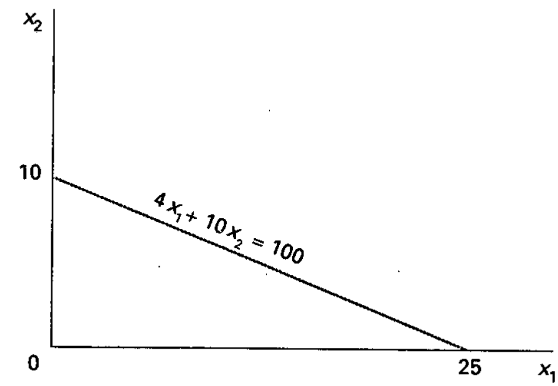
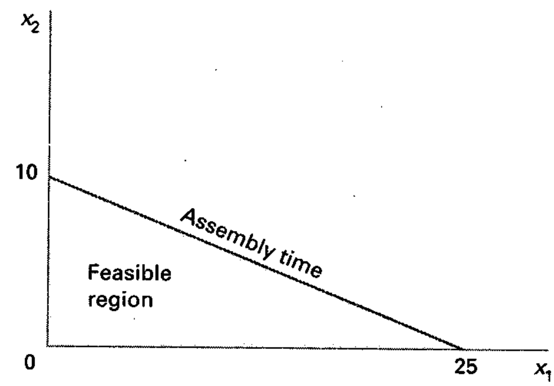


FIGURE 6S.3

The feasible region, given the first constraint and the nonnegativity constraints



that point into the left side of the equation of the line. If the result is less than 100, this tells us that all points on that side of the line are less than the value of the line (e.g., 100). Conversely, if the result is greater than 100, this indicates that the other side of the line represents the set of points that will yield values that are less than 100. A relatively simple test point to use is the origin (i.e., $x_1 = 0, x_2 = 0$). Substituting these values into the equation yields

$$4(0) + 10(0) = 0$$

Obviously this is less than 100. Hence, the side of the line closest to the origin represents the "less than" area (i.e., the feasible region).

The feasible region for this constraint and the nonnegativity constraints then becomes the shaded portion shown in Figure 6S.3.

For the sake of illustration, suppose we try one other point, say $x_1 = 10, x_2 = 10$. Substituting these values into the assembly constraint yields

$$4(10) + 10(10) = 140$$

Clearly this is greater than 100. Therefore, all points on this side of the line are greater than 100 (see Figure 6S.4).

Continuing with the problem, we can add the two remaining constraints to the graph. For the inspection constraint:

1. Convert the constraint into the equation of a straight line by replacing the inequality sign with an equality sign:

   $2x_1 + 1x_2 \leq 22$ becomes $2x_1 + 1x_2 = 22$

2. Set x_1 equal to zero and solve for x_2:

   $2(0) + 1x_2 = 22$

   Solving, we find $x_2 = 22$. Thus, the line will intersect the x_2 axis at 22.

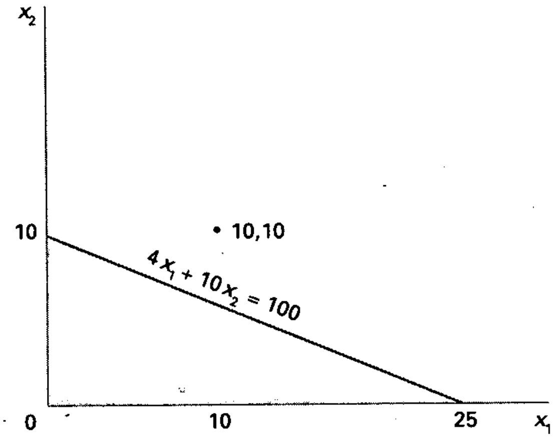


FIGURE 6S.4

The point 10, 10 is above the constraint line

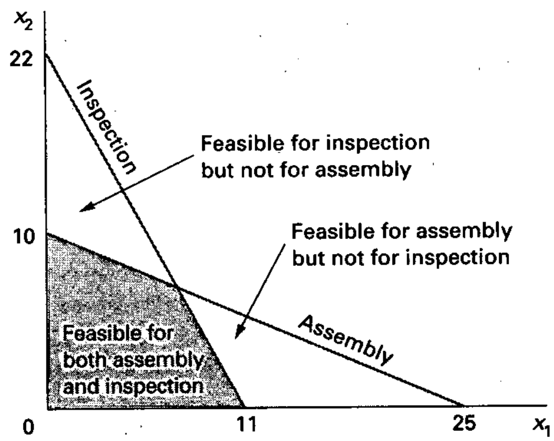


FIGURE 6S.5

Partially completed graph, showing the assembly, inspection, and nonnegativity constraints

3. Next, set x_2 equal to zero and solve for x_1:

   $2x_1 + 1(0) = 22$

   Solving, we find $x_1 = 11$. Thus, the other end of the line will intersect the x_1 axis at 11.
4. Add the line to the graph (see Figure 6S.5).

Note that the area of feasibility for this constraint is below the line (Figure 6S.5). Again the area of feasibility at this point is shaded in for illustration, although when graphing problems, it is more practical to refrain from shading in the feasible region until all constraint lines have been drawn. However, because constraints are plotted one at a time, using a small arrow at the end of each constraint to indicate the direction of feasibility can be helpful.

The storage constraint is handled in the same manner:

1. Convert it into an equality:

   $3x_1 + 3x_2 = 39$
2. Set x_1 equal to zero and solve for x_2:

   $3(0) + 3x_2 = 39$

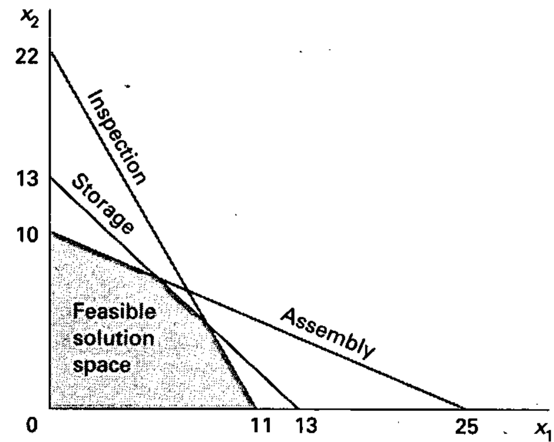
   Solving, $x_2 = 13$. Thus, $x_2 = 13$ when $x_1 = 0$.
3. Set x_2 equal to zero and solve for x_1:

   $3x_1 + 3(0) = 39$

   Solving, $x_1 = 13$. Thus, $x_1 = 13$ when $x_2 = 0$.

FIGURE 6S.6

Completed graph of the microcomputer problem showing all constraints and the feasible solution space



4. Add the line to the graph (see Figure 6S.6).

Identifying the Feasible Solution Space

The feasible solution space is the set of all points that satisfies *all* constraints. (Recall that the x_1 and x_2 axes form nonnegativity constraints.) The heavily shaded area shown in Figure 6S.6 is the feasible solution space for our problem.

The next step is to determine which point in the feasible solution space will produce the optimal value of the objective function. This determination is made using the objective function.

Plotting the Objective Function Line

Plotting an objective function line involves the same logic as plotting a constraint line: Determine where the line intersects each axis. Recall that the objective function for the microcomputer problem is

$$60x_1 + 50x_2$$

This is not an equation because it does not include an equal sign. We can get around this by simply setting it equal to some quantity. Any quantity will do, although one that is evenly divisible by both coefficients is desirable.

Suppose we decide to set the objective function equal to 300. That is,

$$60x_1 + 50x_2 = 300$$

We can now plot the line on our graph. As before, we can determine the x_1 and x_2 intercepts of the line by setting one of the two variables equal to zero, solving for the other, and then reversing the process. Thus, with $x_1 = 0$, we have

$$60(0) + 50x_2 = 300$$

Solving, we find $x_2 = 6$. Similarly, with $x_2 = 0$, we have

$$60x_1 + 50(0) = 300$$

Solving, we find $x_1 = 5$. This line is plotted in Figure 6S.7.

The profit line can be interpreted in the following way. It is an *isoprofit* line; every point on the line (i.e., every combination of x_1 and x_2 that lies on the line) will provide a profit of \$300. We can see from the graph many combinations that are both on the \$300 profit line and within the feasible solution space. In fact, considering noninteger as well as integer solutions, the possibilities are infinite.

Suppose we now consider another line, say the \$600 line. To do this, we set the objective function equal to this amount. Thus,

$$60x_1 + 50x_2 = 600$$

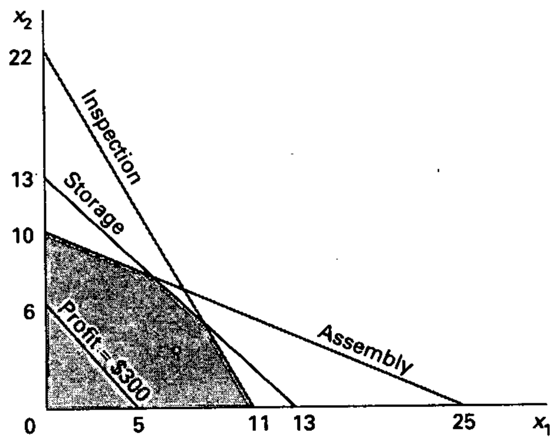


FIGURE 6S.7

Microcomputer problem with $300 profit line added

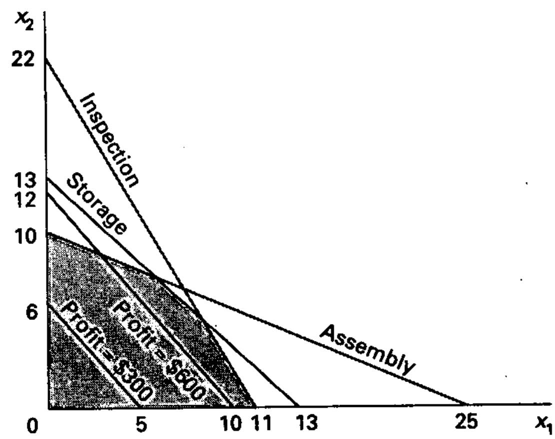


FIGURE 6S.8

Microcomputer problem with profit lines of $300 and $600

Solving for the x_1 and x_2 intercepts yields these two points:

x_1 intercept	x_2 intercept
$x_1 = 10$	$x_1 = 0$
$x_2 = 0$	$x_2 = 12$

This line is plotted in Figure 6S.8, along with the previous $300 line for purposes of comparison.

Two things are evident in Figure 6S.8 regarding the profit lines. One is that the $600 line is *farther* from the origin than the $300 line; the other is that the two lines are *parallel.* The lines are parallel because they both have the same slope. The slope is not affected by the right side of the equation. Rather, it is determined solely by the coefficients 60 and 50. It would be correct to conclude that regardless of the quantity we select for the value of the objective function, the resulting line will be parallel to these two lines. Moreover, if the amount is greater than 600, the line will be even farther away from the origin than the $600 line. If the value is less than 300, the line will be closer to the origin than the $300 line. And if the value is between 300 and 600, the line will fall between the $300 and $600 lines. This knowledge will help in determining the optimal solution.

Consider a third line, one with the profit equal to $900. Figure 6S.9 shows that line along with the previous two profit lines. As expected, it is parallel to the other two, and even farther away from the origin. However, the line does not touch the feasible solution space at all. Consequently, there is no feasible combination of x_1 and x_2 that will yield that amount of profit. Evidently, the maximum possible profit is an amount between $600 and $900, which we can see by referring to Figure 6S.9. We could continue to select profit lines in this manner, and

FIGURE 6S.9

Microcomputer problem with profit lines of $300, $600, and $900

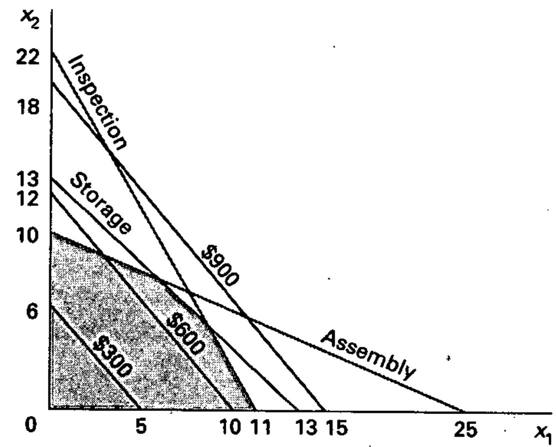
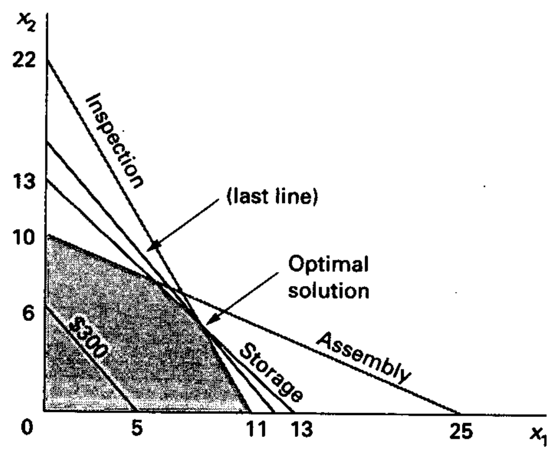


FIGURE 6S.10

Finding the optimal solution to the microcomputer problem



eventually, we could determine an amount that would yield the greatest profit. However, there is a much simpler alternative. We can plot just one line, say the $300 line. We know that all other lines will be parallel to it. Consequently, by moving this one line parallel to itself we can "test" other profit lines. We also know that as we move away from the origin, the profits get larger. What we want to know is how far the line can be moved out from the origin and still be touching the feasible solution space, and the values of the decision variables at that point of greatest profit (i.e., the optimal solution). Locate this point on the graph by placing a straight edge along the $300 line (or any other convenient line) and sliding it away from the origin, being careful to keep it parallel to the line. This approach is illustrated in Figure 6S.9.

Once we have determined where the optimal solution is in the feasible solution space, we must determine the values of the decision variables at that point. Then, we can use that information to compute the profit for that combination.

Note that the optimal solution is at the intersection of the inspection boundary and the storage boundary (see Figure 6S.10). In other words, the optimal combination of x_1 and x_2 must satisfy both boundary (equality) conditions. We can determine those values by solving the two equations *simultaneously*. The equations are

Inspection	$2x_1 + 1x_2 = 22$
Storage	$3x_1 + 3x_2 = 39$

The idea behind solving two *simultaneous equations* is to algebraically eliminate one of the unknown variables (i.e., to obtain an equation with a single unknown). This can be accomplished by multiplying the constants of one of the equations by a fixed amount and then adding (or subtracting) the modified equation from the other. (Occasionally, it is easier to multiply each equation by a fixed quantity.) For example, we can eliminate x_2 by multiplying the inspection equation by 3 and then subtracting the storage equation from the modified inspection equation. Thus,

$3(2x_1 + 1x_2 = 22)$ becomes $6x_1 + 3x_2 = 66$

Subtracting the storage equation from this produces

$$\begin{array}{r} 6x_1 + 3x_2 = 66 \\ -\ \underline{(3x_1 + 3x_2 = 39)} \\ 3x_1 + 0x_2 = 27 \end{array}$$

Solving the resulting equation yields $x_1 = 9$. The value of x_2 can be found by substituting $x_1 = 9$ into either of the original equations or the modified inspection equation. Suppose we use the original inspection equation. We have

$2(9) + 1x_2 = 22$

Solving, we find $x_2 = 4$.

Hence, the optimal solution to the microcomputer problem is to produce nine type 1 computers and four type 2 computers per day. We can substitute these values into the objective function to find the optimal profit:

$\$60(9) + \$50(4) = \$740$

Hence, the last line—the one that would last touch the feasible solution space as we moved away from the origin parallel to the \$300 profit line—would be the line where profit equaled \$740.

In this problem, the optimal values for both decision variables are integers. This will not always be the case; one or both of the decision variables may turn out to be noninteger. In some situations noninteger values would be of little consequence. This would be true if the decision variables were measured on a continuous scale, such as the amount of water, sand, sugar, fuel oil, time, or distance needed for optimality, or if the contribution per unit (profit, cost, etc.) were small, as with the number of nails or ball bearings to make. In some cases, the answer would simply be rounded down (maximization problems) or up (minimization problems) with very little impact on the objective function. Here, we assume that noninteger answers are acceptable as such.

Let's review the procedure for finding the optimal solution using the objective function approach:

1. Graph the constraints.
2. Identify the feasible solution space.
3. Set the objective function equal to some amount that is divisible by each of the objective function coefficients. This will yield integer values for the x_1 and x_2 intercepts and simplify plotting the line. Often, the product of the two objective function coefficients provides a satisfactory line. Ideally, the line will cross the feasible solution space close to the optimal point, and it will not be necessary to slide a straight edge because the optimal solution can be readily identified visually.
4. After identifying the optimal point, determine which two constraints intersect there. Solve their equations simultaneously to obtain the values of the decision variables at the optimum.
5. Substitute the values obtained in the previous step into the objective function to determine the value of the objective function at the optimum.

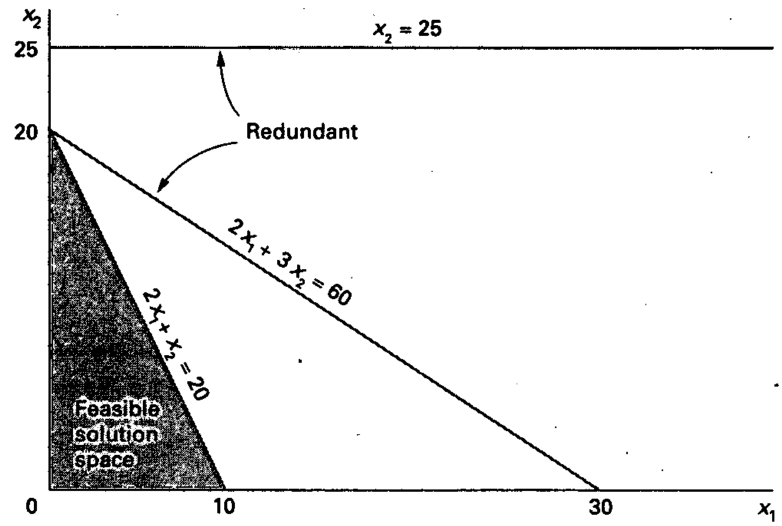
Redundant Constraints

In some cases, a constraint does not form a unique boundary of the feasible solution space. Such a constraint is called a **redundant constraint.** Two such constraints are illustrated in Figure 6S.11. Note that a constraint is redundant if it meets the following test: Its removal would not alter the feasible solution space.

redundant constraint A constraint that does not form a unique boundary of the feasible solution space.

FIGURE 6S.11

Examples of redundant constraints



When a problem has a redundant constraint, at least one of the other constraints in the problem is more restrictive than the redundant constraint.

Solutions and Corner Points

The feasible solution space in graphical linear programming is typically a polygon. Moreover, the solution to any problem will be at one of the corner points (intersections of constraints) of the polygon. It is possible to determine the coordinates of each corner point of the feasible solution space, and use those values to compute the value of the objective function at those points. Because the solution is always at a corner point, comparing the values of the objective function at the corner points and identifying the best one (e.g., the maximum value) is another way to identify the optimal corner point. Using the graphical approach, it is much easier to plot the objective function and use that to identify the optimal corner point. However, for problems that have more than two decision variables, and the graphical method isn't appropriate, this alternate approach is used to find the optimal solution.

In some instances, the objective function will be *parallel* to one of the constraint lines that forms a *boundary of the feasible solution space.* When this happens, *every* combination of x_1 and x_2 on the segment of the constraint that touches the feasible solution space represents an optimal solution. Hence, there are multiple optimal solutions to the problem. Even in such a case, the solution will also be a corner point—in fact, the solution will be at *two* corner points: those at the ends of the segment that touches the feasible solution space. Figure 6S.12 illustrates an objective function line that is parallel to a constraint line.

Minimization

Graphical minimization problems are quite similar to maximization problems. There are, however, two important differences. One is that at least one of the constraints must be of the = or ≥ variety. This causes the feasible solution space to be away from the origin. The other difference is that the optimal point is the one closest to the origin. We find the optimal corner point by sliding the objective function (which is an *isocost* line) *toward* the origin instead of away from it.

EXAMPLE S-3

Solve the following problem using graphical linear programming.

$$
\begin{aligned}
\text{Minimize} \quad & Z = 8x_1 + 12x_2 \\
\text{Subject to} \quad & 5x_1 + 2x_2 \geq 20 \\
& 4x_1 + 3x_2 \geq 24 \\
& x_2 \geq 2 \\
& x_1, x_2 \geq 0
\end{aligned}
$$

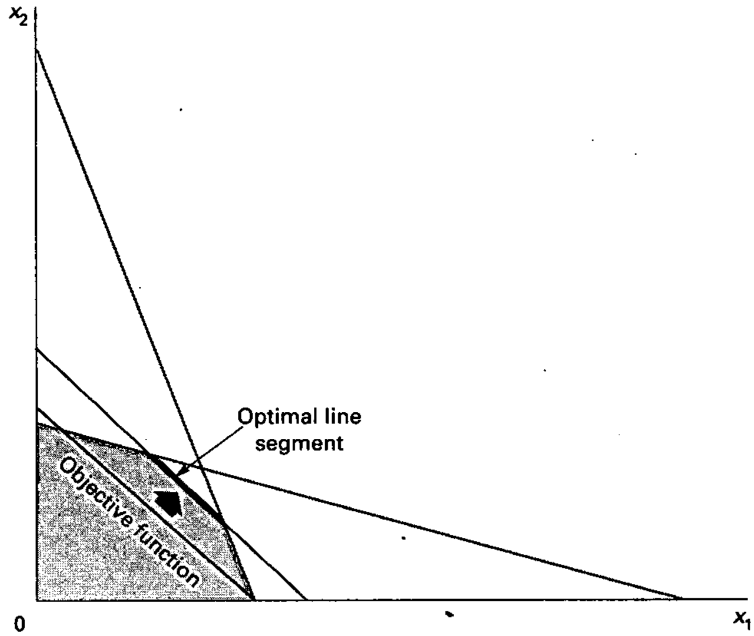


FIGURE 6S.12

Some LP problems have multiple optimal solutions

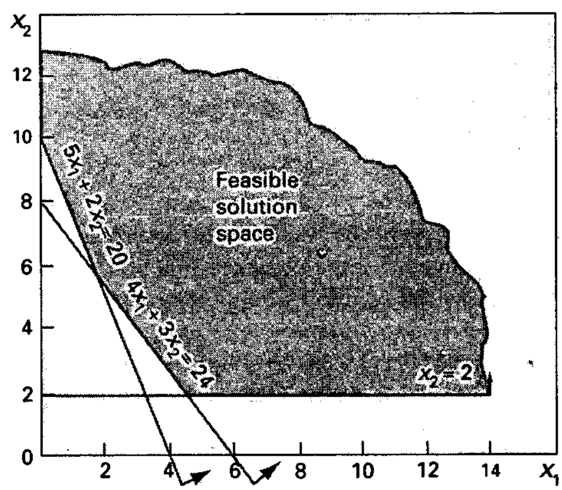


FIGURE 6S.13

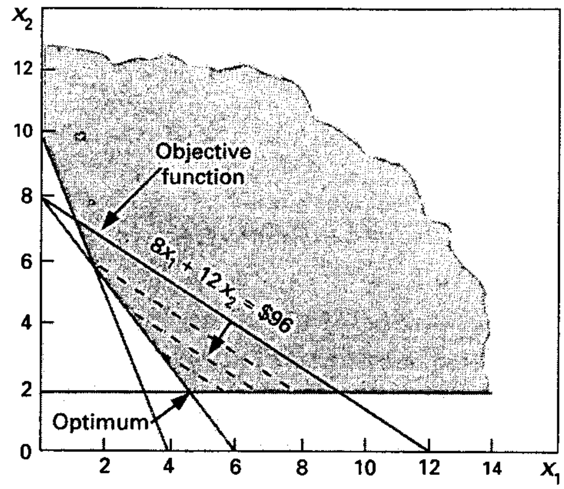
The constraints define the feasible solution space

SOLUTION

1. Plot the constraints (shown in Figure 6S.13).
   a. Change constraints to equalities.
   b. For each constraint, set $x_1 = 0$ and solve for x_2, then set $x_2 = 0$ and solve for x_1.
   c. Graph each constraint. Note that $x_2 = 2$ is a horizontal line parallel to the x_1 axis and 2 units above it.
2. Shade the feasible solution space (see Figure 6S.13).
3. Plot the objective function.
   a. Select a value for the objective function that causes it to cross the feasible solution space. Try $8 \times 12 = 96$; $8x_1 + 12x_2 = 96$ (acceptable).
   b. Graph the line (see Figure 6S.14).
4. Slide the objective function toward the origin, being careful to keep it parallel to the original line.
5. The optimum (last feasible point) is shown in Figure 6S.14. The x_2 coordinate ($x_2 = 2$) can be determined by inspection of the graph. Note that the optimum point is at the intersection

FIGURE 6S.14

The optimum is the last point the objective function touches as it is moved toward the origin



of the line $x_2 = 2$ and the line $4x_1 + 3x_2 = 24$. Substituting the value of $x_2 = 2$ into the latter equation will yield the value of x_1 at the intersection:

$4x_1 + 3(2) = 24 \qquad x_1 = 4.5$

Thus, the optimum is $x_1 = 4.5$ units and $x_2 = 2$.

6. Compute the minimum cost:

$8x_1 + 12x_2 = 8(4.5) + 12(2) = 60$

Slack and Surplus

binding constraint A constraint that forms the optimal corner point of the feasible solution space.

surplus When the values of decision variables are substituted into a $\geq$ constraint the amount by which the resulting value exceeds the right-side value.

slack When the values of decision variables are substituted into a $\leq$ constraint the amount by which the resulting value is less than the right-side value.

If a constraint forms the optimal corner point of the feasible solution space, it is called a **binding constraint.** In effect, it limits the value of the objective function; if the constraint could be relaxed (less restrictive), an improved solution would be possible. For constraints that are not binding, making them less restrictive will have no impact on the solution.

If the optimal values of the decision variables are substituted into the left side of a binding constraint, the resulting value will exactly equal the right-hand value of the constraint. However, there will be a difference with a nonbinding constraint. If the left side is greater than the right side, we say that there is **surplus;** if the left side is less than the right side, we say that there is **slack.** Slack can only occur in a $\leq$ constraint; it is the amount by which the left side is less than the right side when the optimal values of the decision variables are substituted into the left side. And surplus can only occur in a $\geq$ constraint; it is the amount by which the left side exceeds the right side of the constraint when the optimal values of the decision variables are substituted into the left side.

For example, suppose the optimal values for a problem are $x_1 = 10$ and $x_2 = 20$. If one of the constraints is

$3x_1 + 2x_2 \leq 100$

substituting the optimal values into the left side yields

$3(10) + 2(20) = 70$

Because the constraint is $\leq$, the difference between the values of 100 and 70 (i.e., 30) is slack. Suppose the optimal values had been $x_1 = 20$ and $x_2 = 20$. Substituting these values into the left side of the constraint would yield $3(20) + 2(20) = 100$. Because the left side equals the right side, this is a binding constraint; slack is equal to zero.

Now consider this constraint:

$4x_1 + x_2 \geq 50$

Suppose the optimal values are $x_1 = 10$ and $x_2 = 15$; substituting into the left side yields

$$4(10) + 15 = 55$$

Because this is a $\geq$ constraint, the difference between the left- and right-side values is *surplus*. If the optimal values had been $x_1 = 12$ and $x_2 = 2$, substitution would result in the left side being equal to 50. Hence, the constraint would be a binding constraint, and there would be no surplus (i.e., surplus would be zero).

THE SIMPLEX METHOD

The **simplex** method is a general-purpose linear programming algorithm widely used to solve large-scale problems. Although it lacks the intuitive appeal of the graphical approach, its ability to handle problems with more than two decision variables makes it extremely valuable for solving problems often encountered in operations management.

simplex A linear programming algorithm that can solve problems having more than two decision variables.

Although manual solution of linear programming problems using simplex can yield a number of insights on how solutions are derived, space limitations preclude describing it here. However, it is available on the CD that accompanies this book. The discussion here will focus on computer solutions.

COMPUTER SOLUTIONS

The microcomputer problem will be used to illustrate computer solutions. We repeat it here for ease of reference.

Maximize $60x_1 + 50x_2$ where x_1 = the number of type 1 computers
x_2 = the number of type 2 computers

Subject to

Assembly	$4x_1 + 10x_2 \leq 100$ hours
Inspection	$2x_1 + 1x_2 \leq 22$ hours
Storage	$3x_1 + 3x_2 \leq 39$ cubic feet
	$x_1, x_2 \geq 0$

Solving LP Models Using MS Excel

Solutions to linear programming models can be obtained from spreadsheet software such as Microsoft's Excel. Excel has a routine called *Solver* that performs the necessary calculations.

To use Solver:

1. First, enter the problem in a worksheet, as shown in Figure 6S.15. What is not obvious from the figure is the need to enter a formula for each cell where there is a zero (Solver automatically inserts the zero after you input the formula). The formulas are for the value of the objective function and the constraints, in the appropriate cells. Before you enter the formulas, designate the cells where you want the optimal values of x_1 and x_2. Here, cells D4 and E4 are used. To enter a formula, click on the cell that the formula will pertain to, and then enter the formula, starting with an equal sign. We want the optimal value of the objective function to appear in cell G4. For G4, enter the formula

```
=60*D4+50*E4
```

The constraint formulas, using cells C7, C8, and C9, are

for C7: `=4*D4+10*E4`
for C8: `=2*D4+1*E4`
for C9: `=3*D4+3*E4`

2. Now, click on Tools on the top of the worksheet, and in that menu, click on Solver. The Solver menu will appear as illustrated in Figure 6S.16. Begin by setting the Target Cell (i.e., indicating the cell where you want the optimal value of the objective function to appear). Note,

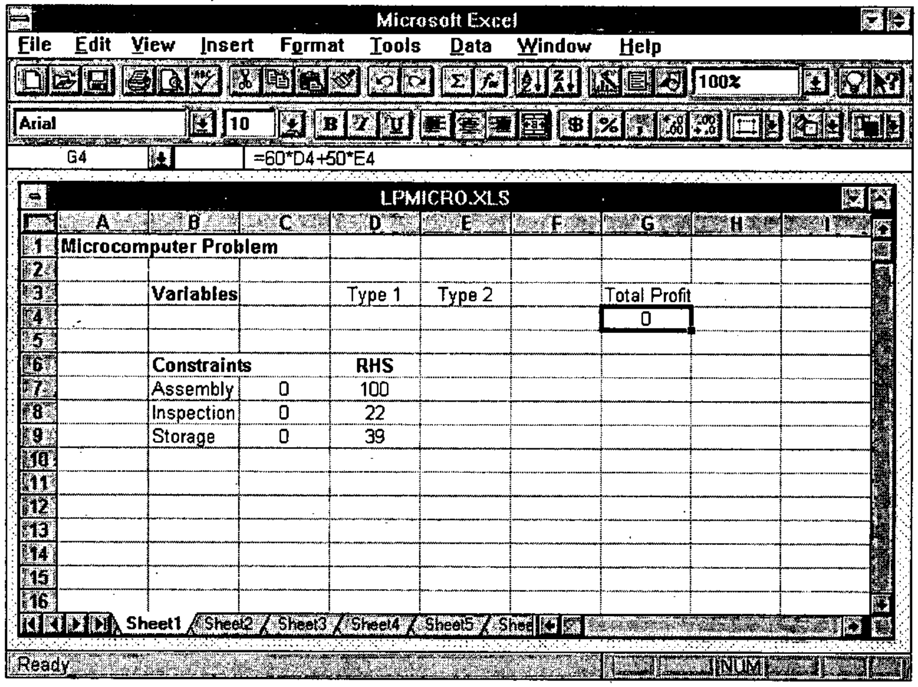


FIGURE 6S.15

MS Excel worksheet for microcomputer problem

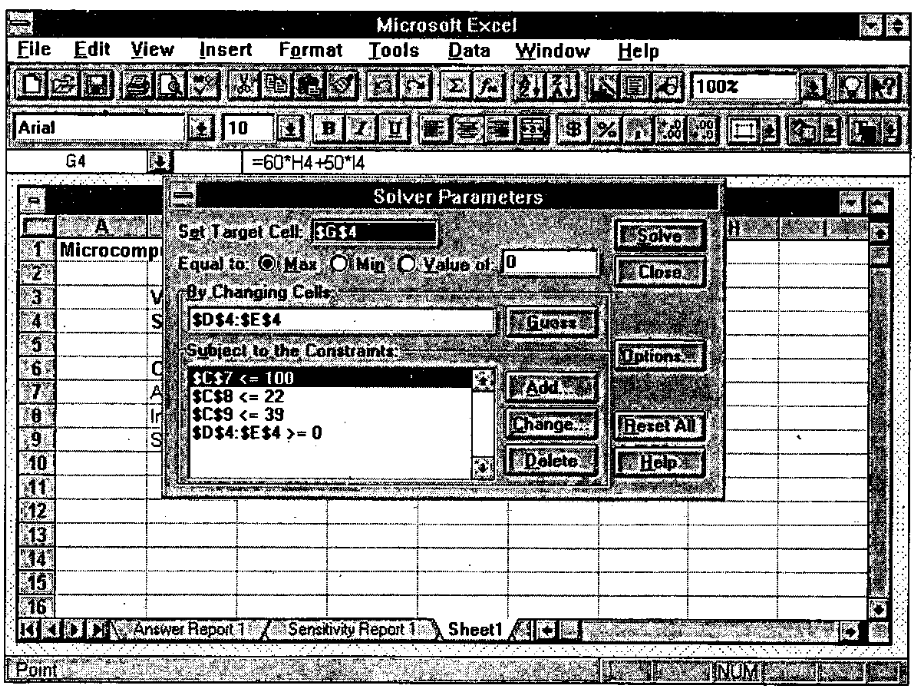


FIGURE 6S.16

MS Excel Solver parameters for microcomputer problem

if the activated cell is the cell designated for the value of Z when you click on the Tools menu, Solver will automatically set that cell as the target cell.

Highlight Max if it isn't already highlighted. The Changing Cells are the cells where you want the optimal values of the decision variables to appear. Here, they are cells D4 and E4. We indicate this by the range D4:E4 (Solver will add the $signs).

Finally, add the constraints by clicking on Add . . . When that menu appears, for each constraint, enter the cell that contains the formula for the left side of the constraint, then select the appropriate inequality sign, and then enter either the right-side amount or the cell that has the

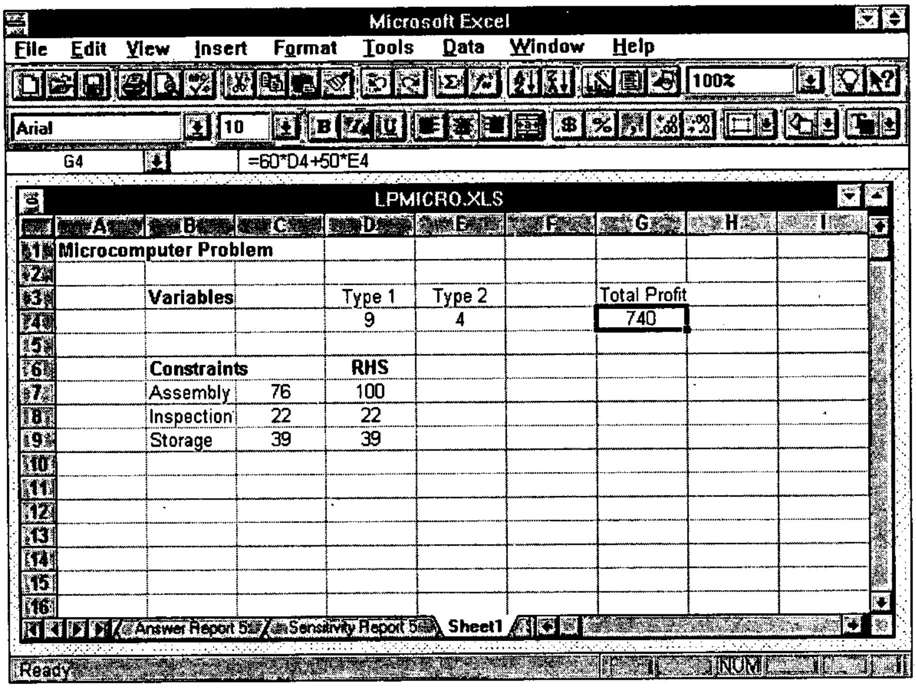


FIGURE 6S.17

MS Excel worksheet solution for microcomputer problem

right-side amount. Here, the right-side amounts are used. After you have entered each constraint, click on Add, and then enter the next constraint. (Note, constraints can be entered in any order.) For the nonnegativity constraints, enter the range of cells designated for the optimal values of the decision variables. Then, click on OK rather than Add, and you will return to the Solver menu. Click on Options . . . , and in the Options menu, click on Assume Linear Model, and then click on OK. This will return you to the Solver Parameters menu. Click on Solve.

3. The Solver Results menu will then appear, indicating that a solution has been found, or that an error has occurred. If there has been an error, go back to the Solver Parameters menu and check to see that your constraints refer to the correct changing cells, and that the inequality directions are correct. Make the corrections and click on Solve.

Assuming everything is correct, in the Solver Results menu, in the Reports box, highlight both Answer and Sensitivity, and then click on OK.

4. Solver will incorporate the optimal values of the decision variables and the objective function in your original layout on your worksheet (see Figure 6S.17). We can see that the optimal values are type 1 = 9 units and type 2 = 4 units, and the total profit is 740. The answer report will also show the optimal values of the decision variables (upper part of Figure 6S.18), and some information on the constraints (lower part of Figure 6S.18). Of particular interest here is the indication of which constraints have slack and how much slack. We can see that the constraint entered in cell C7 (assembly) has a slack of 24, and that the constraints entered in cells C8 (inspection) and C9 (storage) have slack equal to zero, indicating that they are binding constraints.

SENSITIVITY ANALYSIS

Sensitivity analysis is a means of assessing the impact of potential changes to the parameters (the numerical values) of an LP model. Such changes may occur due to forces beyond a manager's control; or a manager may be contemplating making the changes, say, to increase profits or reduce costs.

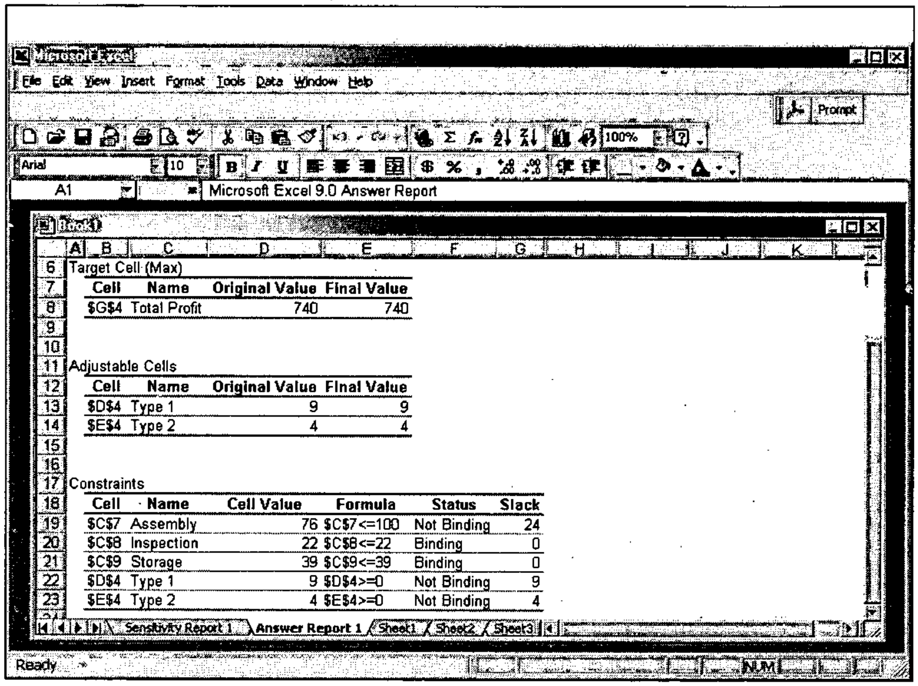
sensitivity analysis Assessing the impact of potential changes to the numerical values of an LP model.

There are three types of potential changes:

1. Objective function coefficients.
2. Right-hand values of constraints.
3. Constraint coefficients.

FIGURE 6S.18

MS Excel Answer Report for microcomputer problem



Target Cell (Max)

Cell	Name	Original Value	Final Value
G4	Total Profit	740	740

Adjustable Cells

Cell	Name	Original Value	Final Value
D4	Type 1	9	9
E4	Type 2	4	4

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
C7	Assembly	76	C7<=100	Not Binding	24
C8	Inspection	22	C8<=22	Binding	0
C9	Storage	39	C9<=39	Binding	0
D4	Type 1	9	D4>=0	Not Binding	9
E4	Type 2	4	E4>=0	Not Binding	4

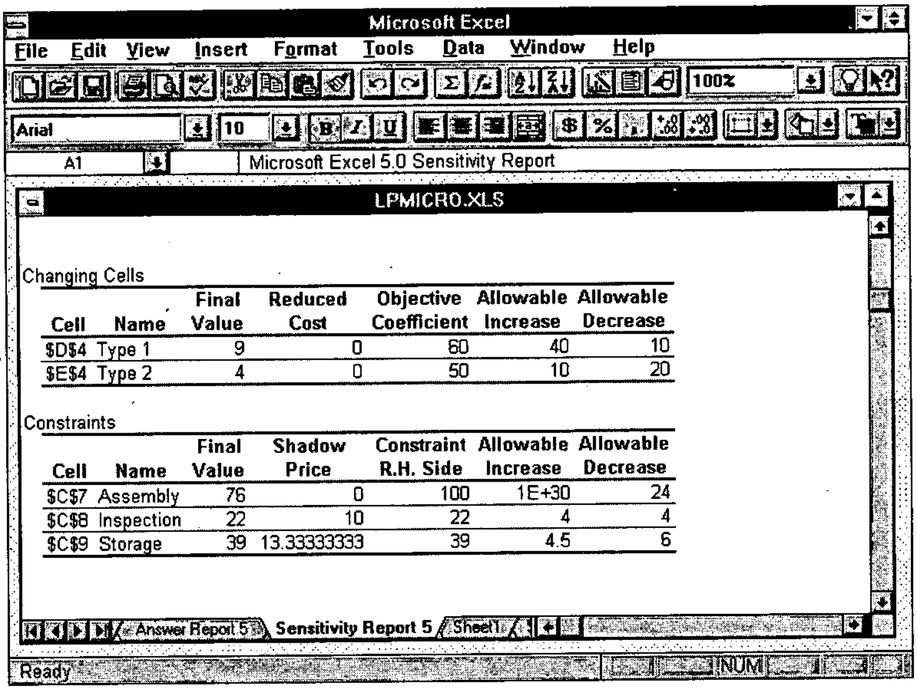
We will consider the first two of these here. We begin with changes to objective function coefficients.

Objective Function Coefficient Changes

A change in the value of an objective function coefficient can cause a change in the optimal solution of a problem. In a graphical solution, this would mean a change to another corner point of the feasible solution space. However, not every change in the value of an objective function coefficient will lead to a changed solution; generally there is a *range of values for which the optimal values of the decision variables will not change.* For example, in the microcomputer problem, if the profit on type 1 computers increased from $60 per unit to, say, $65 per unit, the optimal solution would still be to produce nine units of type 1 and four units of type 2 computers. Similarly, if the profit per unit on type 1 computers decreased from $60 to, say, $58, producing nine of type 1 and four of type 2 would still be optimal. These sorts of changes are not uncommon; they may be the result of such things as price changes in raw materials, price discounts, cost reductions in production, and so on. Obviously, when a change does occur in the value of an objective function coefficient, it can be helpful for a manager to know if that change will affect the optimal values of the decision variables. The manager can quickly determine this by referring to that coefficient's **range of optimality,** which is the range in possible values of that objective function coefficient over which the optimal values of the decision variables will not change. Before we see how to determine the range, consider the implication of the range. The range of optimality for the type 1 coefficient in the microcomputer problem is 50 to 100. That means that as long as the coefficient's value is in that range, the optimal values will be 9 units of type 1 and 4 units of type 2. Conversely, *if a change extends beyond the range of optimality, the solution will change.*

range of optimality Range of values over which the solution quantities of all the decision variables remain the same.

Similarly, suppose, instead, the coefficient (unit profit) of type 2 computers was to change. Its range of optimality is 30 to 60. As long as the change doesn't take it outside of this range, nine and four will still be the optimal values. Note, however, even for changes that are *within* the range of optimality, the optimal value of the objective function *will* change. If the type 1 coefficient increased from $60 to $61, and nine units of type 1 is still optimum, profit would increase by $9: nine units times $1 per unit. Thus, for a change that is within the range of optimality, a revised value of the objective function must be determined.



Changing Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
D4	Type 1	9	0	60	40	10
E4	Type 2	4	0	50	10	20

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
C7	Assembly	76	0	100	1E+30	24
C8	Inspection	22	10	22	4	4
C9	Storage	39	13.33333333	39	4.5	6

FIGURE 6S.19

MS Excel sensitivity report for microcomputer problem

Now let's see how we can determine the range of optimality using computer output.

Using MS Excel There is a table for the Changing Cells (see Figure 6S.19). It shows the value of the objective function that was used in the problem for each type of computer (i.e., 60 and 50), and the allowable increase and allowable decrease for each coefficient. By subtracting the allowable decrease from the original value of the coefficient, and adding the allowable increase to the original value of the coefficient, we obtain the range of optimality for each coefficient. Thus, we find for type 1:

$$60 - 10 = 50 \qquad \text{and} \qquad 60 + 40 = 100$$

Hence, the range for the type 1 coefficient is 50 to 100. For type 2:

$$50 - 20 = 30 \qquad \text{and} \qquad 50 + 10 = 60$$

Hence the range for the type 2 coefficient is 30 to 60.

In this example, both of the decision variables are *basic* (i.e., nonzero). However, in other problems, one or more decision variables may be *nonbasic* (i.e., have an optimal value of zero). In such instances, unless the value of that variable's objective function coefficient increases by more than its *reduced cost,* it won't come into solution (i.e., become a basic variable). Hence, the range of optimality (sometimes referred to as the *range of insignificance*) for a nonbasic variable is from negative infinity to the sum of its current value and its reduced cost.

Now let's see how we can handle multiple changes to objective function coefficients, that is, a change in more than one coefficient. To do this, divide each coefficient's change by the allowable change in the same direction. Thus, if the change is a decrease, divide that amount by the allowable decrease. Treat all resulting fractions as positive. Sum the fractions. If the sum does not exceed 1.00, then multiple changes are within the range of optimality and will not result in any change to the optimal values of the decision variables.

Changes in the Right-Hand Side (RHS) Value of a Constraint

In considering right-hand side changes, it is important to know if a particular constraint is binding on a solution. A constraint is binding if substituting the values of the decision variables of that solution into the left side of the constraint results in a value that is equal to the

shadow price Amount by which the value of the objective function would change with a one-unit change in the RHS value of a constraint.

range of feasibility Range of values for the RHS of a constraint over which the shadow price remains the same.

RHS value. In other words, that constraint stops the objective function from achieving a better value (e.g., a greater profit or a lower cost). Each constraint has a corresponding **shadow price,** which is a marginal value that indicates the amount by which the value of the objective function would change if there were a one-unit change in the RHS value of that constraint. If a constraint is nonbinding, its shadow price is zero, meaning that increasing or decreasing its RHS value by one unit will have no impact on the value of the objective function. Nonbinding constraints have either slack (if the constraint is $\leq$) or surplus (if the constraint is $\geq$). Suppose a constraint has 10 units of slack in the optimal solution, which means 10 units that are unused. If we were to increase or decrease the constraint's RHS value by one unit, the only effect would be to increase or decrease its slack by one unit. But there is no profit associated with slack, so the value of the objective function wouldn't change. On the other hand, if the change is to the RHS value of a binding constraint, then the optimal value of the objective function would change. Any change in a binding constraint will cause the optimal values of the decision variables to change, and hence, cause the value of the objective function to change. For example, in the microcomputer problem, the inspection constraint is a binding constraint; it has a shadow price of 10. That means if there was one hour less of inspection time, total profit would decrease by $10, or if there was one more hour of inspection time available, total profit would increase by $10. In general, multiplying the amount of change in the RHS value of a constraint by the constraint's shadow price will indicate the change's impact on the optimal value of the objective function. However, this is only true over a limited range called the **range of feasibility.** In this range, the value of the shadow price remains constant. Hence, as long as a change in the RHS value of a constraint is within its range of feasibility, the shadow price will remain the same, and one can readily determine the impact on the objective function.

Let's see how to determine the range of feasibility from computer output.

Using MS Excel In the sensitivity report there is a table labeled "Constraints" (see Figure 6S.19). The table shows the shadow price for each constraint, its RHS value, and the allowable increase and allowable decrease. Adding the allowable increase to the RHS value and subtracting the allowable decrease will produce the range of feasibility for that constraint. For example, for the inspection constraint, the range would be

$$22 + 4 = 26; \qquad 22 - 4 = 18$$

Hence, the range of feasibility for Inspection is 18 to 26 hours. Similarly, for the storage constraint, the range is

$$39 - 6 = 33 \quad \text{to} \quad 39 + 4.5 = 43.5$$

The range for the assembly constraint is a little different; the assembly constraint is nonbinding (note the shadow price of 0) while the other two are binding (note their nonzero shadow prices). The assembly constraint has a slack of 24 (the difference between its RHS value of 100 and its final value of 76). With its slack of 24, its RHS value could be decreased by as much as 24 (to 76) before it would become binding. Conversely, increasing its right-hand side will only produce more slack. Thus, no amount of increase in the RHS value will make it binding, so there is no upper limit on the allowable increase. Excel indicates this by the large value (1E+30) shown for the allowable increase. So its range of feasibility has a lower limit of 76 and no upper limit.

If there are changes to more than one constraint's RHS value, analyze these in the same way as multiple changes to objective function coefficients. That is, if the change is an increase, divide that amount by that constraint's allowable increase; if the change is a decrease, divide the decrease by the allowable decrease. Treat all resulting fractions as positives. Sum the fractions. As long as the sum does not exceed 1.00, the changes are within the range of feasibility for multiple changes, and the shadow prices won't change.

Table 6S.1 summarizes the impacts of changes that fall within either the range of optimality or the range of feasibility.

Now let's consider what happens if a change goes beyond a particular range. In a situation involving the range of optimality, a change in an objective function that is beyond the range of

TABLE 6S.1
Summary of the impact of changes within their respective ranges

CHANGES TO OBJECTIVE FUNCTION COEFFICIENTS THAT ARE WITHIN THE RANGE OF OPTIMALITY	
Component	**Result**
Values of decision variables	No change
Value of objective function	Will change

CHANGES TO RHS VALUES OF CONSTRAINTS THAT ARE WITHIN THE RANGE OF FEASIBILITY	
Component	**Result**
Value of shadow price	No change
List of basic variables	No change
Values of basic variables	Will change
Value of objective function	Will change

optimality will result in a new solution. Hence, it will be necessary to recompute the solution. For a situation involving the range of feasibility, there are two cases to consider. The first case would be increasing the RHS value of a ≤ constraint to beyond the upper limit of its range of feasibility. This would produce slack equal to the amount by which the upper limit is exceeded. Hence, if the upper limit is 200, and the increase is 220, the result is that the constraint has a slack of 20. Similarly, for a ≥ constraint, going below its lower bound creates a surplus for that constraint. The second case for each of these would be exceeding the opposite limit (the lower bound for a ≤ constraint, or the upper bound for a ≥ constraint). In either instance, a new solution would have to be generated.

KEY TERMS

binding constraint, 280
constraints, 266
decision variables, 266
feasible solution space, 266
graphical linear programming, 268
objective function, 266
parameters, 267
range of feasibility, 286
range of optimality, 284
redundant constraint, 277
sensitivity analysis, 283
shadow price, 286
simplex, 281
slack, 280
surplus, 280

SOLVED PROBLEMS

Problem 1

A small construction firm specializes in building and selling single-family homes. The firm offers two basic types of houses, model A and model B. Model A houses require 4,000 labor hours, 2 tons of stone, and 2,000 board feet of lumber. Model B houses require 10,000 labor hours, 3 tons of stone, and 2,000 board feet of lumber. Due to long lead times for ordering supplies and the scarcity of skilled and semi-skilled workers in the area, the firm will be forced to rely on its present resources for the upcoming building season. It has 400,000 hours of labor, 150 tons of stone, and 200,000 board feet of lumber. What mix of model A and B houses should the firm construct if model A yields a profit of $3,000 per unit and model B yields $6,000 per unit? Assume that the firm will be able to sell all the units it builds.

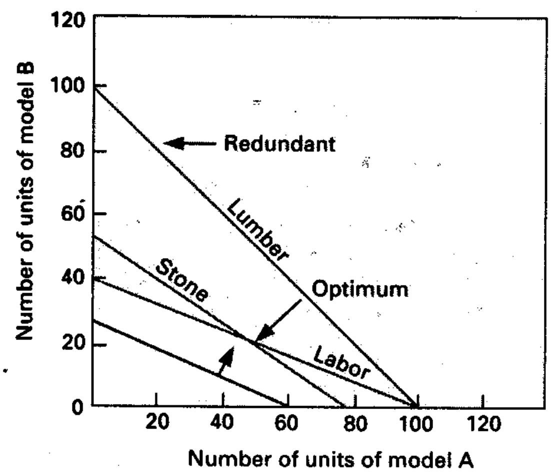
Solution

a. Formulate the objective function and constraints:[1]

[1]For the sake of consistency, we will assign to the horizontal axis the first decision variable mentioned in the problem. In this case, variable *A* will be represented on the horizontal axis and variable *B* on the vertical axis.

Maximize	$Z = 3{,}000A + 6{,}000B$			
Subject to				
Labor	$4{,}000A + 10{,}000B$	$\leq$	400,000 labor hours
Stone	$2A + 3B$	$\leq$	150 tons
Lumber	$2{,}000A + 2{,}000B$	$\leq$	200,000 board feet
	A, B	$\geq$	0

b. Graph the constraints and objective function, and identify the optimum corner point (see graph). Note that the lumber constraint is *redundant:* It does not form a boundary of the feasible solution space.



c. Determine the optimal quantities of models A and B, and compute the resulting profit. Because the optimum point is at the intersection of the stone and labor constraints, solve those two equations for their common point:

$$\begin{array}{rr} \text{Labor } 4{,}000A + 10{,}000B = & 400{,}000 \\ \underline{-2{,}000 \times (\text{Stone } 2A + \quad 3B = } & \underline{150)} \\ 4{,}000B = & 100{,}000 \\ B = & 25 \end{array}$$

Substitute $B = 25$ in one of the equations, and solve for A:

$2A + 3(25) = 150 \qquad A = 37.5$

$Z = 3{,}000(37.5) + 6{,}000(25) = 262{,}500$

Problem 2

This LP model was solved by computer:

Maximize $15x_1 + 20x_2 + 14x_3$

where x_1 = quantity of product 1
x_2 = quantity of product 2
x_3 = quantity of product 3

Subject to

Labor	$5x_1 + 6x_2 + 4x_3 \leq 210$ hours
Material	$10x_1 + 8x_2 + 5x_3 \leq 200$ pounds
Machine	$4x_1 + 2x_2 + 5x_3 \leq 170$ minutes
	$x_1, x_2, x_3 \geq 0$

The following information was obtained from the output. The ranges were also computed based on the output, and they are shown as well.

```
Total profit = 548.00

Variable      Value    Reduced Cost    Range of Optimality
Product 1       0          10.6          0.00 to 25.60
Product 2       5           0            9.40 to 22.40
Product 3      32           0           12.50 to 50.00

Constraint    Slack    Shadow Price    Range of Feasibility
Labor          52          0.0         158.00 to unlimited
Material        0          2.4         170.00 to 270.91
Machine         0          0.4          50.00 to 200.00
```

a. Which decision variables are basic (i.e., in solution)?

b. By how much would the profit per unit of product 1 have to increase in order for it to have a nonzero value (i.e., for it to become a basic variable)?

c. If the profit per unit of product 2 increased by \$2 to \$22, would the optimal production quantities of products 2 and 3 change? Would the optimal value of the objective function change?

d. If the available amount of labor decreased by 12 hours, would that cause a change in the optimal values of the decision variables or the optimal value of the objective function? Would anything change?

e. If the available amount of material increased by 10 pounds to 210 pounds, how would that affect the optimal value of the objective function?

f. If profit per unit on product 2 increased by \$1 and profit per unit on product 3 decreased by \$.50, would that fall within the range of multiple changes? Would the values of the decision variables change? What would be the revised value of the objective function?

Solution

a. Products 2 and 3 are in solution (i.e., have nonzero values); the optimal value of product 2 is 5 units, and the optimal value of product 3 is 32 units.

b. The amount of increase would have to equal its *reduced cost* of \$10.60.

c. No, because the change would be within its range of optimality, which has an upper limit of \$22.40. The objective function value would increase by an amount equal to the quantity of product 2 and its increased unit profit. Hence, it would increase by 5(\$2) = \$10 to \$558.

d. Labor has a slack of 52 hours. Consequently, the only effect would be to decrease the slack to 40 hours.

e. Yes. The change is within the range of feasibility. The objective function value will increase by the amount of change multiplied by material's shadow price of \$2.40. Hence, the objective function value would increase by 10(\$2.40) = \$24.00. (Note: If the change had been a *decrease* of 10 pounds, which is also within the range of feasibility, the value of the objective function would have *decreased* by this amount.)

f. To determine if the changes are within the range for multiple changes, we first compute the ratio of the amount of each change to the end of the range *in the same direction.* For product 2, it is \$1/\$2.40 = .417; for product 3, it is −\$.50/−\$1.50 = .333. Next, we compute the sum of these ratios: .417 + .333 = .750. Because this does not exceed 1.00, we conclude that these changes are within the range. This means that the optimal values of the decision variables will not change. We can compute the change to the value of the objective function by multiplying each product's optimal quantity by its changed profit per unit: 5(\$1) + 32(−\$.50) = −\$11. Hence, with these changes, the value of the objective function would decrease by \$11; its new value would be \$548 − \$11 = \$537.

DISCUSSION AND REVIEW QUESTIONS

1. For which decision environment is linear programming most suited?
2. What is meant by the term *feasible solution space?* What determines this region?
3. Explain the term *redundant constraint.*
4. What is an isocost line? An isoprofit line?
5. What does sliding an objective function line toward the origin represent? Away from the origin?

6. Briefly explain these terms:
   a. Basic variable
   b. Shadow price
   c. Range of feasibility
   d. Range of optimality

PROBLEMS

1. Solve these problems using graphical linear programming and answer the questions that follow. Use simultaneous equations to determine the optimal values of the decision variables.
   a. Maximize $Z = 4x_1 + 3x_2$

      Subject to

Material	$6x_1 + 4x_2 \leq 48$ lb
Labor	$4x_1 + 8x_2 \leq 80$ hr
	$x_1, x_2 \geq 0$

   b. Maximize $Z = 2x_1 + 10x_2$

      Subject to

Durability	$10x_1 + 4x_2 \geq 40$ wk
Strength	$1x_1 + 6x_2 \geq 24$ psi
Time	$1x_1 + 2x_2 \leq 14$ hr
	$x_1, x_2 \geq 0$

   c. Maximize $Z = 6A + 3B$ (revenue)

      Subject to

Material	$20A + 6B \leq 600$ lb
Machinery	$25A + 20B \leq 1{,}000$ hr
Labor	$20A + 30B \leq 1{,}200$ hr
	$A, B \geq 0$

   (1) What are the optimal values of the decision variables and *Z*?
   (2) Do any constraints have (nonzero) slack? If yes, which one(s) and how much slack does each have?
   (3) Do any constraints have (nonzero) surplus? If yes, which one(s) and how much surplus does each have?
   (4) Are any constraints redundant? If yes, which one(s)? Explain briefly.

2. Solve these problems using graphical linear programming and then answer the questions that follow. Use simultaneous equations to determine the optimal values of the decision variables.
   a. Minimize $Z = 1.80S + 2.20T$

      Subject to

Potassium	$5S + 8T \geq 200$ gr
Carbohydrate	$15S + 6T \geq 240$ gr
Protein	$4S + 12T \geq 180$ gr
T	$T \geq 10$ gr
	$S, T \geq 0$

   b. Minimize $Z = 2x_1 + 3x_2$

      Subject to

D	$4x_1 + 2x_2 \geq 20$
E	$2x_1 + 6x_2 \geq 18$
F	$1x_1 + 2x_2 \leq 12$
	$x_1, x_2 \geq 0$

(1) What are the optimal values of the decision variables and Z?
(2) Do any constraints have (nonzero) slack? If yes, which one(s) and how much slack does each have?
(3) Do any constraints have (nonzero) surplus? If yes, which one(s) and how much surplus does each have?
(4) Are any constraints redundant? If yes, which one(s)? Explain briefly.

3. An appliance manufacturer produces two models of microwave ovens: H and W. Both models require fabrication and assembly work; each H uses four hours of fabrication and two hours of assembly, and each W uses two hours of fabrication and six hours of assembly. There are 600 fabrication hours available this week and 480 hours of assembly. Each H contributes $40 to profits, and each W contributes $30 to profits. What quantities of H and W will maximize profits?

4. A small candy shop is preparing for the holiday season. The owner must decide how many bags of deluxe mix and how many bags of standard mix of Peanut/Raisin Delite to put up. The deluxe mix has ⅔ pound raisins and ⅓ pound peanuts, and the standard mix has ½ pound raisins and ½ pound peanuts per bag. The shop has 90 pounds of raisins and 60 pounds of peanuts to work with.
   Peanuts cost $.60 per pound and raisins cost $1.50 per pound. The deluxe mix will sell for $2.90 per pound, and the standard mix will sell for $2.55 per pound. The owner estimates that no more than 110 bags of one type can be sold.
   a. If the goal is to maximize profits, how many bags of each type should be prepared?
   b. What is the expected profit?

5. A retired couple supplement their income by making fruit pies, which they sell to a local grocery store. During the month of September, they produce apple and grape pies. The apple pies are sold for $1.50 to the grocer, and the grape pies are sold for $1.20. The couple is able to sell all of the pies they produce owing to their high quality. They use fresh ingredients. Flour and sugar are purchased once each month. For the month of September, they have 1,200 cups of sugar and 2,100 cups of flour. Each apple pie requires 1½ cups of sugar and 3 cups of flour, and each grape pie requires 2 cups of sugar and 3 cups of flour.
   a. Determine the number of grape and the number of apple pies that will maximize revenues if the couple working together can make an apple pie in six minutes and a grape pie in three minutes. They plan to work no more than 60 hours.
   b. Determine the amounts of sugar, flour, and time that will be unused.

6. Solve each of these problems by computer and obtain the optimal values of the decision variables and the objective function.
   a. Maximize $4x_1 + 2x_2 + 5x_3$

   Subject to

   $$1x_1 + 2x_2 + 1x_3 \le 25$$
   $$1x_1 + 4x_2 + 2x_3 \le 40$$
   $$3x_1 + 3x_2 + 1x_3 \le 30$$
   $$x_1, x_2, x_3 \ge 0$$

   b. Maximize $10x_1 + 6x_2 + 3x_3$

   Subject to

   $$1x_1 + 1x_2 + 2x_3 \le 25$$
   $$2x_1 + 1x_2 + 4x_3 \le 40$$
   $$1x_1 + 2x_2 + 3x_3 \le 40$$
   $$x_1, x_2, x_3 \ge 0$$

7. For Problem 6*a*, determine the following:
   a. The range of feasibility for each constraint.
   b. The range of optimality for the coefficients of the objective function.

8. For Problem 6*b*:
   a. Find the range of feasibility for each constraint, and interpret your answers.
   b. Determine the range of optimality for each coefficient of the objective function. Interpret your results.

9. A small firm makes three similar products, which all follow the same three-step process, consisting of milling, inspection, and drilling. Product A requires 12 minutes of milling, 5 minutes for inspection, and 10 minutes of drilling per unit; product B requires 10 minutes of milling, 4 minutes for inspection, and 8 minutes of drilling per unit; and product C requires 8 minutes of milling, 4 minutes for inspection, and 16 minutes of drilling. The department has 20 hours available during the next period for milling, 15 hours for inspection, and 24 hours for drilling. Product A contributes $2.40 per unit to profit, B contributes $2.50 per unit, and C contributes $3.00 per unit. Determine the optimal mix of products in terms of maximizing contribution to profits for the period. Then, find the range of optimality for the profit coefficient of each variable.

10. Formulate and then solve a linear programming model of this problem, to determine how many containers of each product to produce tomorrow to maximize profits. The company makes four juice products using orange, grapefruit, and pineapple juice.

Product	Retail Price per Quart
Orange juice	$1.00
Grapefruit juice	.90
Pineapple juice	.80
All-in-One	1.10

The All-in-One juice has equal parts of orange, grapefruit, and pineapple juice. Each product is produced in a one-quart size (there are four quarts in a gallon). On hand are 400 gallons of orange juice, 300 gallons of grapefruit juice, and 200 gallons of pineapple juice. The cost per gallon is $2.00 for orange juice, $1.60 for grapefruit juice, and $1.40 for pineapple juice.

In addition, the manager wants grapefruit juice to be used for no more than 30 percent of the number of containers produced. She wants the ratio of the number of containers of orange juice to the number of containers of pineapple juice to be at least 7 to 5.

11. A wood products firm uses available time at the end of each week to make goods for stock. Currently, two products on the list of items are produced for stock: a chopping board and a knife holder. Both items require three operations: cutting, gluing, and finishing. The manager of the firm has collected the following data on these products:

		TIME PER UNIT (MINUTES)		
Item	Profit/Unit	Cutting	Gluing	Finishing
Chopping board	$2	1.4	5	12
Knife holder	$6	0.8	13	3

The manager has also determined that, during each week, 56 minutes are available for cutting, 650 minutes are available for gluing, and 360 minutes are available for finishing.

a. Determine the optimal quantities of the decision variables.

b. Which resources are not completely used by your solution? How much of each resource is unused?

12. The manager of the deli section of a grocery superstore has just learned that the department has 112 pounds of mayonnaise, of which 70 pounds is approaching its expiration date and must be used. To use up the mayonnaise, the manager has decided to prepare two items: a ham spread and a deli spread. Each pan of the ham spread will require 1.4 pounds of mayonnaise, and each pan of the deli spread will require 1.0 pound. The manager has received an order for 10 pans of ham spread and 8 pans of the deli spread. In addition, the manager has decided to have at least 10 pans of each spread available for sale. Both spreads will cost $3 per pan to make, but ham spread sells for $5 per pan and deli spread sells for $7 per pan.

a. Determine the solution that will minimize cost.

b. Determine the solution that will maximize profit.

13. A manager wants to know how many units of each product to produce on a daily basis in order to achieve the highest contribution to profit. Production requirements for the products are shown in the following table.

Product	Material 1 (pounds)	Material 2 (pounds)	Labor (hours)
A	2	3	3.2
B	1	5	1.5
C	6	—	2.0

Material 1 costs \$5 a pound, material 2 costs \$4 a pound, and labor costs \$10 an hour. Product A sells for \$80 a unit, product B sells for \$90 a unit, and product C sells for \$70 a unit. Available resources each day are 200 pounds of material 1; 300 pounds of material 2; and 150 hours of labor.

The manager must satisfy certain output requirements: The output of product A should not be more than one-third of the total number of units produced; the ratio of units of product A to units of product B should be 3 to 2; and there is a standing order for 5 units of product A each day. Formulate a linear programming model for this problem, and then solve.

14. A chocolate maker has contracted to operate a small candy counter in a fashionable store. To start with, the selection of offerings will be intentionally limited. The counter will offer a regular mix of candy made up of equal parts of cashews, raisins, caramels, and chocolates, and a deluxe mix that is one-half cashews and one-half chocolates, which will be sold in one-pound boxes. In addition, the candy counter will offer individual one-pound boxes of cashews, raisins, caramels, and chocolates.

A major attraction of the candy counter is that all candies are made fresh at the counter. However, storage space for supplies and ingredients is limited. Bins are available that can hold the amounts shown in the table:

Ingredient	Capacity (pounds per day)
Cashews	120
Raisins	200
Caramels	100
Chocolates	160

In order to present a good image and to encourage purchases, the counter will make at least 20 boxes of each type of product each day. Any leftover boxes at the end of the day will be removed and given to a nearby nursing home for goodwill.

The profit per box for the various items has been determined as follows:

Item	Profit per Box
Regular	\$.80
Deluxe	.90
Cashews	.70
Raisins	.60
Caramels	.50
Chocolates	.75

a. Formulate the LP model.
b. Solve for the optimal values of the decision variables and the maximum profit.

15. Given this linear programming model, solve the model and then answer the questions that follow.

Maximize $12x_1 + 18x_2 + 15x_3$ where x_1 = the quantity of product 1 to make etc.

Subject to

Machine	$5x_1 + 4x_2 + 3x_3 \le 160$ minutes
Labor	$4x_1 + 10x_2 + 4x_3 \le 288$ hours
Materials	$2x_1 + 2x_2 + 4x_3 \le 200$ pounds
Product 2	$x_2 \le 16$ units
	$x_1, x_2, x_3 \ge 0$

a. Are any constraints binding? If so, which one(s)?
b. If the profit on product 3 was changed to $22 a unit, what would the values of the decision variables be? The objective function? Explain.
c. If the profit on product 1 was changed to $22 a unit, what would the values of the decision variables be? The objective function? Explain.
d. If 10 hours less of labor time were available, what would the values of the decision variables be? The objective function? Explain.
e. If the manager decided that as many as 20 units of product 2 could be produced (instead of 16), how much additional profit would be generated?
f. If profit per unit on each product increased by $1, would the optimal values of the decision variables change? Explain. What would the optimal value of the objective function be?

16. A garden store prepares various grades of pine bark for mulch: nuggets (x_1), mini-nuggets (x_2), and chips (x_3). The process requires pine bark, machine time, labor time, and storage space. The following model has been developed.

Maximize	$9x_1 + 9x_2 + 6x_3$ (profit)
Subject to	
Bark	$5x_1 + 6x_2 + 3x_3 \leq 600$ pounds
Machine	$2x_1 + 4x_2 + 5x_3 \leq 660$ minutes
Labor	$2x_1 + 4x_2 + 3x_3 \leq 480$ hours
Storage	$1x_1 + 1x_2 + 1x_3 \leq 150$ bags
	$x_1, x_2, x_3 \geq 0$

a. What is the marginal value of a pound of pine bark? Over what range is this price value appropriate?
b. What is the maximum price the store would be justified in paying for additional pine bark?
c. What is the marginal value of labor? Over what range is this value in effect?
d. The manager obtained additional machine time through better scheduling. How much additional machine time can be effectively used for this operation? Why?
e. If the manager can obtain *either* additional pine bark or additional storage space, which one should she choose and how much (assuming additional quantities cost the same as usual)?
f. If a change in the chip operation increased the profit on chips from $6 per bag to $7 per bag, would the optimal quantities change? Would the value of the objective function change? If so, what would the new value(s) be?
g. If profits on chips increased to $7 per bag and profits on nuggets decreased by $.60, would the optimal quantities change? Would the value of the objective function change? If so, what would the new value(s) be?
h. If the amount of pine bark available decreased by 15 pounds, machine time decreased by 27 minutes, and storage capacity increased by five bags, would this fall in the range of feasibility for multiple changes? If so, what would the value of the objective function be?

Son, Ltd.

CASE

Son, Ltd., manufactures a variety of chemical products used by photoprocessors. Son was recently bought out by a conglomerate, and managers of the two organizations have been working together to improve the efficiency of Son's operations.

Managers have been asked to adhere to weekly operating budgets and to develop operating plans using quantitative methods whenever possible. The manager of one department has been given a weekly operating budget of $11,980 for production of three chemical products, which for convenience shall be referred to as Q, R, and W. The budget is intended to pay for direct labor and materials. Processing requirements for the three products, on a per unit basis, are shown in the table.

The company has a contractual obligation for 85 units of product R per week.

Material A costs $4 per pound, as does material B. Labor costs $8 an hour.

Product Q sells for $122 a unit, product R sells for $115 a unit, and product W sells for $76 a unit.

(continued)

(concluded)

The manager is considering a number of different proposals regarding the quantity of each product to produce. The manager is primarily interested in maximizing contribution. Moreover, the manager wants to know how much labor will be needed, as well as the amount of each material to purchase.

Questions

Prepare a report that addresses the following issues:

1. The optimal quantities of products and the necessary quantities of labor and materials.
2. One proposal is to make equal amounts of the products. What amount of each will maximize contribution, and what quantities of labor and materials will be needed? How much less will total contribution be if this proposal is adopted?
3. How would you formulate the constraint for material A if it was determined that there is a 5 percent waste factor for material A and equal quantities of each product are required?

Product	Labor (hours)	Material A (pounds)	Material B (pounds)
Q	5	2	1
R	4	2	—
W	2	½	2

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CHAPTER 7

Design of Work Systems

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Explain the importance of work design.
2. Briefly describe the two basic approaches to job design.
3. Discuss the advantages and disadvantages of specialization.
4. Explain the term *knowledge-based pay*.
5. Explain the purpose of methods analysis and describe how methods studies are performed.
6. Describe four commonly used techniques for motion study.
7. Discuss the impact of working conditions on job design.
8. Define a standard time.
9. Describe and compare time study methods and perform calculations.
10. Describe work sampling and perform calculations.
11. Compare stopwatch time study and work sampling.
12. Contrast time and output pay systems.

CHAPTER OUTLINE

This chapter covers work design. Work design involves *job design, work measurement* and the establishment of time standards, and worker *motivation* and *compensation.*

As you read this chapter, note how decisions in other design areas have an impact on work systems. For example, product or service design decisions (e.g., operate a coal mine, offer computer dating service, sell sports equipment) in large measure determine the kinds of activities workers will be involved with. Similarly, layout decisions often influence work design. Process layouts tend to necessitate broader job content than product layouts. The implication of these interrelationships is that it is essential to adopt a systems approach to design; decisions in one area must be related to the overall system.

INTRODUCTION

The importance of work system design is underscored by the organization's dependence on human efforts (i.e., work) to accomplish its goals. Work design is one of the oldest aspects of operations management. In the past, it has often been deemphasized in operations management courses in favor of other topics. Recent years, however, have seen renewed interest that has come from somewhat different directions: Some of the interest has been sparked by increasing concerns over productivity. It is perhaps ironic that one of the oldest fields of operations management is now an important key to productivity improvement and to continuous improvement.

Operations Strategy

It is important for management to make design of work systems a key element of its operations strategy. Despite the major advances in computers and operations technology, people are still the heart of a business; they can make or break it, regardless of the technology used. Technology is important, of course, but technology alone is not enough.

The topics described in this chapter all have an impact on productivity. Although they lack the glamour of high tech, they are essential to the fundamentals of work design.

Workers can be a valuable source of insight and creativity because they actually perform the jobs and are closest to the problems that arise. All too often, managers overlook contributions and potential contributions of employees, sometimes from ignorance and sometimes from a false sense of pride. Union–management differences are also a factor. More and more, though, companies are attempting to develop a spirit of cooperation between employees and managers, based in part on the success of Japanese companies.

In the same vein, an increasing number of companies are focusing some of their attention on improving the quality of work life and instilling pride and respect among workers. Many organizations are reaping surprising gains through worker *empowerment,* giving workers more say over their jobs.

Lean production puts added stress on workers. Managers should be aware of this, and try to minimize negative effects.

JOB DESIGN

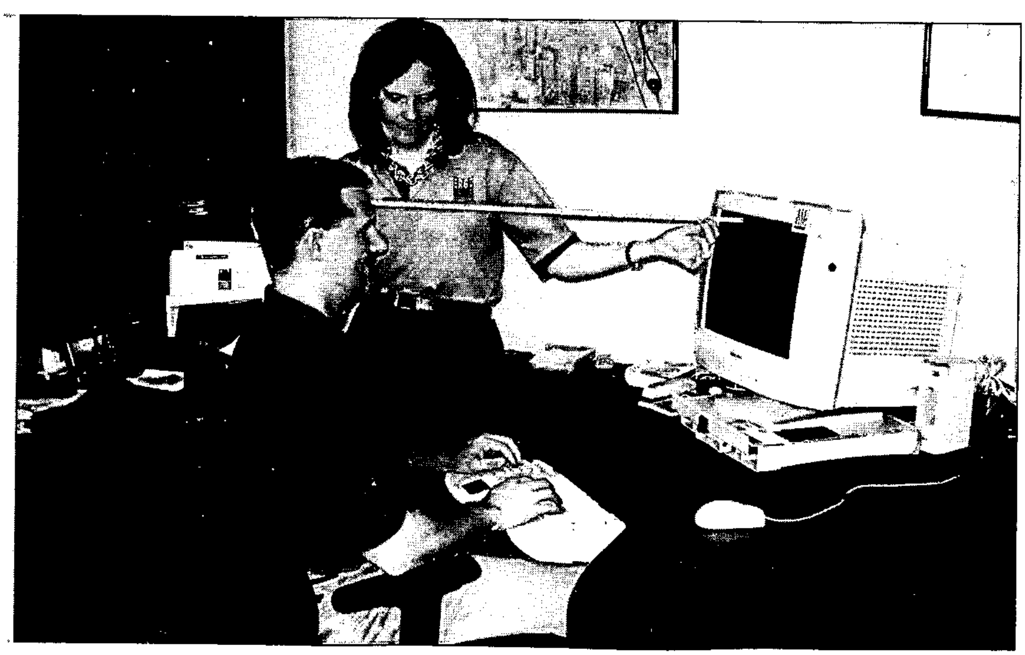
job design The act of specifying the contents and methods of jobs.

ergonomics Incorporation of human factors in the design of the workplace.

Job design involves specifying the content and methods of jobs. Job designers focus on *what* will be done in a job, *who* will do the job, *how* the job will be done, and *where* the job will be done. The objectives of job design include productivity, safety, and quality of work life.

Ergonomics is an important part of job design. **Ergonomics** is the incorporation of human factors in the design of the workplace. It relates to design of equipment, design of work methods, and the overall design of the work environment. Among other things, ergonomics seeks to prevent common workplace injuries such as back injuries and repetitive-motion injuries by taking into account the fact that people vary in their physical dimensions and capabilities. Companies have compelling interests in reducing worker injuries. Injuries result in lower productivity, lost workdays, and increases in workers' compensation and health premiums.

The factors that affect job design and the implications of various alternatives are often so complex that a person without a good background in job design is likely to overlook important



Correct positioning of equipment and tools can help reduce fatigue and increase employee productivity. Here, a trainer from Ergoworks Consulting in Gaithersburg, Maryland, recommends proper monitor height to an office worker.

www.ergoworksconsulting.com

aspects of it. Workers and managers alike should be consulted in order to take advantage of their knowledge and to keep them informed. Because they are intimately involved with the work, employees can be a source of valuable ideas for job improvements. Managerial support for job design depends on the commitment and involvement of managers. It is usually easier to sell a design to workers if they have been included in the process. Finally, establishing a written record of the job design can serve as a basis for referral if questions arise about it.

Current practice in job design contains elements of two basic schools of thought. One might be called the *efficiency* school because it emphasizes a systematic, logical approach to job design; the other is called the *behavioral* school because it emphasizes satisfaction of wants and needs.

The efficiency approach, a refinement of Frederick Winslow Taylor's scientific management concepts, received considerable emphasis in the past. The behavioral approach followed and has continued to make inroads into many aspects of job design. It is noteworthy that specialization is a primary issue of disagreement between the efficiency and behavioral approaches.

Specialization

specialization Work that concentrates on some aspect of a product or service.

The term **specialization** describes jobs that have a very narrow scope. Examples range from assembly lines to medical specialties. College professors often specialize in teaching certain courses, some auto mechanics specialize in transmission repair, and some bakers specialize in wedding cakes. The main rationale for specialization is the ability to concentrate one's efforts and thereby become proficient at that type of work.

Sometimes the amount of knowledge or training required of a specialist and the complexity of the work suggest that individuals who choose such work are very happy with their jobs. This seems to be especially true in the "professions" (e.g., doctors, lawyers, professors). At the other end of the scale are assembly-line workers, who are also specialists, although much less glamorous. The advantage of these highly specialized jobs is that they yield high productivity and relatively low unit costs, and they are largely responsible for the high standard of living that exists today in industrialized nations.

Unfortunately, many of the lower-level jobs can be described as monotonous or downright boring, and they are the source of much of the dissatisfaction among many industrial workers. Even so, it would be wrong to conclude that all workers oppose this type of work. Some workers undoubtedly prefer a job with limited requirements and responsibility for making decisions. Others are not capable of handling jobs with greater scopes. Nonetheless, many workers are frustrated and this manifests itself in a number of ways. Turnover and absenteeism are often high; in the automotive industry, for example, absenteeism runs as high as 20 percent, although not every absentee is a frustrated worker on an assembly line. Workers may also take out their frustrations through disruptive tactics, deliberate slowdowns, or poor attention to product quality.

The seriousness of these problems caused job designers and others to seek ways of alleviating them. Some of those approaches are discussed in the following sections. Before we turn to them, note that the advantages and disadvantages of specialization are summarized in Table 7.1.

Behavioral Approaches to Job Design

In an effort to make jobs more interesting and meaningful, job designers frequently consider job enlargement, job rotation, job enrichment, and increased use of mechanization.

job enlargement Giving a worker a larger portion of the total task, by horizontal loading.

Job enlargement means giving a worker a larger portion of the total task. This constitutes *horizontal loading*—the additional work is on the same level of skill and responsibility as the original job. The goal is to make the job more interesting by increasing the variety of skills required and by providing the worker with a more recognizable contribution to the overall output. For example, a production worker's job might be expanded so that he or she is responsible for a *sequence* of activities instead of only one activity.

job rotation Workers periodically exchange jobs.

Job rotation means having workers periodically exchange jobs. A firm can use this approach to avoid having one or a few employees stuck in monotonous jobs. It works best when workers can be transferred to more interesting jobs; there is little advantage in having workers exchange one boring job for another. Job rotation allows workers to broaden their learning experience and enables them to fill in for others in the event of sickness or absenteeism.

TABLE 7.1
Major advantages and disadvantages of specialization in business

Advantages	
For management:	For labor:
1. Simplifies training	1. Low education and skill requirements
2. High productivity	2. Minimum responsibilities
3. Low wage costs	3. Little mental effort needed
Disadvantages	
For management:	For labor:
1. Difficult to motivate quality	1. Monotonous work
2. Worker dissatisfaction, possibly resulting in absenteeism, high turnover, disruptive tactics, poor attention to quality	2. Limited opportunities for advancement
	3. Little control over work
	4. Little opportunity for self-fulfillment

job enrichment Increasing responsibility for planning and coordination tasks, by vertical loading.

Job enrichment involves an increase in the level of responsibility for planning and coordination tasks. It is sometimes referred to as *vertical loading.* An example of this is to have stock clerks in supermarkets handle reordering of goods, thus increasing their responsibilities. The job enrichment approach focuses on the motivating potential of worker satisfaction.

The importance of these approaches to job design is that they have the potential to increase the motivational power of jobs by increasing worker satisfaction through improvement in the *quality of work life.* Many firms are currently involved in or seriously considering programs related to quality of work life. In addition to the aforementioned approaches, organizations are also experimenting with choice of locations (e.g., medium-sized cities or campuslike settings), flexible work hours, and teams.

Motivation

Motivation is a key factor in many aspects of work life. Not only can it influence quality and productivity, it also contributes to the work environment. People work for a variety of reasons. And although compensation is often the leading reason, it is not the only reason. Other reasons include socialization, self-actualization, status, the physiological aspects of work, and a sense of purpose and accomplishment. Awareness of these factors can help management to develop a motivational framework that encourages workers to respond in a positive manner to the goals of the organization. A detailed discussion of motivation is beyond the scope of this book, but its importance to work design should be obvious.

Another factor that influences productivity and employee–management relations is *trust.* In an ideal work environment, there is a high level of trust between workers and managers. When managers trust employees, there is a greater tendency to give employees added responsibilities. When employees trust management, they are more likely to respond positively. Conversely, when they do not trust management, they are more likely to respond in less desirable ways. The following reading discusses the issue of employees distrusting managers.

Workplace Upheavals Seem to Be Eroding Employees' Trust

READING

Sue Shellenbarger

A former finance-department employee of a multinational manufacturer recalls the day his trust in his employer was shattered.

A devastating earthquake in Turkey had killed and injured thousands of people. He and his coworkers were panicked because they couldn't reach fellow employees there. At that time, he overheard his boss of three months telling the finance manager to revise sales projections for Turkey downward

(continued)

(concluded)

because they were likely to suffer—sales that accounted for only a fraction of 1% of the company's total.

"Ten thousand people, including possibly some of our own employees, were missing or dead, and she was worried about hitting sales targets," says the employee, who asked that his name not be used because he fears retaliation. "I gave my notice the following week."

Management gurus pretty much agree that trust in the workplace has been eroding since the 1980s, largely due to the layoff and acquisition binges and the accelerating pace of change. A study of 1,800 workers by Aon's Loyalty Institute, Ann Arbor, Mich., says more than one in eight, or 13%, of U.S. workers distrust their employers on the most basic level—that is, they don't feel free from fear, intimidation or harassment at work. Watson Wyatt Worldwide, Bethesda, Md., found in a study of 7,500 employees that only half trusted their senior managers.

Now that it's gone, many workplace experts are waking up to how important trust is, especially in a tight labor market. The Aon research shows that trust is such a basic requirement that without it a company's other benefits and programs won't raise employee commitment very much. Watson Wyatt also found a correlation between trust and profit. Companies where employees trusted top executives posted shareholder returns 42 percentage points higher than companies where distrust was the rule.

A common view among managers is that it's unwise, impractical or impossible to try to cultivate trust amid nonstop change and reorganizations. But that's a misfire, says the Loyalty Institute's David Stum. "The American worker knows quite well that change is never-ending. How it's handled is what can lead the worker to be secure or insecure." The basic question, Mr. Stum says, is, "Do I trust my company to be fair and honest as it goes through changes?"

The rules for building trust at work are actually pretty simple—the kinds of things we try to teach kids in elementary school. Dennis and Michelle Reina, co-authors of the 1999 book *Trust & Betrayal in the Workplace*, cite such behaviors as respecting others, sharing information, admitting mistakes, giving constructive feedback, keeping secrets, avoiding gossip and backbiting, being consistent and involving others in decision-making.

Some companies are consciously taking steps to build trust. SRA International, a Fairfax, Va., systems consultant, requires all 2,000 of its employees to take mandatory training on respect, fairness, ethics and honesty.

For employers with patience, the payoff is worth the effort. The Reinas, organizational development consultants in Stowe, Vt., tell of a manufacturing plant in a small New England town where managers had to lay off 100 of 420 employees. They held meetings to share information. They hung out on the shop floor on all three shifts to answer employees' questions and to hear their worries. They set up outplacement centers and invited other employers to the plant to meet their people.

Not surprisingly, Ms. Reina says, when jobs opened up again at the plant, more than 80% of the layoff victims came running back.

Source: "Workplace Upheavals Seem to be Eroding," Sue Shellenbarger, *The Wall Street Journal*, June 21, 2000, p. B1.

Teams

The efforts of business organizations to become more productive, competitive, and customer-oriented have caused them to rethink how work is accomplished. Significant changes in the structure of some work environments have been the increasing use of teams and the way workers are paid, particularly in lean production systems.

In the past, nonroutine job assignments, such as dealing with customer complaints or improving a process, were typically given to one individual or to several individuals who reported to the same manager. More recently, nonroutine assignments are being given to teams who develop and implement solutions to problems.

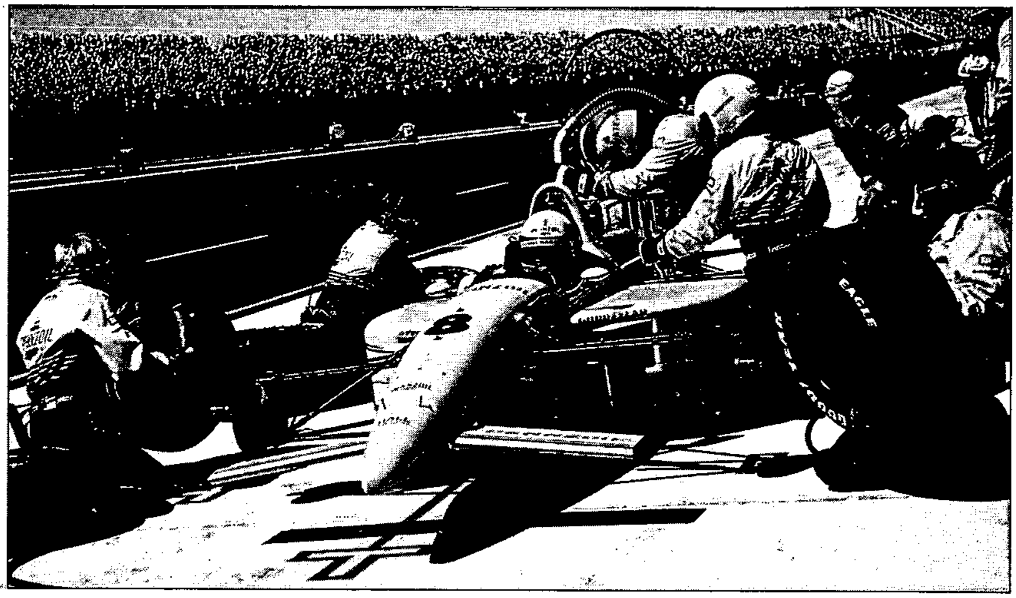
There are a number of different forms of teams. One is a short-term team formed to collaborate on a topic such as quality improvement, product or service design, or solving a problem. Team members may be drawn from the same functional area or from several functional areas, depending on the scope of the problem. Other teams are more long term. One form of long-term team that is increasingly being used, especially in lean production settings, is the *self-directed team.*

self-directed teams Groups empowered to make certain changes in their work processes.

Self-directed teams, sometimes referred to as *self-managed teams,* are designed to achieve a higher level of teamwork and employee involvement. Although such teams are not given absolute authority to make all decisions, they are typically empowered to make changes in the work processes under their control. The underlying concept is that the workers, who are close to the process and have the best knowledge of it, are better suited than management to make the most effective changes to improve the process. Moreover, because they have a vested interest and personal involvement in the changes, they tend to work harder to ensure that the

At this pit stop at the Michigan International Speedway, the Pennzoil team takes no more than 15 seconds to do a thorough maintenance check of the race car's engine, fluid levels, and tires.

www.mispeedway.com

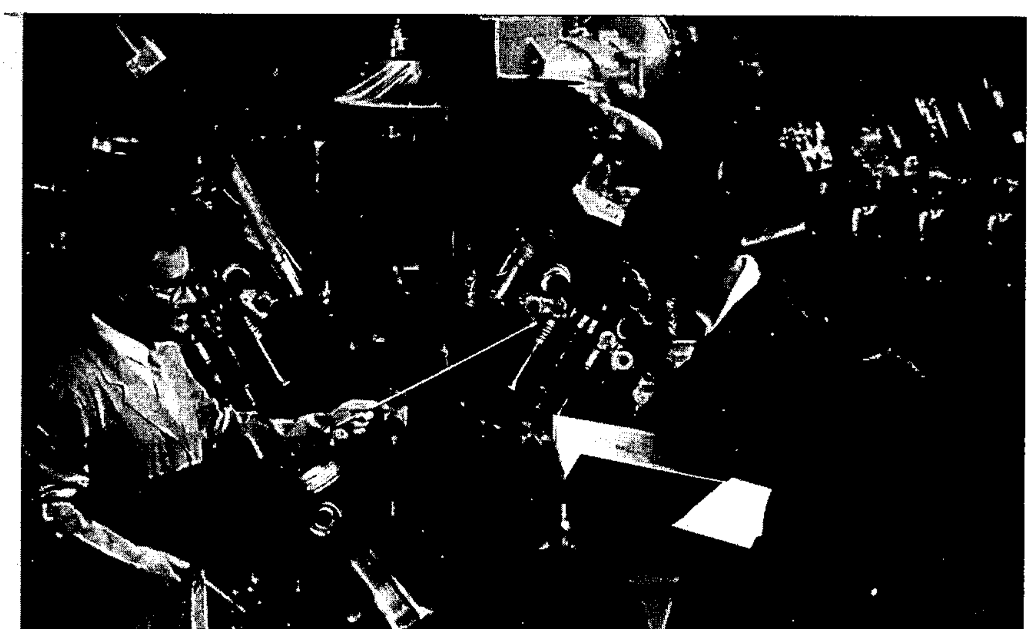


desired results are achieved than they would if management had implemented the changes. For these teams to function properly, team members must be trained in quality, process improvement, and teamwork. Self-directed teams have a number of benefits. One is that fewer managers are necessary; very often one manager can handle several teams. Also, self-directed teams can provide improved responsiveness to problems, they have a personal stake in making the process work, and they require less time to implement improvements.

Generally, the benefits of teams include higher quality, higher productivity, and greater worker satisfaction. Moreover, higher levels of employee satisfaction can lead to less turnover and absenteeism, resulting in lower costs to train new workers and less need to fill in for absent employees. This does not mean that organizations will have no difficulties in applying the team concept. Managers, particularly middle managers, often feel threatened as teams assume more of the traditional functions of managers.

Moreover, among the leading problems of teams are conflicts between team members, which can have a detrimental impact on the effectiveness of a team.

New products and components often call for employee orientation to the new features as these may affect procedures for assembly. An instructor describes new engine features to a team at the DASA Daimler Benz-Konzern, Friedrichshafen works plant in Germany.



Expert Robert Bacal has a list of requirements for successful team building:[1]

1. Clearly stated and commonly held vision and goals
2. Talent and skills required to meet goals
3. Clear understanding of team members' roles and functions
4. Efficient and shared understanding of procedures and norms
5. Effective and skilled interpersonal relations
6. A system of reinforcement and celebration
7. Clear understanding of the team's relationship to the greater organization

Living with a Self-Directed Work Team

READING

Peter Grazier

As the concept of self-direction continues to grow, it helps to look at the basic principles involved. Sometimes this is best served by listening to the people who are actually living it. I once spent a day with two self-directed teams at Sterling Health U.S.A. in Myerstown, Pennsylvania, and what I learned from these people continues to serve as a guide to many of the typical situations that self-directed teams experience.

How do roles change in this new system? What happens to the supervisor? Can front-line people really take on many of the tasks previously reserved for management?

The "Supervisor"

The two teams were the "High Speed Line" and the "Klockner Line" (named for one of its machines). These teams packaged some of Sterling's products which include Bayer Aspirin, Bayer Select, Midol, Panadol, Stridex, and others. At the time, the two teams had operated as self-directed work teams (SDWT's) for about 3 years, so the opportunity to observe work groups in transition was excellent.

At 7:00 A.M. I met with Bill Wagner who, although called a production supervisor, was really a coordinator for three lines. Bill saw his roll as a planner, coordinator, resource person, coach, and trouble shooter if any of the teams needed assistance outside its areas of expertise. Although Bill was fairly new he fit the role of the "transitioned supervisor" well. His role was to coordinate with other supervisors, serve as a liaison between production personnel and support groups, and coach team members.

Bill felt strongly that he did not need to be involved in the day-to-day decisions of his SDWT's, and I was truly impressed by his ability to delegate decisions to his lines. During the day I observed team members expertly handling line adjustments and production glitches, all without calling their "supervisor" for assistance.

The First Team

At 8:15 A.M. Bill took me out to the *High Speed Line* and introduced me to the team members. Comprising this team were 6 operators, 1 mechanic, and 1 material handler. The High Speed Line essentially took the finished Bayer caplets (produced in another area), put them into plastic bottles, labeled them, boxed them, then packaged them for shipping. Of course there were other detailed operations such as bottle cleaning, inventory control, capping, shrink wrapping, and such.

When I explained what my work was about and that I was there to learn about self-direction from them, team members opened up immediately and began sharing the experiences of their 3-year transition. Except for two short breaks and lunch, all of our discussions were conducted while they were working.

I first spoke with Fern and Delores who were at the end of the line placing finished "6-packs" of Bayer Select into the cardboard shipping boxes. . . Discussing self-direction, they said that at first they were afraid of their new responsibilities. They were particularly concerned with doing their own quality assurance and accurately recording information that would be audited by the FDA. They were nervous about making mistakes and being knowledgeable enough to do their new jobs well. And the comment that was particularly revealing to me was "We had doubts that we could learn it." Throughout the day's discussions it was clear that the concept of self-direction challenges everyone, managers and workers alike, to break through their comfort zones when taking on new and different roles.

While talking with Fern and Delores, Nancy came by and took over for Delores. I was told that each line controls its own method for work assignments. On the High Speed Line, they rotate positions every hour to relieve stress and share work equally. During the rotation there is a "floater" position that allows some rest from the hands-on operations, but does focus

(continued)

[1]Robert Bacal, "The Six Deadly Sins of Team-Building," www.performance-appraisals.org.

on the paperwork. When they first started as a SDWT, they had frequent meetings to set up their process, but today everyone knows the system and meetings are less frequent.

As I spoke with other team members, I heard a central theme. Everyone spoke highly of the SDWT concept. I was hearing comments over and over that seemed to echo and validate Frederick Herzberg's historic work on motivation and job enrichment:

- "Before, the group leader made all the decisions. You didn't know why the decisions were made . . . now we do."
- "We now have more responsibility, more pride in our work. We are solely responsible."
- "I am now more secure as a person . . . this is a wonderful challenge."
- "You never knew where you were going to be from day to day, now you do."
- "I don't ever want to go back to the old way."

At about 9:45 A.M., the line went down because the shrink-wrapping machine needed some adjusting. Afterwards, I spoke with the team mechanic, Gary. Previously, mechanics were not part of the line teams, and needed to be called when there were problems. The time it took to locate the mechanic caused additional down time, so today the mechanic is a member of the SDWT. I asked Gary about his use of time when not making adjustments and repairs to the line. He immediately began to speak of SMED (Single-Minute Exchange of Die) concepts. Sterling used the term "SMED" to describe quick changeover concepts in general, not just die changes. Gary showed me simple, but brilliant, innovations the team had made to reduce changeover time. In one application alone, time was reduced from two hours to ten minutes. He makes valuable use of his time by creating prototypes of team ideas.

As we approached lunch time, I began probing into problems and areas for improvement. Most of their frustrations reflected issues outside of their control. One person mentioned that at times there seems to be no rhyme or reason to production scheduling, causing unnecessary changeovers. Additionally, the team would like to have more input on bottle design. One of their products has an odd shaped bottle that "takes two days to set up and three days to get right." Lunchtime lasted 30 minutes, with team members returning quickly and starting the line immediately.

The Second Team

I moved on to the next team, the "Klockner Line." The people on this line were packaging Midol caplets into "blister packs," then into cartons, then into cardboard boxes for shipping. As with the High Speed Line, everyone on this line spoke favorably about self-direction, making it clear that they never wanted to return to "the old way."

This team showed me a number of SMED innovations they had made that had drastically reduced changeover times. A year earlier it took the team eight hours to reconfigure their machine to run a different product. They reduced it to less than one hour!

One of the issues that surfaced regarded administrative support systems. Specifically, the team recently developed an idea to reduce down time that required the addition of a metal plate to one of the machines. Although the design and procurement of the plate seemed relatively straightforward, it took two months to get the part (even with the supervisor circumventing the system some). Team members were somewhat vexed that as the company moves forward with improvement concepts in the manufacturing areas, the administrative systems are not improving as quickly to support flexibility and rapid change.

All afternoon I had the feeling that I was observing a team of people that truly "owned" their line. Instead of watching people just operate machinery, I was observing people operating, adjusting, repairing, cleaning, testing, quality checking, logging, and "paperworking." About 3:00 P.M. I watched the Klockner Line Team change over their line for another product. The changeover was less than an hour and would have been faster if a screw had not become stuck. (Perhaps another SMED opportunity?)

When I probed this team for problems, several spoke about occasional personality clashes. Although they felt they have made good progress in this area, it is still something they have to work on. Not everyone on the teams had received group dynamics training, a concern echoed by many teams throughout my career. Without such training, team members tend to experience more frustration as they struggle with more intensive people interaction.

At about 4:00 P.M. team members from the second shift began receiving turnover information from the first shift people, and the line kept running—smooth transition.

In addition to the above, what else did I learn about self-direction from these people?

- There was a reduction in the number of group leaders (foremen). Some were transferred into other positions and some became line operators, at no reduction in pay.
- Most of the new skills that team members learned were taught to them by previous group leaders, quality assurance people, and each other.
- One of the issues that both the supervisor and team members struggle with is when the supervisor should make a decision for the team. Some of the team members would like the supervisor to intervene whenever they are stuck or need a quick decision. Since the supervisor in a transitioning work setting must resist the tendency to take over, it becomes a difficult decision about when to intervene.
- Team members see the tremendous potential in self-direction, and they would like to see the company move more directly to expand it into other departments.
- At this time the supervisor is still responsible for the performance evaluations of all team members. (In some organizations, peer reviews are being used with good results.)

(continued)

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Although I was mentally energized by the day's experience, I was completely exhausted as I walked to my car. These people are working in a pressured, high-performance environment. They set high standards for themselves as "owners" of their lines, proving that frontline people can and will accept responsibility when given a modicum of control over their own destinies.

Source: From Peter Grazier, "Living with a Self-Directed Work Team and Why Self-Direction Works."

Methods Analysis

One of the techniques used by self-directed teams and work analysts is **methods analysis,** which focuses on how a job is done. Job design often begins with an analysis of the overall operation. It then moves from general to specific details of the job, concentrating on arrangement of the workplace and movements of materials and/or workers. Methods analysis can be a good source of productivity improvements.

methods analysis Analyzing how a job is done.

The need for methods analysis can come from a number of different sources:

1. Changes in tools and equipment.
2. Changes in product design or introduction of new products.
3. Changes in materials or procedures.
4. Government regulations or contractual agreements.
5. Other factors (e.g., accidents, quality problems).

Methods analysis is done for both existing jobs and new jobs. For a new job it is needed to establish a method. For an existing job the procedure usually is to have the analyst observe the job as it is currently being performed and then devise improvements. For a new job, the analyst must rely on a job description and an ability to visualize the operation.

The basic procedure in methods analysis is

1. Identify the operation to be studied, and gather all pertinent facts about tools, equipment, materials, and so on.
2. For existing jobs, discuss the job with the operator and supervisor to get their input.
3. Study and document the present method of an existing job using process charts. For new jobs, develop charts based on information about the activities involved.
4. Analyze the job.
5. Propose new methods.
6. Install the new methods.
7. Follow up implementation to assure that improvements have been achieved.

Selecting an Operation to Study Sometimes a foreman or supervisor will request that a certain operation be studied. At other times, methods analysis will be part of an overall program to increase productivity and reduce costs. Some general guidelines for selecting a job to study are to consider jobs that

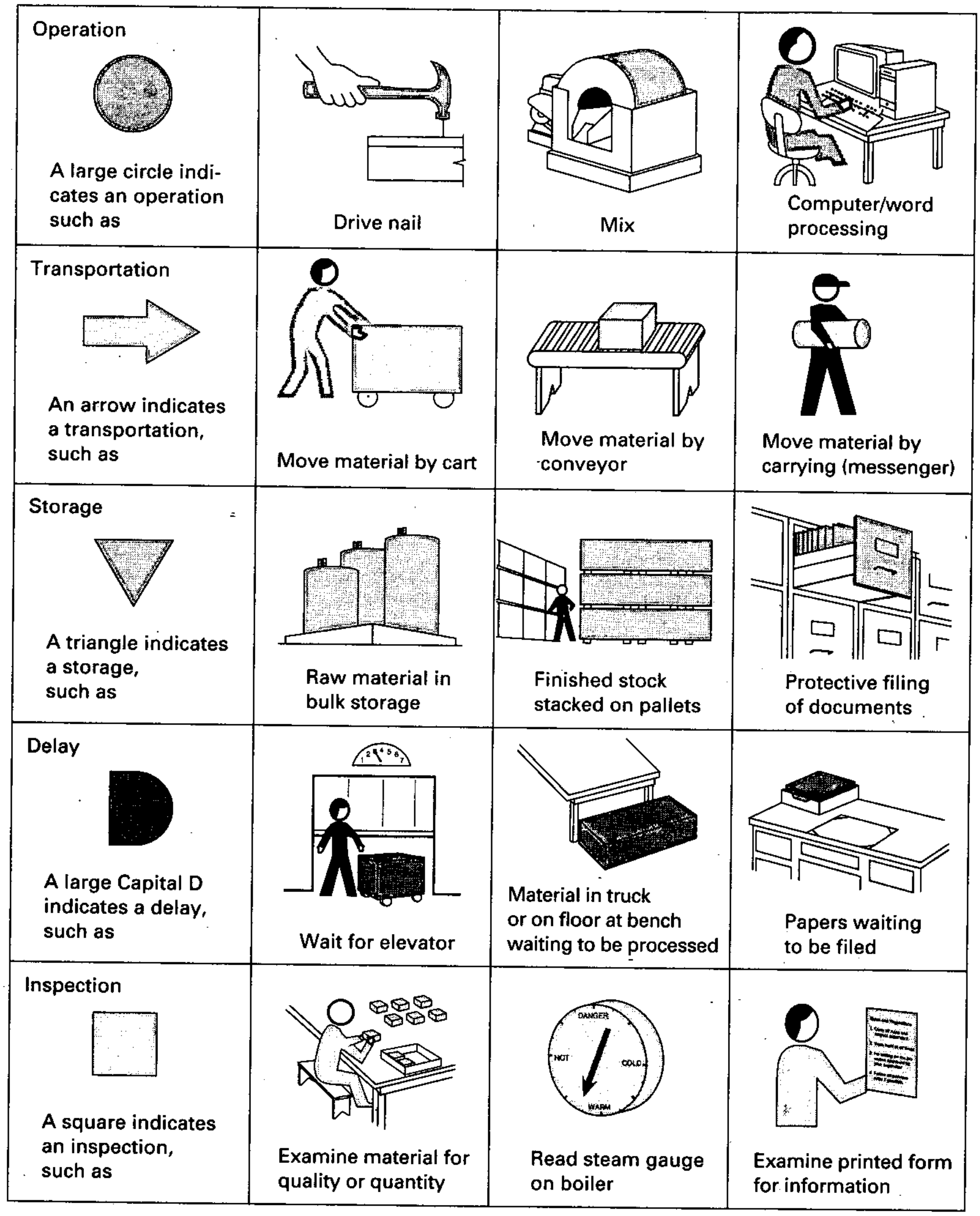
1. Have a high labor content.
2. Are done frequently.
3. Are unsafe, tiring, unpleasant, and/or noisy.
4. Are designated as problems (e.g., quality problems, processing bottlenecks).

Documenting the Current Method Use charts, graphs, and verbal descriptions of the way the job is now being performed. This will provide a good understanding of the job and serve as a basis of comparison against which revisions can be judged.

FIGURE 7.1

Process chart symbols

Source: Adapted from Benjamin W. Niebel, *Motion and Time Study,* 8th ed. Copyright © 1988 Richard D. Irwin, Inc. Used by permission of McGraw-Hill Companies, Inc., p. 35.



Analyzing the Job and Proposing New Methods Job analysis requires careful thought about the what, why, when, where, and who of the job. Often, simply going through these questions will clarify the review process by encouraging the analyst to take a devil's advocate attitude toward both present and proposed methods.

Analyzing and improving methods is facilitated by the use of various charts such as *flow process charts* and *worker-machine charts.*

flow process chart Chart used to examine the overall sequence of an operation by focusing on movements of the operator or flow of materials.

Flow process charts are used to review and critically examine the overall sequence of an operation by focusing on the movements of the operator or the flow of materials. These charts are helpful in identifying nonproductive parts of the process (e.g., delays, temporary storages, distances traveled). Figure 7.1 describes the symbols used in constructing a flow process chart, and Figure 7.2 illustrates a flow process chart.

The uses for flow process charts include studying the flow of material through a department, studying the sequence that documents or forms take, analyzing movement and care of surgical patients, layout of department and grocery stores, and mail handling.

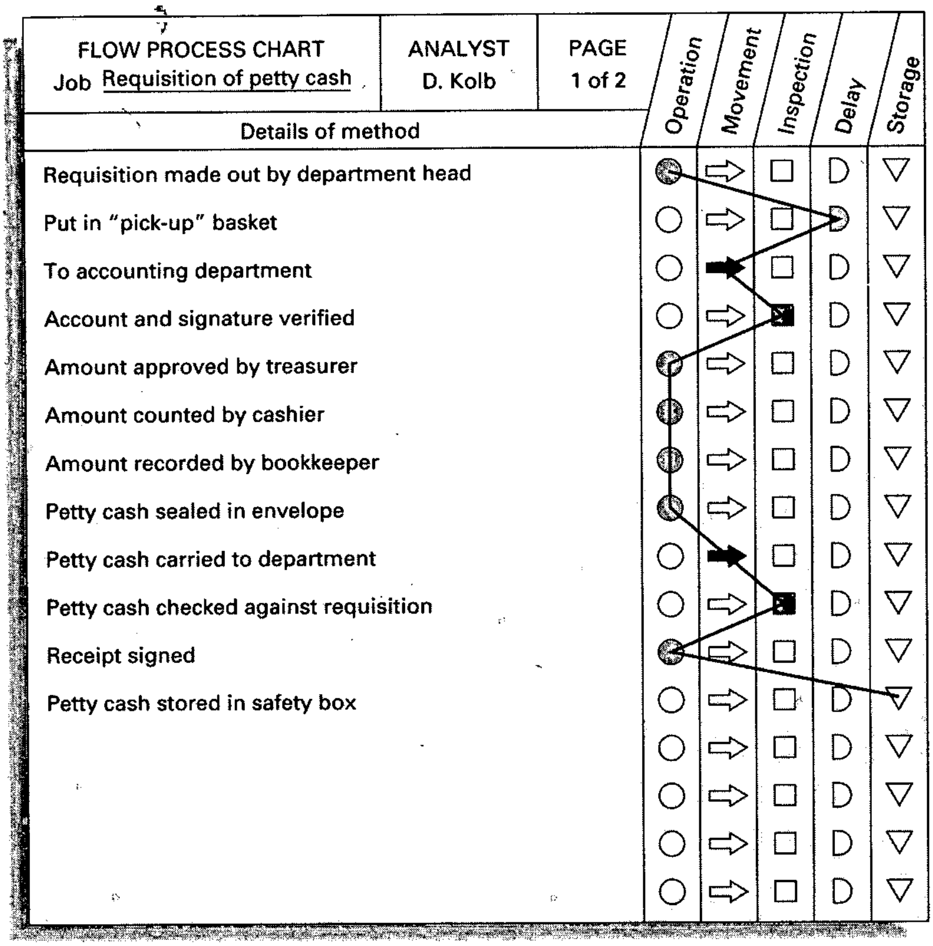


FIGURE 7.2

Format of a flow process chart

Source: Elias M. Awad, *Systems Analysis and Design,* 4th ed. Copyright © 1985 by Richard D. Irwin, Inc. Used by permission of McGraw-Hill Companies, Inc., p. 113.

Experienced analysts usually develop a checklist of questions they ask themselves to generate ideas for improvements. Some representative questions are

1. Why is there a delay or storage at this point?
2. How can travel distances be shortened or avoided?
3. Can materials handling be reduced?
4. Would a rearrangement of the workplace result in greater efficiency?
5. Can similar activities be grouped?
6. Would the use of additional or improved equipment be helpful?
7. Does the worker have any ideas for improvements?

A **worker-machine chart** is helpful in visualizing the portions of a work cycle during which an operator and equipment are busy or idle. The analyst can easily see when the operator and machine are working independently and when their work overlaps or is interdependent. One use of this type of chart is to determine how many machines or how much equipment the operator can manage. Figure 7.3 presents an example of a worker-machine chart. Among other things, the chart highlights worker and machine utilization.

worker-machine chart Chart used to determine portions of a work cycle during which an operator and equipment are busy or idle.

Installing the Improved Method Successful implementation of proposed method changes requires convincing management of the desirability of the new method and obtaining the cooperation of workers. If workers have been consulted throughout the process and have made suggestions that are incorporated in the proposed changes, this part of the task will be

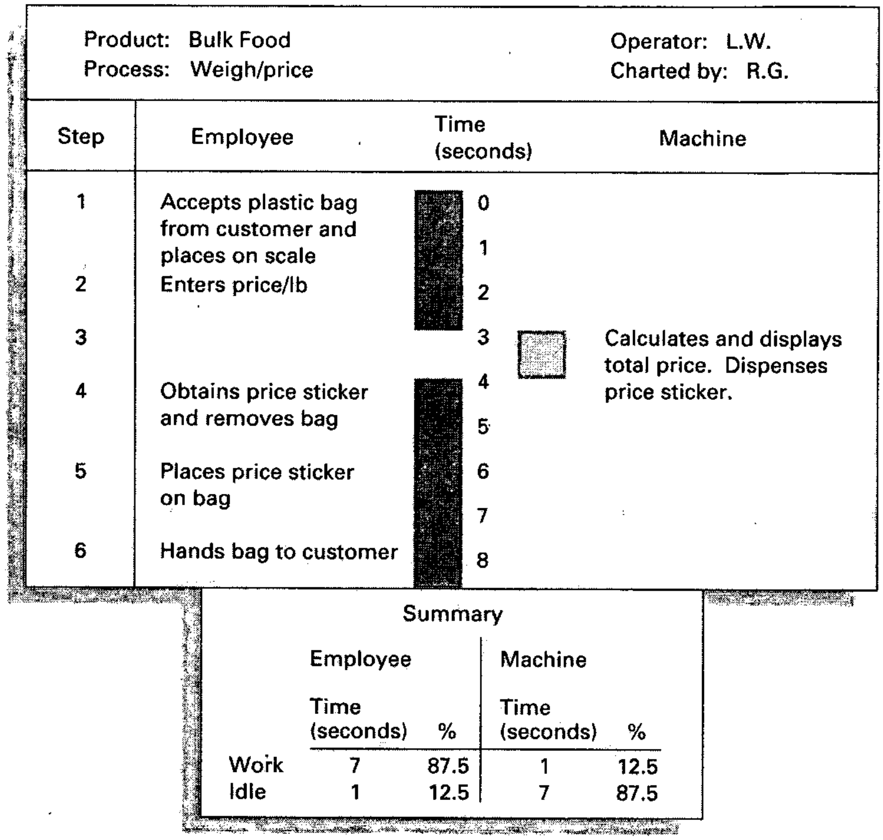


FIGURE 7.3
Worker-machine chart

considerably easier than if the analyst has assumed sole responsibility for the development of the proposal.

If the proposed method constitutes a major change from the way the job has been performed in the past, workers may have to undergo a certain amount of retraining, and full implementation may take some time to achieve.

The Follow-Up In order to ensure that changes have been made and that the proposed method is functioning as expected, the analyst should review the operation after a reasonable period and consult again with the operator.

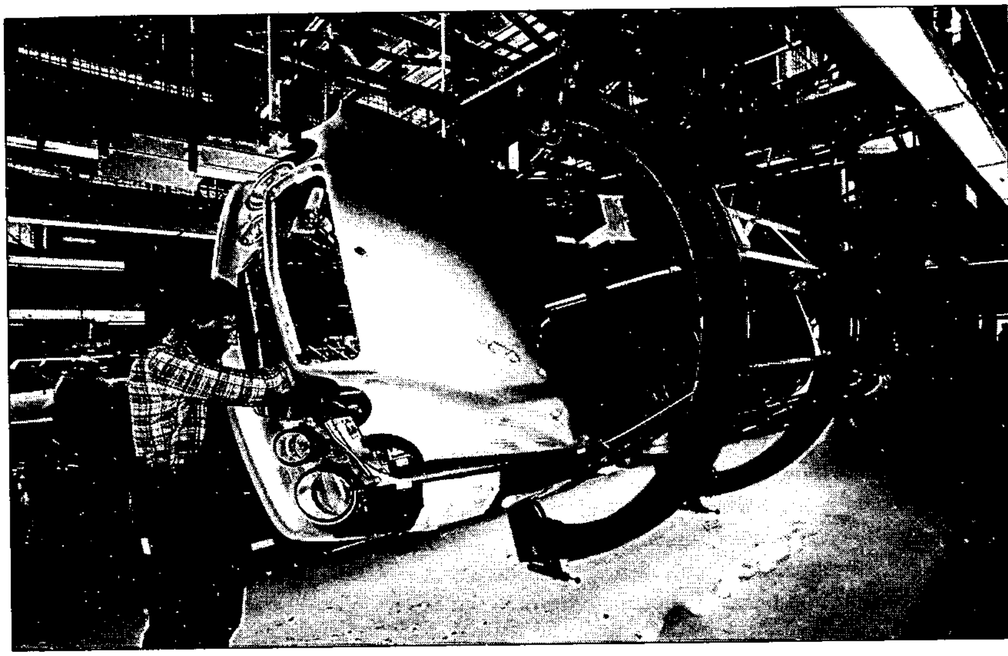
motion study Systematic study of the human motions used to perform an operation.

Motion Study

Motion study is the systematic study of the human motions used to perform an operation. The purpose is to eliminate unnecessary motions and to identify the best sequence of motions for maximum efficiency. Hence, motion study can be an important avenue for productivity improvements. Present practice evolved from the work of Frank Gilbreth, who originated the concepts in the bricklaying trade in the early twentieth century. Through the use of motion study techniques, Gilbreth is generally credited with increasing the average number of bricks laid per hour by a factor of 3, even though he was not a bricklayer by trade. When you stop to realize that bricklaying had been carried on for centuries, Gilbreth's accomplishment is even more remarkable.

There are a number of different techniques that motion study analysts can use to develop efficient procedures. The most-used techniques are

1. Motion study principles
2. Analysis of therbligs
3. Micromotion study
4. Charts



At the Mercedes Benz factory in Sindelfingen, Germany, sedans are turned as they proceed through assembly. The tilted assembly line allows easy access and installation of car components.

www.mercedes-benz.com

Gilbreth's work laid the foundation for the development of **motion study principles,** which are guidelines for designing motion-efficient work procedures. The guidelines are divided into three categories: principles for use of the body, principles for arrangement of the workplace, and principles for the design of tools and equipment. Table 7.2 lists some examples of the principles.

motion study principles Guidelines for designing motion-efficient work procedures.

In developing work methods that are motion efficient, the analyst tries to:

1. Eliminate unnecessary motions.
2. Combine activities.
3. Reduce fatigue.
4. Improve the arrangement of the workplace.
5. Improve the design of tools and equipment.

TABLE 7.2
Motion study principles

A. The use of the human body. Examples:
   1. Both hands should begin and end their basic divisions of accomplishment simultaneously and should not be idle at the same instant, except during rest periods.
   2. The motions made by the hands should be made symmetrically.
   3. Continuous curved motions are preferable to straight-line motions involving sudden and sharp changes in direction.

B. The arrangement and conditions of the workplace. Examples:
   1. Fixed locations for all tools and material should be located to permit the best sequence and to eliminate or reduce the therbligs' search and select.
   2. Gravity bins and drop delivery should reduce reach and move times; wherever possible, ejectors should remove finished parts automatically.

C. The design of tools and equipment. Examples:
   1. All levers, handles, wheels, and other control devices should be readily accessible to the operator and designed to give the best possible mechanical advantage and to utilize the strongest available muscle group.
   2. Parts should be held in position by fixtures.

Source: Adapted from Benjamin W. Niebel, *Motion and Time Study,* 8/e. Copyright © 1988 Richard D. Irwin, Inc. Used by permission of McGraw-Hill Companies, Inc., pp. 206–207.

therbligs Basic elemental motions that make up a job.

Therbligs are basic elemental motions. The term *therblig* is Gilbreth spelled backwards (except for the *th*). The approach is to break jobs down into basic elements and base improvements on an analysis of these basic elements by eliminating, combining, or rearranging them.

Although a complete description of therbligs is outside the scope of this text, a list of some common ones will illustrate the nature of these basic elemental motions:

Search implies hunting for an item with the hands and/or the eyes.

Select means to choose from a group of objects.

Grasp means to take hold of an object.

Hold refers to retention of an object after it has been grasped.

Transport load means movement of an object after hold.

Release load means to deposit the object.

Some other therbligs are *inspect, position, plan, rest,* and *delay.*

Describing a job using therbligs often takes a substantial amount of work. However, for short, repetitive jobs, therbligs analysis may be justified.

micromotion study Use of motion pictures and slow motion to study motions that otherwise would be too rapid to analyze.

Frank Gilbreth and his wife, Lillian, an industrial psychologist, were also responsible for introducing motion pictures for studying motions, called **micromotion study.** This approach is applied not only in industry but in many other areas of human endeavor, such as sports and health care. Use of the camera and slow-motion replay enables analysts to study motions that would otherwise be too rapid to see. In addition, the resulting films provide a permanent record that can be referred to, not only for training workers and analysts but also for settling job disputes involving work methods.

The cost of micromotion study limits its use to repetitive activities, where even minor improvements can yield substantial savings owing to the number of times an operation is repeated, or where other considerations justify its use (e.g., surgical procedures).

Motion study analysts often use charts as tools for analyzing and recording motion studies. Activity charts and process charts such as those described earlier can be quite helpful. In addition, analysts may use a *simo chart* (see Figure 7.4) to study simultaneous motions of the hands. These charts are invaluable in studying operations such as data entry, sewing, surgical and dental procedures, and certain assembly operations.

Working Conditions

Working conditions are an important aspect of job design. Physical factors such as temperature, humidity, ventilation, illumination, and noise can have a significant impact on worker performance in terms of productivity, quality of output, and accidents. In many instances, government regulations apply.

Temperature and Humidity Although human beings can function under a fairly wide range of temperatures and humidity, work performance tends to be adversely affected if temperatures or humidities are outside a very narrow *comfort band.* That comfort band depends on how strenuous the work is; the more strenuous the work, the lower the comfort range.

Heating and cooling are less of a problem in offices than in factories and other work environments where high ceilings allow heat to rise and where there is often a constant flow of trucks and other moving and handling equipment through large doors. These conditions make it difficult to maintain a constant temperature. Solutions range from selection of suitable clothing to space heating or cooling devices.

Ventilation Unpleasant and noxious odors can be distracting and dangerous to workers. Moreover, unless smoke and dust are periodically removed, the air can quickly become stale and annoying.

Illumination The amount of illumination required depends largely on the type of work being performed; the more detailed the work, the higher the level of illumination needed for

FIGURE 7.4

A simultaneous motion chart

Source: From Benjamin W. Niebel, *Motion and Time Study*, 8th ed. Copyright © 1988 Richard D. Irwin, Inc. Used by permission of McGraw-Hill Companies, Inc., p. 229.

SIMO CHART

OPERATOR: Ken Reisch
DATE: May 21,
OPERATION: Assembly
PART: Lace Finger
METHOD: Proposed
CHART BY: Joseph Riley

TIME SCALE (winks)	ELEMENT TIME	LEFT-HAND DESCRIPTION	SYMBOL	MOTION CLASS 1 2 3 4 5 5 4 3 2 1	SYMBOL	RIGHT-HAND DESCRIPTION	ELEMENT TIME	TIME SCALE (winks)
4548	12	Reach for finger	RE		RE	Reach for finger	12	4548
4560	19	Grasp finger	G		G	Grasp finger	19	4560
4579	31	Move finger	M		M	Move finger	31	4579
4610	75	Position and release finger	P RL		P RL	Position and release finger	75	4610
4685	15	Reach for clamp	RE		RE	Reach for clamp	15	4685
4700	15	Grasp clamp	G		G	Grasp clamp	15	4700
4715								4715
	12	Grasp assembly	G		G	Grasp assembly	12	
7541	18	Move and release assembly	M RL		M RL	Move and release assembly	18	7541
7559								7559

SUMMARY

%	TIME	LEFT-HAND SUMMARY	SYM.	RIGHT-HAND SUMMARY	TIME	%
8.56	249	Reach	RE	Reach	245	8.4
7.49	218	Grasp	G	Grasp	221	7.6
12.16	354	Move	M	Move	413	14.2
30.47	887	Position	P	Position	1124	38.6
39.33	1145	Use	U	Use	876	30.1
1.03	30	Idle	I	Idle	0	0.0
.96	28	Release	RL	Release	32	1.1
100.0	2911	TOTALS			2911	100.0

adequate performance. Other important considerations are the amount of glare and contrast. From a safety standpoint, good lighting in halls, stairways, and other dangerous points is important. However, because illumination is expensive, high illumination in all areas is not generally desirable.

Sometimes natural daylight can be used as a source of illumination. Not only is it free; it also provides some psychological benefits. Workers in windowless rooms may feel cut off from the outside world and experience various psychological problems. On the down side, the inability to control natural light (e.g., cloudy days) can result in dramatic changes in light intensity.

FIGURE 7.5

Decibel values of typical sounds (db)

Source: From Benjamin W. Niebel, *Motion and Time Study,* 8th ed. Copyright © 1988 Richard D. Irwin, Inc. Used by permission of McGraw-Hill Companies, Inc., p. 248.

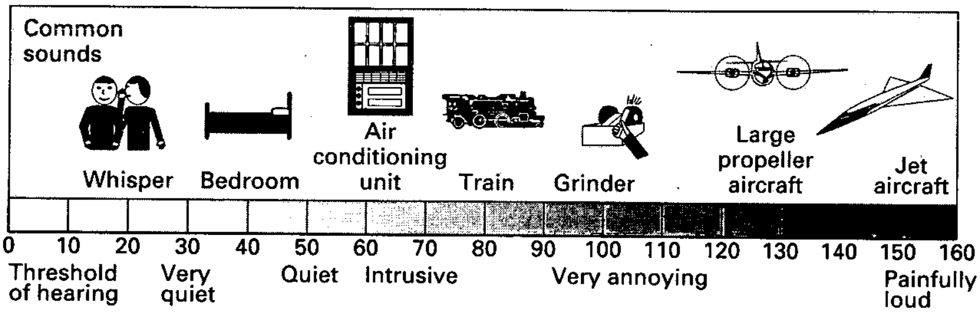
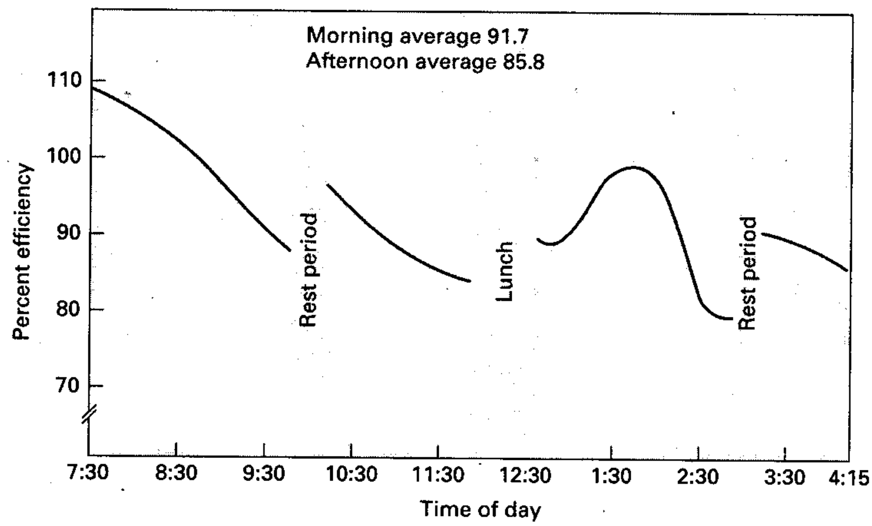


FIGURE 7.6

A typical relationship between worker efficiency and time of day

Source: From Benjamin W. Niebel, *Motion and Time Study,* 8th ed. Copyright © 1988 Richard D. Irwin, Inc. Used by permission of McGraw-Hill Companies, Inc., p. 270.



Noise and Vibrations Noise is unwanted sound. It is caused by both equipment and humans. Noise can be annoying or distracting, leading to errors and accidents. It also can damage or impair hearing if it is loud enough. Figure 7.5 illustrates loudness levels of some typical sounds.

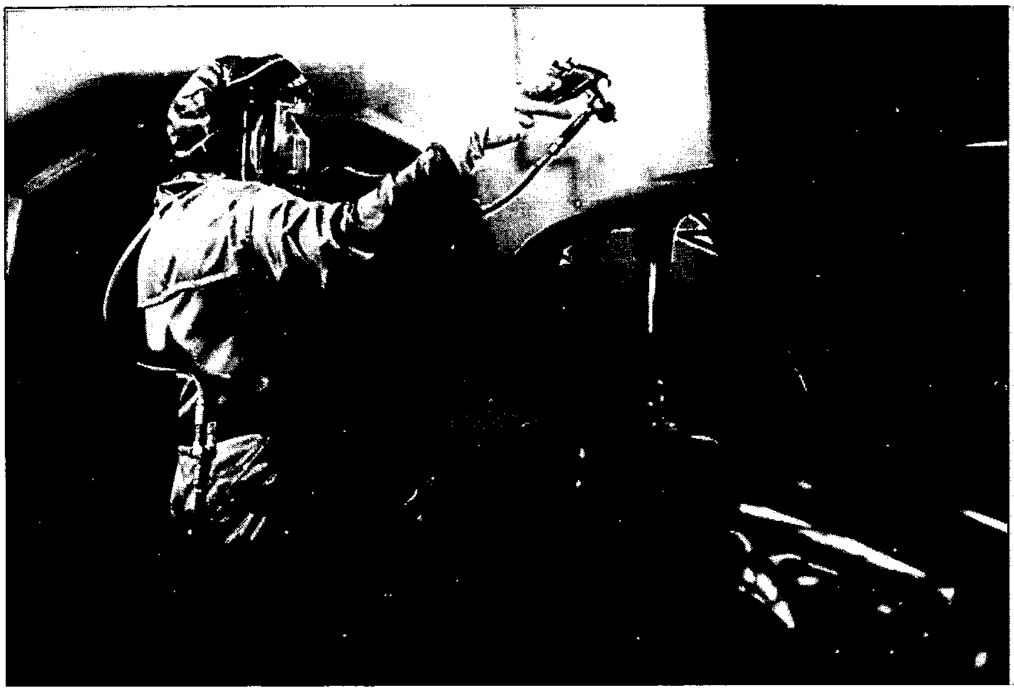
In some instances, the source of noise can be isolated from other work areas. If that isn't feasible, acoustical walls and ceilings or baffles that deflect sound waves may prove useful. Sometimes the only solution is to provide protective devices for those in the immediate vicinity (e.g., personnel who guide jet aircraft into landing gates wear protective devices over their ears).

Vibrations can be a factor in job design even without a noise component, so merely eliminating sound may not be sufficient in every case. Vibrations can come from tools, machines, vehicles, human activity, air-conditioning systems, pumps, and other sources. Corrective measures include padding, stabilizers, shock absorbers, cushioning, and rubber mountings.

Work Breaks The frequency, length, and timing of work breaks can have a significant impact on both productivity and quality of output. One indication of the relationship between worker efficiency and work breaks is illustrated in Figure 7.6. It reveals that efficiency generally declines as the day wears on, but it also shows how breaks for lunch and rest can cause an upward shift in efficiency.

Safety Worker safety is one of the most basic issues in job design. This area needs constant attention from management, employees, and designers. Workers cannot be effectively motivated if they feel they are in physical danger.

From an employer standpoint, accidents are undesirable because they are expensive (insurance and compensation); they usually involve damage to equipment and/or products; they



Protection against hazards is necessary where material or equipment may pose a danger. An employee wears protective clothing and an air mask while spray painting a Porsche in Stuttgart, Baden-Wurttenberg, Germany. Once the customer selects from among 2000 colors, the car is spray painted by hand in 2–3 days. Only the primer and undercoating are done by robot.

www2.us.porsche.com

require hiring, training, and makeup work; and they generally interrupt work. From a worker standpoint, accidents mean physical suffering, mental anguish, potential loss of earnings, and disruption of the work routine.

Causes of Accidents. The two basic causes of accidents are worker *carelessness* and accident *hazards*. Under the heading of carelessness come unsafe acts. Examples include driving at high speeds, drinking and driving, failure to use protective equipment, overriding safety controls (e.g., taping control buttons down), disregarding safety procedures (e.g., running, throwing objects, cutting through, failing to observe one-way signs), improper use of tools and equipment, and failure to use reasonable caution in danger zones. Unsafe conditions include unprotected pulleys, chains, material-handling equipment, machinery, and so on. Also, poorly lit walkways, stairs, and loading docks constitute hazards. Toxic wastes, gases and vapors, and radiation hazards must be contained. In many instances, these cannot be detected without special equipment, so they would not be obvious to workers or emergency personnel. Protection against hazards involves use of proper lighting, clearly marked danger zones, use of protective equipment (hardhats, goggles, earmuffs, gloves, heavy shoes and clothing), safety devices (machine guards, dual control switches that require an operator to use both hands), emergency equipment (emergency showers, fire extinguishers, fire escapes), and thorough instruction in safety procedures and use of regular and emergency equipment. Housekeeping (clean floors, open aisles, waste removal) is another important safety factor.

An effective program of safety and accident control requires the cooperation of both workers and management. Workers must be trained in proper procedures and attitudes, and they can contribute to a reduction in hazards by pointing out hazards to management. Management must enforce safety procedures and use of safety equipment. If supervisors allow workers to ignore safety procedures or look the other way when they see violations, workers will be less likely to take proper precautions. Some firms use contests that compare departmental safety records. However, accidents cannot be completely eliminated, and a freak accident may seriously affect worker morale and might even contribute to additional accidents. Posters can be effective, particularly if they communicate in specific terms how to avoid accidents. For example, the admonition to "be careful" is not nearly as effective as "wear hardhats," "walk, don't run," or "hold on to rail."

OSHA Occupational Safety and Health Act of 1970; Occupational Safety and Health Administration.

www.osha.gov

The enactment of the Occupational Safety and Health Act **(OSHA)** in 1970, and the creation of the Occupational Safety and Health Administration, emphasized the importance of safety considerations in systems design. The law was intended to ensure that workers in all organizations have healthy and safe working conditions. It provides specific safety regulations with inspectors to see that they are adhered to. Inspections are carried out both at random and to investigate complaints of unsafe conditions. OSHA officials are empowered to issue warnings, to impose fines, and even to invoke court-ordered shutdowns for unsafe conditions.

OSHA must be regarded as a major influence on operations management decisions in all areas relating to worker safety. OSHA has promoted the welfare and safety of workers in its role as a catalyst, spurring companies to make changes that they knew were needed but "hadn't gotten around to making."

Ethical Issues Ethical issues affect operations through work methods, working conditions and employee safety, accurate record keeping, unbiased performance appraisals, fair compensation, and opportunities for advancement.

What Works to Cut CTD Risk, Improve Job Productivity?

READING

A panel of America's leading ergonomists offers case studies that show how workplace changes can cut CTDs [cumulative trauma disorders] and boost productivity. The ideas aren't complex or expensive, and are usually developed first by plant personnel.

The new focus on "empowerment" of individual workers in America's corporations has produced some impressive results in the field of workplace ergonomics. Employees, supervisors and other in-house staff can be taught to analyze jobs and develop ideas for improvement. These individuals can be provided with training and armed with worksheets and problem-solving tools to improve their work areas. The solutions they come up with are often inexpensive or cost nothing at all.

To be sure, an ergonomist usually needs to be involved in the process: as the trainer, as a reference to help insure that the ideas are going in the right direction, to provide experience and the perspective of a trained professional and to address subtle issues or measurements which require special expertise. The effort, however, should center on the team in the workplace.

As in-house personnel become more familiar with the ergonomics process, ideas typically begin to emerge naturally without using a formal procedure. However, for the hard-to-fix problems, going through the formal process of filling out a worksheet, videotaping the job and brainstorming ideas is almost always beneficial. How effective is this team approach?

What follows are four case studies of how such groups made substantial improvements in their company's work sites:

Case Study 1: Improving the Tilt

The job: In this instance, the team focused on the operator of a bench-mounted machine. The hazards: The ergonomic problems included the operator working with a bent neck and bent wrists, in large part due to having to [compensate for] a flat work surface. The improvements: The back legs of the machine were mounted on a small block of wood, thus tilting the machine forward. Both the wrist and neck postures were simultaneously placed in an improved posture, lowering the risk of CTDs.

Cost of the improvements: None.

Case Study 2: Meat Cutting

The job: A butcher using a knife to cut meat. The hazards: The worker used highly forceful arm motions with outstretched arms and wrists bent. The improvements: For certain cuts, the front of the board was mounted on removable stops, to permit the board to be tilted at a 45-degree angle downward and away from the butcher. Thus, the butcher could press down, rather than forward, taking advantage of gravity and larger muscle groups. The arm and wrist were also placed in a better posture.

Cost of the improvements: Less than $100.

Case Study 3: Meat Packing

The job: Removing organs with a knife. The hazards: The worker was using constant, static grasping force to hold the knife, as well as repetitive hand motions to both cut and hold the meat. The improvements: A fixture was built and mounted to the work surface to hold the knife. This appliance was innovatively designed for quick exchange of dull knives for sharpened ones, which took place five to six times a shift. (The fixture also had appropriate safety guarding.) With this knife in place, the meat could then be grasped with both hands and easily pulled through the cutting tool.

Cost of the improvements: Less than $50.

(continued)

(concluded)

Case Study 4: Manufacturing

The job: Assembling of the final product. The hazards: The job involved repetitive lifting of the product from the main conveyor line to the workstation, then back to the conveyor. The improvements: A six-inch length of roller conveyor was added between the workstation and the main conveyor, allowing the product to be slid rather than lifted.

Cost of the improvement: Less than $50.

WORK MEASUREMENT

Job design determines the *content* of a job, and methods analysis determines *how* a job is to be performed. **Work measurement** is concerned with determining the *length of time* it should take to complete the job. Job times are vital inputs for workforce planning, estimating labor costs, scheduling, budgeting, and designing incentive systems. Moreover, from the workers' standpoint, time standards reflect the amount of time it should take to do a given job working under typical conditions. The standards include expected activity time plus allowances for probable delays.

work measurement Determining how long it should take to do a job.

A **standard time** is the amount of time it should take a qualified worker to complete a specified task, working at a sustainable rate, using given methods, tools and equipment, raw material inputs, and workplace arrangement. Whenever a time standard is developed for a job, it is essential to provide a complete description of the parameters of the job because the actual time to do the job is sensitive to all of these factors; changes in any one of the factors can materially affect time requirements. For instance, changes in product design or changes in job performance brought about by a methods study should trigger a new time study to update the standard time. As a practical matter, though, minor changes are occasionally made that do not justify the expense of restudying the job. Consequently, the standards for many jobs may be slightly inaccurate. Periodic time studies may be used to update the standards.

standard time The amount of time it should take a qualified worker to complete a specified task, working at a sustainable rate, using given methods, tools and equipment, raw materials, and workplace arrangement.

Organizations develop time standards in a number of different ways. Although some small manufacturers and service organizations rely on subjective estimates of job times, the most commonly used methods of work measurement are (1) stopwatch time study, (2) historical times, (3) Predetermined data, and (4) work sampling. The following pages describe each of these techniques in some detail.

Stopwatch Time Study

Stopwatch time study was formally introduced by Frederick Winslow Taylor in the late nineteenth century. Today it is the most widely used method of work measurement. It is especially appropriate for short, repetitive tasks.

Stopwatch time study is used to develop a time standard based on observations of one worker taken over a number of cycles. That is then applied to the work of all others in the organization who perform the same task. The basic steps in a time study are

stopwatch time study Development of a time standard based on observations of one worker taken over a number of cycles.

1. Define the task to be studied, and inform the worker who will be studied.
2. Determine the number of cycles to observe.
3. Time the job, and rate the worker's performance.
4. Compute the standard time.

The analyst who studies the job should be thoroughly familiar with it since it is not unusual for workers to attempt to include extra motions during the study in hope of gaining a standard that allows more time per piece (i.e., the worker will be able to work at a slower pace and still meet the standard). Furthermore, the analyst will need to check that the job is being performed efficiently before setting the time standard.

In most instances, an analyst will break all but very short jobs down into basic elemental motions (e.g., reach, grasp) and obtain times for each element. There are several reasons for this: One is that some elements are not performed in every cycle, and the breakdown enables the analyst to get a better perspective on them. Another is that the worker's proficiency may not be the same for all elements of the job. A third reason is to build a file of elemental times that can be used to set times for other jobs. This use will be described later.

Workers sometimes feel uneasy about being studied and fear changes that might result. The analyst should make an attempt to discuss these things with the worker prior to studying an operation to allay such fears and to enlist the cooperation of the worker.

The number of cycles that must be timed is a function of three things: (1) the variability of observed times, (2) the desired accuracy, and (3) the desired level of confidence for the estimated job time. Very often the desired accuracy is expressed as a percentage of the mean of the observed times. For example, the goal of a time study may be to achieve an estimate that is within 10 percent of the actual mean. The sample size needed to achieve that goal can be determined using this formula:

$$n = \left(\frac{zs}{a\bar{x}}\right)^2 \qquad (7\text{–}1)$$

where

z = Number of normal standard deviations needed for desired confidence

s = Sample standard deviation

a = Desired accuracy percentage

$\bar{x}$ = Sample mean

Typical values of z used in this computation are:[2]

Desired Confidence (%)	z Value
90	1.65
95	1.96
95.5	2.00
98	2.33
99	2.58

Of course, the value of z for any desired confidence can be obtained from the normal table in Appendix B, Table A.

An alternate formula used when the desired accuracy, e, is stated as an *amount* (e.g., within one minute of the true mean) instead of a percentage is

$$n = \left(\frac{zs}{e}\right)^2 \qquad (7\text{–}2)$$

where

e = Maximum acceptable error

To make a preliminary estimate of sample size, it is typical to take a small number of observations (i.e., 10 to 20) and compute values of $\bar{x}$ and s to use in the formula for n. Toward the end of the study, the analyst may want to recompute n using revised estimates of $\bar{x}$ and s based on the increased data available.

Note: These formulas may or may not be used in practice, depending on the person doing the time study. Often, an experienced analyst will rely on his or her judgment in deciding on the number of cycles to time.

[2]Theoretically, a t rather than a z value should be used because the population standard deviation is unknown. However, the use of z is simpler and provides reasonable results when the number of observations is 30 or more, as it generally is. In practice, z is used almost exclusively.

EXAMPLE 1

A time study analyst wants to estimate the time required to perform a certain job. A preliminary study yielded a mean of 6.4 minutes and a standard deviation of 2.1 minutes. The desired confidence is 95 percent. How many observations will he need (including those already taken) if the desired maximum error is

a. ±10 percent of the sample mean?

b. One-half minute?

SOLUTION

a. $s = 2.1$ minutes $\quad z = 1.96$

$\bar{x} = 6.4$ minutes $\quad a = 10\%$

$$n = \left(\frac{zs}{a\bar{x}}\right)^2 = \left(\frac{1.96(2.1)}{.10(6.4)}\right)^2 = 41.36 \text{ (round up to 42)}$$

b. $e = .5$ $\quad$ $$n = \left(\frac{zs}{e}\right)^2 = \left(\frac{1.96(2.1)}{.5}\right)^2 = 67.77 \text{ (round up to 68)}$$

Development of a time standard involves computation of three times: the *observed time* (OT), the *normal time* (NT), and the *standard time* (ST).

Observed Time The observed time is simply the average of the recorded times. Thus,

$$\text{OT} = \frac{\sum x_i}{n} \qquad (7\text{–}3)$$

where

OT = Observed time

$\sum x_i$ = Sum of recorded times

n = Number of observations

Note: If a job element does not occur each cycle, its average time should be determined separately and that amount should be included in the observed time, OT.

Normal Time The normal time is the observed time adjusted for worker performance. It is computed by multiplying the observed time by a *performance rating.* That is,

$$\text{NT} = \text{OT} \times \text{PR} \qquad (7\text{–}4)$$

where

NT = Normal time

PR = Performance rating

This assumes that a single performance rating has been made for the entire job. If ratings are made on an element-by-element basis, the normal time is obtained by multiplying each element's average time by its performance rating and summing those values:

$$\text{NT} = \sum(\bar{x}_j \times \text{PR}_j) \qquad (7\text{–}5)$$

where

$\bar{x}_j$ = Average time for element j

PR_j = Performance rating for element j

The reason for including this adjustment factor is that the worker being observed may be working at a rate different from a "normal" rate, either to deliberately slow the pace or because his or her natural abilities differ from the norm. For this reason, the observer assigns a performance rating, to adjust the observed times to an "average" pace. A normal rating is 1.00. A performance rating of .9 indicates a pace that is 90 percent of normal, whereas a rating of 1.05 indicates a pace that is slightly faster than normal. For long jobs, each element may be rated; for short jobs, a single rating may be made for an entire cycle.

When assessing performance, the analyst must compare the observed performance to his or her concept of normal. Obviously, there is room for debate about what constitutes normal performance, and performance ratings are sometimes the source of considerable conflict between labor and management. Although no one has been able to suggest a way around these subjective evaluations, sufficient training and periodic *recalibration* of analysts using training films can provide a high degree of consistency in the ratings of different analysts.

Standard Time The normal time does not take into account such factors as personal delays (getting a drink of water or going to the restroom), unavoidable delays (machine adjustments and repairs, talking to a supervisor, waiting for materials), or rest breaks. The standard time for a job is the normal time multiplied by an *allowance factor* for these delays.

The standard time is

$$\text{ST} = \text{NT} \times \text{AF} \tag{7–6}$$

where

ST = Standard time
AF = Allowance factor

Allowances can be based on either job time or time worked (e.g., a workday). If allowances are based on the *job time,* the allowance factor is computed using the formula

$$\text{AF}_{\text{job}} = 1 + A; \qquad A = \text{Allowance percentage based on job time} \tag{7–7}$$

This is used when different jobs have different allowances. If allowances are based on a percentage of the time worked (i.e., the *workday*), the appropriate formula is

$$\text{AF}_{\text{day}} = \frac{1}{1 - A}; \qquad A = \text{Allowance percentage based on workday} \tag{7–8}$$

This is used when jobs are the same or similar and have the same allowance factors.

EXAMPLE 2

Compute the allowance factor for these two cases:

a. The allowance is 20 percent of *job* time.
b. The allowance is 20 percent of *work* time.

SOLUTION

$A = .20$

a. $\text{AF} = 1 + A = 1.20$, or 120%

b. $\text{AF} = \frac{1}{1 - A} = \frac{1}{1 - .20} = 1.25$, or 125%

Table 7.3 illustrates some typical allowances. In practice, allowances may be based on the judgment of the time study analyst, work sampling (described later in the chapter), or negotiations between labor and management.

Example 3 illustrates the time study process from observed times to the standard time.

EXAMPLE 3

A time study of an assembly operation yielded the following observed times for one element of the job, for which the analyst gave a performance rating of 1.13 Using an allowance of 20 percent of *job* time, determine the appropriate standard time for this operation.

TABLE 7.3
Typical allowance percentages for working conditions

	Percent
A. Constant allowances:	
1. Personal allowance	5
2. Basic fatigue allowances	4
B. Variable allowances:	
1. Standing allowance	2
2. Abnormal position allowance:	
a. Slightly awkward	0
b. Awkward (bending)	2
c. Very awkward (lying, stretching)	7
3. Use of force or muscular energy (lifting, pulling, or pushing): Weight lifted (in pounds):	
5	0
10	1
15	2
20	3
25	4
30	5
35	7
40	9
45	11
50	13
60	17
70	22
4. Bad light:	
a. Slightly below recommended	0
b. Well below	2
c. Very inadequate	5
5. Atmospheric conditions (heat and humidity)—variable	0–10
6. Close attention:	
a. Fairly fine work	0
b. Fine or exacting	2
c. Very fine or very exacting	5
7. Noise level:	
a. Continuous	0
b. Intermittent—loud	2
c. Intermittent—very loud	5
d. High-pitched—loud	5
8. Mental strain:	
a. Fairly complex process	1
b. Complex or wide span of attention	4
c. Very complex	8
9. Monotony:	
a. Low	0
b. Medium	1
c. High	4
10. Tediousness:	
a. Rather tedious	0
b. Tedious	2
c. Very tedious	5

Source: From Benjamin W. Niebel, *Motion and Time Study,* 8th ed. Copyright © 1988 by Richard D. Irwin, Inc. Used by permission of McGraw-Hill Companies, Inc., p. 416.

i Observation	Time, *x* (minutes)	*i* Observation	Time, *x* (minutes)
1	1.12	6	1.18
2	1.15	7	1.14
3	1.16	8	1.14
4	1.12	9	1.19
5	1.15	Total	10.35

$n = 9$ PR $= 1.13$ $A = .20$

SOLUTION

1. $\text{OT} = \frac{\sum xi}{n} = \frac{10.35}{9} = 1.15$ minutes.
2. $\text{NT} = \text{OT} \times \text{PR} = 1.15(1.13) = 1.30$ minutes.
3. $\text{ST} = \text{NT} \times (1 + A) = 1.30(1.20) = 1.56$ minutes.

Note: If an abnormally short time has been recorded, it typically would be assumed to be the result of observational error and thus discarded. If one of the observations in Example 3 had been .10, it would have been discarded. However, if an abnormally *long* time has been recorded, the analyst would want to investigate that observation to determine whether some irregularly occurring aspect of the task (e.g., retrieving a dropped tool or part) exists, which should legitimately be factored into the job time.

Despite the obvious benefits that can be derived from work measurement using time study, some limitations also must be mentioned. One limitation is the fact that only those jobs that can be observed can be studied. This precludes most managerial and creative jobs, because these involve mental as well as physical aspects. Also, the cost of the study rules out its use for irregular operations and infrequently occurring jobs. Finally, it disrupts the normal work routine, and workers resent it in many cases.

Standard Elemental Times

standard elemental times Time standards derived from a firm's historical time data.

Standard elemental times are derived from a firm's own historical time study data. Over the years, a time study department can accumulate a file of elemental times that are common to many jobs. After a while, many elemental times can be simply retrieved from the file, eliminating the need for analysts to go through a complete time study to obtain them.

The procedure for using standard elemental times consists of the following steps:

1. Analyze the job to identify the standard elements.
2. Check the file for elements that have historical times, and record them. Use time study to obtain others, if necessary.
3. Modify the file times if necessary (explained below).
4. Sum the elemental times to obtain the normal time, and factor in allowances to obtain the standard time.

In some cases, the file times may not pertain exactly to a specific task. For instance, standard elemental times might be on file for "move the tool 3 centimeters" and "move the tool 9 centimeters," when the task in question involves a move of 6 centimeters. However, it is often possible to interpolate between values on file to obtain the desired time estimate.

One obvious advantage of this approach is the potential savings in cost and effort created by not having to conduct a complete time study for each job. A second advantage is that there is less disruption of work, again because the analyst does not have to time the worker. A third advantage is that performance ratings do not have to be done; they are generally *averaged* in the file times. The main disadvantage of this approach is that times may not exist for enough standard elements to make it worthwhile, and the file times may be biased or inaccurate.

The method described in the following section is a variation of this approach, which helps avoid some of these problems.

Predetermined Time Standards

Predetermined time standards involve the use of published data on standard elemental times. A commonly used system is *methods-time measurement* (MTM), which was developed in the late 1940s by the Methods Engineering Council. The MTM tables are based on extensive research of basic elemental motions and times. To use this approach, the analyst must divide the job into its basic elements (reach, move, turn, disengage), measure the distances involved (if applicable), rate the difficulty of the element, and then refer to the appropriate table of data to obtain the time for that element. The standard time for the job is obtained by adding the times for all of the basic elements. Times of the basic elements are measured in time measurement units (TMUs); one TMU equals .0006 minute. One minute of work may cover quite a few basic elements; a typical job may involve several hundred or more of these basic elements. The analyst needs a considerable amount of skill to adequately describe the operation and develop realistic time estimates. Table 7.4 presents a portion of the MTM tables, to give you an idea of the kind of information they provide.

predetermined time standards Published data based on extensive research to determine standard elemental times.

A high level of skill is required to generate a predetermined time standard. Analysts generally take training or certification courses to develop the necessary skills to do this kind of work.

Among the advantages of predetermined time standards are the following:

1. They are based on large numbers of workers under controlled conditions.
2. The analyst is not required to rate performance in developing the standard.
3. There is no disruption of the operation.
4. Standards can be established even before a job is done.

Although proponents of predetermined standards claim that the approach provides much better accuracy than stopwatch studies, not everyone agrees with that claim. Some argue that many activity times are too specific to a given operation to be generalized from published data. Others argue that different analysts perceive elemental activity breakdowns in different ways, and that this adversely affects the development of times and produces varying time estimates among analysts. Still others claim that analysts differ on the degree of difficulty they assign a given task and thereby obtain different time standards.

Work Sampling

Work sampling is a technique for estimating the proportion of time that a worker or machine spends on various activities and the idle time.

work sampling Technique for estimating the proportion of time that a worker or machine spends on various activities and the idle time.

Unlike time study, work sampling does not require timing an activity, nor does it even involve continuous observation of the activity. Instead, an observer makes brief observations of a worker or machine at random intervals and simply notes the nature of the activity. For example, a machine may be busy or idle; a secretary may be typing, filing, talking on the telephone, and so on; and a carpenter may be carrying supplies, taking measurements, cutting wood, and so on. The resulting data are *counts* of the number of times each category of activity or nonactivity was observed.

Although work sampling is occasionally used to set time standards, its two primary uses are in (1) ratio-delay studies, which concern the percentage of a worker's time that involves unavoidable delays or the proportion of time a machine is idle, and (2) analysis of nonrepetitive jobs. In a ratio-delay study, a hospital administrator, for example, might want to estimate the percentage of time that a certain piece of X-ray equipment is not in use. In a nonrepetitive job, such as secretarial work or maintenance, it can be important to establish the percentage of time an employee spends doing various tasks.

Nonrepetitive jobs typically involve a broader range of skills than repetitive jobs, and workers in these jobs are often paid on the basis of the highest skill involved. Therefore, it is important to determine the proportion of time spent on the high-skill level. For example, a secretary may do word processing, file, answer the telephone, and do other routine office work. If the secretary spends a high percentage of time filing instead of doing word processing the compensation will be lower than for a secretary who spends a high percentage of time doing word processing. Work sampling can be used to verify those percentages and can therefore be

TABLE 7.4 A portion of the MTM tables

TIME (TMU)					WEIGHT ALLOWANCE			
Distance Moved (inches)	A	B	C	Hand in Motion B	Weight (pounds) up to:	Dynamic Factor	Static Constant TMU	Case and Description
3/4 or less	2.0	2.0	2.0	1.7				
1	2.5	2.9	3.4	2.3	2.5	1.00	0	
2	3.6	4.6	5.2	2.9				
3	4.9	5.7	6.7	3.6	7.5	1.06	2.2	**A. Move object to other hand or against stop.**
4	6.1	6.9	8.0	4.3				
5	7.3	8.0	9.2	5.0	12.5	1.11	3.9	
6	8.1	8.9	10.3	5.7				
7	8.9	9.7	11.1	6.5	17.5	1.17	5.6	
8	9.7	10.6	11.8	7.2				
9	10.5	11.5	12.7	7.9	22.5	1.22	7.4	**B. Move object to approximate or indefinite location.**
10	11.3	12.2	13.5	8.6				
12	12.9	13.4	15.2	10.0	27.5	1.28	9.1	
14	14.4	14.6	16.9	11.4				
16	16.0	15.8	18.7	12.8	32.5	1.33	10.8	
18	17.6	17.0	20.4	14.2				
20	19.2	18.2	22.1	15.6	37.5	1.39	12.5	
22	20.8	19.4	23.8	17.0				
24	22.4	20.6	25.5	18.4	42.5	1.44	14.3	**C. Move object to exact location.**
26	24.0	21.8	27.3	19.8				
28	25.5	23.1	29.0	21.2	47.5	1.50	16.0	
30	27.1	24.3	30.7	22.7				
Additional	0.8	0.6	0.85	TMU per inch over 30 inches				

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an important tool in developing the job description. In addition, work sampling can be part of a program for validation of job content that is needed for "bona fide occupational qualifications"—that is, advertised jobs requiring the skills that are specified.

Work sampling estimates include some degree of error. Hence, it is important to treat work sampling estimates as *approximations* of the actual proportion of time devoted to a given activity. The goal of work sampling is to obtain an estimate that provides a specified confidence not differing from the true value by more than a specified error. For example, a hospital administrator might request an estimate of X-ray idle time that will provide a 95 percent confidence of being within 4 percent of the actual percentage. Hence, work sampling is designed to produce a value, $\hat{p}$, which estimates the true proportion, p, within some allowable error, e: $\hat{p} \pm e$. The variability associated with sample estimates of p tends to be approximately normal for large sample sizes. The amount of maximum probable error is a function of both the sample size and the desired level of confidence.

For large samples, the maximum error e can be computed using the formula

$$e = z\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} \qquad (7\text{–}9)$$

where

z = Number of standard deviations needed to achieve desired confidence

$\hat{p}$ = Sample proportion (the number of occurrences divided by the sample size)

n = Sample size

In most instances, management will specify the desired confidence level and amount of allowable error, and the analyst will be required to determine a sample size sufficient to obtain these results. The appropriate value for n can be determined by solving formula 7–9 for n, which yields

$$n = \left(\frac{z}{e}\right)^2 \hat{p}(1-\hat{p}) \qquad (7\text{–}10)$$

EXAMPLE 4

The manager of a small supermarket chain wants to estimate the proportion of time stock clerks spend making price changes on previously marked merchandise. The manager wants a 98 percent confidence that the resulting estimate will be within 5 percent of the true value. What sample size should she use?

SOLUTION

$e = .05$ $\qquad$ $z = 2.33$ (see p. 316) $\qquad$ $\hat{p}$ is unknown

When no sample estimate of p is available, a preliminary estimate of sample size can be obtained using $\hat{p} = .50$. After 20 or so observations, a new estimate of $\hat{p}$ can be obtained from those observations and a revised value of n computed using the new $\hat{p}$. It would be prudent to recompute the value of n at two or three points during the study to obtain a better indication of the necessary sample size. Thus, the initial estimate of n is

$$n = \left(\frac{2.33}{.05}\right)^2 .50(1 - .50) = 542.89, \text{ or } 543 \text{ observations}$$

Suppose that, in the first 20 observations, stock clerks were found to be changing prices twice, making $\hat{p} = 2/20 = .10$. The revised estimate of n at that point would be

$$n = \left(\frac{2.33}{.05}\right)^2 .10(1 - .10) = 195.44, \text{ or } 196$$

Suppose a second check is made after a total of 100 observations, and $\hat{p} = .11$ at this point (including the initial 20 observations). Recomputing n yields

$$n = \left(\frac{2.33}{.05}\right)^2 .11(.89) = 212.60, \text{ or } 213$$

Perhaps the manager might make one more check to settle on a final value for n. If the computed value of n is less than the number of observations already taken, sampling would be terminated at that point.

Note: If the resulting value of n is noninteger, round *up*.

Determining the sample size is only one part of work sampling. The overall procedure consists of the following steps:

1. Clearly identify the worker(s) or machine(s) to be studied.
2. Notify the workers and supervisors of the purpose of the study to avoid arousing suspicions.
3. Compute an initial estimate of sample size using a preliminary estimate of *p*, if available (e.g., from analyst experience or past data). Otherwise, use $\hat{p} = .50$.
4. Develop a random observation schedule.
5. Begin taking observations. Recompute the required sample size several times during the study.
6. Determine the estimated proportion of time spent on the specified activity.

Careful problem definition can prevent mistakes such as observing the wrong worker or wrong activity. It is also important to obtain random observations to get valid results.

Observations must be spread out over a period of time so that a true indication of variability is obtained. If observations are bunched too closely in time, the behaviors observed during that time may not genuinely reflect typical performance.

random number table Table consisting of unordered sequences of numbers, used to determine random observation schedules.

Determination of a random observation schedule involves the use of a **random number table** (see Table 7.5), which consists of *unordered sequences* of numbers (i.e., random). Use of these tables enables the analyst to incorporate randomness into the observation schedule. Numbers obtained from the table can be used to identify observation times for a study. Any size number (i.e., any number of digits read as one number) can be obtained from the table. The digits are in groups of four for convenience only. The basic idea is to obtain numbers from the table and to convert each one so that it corresponds to an observation time. There are a number of ways to accomplish this. In the approach used here, we will obtain three sets of numbers from the table for each observation: the first set will correspond to the *day,* the second to the *hour,* and the third to the *minute* when the observation is to be made. The number of digits necessary for any set will relate to the number of days in the study, the number of hours per day, and minutes per hour. For instance, if the study covers 47 days, a two-digit number will be needed; if the activity is performed for eight hours per day, a one-digit number will be needed for hours. Of course, since each hour has 60 minutes, a two-digit number will be needed for minutes. Thus, we need a two-digit number for the day, a one-digit number for the hour, and a two-digit number for minutes. A study requiring observations over a seven-day period in an office that works nine hours per day needs one-digit numbers for days, one-digit numbers for hours, and two-digit numbers for minutes.

Suppose that three observations will be made in the last case (i.e., 7 days, 9 hours, 60 minutes). We might begin by determining the days on which observations will be made, then the hours, and finally the minutes. Let's begin with the first row in the random number table and

TABLE 7.5
Portion of a random number table

	1	2	3	4	5	6
1	6912	7264	2801	8901	4627	8387
2	3491	1192	0575	7547	2093	4617
3	4715	2486	2776	2664	3856	0064
4	1632	1546	1950	1844	1123	1908
5	8510	7209	0938	2376	0120	4237
6	3950	1328	7343	6083	2108	2044
7	7871	7752	0521	8511	3956	3957
8	2716	1396	7354	0249	7728	8818
9	2935	8259	9912	3761	4028	9207
10	8533	9957	9585	1039	2159	2438
11	0508	1640	2768	4666	9530	3352
12	2951	0131	4359	3095	4421	3018

read across: The first number is 6, which indicates day 6. The second number is 9. Since it exceeds the number of days in the study, it is simply ignored. The third number is 1, indicating day 1, and the next is 2, indicating day 2. Hence, observations will be made on days 6, 1, and 2. Next we determine the hours. Suppose we read the second row of column 1, again obtaining one-digit numbers. We find

3 (= 3rd hour), 4 (= 4th hour), 9 (= 9th hour)

Moving to the next row and reading two-digit numbers, we find

47 (= 47th minute), 15 (= 15th minute), 24 (= 24th minute)

Combining these results yields

Day	Hour	Minute
6.......	3	47
1.......	4	15
2.......	9	24

This means that on day 6 of the study an observation is to be made during the 47th minute of the 3rd hour; on day 1, during the 15th minute of the 4th hour; and on day 2, during the 24th minute of the 9th hour. For simplicity, these times can be put in chronological order by day Thus,

Day	Hour	Minute
1.......	4	15
2.......	9	24
6.......	3	47

A complete schedule of observations might appear as follows, after all numbers have been arranged in chronological order, assuming 10 observations per day for two days:

DAY 1

Observation	Time	Busy (✓)	Idle (✓)
1	8:15		
2	9:24		
3	9:02		
4	9:31		
5	9:48		
6	10:05		
7	10:20		
8	11:02		
9	1:13		
10	3:55		

DAY 2

Observation	Time	Busy (✓)	Idle (✓)
1	8:04		
2	9:15		
3	9:24		
4	9:35		
5	10:12		
6	10:27		
7	10:38		
8	10:58		
9	11:50		
10	1:14		

The general procedure for using a random number table is to read the numbers in some sequence (across rows, down or up columns), discarding any that lack correspondence. It is important to vary the starting point from one study to the next to avoid taking observations at the same times, because workers will quickly learn the times that observations are made, and the random feature would be lost. One way to choose a starting point is to use the serial number on a dollar bill to select a starting point.

TABLE 7.6
Work sampling compared with stopwatch time study

Advantages
1. Observations are spread out over a period of time, making results less susceptible to short-term fluctuations.
2. There is little or no disruption of work.
3. Workers are less resentful.
4. Studies are less costly and less time-consuming, and the skill requirements of the analyst are much less.
5. Studies can be interrupted without affecting the results.
6. Many different studies can be conducted simultaneously.
7. No timing device is required.
8. It is well suited for nonrepetitive tasks.
Disadvantages
1. There is much less detail on the elements of a job.
2. Workers may alter their work patterns when they spot the observer, thereby invalidating the results.
3. In many cases, there is no record of the method used by the worker.
4. Observers may fail to adhere to a random schedule of observations.
5. It is not well suited for short, repetitive tasks.
6. Much time may be required to move from one workplace to another and back to satisfy the randomness requirement.

In sum, the procedure for identifying random times at which to make work sampling observations involves the following steps:

1. Determine the number of days in the study and the number of hours per day. This will indicate the required number of digits for days and hours.
2. Obtain the necessary number of sets for *days,* ignoring any sets that exceed the number of days.
3. Repeat step 2 for *hours.*
4. Repeat step 2 for *minutes.*
5. Link the days, hours, and minutes in the order they were obtained.
6. Place the observation times in chronological order.

Table 7.6 presents a comparison of work sampling and time study. It suggests that a work sampling approach to determining job times is less formal and less detailed, and best suited to nonrepetitive jobs.

COMPENSATION

Compensation is a significant issue for the design of work systems. It is important for organizations to develop suitable compensation plans for their employees. If wages are too low, organizations may find it difficult to attract and hold competent workers and managers. If wages are too high, the increased costs may result in lower profits, or may force the organization to increase its prices, which might adversely affect demand for the organization's products or services.

time-based system Compensation based on time an employee has worked during a pay period.

output-based (incentive) system Compensation based on amount of output an employee produced during a pay period.

Organizations use two basic systems for compensating employees: *time-based systems* and *output-based systems.* **Time-based systems,** also known as *hourly* and *measured daywork* systems, compensate employees for the time the employee has worked during a pay period. Salaried workers also represent a form of time-based compensation. **Output-based (incentive) systems** compensate employees according to the amount of output they produce during a pay period, thereby tying pay directly to performance.

Time-based systems are more widely used than incentive systems, particularly for office, administrative, and managerial employees, but also for blue-collar workers. One reason for this is that computation of wages is straightforward and managers can readily estimate labor costs for a given employee level. Employees often prefer time-based systems because the pay is steady and they know how much compensation they will receive for each pay period. In addition, employees may resent the pressures of an output-based system.

Another reason for using time-based systems is that many jobs do not lend themselves to the use of incentives. In some cases, it may be difficult or impossible to measure output. For example, jobs that require creative or mental work cannot be easily measured on an output basis. Other jobs may include irregular activities or have so many different forms of output that measuring output and determining pay are fairly complex. In the case of assembly lines, the use of *individual* incentives could disrupt the even flow of work; however, *group* incentives are sometimes used successfully in such cases. Finally, *quality* considerations may be as important as *quantity* considerations. In health care, for example, emphasis is generally placed on both the quality of patient care and the number of patients processed.

On the other hand, situations exist where incentives are desirable. Incentives reward workers for their output, presumably causing some workers to produce more than they might under a time-based system. The advantage is that certain (fixed) costs do not vary with increases in output, so the overall cost per unit decreases if output increases. Workers may prefer incentive systems because they see a relationship between their efforts and their pay: An incentive system presents an opportunity for them to earn more money.

On the negative side, incentive systems involve a considerable amount of paperwork, computation of wages is more difficult than under time-based systems, output has to be measured and standards set, cost-of-living increases are difficult to incorporate into incentive plans, and contingency arrangements for unavoidable delays have to be developed.

Table 7.7 lists the main advantages and disadvantages of time-based and output-based plans.

TABLE 7.7
Comparison of time-based and output-based pay systems

	Management	Worker
TIME-BASED		
Advantages	1. Stable labor costs 2. Easy to administer 3. Simple to compute pay 4. Stable output	1. Stable pay 2. Less pressure to produce than under output system
Disadvantages	1. No incentive for workers to increase output	1. Extra efforts not rewarded
OUTPUT-BASED		
Advantages	1. Lower cost per unit 2. Greater output	1. Pay related to efforts 2. Opportunity to earn more
Disadvantages	1. Wage computation more difficult 2. Need to measure output 3. Quality may suffer 4. Difficult to incorporate wage increases 5. Increased problems with scheduling	1. Pay fluctuates 2. Workers may be penalized because of factors beyond their control (e.g., machine breakdown)

In order to obtain maximum benefit from an incentive plan, the plan should be

1. Accurate
2. Easy to apply
3. Consistent
4. Easy to understand
5. Fair

In addition, there should be an obvious relationship between effort and reward, and no limit on earnings.

Incentive systems may focus on the output of each individual or on that of a group.

Individual Incentive Plans

Individual incentive plans take a variety of forms. The simplest plan is *straight piecework.* Under this plan, a worker's pay is a direct linear function of his or her output. In the past, piecework plans were fairly popular. Now minimum wage legislation makes them somewhat impractical. Even so, many of the plans currently in use represent variations of the straight piecework plan. They typically incorporate a base rate that serves as a floor: Workers are guaranteed that amount as a minimum, regardless of output. The base rate is tied to an output standard; a worker who produces less than the standard will be paid at the base rate. This protects workers from pay loss due to delays, breakdowns, and similar problems. In most cases, incentives are paid for output above standard, and the pay is referred to as a *bonus.*

Group Incentive Plans

A variety of group incentive plans, which stress sharing of productivity gains with employees, are in use. Some focus exclusively on output, while others reward employees for output and for reductions in material and other costs.

One form of group incentive is the *team approach,* which many companies are now using for problem solving and continuous improvement. The emphasis is on *team,* not *individual,* performance.

Knowledge-Based Pay Systems

As companies shift toward lean production, a number of changes have had a direct impact on the work environment. One is that many of the buffers that previously existed are gone. Another is that fewer managers are present. Still another is increased emphasis on quality, productivity, and flexibility. Consequently, workers who can perform a variety of tasks are particularly valuable. Organizations are increasingly recognizing this, and they are setting up pay systems to reward workers who undergo training that increases their skill levels. This is sometimes referred to as **knowledge-based pay.** It is a portion of a worker's pay that is based on the knowledge and skill that the worker possesses. Knowledge-based pay has three dimensions: *Horizontal skills* reflect the variety of tasks the worker is capable of performing; *vertical skills* reflect managerial tasks the worker is capable of; and *depth skills* reflect quality and productivity results.

knowledge-based pay A pay system used by organizations to reward workers who undergo training that increases their skills.

Management Compensation

Many organizations that traditionally rewarded managers and senior executives on the basis of *output* are now seriously reconsidering that approach. With the new emphasis on customer service and quality, reward systems are being restructured to reflect new dimensions of performance. In addition, executive pay in many companies is being more closely tied to the success of the company or division that executive is responsible for. Even so, there have been news reports of companies increasing the compensation of top executives even as workers were being laid off and the company was losing large amounts of money!

SUMMARY

The design of work systems involves job design, work measurement, and compensation.

Job design is concerned with the content of jobs and work methods. In the past, job design tended to focus on efficiency, but now there seems to be an increasing awareness and consideration of the behavioral aspects of work and worker satisfaction. Current concern about productivity has thrust job design into the limelight. However, the jobs usually associated with high productivity are often the same jobs that are the greatest source of worker dissatisfaction, creating somewhat of a paradox for job designers.

Analysts often use methods analysis and motion study techniques to develop the "efficiency" aspects of jobs, but these do not directly address behavioral aspects. Nonetheless, they are an important part of job design. Working conditions are also a notable aspect of job design, not only because of the behavioral and efficiency factors but also because of concern for the health and safety of workers.

TABLE 7.8
Summary of formulas

Time Study		Work Sampling	
A. Sample size		A. Maximum error	
$n = \left(\frac{zs}{a\bar{x}}\right)^2$	(7–1)	$e = z\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$	(7–9)
$n = \left(\frac{zs}{e}\right)^2$	(7–2)	B. Sample size	
B. Observed time		$n = \left(\frac{z}{e}\right)^2 \hat{p}(1-\hat{p})$	(7–10)
$OT = \frac{\sum x_i}{n}$	(7–3)	**Symbols:**	
C. Normal time		a = Allowable error as percentage of average time	
$NT = OT \times PR$	(7–4)	A = Allowance percentage	
$NT = \sum(\bar{x}_j \times PR_j)$	(7–5)	e = Maximum acceptable error	
D. Standard time		n = Number of observations needed	
$ST = NT \times AF$	(7–6)	NT = Normal time	
E. Allowance factor		OT = Observed, or average, time	
$AF_{job} = 1 + A$	(7–7)	PR = Performance rating	
$AF_{day} = \frac{1}{1-A}$	(7–8)	s = Standard deviation of observed times	
		ST = Standard time	
		x_i = Time for ith observation ($i = 1, 2, 3, \ldots, n$)	

Work measurement is concerned with specifying the length of time needed to complete a job. Such information is vital for personnel planning, cost estimating, budgeting, scheduling, and worker compensation. Commonly used approaches include stopwatch time study and predetermined times. A related technique is work sampling, which can also be used to obtain data on activity times. More commonly, work sampling is used to estimate the proportion of time a worker spends on a certain aspect of the job. Table 7.8 provides a summary of the formulas used in time studies and work sampling.

Organizations can choose from a variety of compensation plans. It is important to do so carefully, for compensation is key to both the worker and the organization, and, once adopted, it is usually difficult to substantially change a compensation plan.

KEY TERMS

ergonomics, 298
flow process chart, 306
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SOLVED PROBLEMS

Problem 1

A time study analyst timed an assembly operation for 30 cycles, and then computed the average time per cycle, which was 18.75 minutes. The analyst assigned a performance rating of .96, and decided that an appropriate allowance was 15 percent. Assume the allowance factor is based on the *workday.* Determine the following: the observed time (OT), the normal time (NT), and the standard time (ST).

(continued)

Solution

$$OT = \text{Average time} = 18.75 \text{ minutes}$$

$$NT = OT \times \text{Performance rating} = 18.75 \text{ minutes} \times .96 = 18 \text{ minutes}$$

$$AF = \frac{1}{1-A} = \frac{1}{1-.15} = 1.176$$

$$ST = NT \times AF = 18 \times 1.176 = 21.17 \text{ minutes}$$

Problem 2

A time study analyst wants to estimate the number of observations that will be needed to achieve a specified maximum error, with a confidence of 95.5 percent. A preliminary study yielded a mean of 5.2 minutes and a standard deviation of 1.1 minutes. Determine the total number of observations needed for these two cases:

a. A maximum error of ±6% of the sample mean.

b. A maximum error of .40 minute.

Solution

a. $x = 5.2$ minutes $\quad z = 2.00$ for 95.5% from p. 316

$s = 1.1$ minutes $\quad a = .06$

$$n = \left(\frac{zs}{ax}\right)^2 = \left(\frac{2.00(1.1)}{.06(5.2)}\right)^2 = 49.72 \text{ (round to 50 observations)}$$

b. $e = .40$

$$n = \left(\frac{zs}{e}\right)^2 = \left(\frac{2.00(1.1)}{.40}\right)^2 = 30.25 \text{ (round to 31 observations)}$$

Problem 3

Work sampling. An analyst has been asked to prepare an estimate of the proportion of time that a turret lathe operator spends adjusting the machine, with a 90 percent confidence level. Based on previous experience, the analyst believes the proportion will be approximately 30 percent.

a. If the analyst uses a sample size of 400 observations, what is the maximum possible error that will be associated with the estimate?

b. What sample size would the analyst need in order to have the maximum error be no more than ±5 percent?

Solution

$\hat{p} = .30 \quad z = 1.65$ for 90 percent confidence from p. 316

a. $$e = z\sqrt{\frac{\hat{p}(1-\hat{p})}{n}} = 1.65\sqrt{\frac{.3(.7)}{400}} = .038$$

b. $$n = \left(\frac{z}{e}\right)^2 \hat{p}(1-\hat{p}) = \left(\frac{1.65}{.05}\right)^2 (.3)(.7) = 228.69, \text{ or } 229$$

DISCUSSION AND REVIEW QUESTIONS

1. What is job design, and why is it important?
2. What are some of the main advantages and disadvantages of specialization from a management perspective? From a worker's perspective?
3. Contrast the meanings of the terms *job enlargement* and *job enrichment.*
4. What is the purpose of approaches such as job enlargement and job enrichment?
5. Explain the term *knowledge-based pay system.*
6. What are self-directed work teams? What are some potential benefits of using these teams?
7. Some Japanese firms have a policy of rotating their managers among different managerial jobs. In contrast, American managers are more likely to specialize in a certain area (e.g., finance or operations). Discuss the advantages and disadvantages of each of these approaches. Which do you prefer? Why?
8. What are motion study principles? How are they classified?
9. Name some reasons why methods analyses are needed. How is methods analysis linked to productivity improvements?

10. How are devices such as flow process charts and worker-machine charts useful?
11. What is a time standard? What factors must be taken into account when developing standards?
12. What are the main uses of time study information?
13. Could performance rating be avoided by studying a group of workers and averaging their times? Explain briefly.
14. If an average worker could be identified, what advantage would there be in using that person for a time study? What are some reasons why an average worker might not be studied?
15. What are the main limitations of time study?
16. Comment on the following. "At any given instant, the standard times for many jobs will not be strictly correct."
    a. Why is this so?
    b. Does this mean that those standards are useless? Explain.
17. Why do workers sometimes resent time studies?
18. What are the key advantages and disadvantages of:
    a. Time-based pay plans?
    b. Incentive plans?
19. What is work sampling? How does it differ from time study?

TAKING STOCK

1. What are the trade-offs in the following?
   a. Using self-directed teams instead of a more conventional approach with occasional use of teams.
   b. Deciding how often to update standard times due to minor changes in work methods.
   c. Choosing between time study and work sampling for work measurement.
2. Who uses the results of work measurement in an organization, and how do they use them?
3. In what ways does technology have an impact on job design?

CRITICAL THINKING EXERCISE

Explain why it can take as much as 12 months to design, set up, and debug an automated assembly line to produce a product such as an automobile, or why it can take as long as four years to design, set up, and hold the summer or winter Olympics.

PROBLEMS

1. An analyst has timed a metal-cutting operation for 50 cycles. The average time per cycle was 10.40 minutes, and the standard deviation was 1.20 minutes for a worker with a performance rating of 125 percent. Assume an allowance of 16 percent of job time. Find the standard time for this operation.
2. A job was timed for 60 cycles and had an average of 1.2 minutes per piece. The performance rating was 95 percent, and workday allowances are 10 percent. Determine each of the following:
   a. Observed time
   b. Normal time
   c. Standard time
3. A time study was conducted on a job that contains four elements. The observed times and performance ratings for six cycles are shown in the following table.

		OBSERVATIONS (MINUTES PER CYCLE)					
Element	**Performance Rating**	**1**	**2**	**3**	**4**	**5**	**6**
1..........	90%	0.44	0.50	0.43	0.45	0.48	0.46
2..........	85	1.50	1.54	1.47	1.51	1.49	1.52
3..........	110	0.84	0.89	0.77	0.83	0.85	0.80
4..........	100	1.10	1.14	1.08	1.20	1.16	1.26

   a. Determine the average cycle time for each element.
   b. Find the normal time for each element.
   c. Assuming an allowance factor of 15 percent of job time, compute the standard time for this job.
4. Given these observed times (in minutes) for four elements of a job, determine the observed time (OT) for each element. Note: The second element only occurs every other cycle.

	CYCLE					
	1	2	3	4	5	6
Element 1	4.1	4.0	4.2	4.1	4.1	4.1
Element 2	—	1.5	—	1.6	—	1.4
Element 3	3.2	3.2	3.3	3.2	3.3	3.3
Element 4	2.7	2.8	2.7	2.8	2.8	2.8

5. Given these observed times (in minutes) for five elements of a job, determine the observed time (OT) for each element. Note: Some of the elements occur only periodically.

	CYCLE					
	1	2	3	4	5	6
Element 1	2.1	2.0	2.2	2.1	2.1	—
Element 2	—	1.1	—	1.0	—	1.2
Element 3	3.4	3.5	3.3	3.5	3.4	3.3
Element 4	4.0	—	—	4.2	—	—
Element 5	1.4	1.4	1.5	1.5	1.5	1.4

6. Using Table 7.3 (on pg. 319), develop an allowance percentage for a job element that requires the worker to lift a weight of 10 pounds while (1) standing in a slightly awkward position, (2) in light that is slightly below recommended standards, and (3) with intermittent loud noises occurring. The monotony for this element is high. Include a personal allowance of 5 percent and a basic fatigue allowance of 4 percent of job time.
7. A worker-machine operation was found to involve 3.3 minutes of machine time per cycle in the course of 40 cycles of stopwatch study. The worker's time averaged 1.9 minutes per cycle, and the worker was given a rating of 120 percent (machine rating is 100 percent). Midway through the study, the worker took a 10-minute rest break. Assuming an allowance factor of 12 percent of work time, determine the standard time for this job.
8. A recently negotiated union contract allows workers in a shipping department 24 minutes for rest, 10 minutes for personal time, and 14 minutes for delays for each four hours worked. A time study analyst observed a job that is performed continuously and found an average time of 6.0 minutes per cycle for a worker she rated at 95 percent. What standard time is applicable for that operation?
9. The data in the table below represent time study observations for a woodworking operation.
   a. Based on the observations, determine the standard time for the operation, assuming an allowance of 15 percent of job time.
   b. How many observations would be needed to estimate the mean time for element 2 within 1 percent of its true value with a 95.5 percent confidence?
   c. How many observations would be needed to estimate the mean time for element 2 within .01 minute of its true value with a 95.5 percent confidence?

		OBSERVATIONS (MINUTES PER CYCLE)					
Element	Performance Rating	1	2	3	4	5	6
1.........	110%	1.20	1.17	1.16	1.22	1.24	1.15
2.........	115	0.83	0.87	0.78	0.82	0.85	1.32*
3.........	105	0.58	0.53	0.52	0.59	0.60	0.54

*Unusual delay, disregard time.

10. How many observations should a time study analyst plan for in an operation that has a standard deviation of 1.5 minutes per piece if the goal is to estimate the mean time per piece to within 0.4 minute with a confidence of 95.5 percent?
11. How many work cycles should be timed to estimate the average cycle time to within 2 percent of the sample mean with a confidence of 99 percent if a pilot study yielded these times (minutes): 5.2, 5.5, 5.8, 5.3, 5.5, and 5.1?
12. In an initial survey designed to estimate the percentage of time air-express cargo loaders are idle, an analyst found that loaders were idle in 6 of the 50 observations.

a. What is the estimated percentage of idle time?
b. Based on the initial results, approximately how many observations would you require to estimate the actual percentage of idle time to within 5 percent with a confidence of 95 percent?

13. A job in an insurance office involves telephone conversations with policyholders. The office manager estimates that about half of the employee's time is spent on the telephone. How many observations are needed in a work sampling study to estimate that time percentage to within 6 percent and have a confidence of 98 percent?

14. Design a schedule of work sampling observations in which eight observations are made during one eight-hour day. Using Table 7.5, read the *last digit* going down column 4 for hours (e.g., 1 7 4 4 6 . . .), and read across row 3 from left to right in sets of two for minutes (e.g., 47 15 24 86 . . .). Arrange the times chronologically.

15. The manager of a large office intends to conduct a work sampling of the time the staff spends on the telephone. The observations will be taken over a period of 50 workdays. The office is open five days a week for eight hours a day. Although the study will consist of 200 random observations, in this problem you will be asked to determine times for 11 observations. Use random numbers from Table 7.5.
a. Determine times for 11 observations. For days, read sets of two-digit numbers going across row 4 from left to right (e.g., 16 32 15 46 . . .), and do the same in row 5.
b. For hours, read one-digit numbers going *down,* using the first digit of column 1 (e.g., 6 4 3 1 . . .).
c. For minutes, read two-digit numbers going *up* column 4 using the first two digits (e.g., 30 46 10 . . .), and then repeat for the second two digits going *up* column 4 (e.g., 95 66 39 . . .).
d. Arrange the combinations chronologically by day, hour, and minute.
e. Assume March 1 is a Monday and that there are no holidays in March, April, or May.

Convert your observation days to dates in March, April, and May.

16. A work sampling study is to be conducted on rush-hour traffic (4 to 7 P.M.) five days per week. The study will encompass 40 days. Determine the day, hour, and minute for 10 observations using the following procedure:
a. Read two-digit numbers going *down* the first two digits of column 5 (e.g., 46 20 38 . . .), and then down the second two digits of that column (e.g., 27 93 56 . . .) for days.
b. For hours, read one-digit numbers going from left to right across row 1 and then across row 2. (Read only 4s, 5s, and 6s.)
c. For minutes, read two-digit numbers going *down* column 6, first using the *last* two digits (e.g., 87 17 64 . . .), and, after exhausting those numbers, repeat using the first two digits of that column (e.g., 83 46 00 19 . . .).

Arrange your times chronologically by day, then hour, and then minute.

Making Hotplates

READING

Edgar F. Huse

A group of 10 workers were responsible for assembling hotplates (instruments for heating solutions to a given temperature) for hospital and medical laboratory use. A number of different models of hotplates were being manufactured. Some had a vibrating device so that the solution could be mixed while being heated. Others heated only test tubes. Still others could heat solutions in a variety of different containers.

With the appropriate small tools, each worker assembled part of a hotplate. The partially completed hotplate was placed on a moving belt, to be carried from one assembly station to the next. When the hotplate was completed, an inspector would check it over to ensure that it was working properly. Then the last worker would place it in a specially prepared cardboard box for shipping.

The assembly line had been carefully balanced by industrial engineers, who had used a time and motion study to break the job down into subassembly tasks, each requiring about three minutes to accomplish. The amount of time calculated for each subassembly had also been "balanced" so that the task performed by each worker was supposed to take almost exactly the same amount of time. The workers were paid a straight hourly rate.

However, there were some problems. Morale seemed to be low, and the inspector was finding a relatively high percentage of badly assembled hotplates. Controllable rejects—those "caused" by the operator rather than by faulty materials—were running about 23 percent.

(continued)

(concluded)

After discussing the situation, management decided to try something new. The workers were called together and asked if they would like to build the hotplates individually. The workers decided they would like to try this approach, provided they could go back to the old program if the new one did not work well. After several days of training, each worker began to assemble the entire hotplate.

The change was made at about the middle of the year. Productivity climbed quickly. By the end of the year, it had leveled off at about 84 percent higher than during the first half of the year, although no other changes had been made in the department or its personnel. Controllable rejects had dropped from 23 percent to 1 percent during the same period. Absenteeism had dropped from 8 percent to less than 1 percent. The workers had responded positively to the change, and their morale was higher. As one person put it, "Now, it is *my* hotplate." Eventually, the reject rate dropped so low that all routine final inspection was done by the assembly workers themselves. The full-time inspector was transferred to another job in the organization.

Questions

1. What changes in the work situation might account for the increase in productivity and the decrease in controllable rejects?
2. What might account for the drop in absenteeism and the increase in morale?
3. What were the major changes in the situation? Which changes were under the control of the manager? Which were controlled by workers?
4. What might happen if the workers went back to the old assembly line method?

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Supplement to

CHAPTER 7

Learning Curves

LEARNING OBJECTIVES

After completing this supplement, you should be able to:

1. Explain the concept of a learning curve.
2. Make time estimates based on learning curves.
3. List and briefly describe some of the main applications of learning curves.
4. Outline some of the cautions and criticisms of learning curves.
5. Estimate learning rates from data on job times.

SUPPLEMENT OUTLINE

Learning is usually occurring when humans are involved; this is a basic consideration in the design of work systems. It is important to be able to predict how learning will affect task times and costs. This supplement addresses those issues.

THE CONCEPT OF LEARNING CURVES

Human performance of activities typically shows improvement when the activities are done on a repetitive basis: The time required to perform a task decreases with increasing repetitions. *Learning curves* summarize this phenomenon. The degree of improvement and the number of tasks needed to realize the major portion of the improvement is a function of the task being done. If the task is short and somewhat routine, only a modest amount of improvement is likely to occur, and it generally occurs during the first few repetitions. If the task is fairly complex and has a longer duration, improvements will occur over a longer interval (i.e., a larger number of repetitions). Therefore, learning factors have little relevance for planning or scheduling routine activities, but they do have relevance for new or complex repetitive activities.

Figure 7S.1 illustrates the basic relationship between increasing repetitions and a decreasing time per repetition. It should be noted that the curve will never touch the horizontal axis; that is, the time per unit will never be zero.

The general relationship is alternatively referred to as an experience curve, a progress function, or an improvement function. Experts agree that the learning effect is the result of other factors in addition to actual worker learning. Some of the improvement can be traced to preproduction factors, such as selection of tooling and equipment, product design, methods

FIGURE 7S.1

The learning effect: time per repetition decreases as the number of repetitions increases

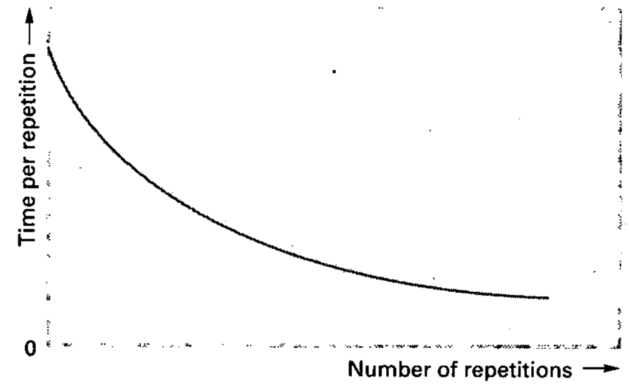
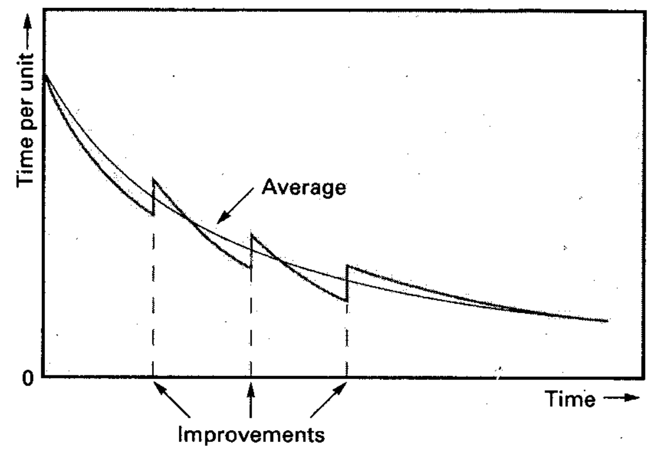


FIGURE 7S.2

Improvements may create a scallop effect in the curve



analysis, and, in general, the amount of effort expended prior to the start of the work. Other contributing factors may involve changes after production has begun, such as changes in methods, tooling, and design. In addition, management input can be an important factor through improvements in planning, scheduling, motivation, and control.

Changes that are made once production is under way can cause a temporary *increase* in time per unit until workers adjust to the change, even though they eventually lead to an increased output rate. If a number of changes are made during production, the learning curve would be more realistically described by a series of scallops instead of a smooth curve, as illustrated in Figure 7S.2. Nonetheless, it is convenient to work with a smooth curve, which can be interpreted as the *average* effect.

From an organizational standpoint, what makes the learning effect more than an interesting curiosity is its *predictability,* which becomes readily apparent if the relationship is plotted on a log-log scale (see Figure 7S.3). The straight line that results reflects a constant learning percentage, which is the basis of learning curve estimates: Empirical evidence shows that every *doubling* of repetitions results in a *constant percentage* decrease in the time per repetition. This applies both to the *average* and to the *unit* time. Typical decreases range from 10 percent to 20 percent. By convention, learning curves are referred to in terms of the *complements* of their improvement rates. For example, an 80 percent learning curve denotes a 20 percent decrease in unit (or average) time with each doubling of repetitions, and a 90 percent curve denotes a 10 percent improvement rate. Note that a 100 percent curve would imply no improvement at all.

EXAMPLE S-1

An activity is known to have an 80 percent learning curve. It has taken a worker 10 hours to produce the first unit. Determine expected completion times for these units: the 2nd, 4th, 8th, and 16th (note successive doubling of units).

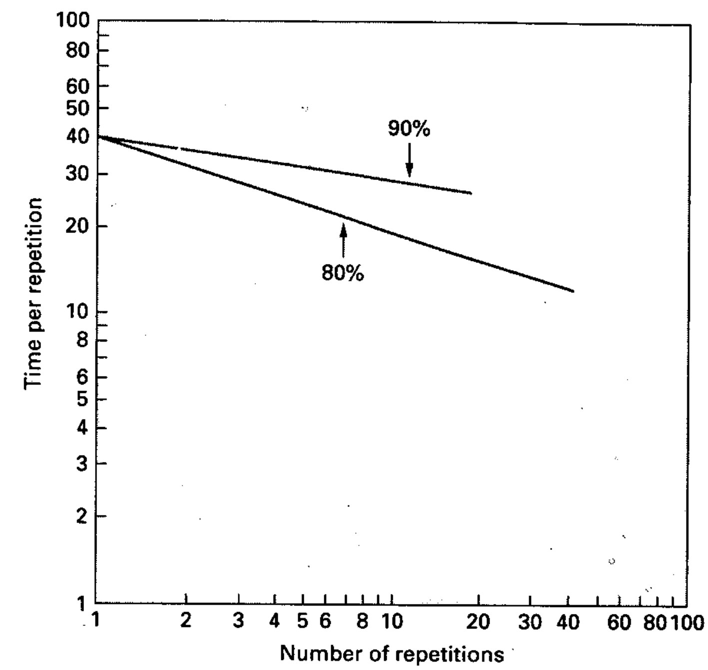


FIGURE 7S.3

On a log-log graph, learning curves are straight lines

SOLUTION

Each time the cumulative output doubles, the time per unit for that amount should be approximately equal to the previous time multiplied by the learning percentage (80 percent in this case). Thus:

Unit	Unit Time (hours)
1.....	= 10
2.....	0.8(10) = 8
4.....	0.8(8) = 6.4
8.....	0.8(6.4) = 5.12
16.....	0.8(5.12) = 4.096

Example S–1 illustrates an important point and also raises an interesting question. The point is that the time reduction *per unit* becomes less and less as the number of repetitions increases. For example, the second unit required two hours less time than the first, and the improvement from the 8th to the 16th unit was only slightly more than one hour. The question raised is: How are times computed for values such as three, five, six, seven, and other units that don't fall into this pattern?

There are two ways to obtain the times. One is to use a formula; the other is to use a table of values.

First, consider the formula approach. The formula is based on the existence of a linear relationship between the time per unit and the number of units when these two variables are expressed in logarithms.

The unit time (i.e., the number of direct labor hours required) for the *n*th unit can be computed using the formula

$$T_n = T_1 \times n^b \qquad (7S\text{–}1)$$

where

T_n = Time for *n*th unit

T_1 = Time for first unit

b = ln (learning percent) ÷ ln 2; ln stands for the natural logarithm

To use the formula, you need to know the time for the first unit and the learning percentage. For example, for an 80 percent curve with $T_1 = 10$ hours, the time for the third unit would be computed as

$$T_3 = 10(3^{\ln .8/\ln 2}) = 7.02$$

Note: log can be used instead of ln.

The second approach is to use a "learning factor" obtained from a table such as Table 7S.1.

The table shows two things for some selected learning percentages. One is a unit value for the number of repetitions (unit number). This enables us to easily determine how long any unit will take to produce. The other is a cumulative value, which enables us to compute the total number of hours needed to complete any given number of repetitions. The computation for both is a relatively simple operation: Multiply the table value by the time required for the first unit.

TABLE 7S.1
Learning curve coefficients

	70%		75%		80%		85%		90%	
Unit Number	Unit Time	Total Time	Unit Time	Total Time	Unit Time	Total Time	Unit Time	Total Time	Unit Time	Total Time
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	.700	1.700	.750	1.750	.800	1.800	.850	1.850	.900	1.900
3	.568	2.268	.634	2.384	.702	2.502	.773	2.623	.846	2.746
4	.490	2.758	.562	2.946	.640	3.142	.723	3.345	.810	3.556
5	.437	3.195	.513	3.459	.596	3.738	.686	4.031	.783	4.339
6	.398	3.593	.475	3.934	.562	4.299	.657	4.688	.762	5.101
7	.367	3.960	.446	4.380	.534	4.834	.634	5.322	.744	5.845
8	.343	4.303	.422	4.802	.512	5.346	.614	5.936	.729	6.574
9	.323	4.626	.402	5.204	.493	5.839	.597	6.533	.716	7.290
10	.306	4.932	.385	5.589	.477	6.315	.583	7.116	.705	7.994
11	.291	5.223	.370	5.958	.462	6.777	.570	7.686	.695	8.689
12	.278	5.501	.357	6.315	.449	7.227	.558	8.244	.685	9.374
13	.267	5.769	.345	6.660	.438	7.665	.548	8.792	.677	10.052
14	.257	6.026	.334	6.994	.428	8.092	.539	9.331	.670	10.721
15	.248	6.274	.325	7.319	.418	8.511	.530	9.861	.663	11.384
16	.240	6.514	.316	7.635	.410	8.920	.522	10.383	.656	12.040
17	.233	6.747	.309	7.944	.402	9.322	.515	10.898	.650	12.690
18	.226	6.973	.301	8.245	.394	9.716	.508	11.405	.644	13.334
19	.220	7.192	.295	8.540	.388	10.104	.501	11.907	.639	13.974
20	.214	7.407	.288	8.828	.381	10.485	.495	12.402	.634	14.608
21	.209	7.615	.283	9.111	.375	10.860	.490	12.892	.630	15.237
22	.204	7.819	.277	9.388	.370	11.230	.484	13.376	.625	15.862
23	.199	8.018	.272	9.660	.364	11.594	.479	13.856	.621	16.483
24	.195	8.213	.267	9.928	.359	11.954	.475	14.331	.617	17.100
25	.191	8.404	.263	10.191	.355	12.309	.470	14.801	.613	17.713
26	.187	8.591	.259	10.449	.350	12.659	.466	15.267	.609	18.323
27	.183	8.774	.255	10.704	.346	13.005	.462	15.728	.606	18.929
28	.180	8.954	.251	10.955	.342	13.347	.458	16.186	.603	19.531
29	.177	9.131	.247	11.202	.338	13.685	.454	16.640	.599	20.131
30	.174	9.305	.244	11.446	.335	14.020	.450	17.091	.596	20.727

To find the time for an individual unit (e.g., the 10th unit), use the formula

$$T_n = T_1 \times \text{unit time factor} \tag{7S–2}$$

Thus, for an 85 percent curve, with $T_1 = 4$ hours, the time for the 10th unit would be $4 \times .583 = 2.33$ hours. To find the time for all units up to a specified unit (e.g., the first 10 units), use the formula

$$\sum T_n = T_1 \times \text{total time factor} \tag{7S–3}$$

Thus, for an 85 percent curve, with $T_1 = 4$ hours, the total time for all 10 units (including the time for unit 1) would be $4 \times 7.116 = 28.464$ hours.

EXAMPLE S-2

Production Airplanes is negotiating a contract for the production of 20 small jet aircraft. The initial jet required the equivalent of 400 days of direct labor. The learning percentage is 80 percent. Estimate the expected number of days of direct labor for

a. The 20th jet.
b. All 20 jets.
c. The average time for 20 jets.

SOLUTION

Using Table 7S.1 with $n = 20$ and an 80 percent learning percentage, you find these factors: Unit time = .381; Total time = 10.485.

a. Expected time for 20th jet: 400(.381) = 152.4 labor days.
b. Expected total time for all 20: 400(10.485) = 4,194 labor days.
c. Average time for 20: 4,194 ÷ 20 = 209.7 labor days.

Use of Table 7S.1 requires a time for the first unit. If for some reason the completion time of the first unit is not available, or if the manager believes the completion time for some later unit is more reliable, the table can be used to obtain an estimate of the initial time.

EXAMPLE S-3

The manager in Example S–2 believes that some unusual problems were encountered in producing the first jet and would like to revise that estimate based on a completion time of 276 days for the third jet.

SOLUTION

The unit value for $n = 3$ and an 80 percent curve is .702 (Table 7S.1). Divide the actual time for unit 3 by the table value to obtain the revised estimate for unit 1's time: 276 days ÷ .702 = 393.2 labor days.

APPLICATIONS OF LEARNING CURVES

Learning curve theory has found useful applications in a number of areas, including

1. Manpower planning and scheduling.
2. Negotiated purchasing.
3. Pricing new products.
4. Budgeting, purchasing, and inventory planning.
5. Capacity planning.

Knowledge of output projections in learning situations can help managers make better decisions about how many workers they will need than they could determine from decisions based on initial output rates. Of course, managers obviously recognize that improvement will occur; what the learning curve contributes is a method for quantifying expected future improvements.

Negotiated purchasing often involves contracting for specialized items that may have a high degree of complexity. Examples include aircraft, computers, and special-purpose equipment. The direct labor cost per unit of such items can be expected to decrease as the size of the order increases. Hence, negotiators first settle on the number of units and then negotiate price on that basis. The government requires learning curve data on contracts that involve large, complex items. For contracts that are terminated before delivery of all units, suppliers can use learning curve data to argue for an increase in the unit price for the smaller number of units. Conversely, the government can use that information to negotiate a lower price per unit on follow-on orders on the basis of projected additional learning gains.

Managers must establish prices for their new products and services, often on the basis of production of a few units. Generalizing from the cost of the first few units would result in a much higher price than can be expected after a greater number of units have been produced. Actually, the manager needs to use the learning curve to avoid underpricing as well as overpricing. The manager may project initial costs by using the learning progression known to represent an organization's past experience, or else do a regression analysis of the initial results.

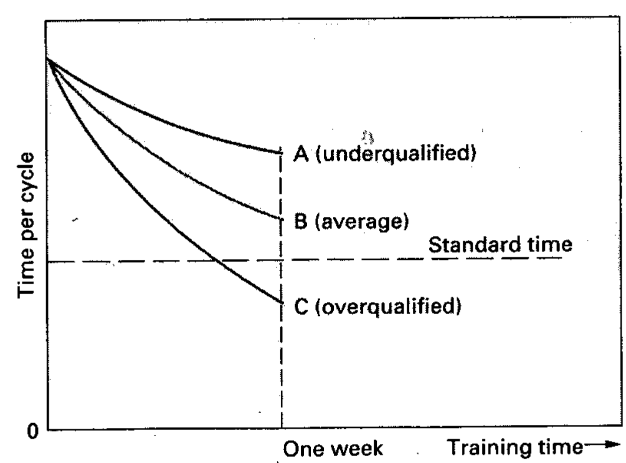
The learning curve projections help managers to plan costs and labor, purchasing, and inventory needs. For example, initial cost per unit will be high and output will be fairly low, so purchasing and inventory decisions can reflect this. As productivity increases, purchasing and/or inventory actions must allow for increased usage of raw materials and purchased parts to keep pace with output. Because of learning effects, the usage rate will increase over time. Hence, failure to refer to a learning curve would lead to substantial *overestimates* of labor needs and *underestimates* of the rate of material usage.

The learning principles can sometimes be used to evaluate new workers during training periods. This is accomplished by measuring each worker's performance, graphing the results, and comparing them to an expected rate of learning. The comparison reveals which workers are underqualified, average, and overqualified for a given type of work (see Figure 7S.4). Moreover, measuring a worker's progress can help predict whether the worker will make a quota within a required period of time.

Boeing uses learning curves to estimate weight reduction in new aircraft designs. Weight is a major factor in winning contracts because it is directly related to fuel economy.

FIGURE 7S.4

Worker learning curves can help guide personnel job placement



EXAMPLE S-4

Use learning curve theory to predict the number of repetitions (units) that will be needed for a trainee to achieve a unit time of 6 minutes if the trainee took 10 minutes to do the first unit and a learning curve of 90 percent is operative.

a. Use the learning table.

b. Use the log formula.

SOLUTION

a. The table approach can be used for the learning percentages that are listed across the top of the table, such as the 90 percent curve in this example. The table approach is based on formula 7S–2:

$T_n = T_1 \times$ unit table factor

Setting T_n equal to the specified time of 6 minutes and solving for the unit table factor yields

6 min = 10 min × unit table factor. Solving, unit table factor = 6 min ÷ 10 min = .600.

From Table 7S.1, under 90% in the Unit Time column, we find .599 at 29 units. Hence, approximately 29 units will be required to achieve the specified time.

b. Using the log formula,

(1) Compute the ratio of specified time to first unit time: 6 min ÷ 10 min = .600.

(2) Compute the ratio of ln learning percentage to ln 2: ln .90 ÷ ln 2 = −0.1053605 ÷ 0.6931472 = −0.1520.

(3) Find n such that $n^{-.1520} = .600$: $\sqrt[-.1520]{.600} = 28.809$. Round to 29. Hence, 29 units (repetitions) will be needed to achieve a time of 6 minutes.

Operations Strategy

Learning curves often have strategic implications for market entry, when an organization hopes to rapidly gain market share. The use of time-based strategies can contribute to this. An increase in market share creates additional volume, enabling operations to quickly move down the learning curve, thereby decreasing costs and, in the process, gaining a competitive advantage. In some instances, the volumes are sufficiently large that operations will shift from batch mode to repetitive operation, which can lead to further cost reductions.

Learning curve projections can be useful for capacity planning. Having realistic time estimates based on learning curve theory, managers can translate that information into actual capacity needs, and plan on that basis.

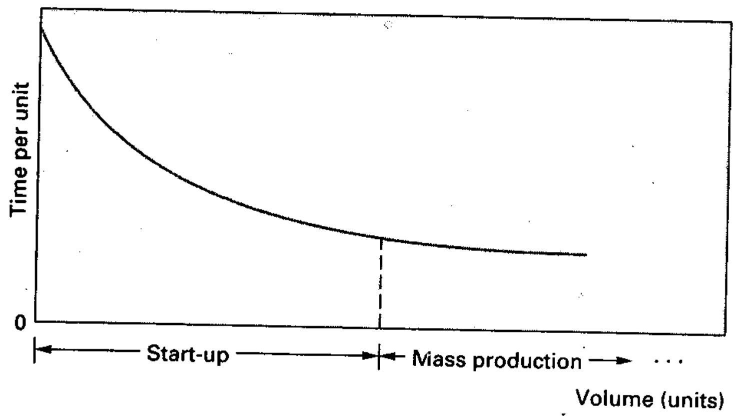
CAUTIONS AND CRITICISMS

Managers using learning curves should be aware of their limitations and pitfalls. This section briefly outlines some of the major cautions and criticisms of learning curves.

1. Learning rates may differ from organization to organization and by type of work. Therefore, it is best to base learning rates on empirical studies rather than assumed rates where possible.
2. Projections based on learning curves should be regarded as *approximations* of actual times and treated accordingly.
3. Because time estimates are based on the time for the first unit, considerable care should be taken to ensure that the time is valid. It may be desirable to revise the base time as later times become available. Since it is often necessary to estimate the time for the first unit prior to production, this caution is very important.
4. It is possible that at some point the curve might level off or even tip upward, especially near the end of a job. The potential for savings at that point is so slight that most jobs do not command the attention or interest to sustain improvements. Then, too, some of the better workers or other resources may be shifted into new jobs that are starting up.
5. Some of the improvements may be more apparent than real: Improvements in times may be caused in part by *increases* in *indirect* labor costs.

FIGURE 7S.5

Learning curves are useful for production start-up, but not usually for mass production



6. In mass production situations, learning curves may be of initial use in predicting how long it will take before the process stabilizes. For the most part, however, the concept does *not* apply to mass production because the decrease in time per unit is imperceptible for all practical purposes (see Figure 7S.5).
7. Users of learning curves sometimes fail to include carryover effects; previous experience with similar activities can reduce activity times, although it should be noted that the *learning rate* remains the same.
8. Shorter product life cycles, flexible manufacturing, and cross-functional workers can affect the ways in which learning curves may be applied.

SOLVED PROBLEMS

Problem 1

An assembly operation has a 90 percent learning curve. The line has just begun work on a new item; the initial unit required 28 hours. Estimate the time that will be needed to complete:

a. The first five units.

b. Units 20 through 25.

Solution

Use the total time factor in the 90 percent column of Table 7S.1.

a. Table value: 4.339.

Estimated time for five units: 28(4.339) = 121.49 hours.

b. The total time for units 20 through 25 can be determined by subtraction:

	Hours
Total time for 25 units:	28(17.713) = 495.96
− Total time for 19 units:	28(13.974) = 391.27
Total time for units 20 through 25	104.69

Problem 2

A manager wants to determine an appropriate learning rate for a new type of work his firm will undertake. He has obtained completion times for the initial six repetitions of a job of this type. What learning rate is appropriate?

Unit	Completion Time (hours)
1	15.9
2	12.0
3	10.1
4	9.1
5	8.4
6	7.5

Solution

According to theory, the time per unit decreases at a constant rate each time the output *doubles* (e.g., unit 1 to 2, 2 to 4, and 3 to 6). The ratios of these observed times will give us an approximate rate. Thus,

$$\frac{\text{Unit 2}}{\text{Unit 1}} = \frac{12.0}{15.9} = .755 \quad \frac{\text{Unit 4}}{\text{Unit 2}} = \frac{9.1}{12.0} = .758 \quad \frac{\text{Unit 6}}{\text{Unit 3}} = \frac{7.5}{10.1} = .743$$

Not surprisingly, there is some variability; the rate is usually a smoothed approximation. Even so, the ratios are fairly close—a rate of 75 percent seems reasonable in this case.

DISCUSSION AND REVIEW QUESTIONS

1. If the learning phenomenon applies to all human activity, why isn't the effect noticeable in mass production or high-volume assembly work?
2. Under what circumstances might a manager prefer a learning rate of approximately 100 percent (i.e., no "learning")?
3. What would a learning percentage of 120 percent imply?
4. Explain how an increase in indirect labor cost can contribute to a decrease in direct labor cost per unit.
5. List the kinds of factors that create the learning effect.
6. Explain how changes in a process, once it is under way, can cause scallops in a learning curve.
7. Name some areas in which learning curves are useful.
8. What factors might cause a learning curve to tip up toward the end of a job?
9. Users of learning curves sometimes fail to include carryover effects; previous experience with similar activities can reduce initial activity times, although it should be noted that the *learning rate* remains the same. What is the implication of this item from the list of cautions and criticisms?

PROBLEMS

1. An aircraft company has an order to refurbish the interiors of 18 jet aircraft. The work has a learning curve percentage of 80. On the basis of experience with similar jobs, the industrial engineering department estimates that the first plane will require 300 hours to refurbish. Estimate the amount of time needed to complete:
   a. The fifth plane.
   b. The first five planes.
   c. All 18 planes.
2. Estimate the time it will take to complete the 4th unit of a 12-unit job involving a large assembly if the initial unit required approximately 80 hours for each of these learning percentages:
   a. 72 percent
   b. 87 percent
   c. 95 percent
3. A contractor intends to bid on a job installing 30 airport security systems. Because this will be a new line of work for the contractor, he believes there will be a learning effect for the job. After reviewing time records from a similar type of activity, the contractor is convinced that an 85 percent curve is appropriate. He estimates that the first job will take his crew eight days to install. How many days should the contractor budget for
   a. The first 10 installations?
   b. The second 10 installations?
   c. The final 10 installations?
4. A job is known to have a learning percentage equal to 82. If the first unit had a completion time of 20 hours, estimate the times that will be needed to complete the third and fourth units.
5. A manager wants to determine an appropriate learning percentage for processing insurance claims for storm damage. Toward that end, times have been recorded for completion of each of the first six repetitions. They are

Repetition	Time (minutes)
1	46
2	39
3	35
4	33
5	32
6	30

a. Determine the approximate learning percentage.

b. Using your answer from part *a,* estimate the average completion time per repetition assuming a total of 30 repetitions are planned.

6. Students in an operations management class have been assigned four similar homework problems. One student noted that it took her 50 minutes to complete the first problem. Assume that the four problems are similar and that a 70 percent learning curve is appropriate. How much time can this student plan to spend solving the remaining problems?

7. A subcontractor is responsible for outfitting six satellites that will be used for solar research. Four of the six have been completed in a total of 600 hours. If the crew has a 75 percent learning curve, how long should it take them to finish the last two units?

8. The 5th unit of a 25-unit job took 14.5 hours to complete. If a 90 percent learning curve is appropriate:
   a. How long should it take to complete the last unit?
   b. How long should it take to complete the 10th unit?
   c. Estimate the average time per unit for the 25 units.

9. The labor cost to produce a certain item is $8.50 per hour. Job setup costs $50 and material costs are $20 per unit. The item can be purchased for $88.50 per unit. The learning rate is 90 percent. Overhead is charged at a rate of 50 percent of labor, materials, and setup costs.
   a. Determine the unit cost for 20 units, given that the first unit took 5 hours to complete.
   b. What is the minimum production quantity necessary to make production cost less than purchase cost?

10. A firm has a training program for a certain operation. The progress of trainees is carefully monitored. An established standard requires a trainee to be able to complete the sixth repetition of the operation in six hours or less. Those who are unable to do this are assigned to other jobs.

    Currently, three trainees have each completed two repetitions. Trainee A had times of 9 hours for the first and 8 hours for the second repetition; trainee B had times of 10 hours and 8 hours for the first and second repetitions; and trainee C had times of 12 and 9 hours.

    Which trainee(s) do you think will make the standard? Explain your reasoning.

11. The first unit of a job took 40 hours to complete. The work has a learning percentage of 88. The manager wants time estimates for units 2, 3, 4, and 5. Develop those time estimates.

12. A manager wants to estimate the remaining time that will be needed to complete a five-unit job. The initial unit of the job required 12 hours, and the work has a learning percentage of 77. Estimate the total time remaining to complete the job.

13. Kara is supposed to have a learning percentage of 82. Times for the first four units were 30.5, 28.4, 27.2, and 27.0 minutes. Does a learning percentage of 82 seem reasonable? Justify your answer using appropriate calculations.

14. The 5th unit of a 10-unit job took five hours to complete. The 6th unit has been worked on for two hours, but is not yet finished. Estimate the *additional* amount of time needed to finish the 10-unit job if the work has a 75 percent learning rate.

15. Estimate the number of repetitions each of the workers listed in the following table will require to reach a time of 7 hours per unit. Time is in hours.

Trainee	T_1	T_2
Art	11	9.9
Sherry	10.5	8.4
Dave	12	10.2

16. Estimate the number of repetitions that new service worker Irene will require to achieve "standard" if the standard is 18 minutes per repetition. She took 30 minutes to do the initial repetition and 25 minutes to do the next repetition.

17. Estimate the number of repetitions each of the workers listed in the following table will require to achieve a standard time of 25 minutes per repetition. Time is in minutes.

Trainee	T_1	T_2
Beverly	36	31
Max	40	36
Antonio	37	30

18. A research analyst performs database searches for a variety of clients. According to her log, a new search requires approximately 55 minutes. Repeated requests on the same or similar topic take less and less time, as her log shows:

Request no.	1	2	3	4	5	6	7	8
Time (min.)	55.0	41.0	35.2	31.0	28.7	26.1	24.8	23.5

How many more searches will it take until the search time gets down to 19 minutes?

Product Recall

CASE

An automobile manufacturer is conducting a product recall after it was discovered that a possible defect in the steering mechanism could cause loss of control in certain cars. The recall covers a span of three model years. The company sent out letters to car owners promising to repair the defect at no cost at any dealership.

The company's policy is to pay the dealer a fixed amount for each repair. The repair is somewhat complicated, and the company expected learning to be a factor. In order to set a reasonable rate for repairs, company engineers conducted a number of repairs themselves. It was then decided that a rate of $88 per repair would be appropriate, based on a flat hourly rate of $22 per hour and a 90 percent learning rate.

Shortly after dealers began making repairs, the company received word that several dealers were encountering resistance from workers who felt the flat rate was much too low and who were threatening to refuse to work on those jobs. One of the dealers collected data on job times and sent that information to the company: Three mechanics each completed two repairs. Average time for the first unit was 9.6 hours, and average time for the second unit was 7.2 hours. The dealer has suggested a rate of $110 per repair.

You have been asked to investigate the situation and to prepare a report.

Questions

1. Prepare a list of questions that you will need to have answered in order to analyze this situation.
2. Prepare a list of observations regarding the information provided in the case.
3. What preliminary thoughts do you have on solutions/partial solutions to the points you have raised?

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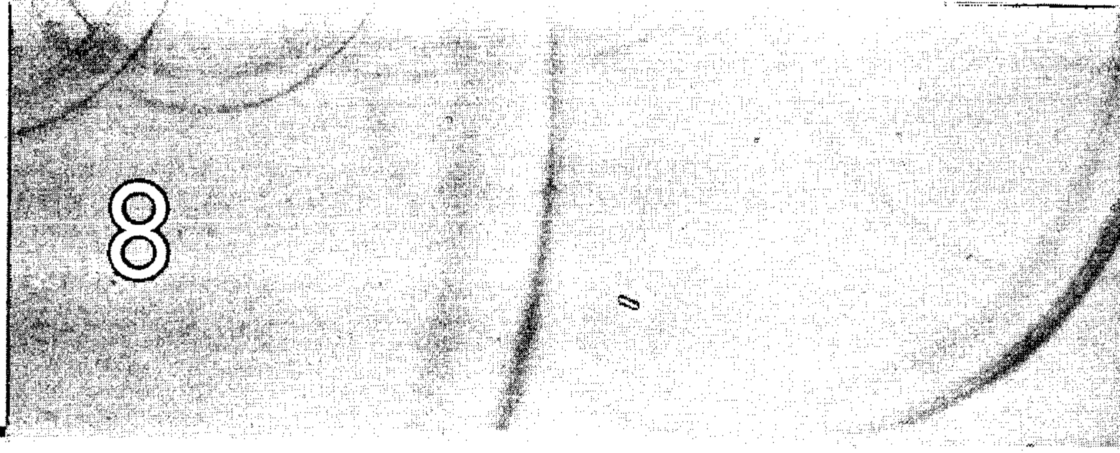
CHAPTER 8



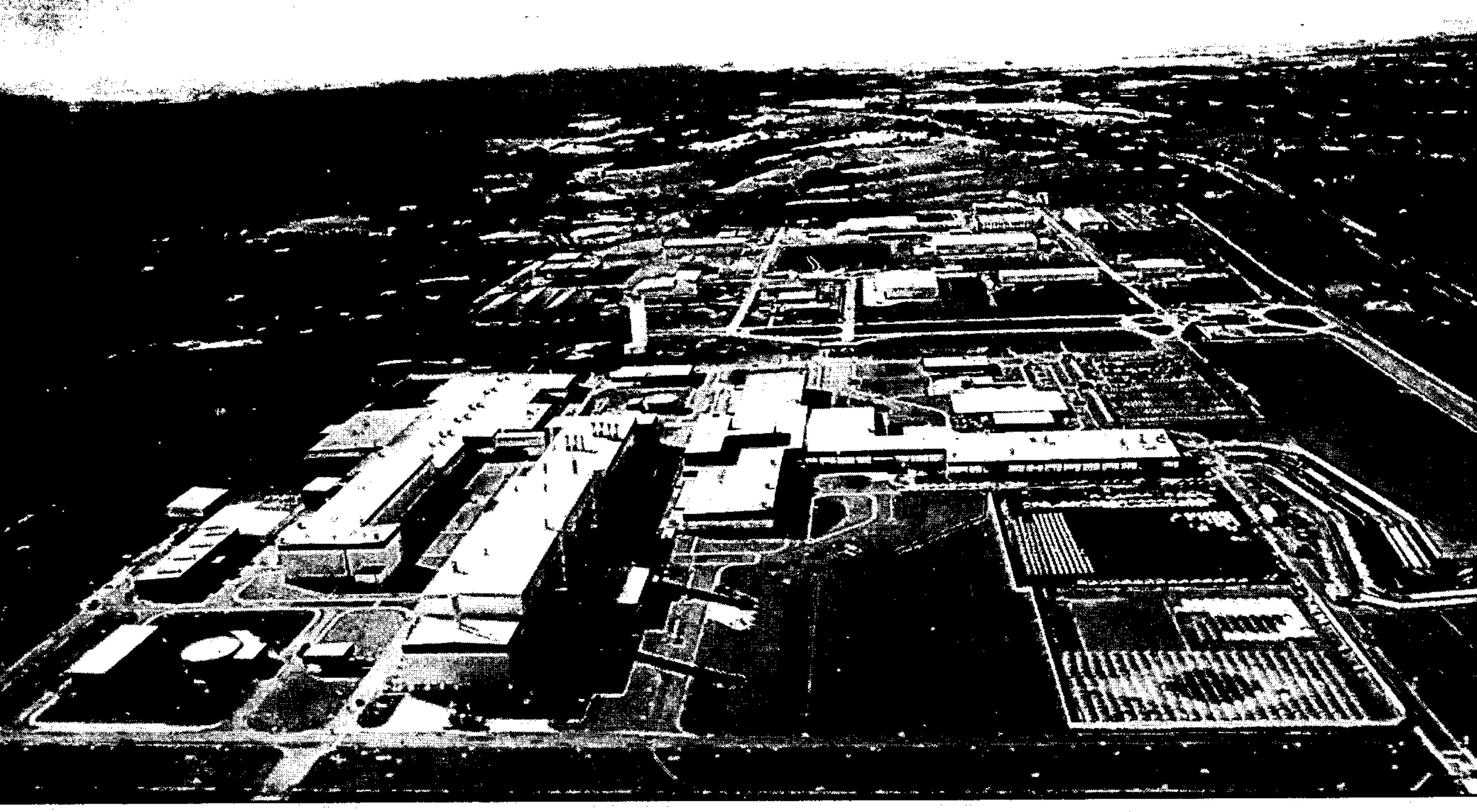
Location Planning and Analysis

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. List some of the main reasons organizations need to make location decisions.
2. Explain why location decisions are important.
3. Discuss the options that are available for location decisions.
4. Describe some of the major factors that affect location decisions.
5. Outline the decision process for making these kinds of decisions.
6. Use the techniques presented to solve typical problems.

CHAPTER OUTLINE



When a well-known real estate broker was asked what the three most important determinants of the value of a property are, he said, "That's easy. Location, location, and location."

In the residential real estate market, location is an important factor. Although the style of house, number of bedrooms and bathrooms, level of maintenance, and how modern the kitchen is undoubtedly enter into the picture, some locations are just more desirable than others.

In many respects, the choice of location for a business organization is every bit as important as it is for a house, although for different reasons.

Location decisions represent a key part of the strategic planning process of virtually every organization. And, although it might appear that location decisions are one-time problems pertaining to new organizations, existing organizations often have a bigger stake in these kinds of decisions than new organizations.

This chapter examines location analysis. It begins with a brief overview of the reasons firms must make location decisions, the nature of these decisions, and a general procedure for developing and evaluating location alternatives.

THE NEED FOR LOCATION DECISIONS

Existing organizations may need to make location decisions for a variety of reasons. Firms such as banks, fast-food chains, supermarkets, and retail stores view locations as part of marketing strategy, and they look for locations that will help them to expand their markets. Basically, the location decisions in those cases reflect the *addition* of new locations to an existing system.

A similar situation occurs when an organization experiences a growth in demand for its products or services that cannot be satisfied by expansion at an existing location. The addition of a new location to complement an existing system is often a realistic alternative.

Some firms face location decisions through depletion of basic inputs. For example, fishing and logging operations are often forced to relocate due to the temporary exhaustion of fish or forests at a given location. Mining and petroleum operations face the same sort of situation, although usually with a longer time horizon.

For other firms, a shift in markets causes them to consider relocation, or the costs of doing business at a particular location reach a point where other locations begin to look more attractive.

THE NATURE OF LOCATION DECISIONS

Location decisions for many types of businesses are made infrequently, but they tend to have a significant impact on the organization. In this section we look at the importance of location decisions, the usual objectives managers have when making location choices, and some of the options that are available to them.

Strategic Importance of Location Decisions

Location decisions are closely tied to an organization's strategies. For example, a strategy of being a low-cost producer might result in locating where labor or material costs are low, or locating near markets or raw materials to reduce transportation costs. A strategy of increasing profits by increasing market share might result in locating in high-traffic areas, and a strategy that emphasizes convenience for the customer might result in having many locations where customers can transact their business or make purchases (e.g., branch banks, ATMs, service stations, fast-food outlets).

Location decisions are also strategically important for other reasons as well. One is that they entail a long-term commitment, which makes mistakes difficult to overcome. Another is that location decisions often have an impact on investment requirements, operating costs and revenues, and operations. A poor choice of location might result in excessive transportation costs, a shortage of qualified labor, loss of competitive advantage, inadequate supplies of raw materials, or some similar condition that is detrimental to operations. For services, a poor location could result in lack of customers and/or high operating costs. For both manufacturing and services, location decisions can have a significant impact on competitive advantage. And another reason for the importance of location decisions is their strategic importance to supply chains.

Objectives of Location Decisions

As a general rule, profit-oriented organizations base their decisions on profit potential, whereas nonprofit organizations strive to achieve a balance between cost and the level of customer service they provide. It would seem to follow that all organizations attempt to identify the "best" location available. However, this is not necessarily the case.

In many instances, no single location may be significantly better than the others. There may be numerous acceptable locations from which to choose, as shown by the wide variety of locations where successful organizations can be found. Furthermore, the number of possible locations that would have to be examined to find the best location may be too large to make an exhaustive search practical. Consequently, most organizations do not set out with the intention of identifying the *one best* location; rather, they hope to find a number of *acceptable* locations from which to choose.

Location criteria can depend on where a business is in the *supply chain.* For instance, at the retail end of a chain, site selection tends to focus more on accessibility, consumer demographics (population density, age distribution, average buyer income), traffic patterns, and local customs. Businesses at the beginning of a supply chain, if they are involved in supplying raw materials, are often located near the source of the raw materials. Businesses in the middle of the chain may locate near suppliers or near their markets, depending on a variety of circumstances. For example, businesses involved in storing and distributing goods often choose a central location to minimize distribution costs.

Web-based retail businesses are much less dependent on location decisions; they can exist just about anywhere.

Location Options

Managers generally consider four options in location planning. One is to expand an existing facility. This option can be attractive if there is adequate room for expansion, especially if the location has desirable features that are not readily available elsewhere. Expansion costs are often less than those of other alternatives.

Another option is to add new locations while retaining existing ones, as is done in many retail operations. In such cases, it is essential to take into account what the impact will be on the total system. Opening a new store in a shopping mall may simply draw customers who already patronize an existing store in the same chain, rather than expand the market. On the other hand, adding locations can be a defensive strategy designed to maintain a market share or to prevent competitors from entering a market.

A third option is to shut down at one location and move to another. An organization must weigh the costs of a move and the resulting benefits against the costs and benefits of remaining in an existing location. A shift in markets, exhaustion of raw materials, and the cost of operations often cause firms to consider this option seriously.

Finally, organizations have the option of doing nothing. If a detailed analysis of potential locations fails to uncover benefits that make one of the previous three alternatives attractive, a firm may decide to maintain the status quo, at least for the time being.

GENERAL PROCEDURE FOR MAKING LOCATION DECISIONS

The way an organization approaches location decisions often depends on its size and the nature or scope of its operations. New or small organizations tend to adopt a rather informal approach to location decisions. New firms typically locate in a certain area simply because the owner lives there. Similarly, managers of small firms often want to keep operations in their backyard, so they tend to focus almost exclusively on local alternatives. Large established companies, particularly those that already operate in more than one location, tend to take a more formal approach. Moreover, they usually consider a wider range of geographic locations. The discussion here pertains mainly to a formal approach to location decisions.

The general procedure for making location decisions usually consists of the following steps:

1. Decide on the criteria to use for evaluating location alternatives, such as increased revenues or community service.
2. Identify important factors, such as location of markets or raw materials.
3. Develop location alternatives:
   a. Identify the general region for a location.
   b. Identify a small number of community alternatives.
   c. Identify site alternatives among the community alternatives.
4. Evaluate the alternatives and make a selection.

Step (1) is simply a matter of managerial preference. Steps (2) through (4) may need some elaboration.

FACTORS THAT AFFECT LOCATION DECISIONS

Many factors influence location decisions. However, it often happens that one or a few factors are so important that they dominate the decision. For example, in manufacturing, the potentially dominating factors usually include availability of an abundant energy and water supply and proximity to raw materials. Thus, nuclear reactors require large amounts of water for cooling, heavy industries such as steel and aluminum production need large amounts of electricity, and so on. Transportation costs can be a major factor. In service organizations, possible dominating factors are market related and include traffic patterns, convenience, and competitors' locations, as well as proximity to the market. For example, car rental agencies locate near airports and midcity, where their customers are.

Once an organization has determined the most important factors, it will try to narrow the search for suitable alternatives to one geographic region. Then a small number of community-site alternatives are identified and subjected to detailed analysis. Human factors can be very important, as the following newsclip reveals.

Innovative MCI Unit Finds Culture Shock in Colorado Springs

NEWSCLIP

Alex Markels

www.mci.com

Convinced this town's spectacular setting would inspire his workers, Richard Liebhaber figured "build it, and they will come."

In 1991, the chief technology officer of MCI Communications Corp. decided to relocate MCI's brain trust—the 4,000-employee Systems Engineering division that created numerous breakthrough products—from MCI's Washington, D.C., headquarters to Colorado Springs. An avid skier, he believed the mountains, low crime rate, healthy climate and rock-bottom real-estate prices would be "a magnet for the best and brightest" computer software engineers.

He rejected warnings from at least half a dozen senior executives that Colorado Springs' isolated and politically conservative setting would actually repel the eclectic, ethnically diverse engineers MCI hoped to attract. Mr. Liebhaber argued that new hires would jump at the chance to live in ski country, while veterans would stay longer, reducing MCI's more than 15% annual turnover rate in Washington. The move, he contended, would also save money by cutting MCI's facilities, labor and recruiting costs. Besides, four other high-tech companies—including Digital Equipment Corp. and Apple Computer Inc.—had recently moved there. "One of the things that gave me more comfort was the fact that these other guys had selected Colorado Springs," Mr. Liebhaber says.

He was mistaken.

While many rank-and-file MCI employees, buoyed by generous relocation packages, made the move, numerous key executives and engineers, and hundreds of the division's 51% minority population, said no, or fled Colorado Springs soon after relocating.

Living in "Wonder Bread"

"It was like living in a loaf of Wonder Bread," says James Finucane, who is of Japanese descent and whose wife is from Argentina. A veteran senior engineer, Mr. Finucane was considered MCI's top engineer until he took a job with a competitor back east in 1994. "There's no culture, no diversity, no research university, no vitality or resiliency to the job market."

The move isolated MCI's engineers from top management and from marketing colleagues at headquarters, undermining the spontaneous collaborations that had generated some of company's most innovative products. Meanwhile, the professionals Mr. Liebhaber hoped to recruit from outside proved difficult and expensive to woo, pushing the move's total cost to about $200 million—far more than MCI officials anticipated. "Most of the savings we had hoped for never materialized," says LeRoy Pingho, a senior executive who oversaw the relocation.

As numerous companies consider relocating to smaller cities and towns, MCI's move shows the perils of transplanting urban professionals to the nation's heartland and segregating key operations. Dozens of former and current employees say Systems Engineering has lost its innovative and productive edge at a time when competition in telecommunications is fiercer than ever.

Moving Expenses

When the move was announced in March 1991, many rank-and-file workers were enthusiastic. MCI's relocation policy paid for every expense imaginable. Costing an average of $100,000 per employee, it included up to six months of temporary housing and living expenses, private-school tuition for workers' children and a full month's pay for miscellaneous expenses. And there were exceptional housing bargains. "In Alexandria, [Va.,] we had a tiny place on a 50-by-112-foot lot," says Jerome Sabolik, a senior software engineer. "For the same money, we got a 3,000-square-foot house on 2½ acres." Thousands of workers—far more than Mr. Liebhaber expected—took advantage of the offer, undercutting his plans to recruit lower-cost employees in Colorado.

But there was far less enthusiasm among senior managers. James Zucco, Mr. Ditchfield's successor and the head of Systems Engineering, stayed behind and eventually left to join AT&T Corp. Also staying put was Gary Wiesenborn, the division's No. 2 executive, who later moved to Bell Atlantic Corp. Mr. Pingho, who oversaw the division's financial planning and budgeting, declined to move and quit in 1993.

There was also significant fallout among the division's minority population. Although MCI declines to provide specific numbers, it confirms there was a reduction. According to former employees who had access to Equal Employment Opportunity Commission data, there were roughly 1,300 African-Americans on Systems Engineering's staff and a combined 700 Asians and Hispanics before the relocation. Since the relocation, minority representation has been cut almost in half, to about 600 blacks and a combined 500 Asians and Hispanics. "It was a disaster for diversity," Mr. Ditchfield says.

But MCI officials say that despite the reduction, its Colorado division is still more ethnically diverse than other local companies. "We think that we have numbers that are significantly better than the available work force there," says William D. Wooten, a senior vice president of human resources.

(continued)

(concluded)

Among those who opted out: Tony Martin, a vice president of operations who is Asian-American, and Rod Avery, who designed the complex billing system for MCI's successful "Friends & Family" long-distance program. One of the company's highest ranking African-Americans, Mr. Avery moved to AT&T.

Source: "Innovative MCI Unit Finds Culture Shock in Colorado Springs," Alex Markels, *The Wall Street Journal* © 1996 Dow Jones & Company, Inc. Used with permission.

Regional Factors

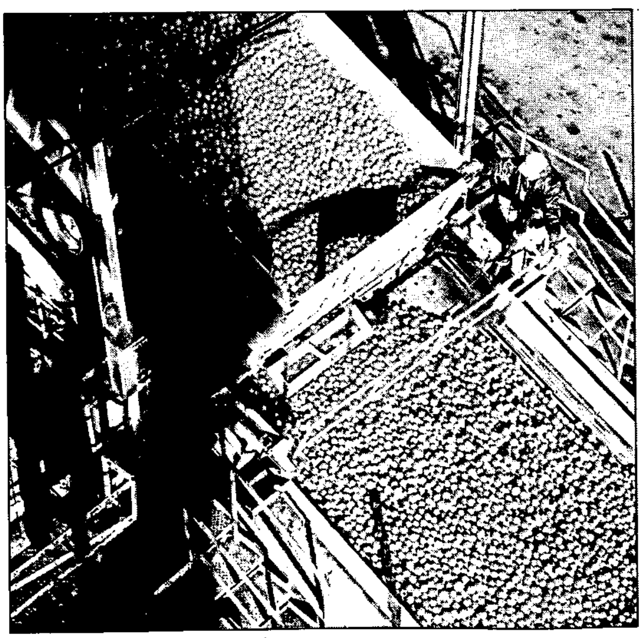
The primary regional factors involve raw materials, markets, and labor considerations.

Location of Raw Materials Firms locate near or at the source of raw materials for three primary reasons: necessity, perishability, and transportation costs. Mining operations, farming, forestry, and fishing fall under *necessity.* Obviously, such operations must locate close to the raw materials. Firms involved in canning or freezing of fresh fruit and vegetables, processing of dairy products, baking, and so on, must consider *perishability* when considering location. *Transportation costs* are important in industries where processing eliminates much of the bulk connected with a raw material, making it much less expensive to transport the product or material after processing. Examples include aluminum reduction, cheese making, and paper production. Where inputs come from different locations, some firms choose to locate near the geographic center of the sources. For instance, steel producers use large quantities of both coal and iron ore, and many are located somewhere between the Appalachian coal fields and iron ore mines. Transportation costs are often the reason that vendors locate near their major customers. Moreover, regional warehouses are used by supermarkets and other retail operations to supply multiple outlets. Often the choice of new locations and additional warehouses reflects the locations of existing warehouses or retail outlets.

Vol. 5, Seg. 3
American President Line

Location of Markets Profit-oriented firms frequently locate near the markets they intend to serve as part of their competitive strategy, whereas nonprofit organizations choose locations relative to the needs of the users of their services. Other factors include distribution costs or the perishability of a finished product.

Retail sales and services are usually found near the center of the markets they serve. Examples include fast-food restaurants, service stations, dry cleaners, and supermarkets. Quite often their products and those of their competitors are so similar that they rely on convenience



Tropicana, an orange juice producer, has processing plants in Florida and California. Locating the processing near their supply, the orange groves, provides time and cost savings in the transportation of perishable fruit.

www.tropicana.com

to attract customers. Hence, these businesses seek locations with high population densities or high traffic. The competition/convenience factor is also important in locating banks, hotels and motels, auto repair shops, drugstores, newspaper kiosks, and shopping centers. Similarly, doctors, dentists, lawyers, barbers, and beauticians typically serve clients who reside within a limited area.

Competitive pressures for retail operations can be extremely vital factors. In some cases, a market served by a particular location may be too small to justify two or more competitors (e.g., one hamburger franchise per block), so that a search for potential locations tends to concentrate on locations without competitors. The opposite also might be true; it could be desirable to locate near competitors. Large department stores often locate near each other, and small stores like to locate in shopping centers that have large department stores as anchors. The large stores attract large numbers of shoppers who become potential customers in the smaller stores or in the other large stores.

Some firms must locate close to their markets because of the perishability of their products. Examples include bakeries, flower shops, and fresh seafood stores. For other types of firms, distribution costs are the main factor in closeness to market. For example, sand and gravel dealers usually serve a limited area because of the high distribution costs associated with their products. Still other firms require close customer contact, so they too tend to locate within the area they expect to serve. Typical examples are tailor shops, home remodelers, home repair services, cabinetmakers, rug cleaners, and lawn and garden services.

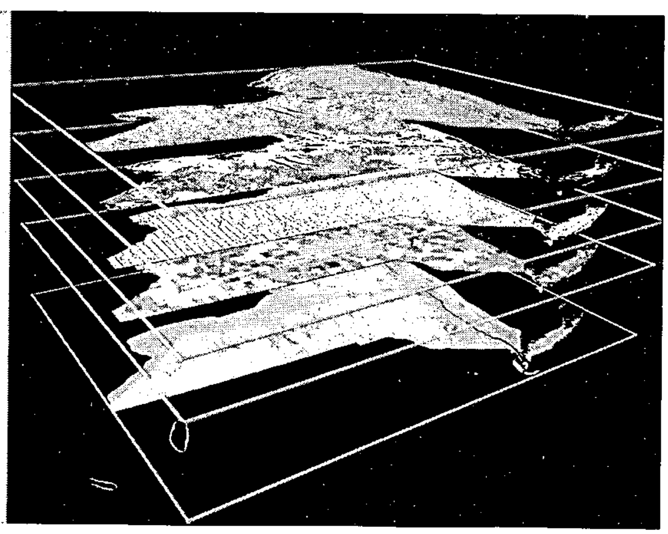
IS

Locations of many government services are near the markets they are designed to serve. Hence, post offices are typically scattered throughout large metropolitan areas. Police and emergency health care locations are frequently selected on the basis of client needs. For instance, police patrols often concentrate on high crime areas, and emergency health care facilities are usually found in central locations to provide ready access from all directions.

geographical information system (GIS) A computer-based tool for collecting, storing, retrieving, and displaying demographic data on maps.

Many foreign manufacturing companies have located manufacturing operations in the United States, because it is a major market for their products. Chief among them are automobile manufacturers, most notably Japanese, but other nations are also represented. Another possible reason that Japanese producers decided to locate in the United States was to offset possible negative consumer sentiment related to job losses of U.S. workers. Thousands of U.S. auto workers are now employed in U.S. manufacturing plants of Japanese and other foreign companies.

A Geographic Information System (GIS) is a tool that can be used for location planning. This graphic of New York State combines information from different databases to answer demographic questions about the state. This information also can be broken down into smaller units, such as counties.



Source: Center for Theory and Simulation, Cornell University New York State Office for Technology.

Software can be helpful in location analysis. For example, a **geographical information system (GIS)** is a computer-based tool for collecting, storing, retrieving, and displaying demographic data on maps. The data might involve age, incomes, type of employment, type of housing, or other similar data. The maps can be global, national, regional, state or province, county, city, or town. Analysts have the ability to answer a number of questions that are either impossible to answer, or very time-consuming to answer, using more traditional methods.

Labor Factors Primary labor considerations are the cost and availability of labor, wage rates in an area, labor productivity and attitudes toward work, and whether unions are a serious potential problem.

Global positioning systems are increasingly used for supply chain and logistics support. With the aid of satellite signals, this tracking device for cars and trucks can pinpoint current location and direct drivers to their exact destinations via the fastest route in real time.

Labor costs are very important for labor-intensive organizations. The shift of the textile industry from the New England states to southern states was due partly to labor costs.

Skills of potential employees may be a factor, although some companies prefer to train new employees rather than rely solely on previous experience. Increasing specialization in many industries makes this possibility even more likely than in the past. Although most companies concentrate on the supply of blue-collar workers, some firms are more interested in scientific and technical people as potential employees, and they look for areas with high concentrations of those types of workers.

Worker attitudes toward turnover, absenteeism, and similar factors may differ among potential locations—workers in large urban centers may exhibit different attitudes than workers in small towns or rural areas. Furthermore, worker attitudes in different parts of the country or in different countries may be markedly different.

Some companies offer their current employees jobs if they move to a new location. However, in many instances, employees are reluctant to move, especially when it means leaving families and friends. Furthermore, in families with two wage earners, relocation would require that one wage earner give up a job and then attempt to find another job in the new location.

Climate and Taxes Climate and taxes sometimes play a role in location decisions. For example, a string of unusually severe winters in northern states may cause some firms to seriously consider moving to a milder climate, especially if delayed deliveries and work disruptions caused by inability of employees to get to work have been frequent. Similarly, the business and personal income taxes in some states reduce their attractiveness to companies seeking new locations. Many companies have been attracted to some Sun Belt states by ample supplies of low-cost energy or labor, the climate, and tax considerations. Also, tax and monetary incentives are major factors in attracting or keeping professional sports franchises.

Community Considerations

Many communities actively try to attract new businesses because they are viewed as potential sources of future tax revenues and new job opportunities. However, communities do not, as a rule, want firms that will create pollution problems or otherwise lessen the quality of life in the community. Local groups may actively seek to exclude certain companies on such grounds, and a company may have to go to great lengths to convince local officials that it will be a "responsible citizen." Furthermore, some organizations discover that even though overall community attitude is favorable, there may still be considerable opposition to specific sites from nearby residents who object to possible increased levels of noise, traffic, or pollution. Examples of this include community resistance to airport expansion, changes in zoning, construction of nuclear facilities, and highway construction.

From a company standpoint, a number of factors determine the desirability of a community as a place for its workers and managers to live. They include facilities for education, shopping, recreation, transportation, religious worship, and entertainment; the quality of police, fire, and medical services; local attitudes toward the company; and the size of the community. Community size can be particularly important if a firm will be a major employer in the community; a future decision to terminate or reduce operations in that location could have a serious impact on the economy of a small community.

Other community-related factors are the cost and availability of utilities, environmental regulations, taxes (state and local, direct and indirect), and often a laundry list of enticements offered by state or local governments that can include bond issues, tax abatements, low-cost loans, grants, and worker training.

Site-Related Factors

The primary considerations related to sites are land, transportation, and zoning or other restrictions.

Evaluation of potential sites may require consulting with engineers or architects, especially in the case of heavy manufacturing or the erection of large buildings or facilities with special requirements. Soil conditions, load factors, and drainage rates can be critical and often necessitate certain kinds of expertise in evaluation.

Because of the long-term commitment usually required, land costs may be secondary to other site-related factors, such as room for future expansion, current utility and sewer capacities—and any limitations on these that could hinder future growth—and sufficient parking space for employees and customers. In addition, for many firms access roads for trucks or rail spurs are important.

Industrial parks may be worthy alternatives for firms involved in light manufacturing or assembly, warehouse operations, and customer service facilities. Typically, the land is already developed—power, water, and sewer hookups have been attended to, and zoning restrictions do not require special attention. On the negative side, industrial parks may place restrictions on the kinds of activities that a company can conduct, which can limit options for future development of a firm's products and services as well as the processes it may consider. Sometimes stringent regulations governing the size, shape, and architectural features of buildings limit managerial choice in these matters. Also, there may not be an adequate allowance for possible future expansion.

For firms with executives who travel frequently, the size and proximity of the airport or train station as well as travel connections can be important, although schedules and connections are subject to change.

Table 8.1 provides a summary of the factors that affect location decisions.

Multiple Plant Manufacturing Strategies

When companies have multiple manufacturing facilities, they can organize operations in several ways. One is to assign different product lines to different plants. Another is to assign different market areas to different plants. And a third is to assign different processes to different plants. Each strategy carries certain cost and managerial implications, as well as competitive advantages.

Product Plant Strategy With this strategy, entire products or product lines are produced in separate plants, and each plant usually supplies the entire domestic market. This is essentially a decentralized approach, with each plant focusing on a narrow set of requirements that entails specialization of labor, materials, and equipment along product lines. Specialization often results in economies of scale and, compared with multipurpose plants, lower operating costs. Plant locations may be widely scattered or clustered relatively close to one another.

Market Area Plant Strategy With this strategy, plants are designed to serve a particular geographic segment of a market (e.g., the West Coast, the Northeast). Individual plants produce most if not all of a company's products and supply a limited geographical area. Although operating costs tend to be higher than those of product plants, significant savings on shipping costs for comparable products can be made. This arrangement is particularly desirable when shipping costs are high due to volume, weight, or other factors. Such arrangements have the

TABLE 8.1
Factors affecting location decisions

Level	Factors	Considerations
Regional	Location of raw materials or supplies	Proximity, modes and costs of transportation, quantity available
	Location of markets	Proximity, distribution costs, target market, trade practices/restrictions
	Labor	Availability (general and for specific skills), age distribution of workforce, work attitudes, union or nonunion, productivity, wage scales, unemployment compensation laws
Community	Quality of life	Schools, churches, shopping, housing, transportation, entertainment, recreation, cost of living
	Services	Medical, fire, and police
	Attitudes	Pro/con
	Taxes	State/local, direct and indirect
	Environmental regulations	State/local
	Utilities	Cost and availability
	Development support	Bond issues, tax abatement, low-cost loans, grants
Site	Land	Cost, degree of development required, soil characteristics and drainage, room for expansion, parking
	Transportation	Type (access roads, rail spurs, air freight)
	Environmental/legal	Zoning restrictions

added benefit of rapid delivery and response to local needs. This approach requires centralized coordination of decisions to add or delete plants, or to expand or downsize current plants due to changing market conditions.

Process Plant Strategy With this strategy, different plants concentrate on different aspects of a process. Automobile manufacturers often use this approach, with different plants for engines, transmissions, body stamping, and even radiators. This approach is best suited to products that have numerous components; separating the production of components results in less confusion than if all production was carried out at the same location.

When an organization uses process plants, coordination of production throughout the system becomes a major issue and requires a highly informed, centralized administration to achieve effective operation. A key benefit is that individual plants are highly specialized and generate volumes that yield economies of scale.

Multiple plants have an additional benefit: the increase in learning opportunities that occurs when similar operations are being done in different plants. Similar problems tend to arise, and solutions to those problems as well as improvements in general in products and processes made at one plant can be shared with other plants.

SERVICE AND RETAIL LOCATIONS

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Service and retail are typically governed by somewhat different considerations than manufacturing organizations in making location decisions. For one thing, nearness to raw materials is usually not a factor, nor is concern about processing requirements. But customer access is usually a prime consideration. Manufacturers tend to be cost-focused, concerned with labor, energy, and material costs and availability, and distribution costs. Service and retail businesses tend to be revenue-focused, concerned with demographics such as age, income, and education, population/drawing area, competition, traffic volume/patterns, and customer access/parking.

Retail and service organizations typically place traffic volume and convenience high on the list of important factors. Specific types of retail or service businesses may pay more attention to certain factors due to the nature of their business or their customers. If a business is unique, and has its own drawing power, nearness to competitors may not be a factor. However, generally retail businesses prefer locations that are near other retailers (although not necessarily competitors) because of the higher traffic volumes and convenience to customers. Thus, automobile dealerships often tend to locate near each other, and restaurants and specialty stores often locate in and around malls, benefiting from the high traffic.

Medical services are often located near hospitals for convenience of patients. Doctors' offices may be located near hospitals, or grouped in other, centralized areas with other doctors' offices. Available public transportation is often a consideration.

Good transportation and/or parking facilities can be vital to retail establishments. Downtown areas have a competitive disadvantage in attracting shoppers compared to malls because malls offer ample free parking and nearness to residential areas.

Customer safety and security can be key factors, particularly in urban settings, for all types of services that involve customers coming to the service location (as opposed, say, to in-home services such as home repair and rug cleaning).

Competitors' locations can be of significance. In some cases, firms will want to locate near competitors to benefit from the concentration of potential customers. Mall stores and auto dealers are good examples. In other cases, locating near similar businesses is not important because there are no competitors. And in some cases, it is important *not* to be near a competitor (e.g., another franchise operation of the same fast-food chain).

www.mallofamerica.com

Mall of America in Minnesota is a four-level shopping mall, as well as a tourist destination. Unique features including an amusement park, night clubs, a huge aquarium, and indoor stock car races serve to draw customers and support anchor stores, such as Bloomingdale's, and a large variety of anchor stores.

Vying for Patients, Hospitals Think Location, Location

NEWSCLIP

Doreen Carvajal

The mood is as vital as the medicine at the elegant Upper East Side clinic squeezed among the fashionable addresses of Calvin Klein, Ralph Lauren and Barneys New York.

Silk magnolias bloom in the marble lobby, and abstract oil paintings dominate the pale rose corridors of Columbia-Presbyterian Medical Center's new satellite at East 60th Street and Madison Avenue.

The clinic is one of many ways for Columbia-Presbyterian to draw new patients for routine services as well as to feed its

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main hospital in Washington Heights for more complicated ones. A free shuttle regularly ferries the clinic's patients northwest along the Hudson River, an indirect route skirting Harlem on the way to the hospital, where the neighbors are not elegant boutiques, but the less fabled Self-Serve Laundromat and El Presidente cafeteria.

Location is becoming fiercely important to hospitals in New York's competitive medical marketplace as managed-care systems, so popular elsewhere, begin to take hold here. In the new world of fixed reimbursements, shorter hospital stays and tighter rationing of highly specialized services, hospitals must make their money from volume rather than from service fees.

The resulting battle for market share—and for new patients—is being waged not with scalpel and stethoscope, but with hammer and nails, in the neighborhoods where potential customers live.

"New York has been relatively slow to follow the rest of the country toward managed health care because it was so regulated," said Kenneth E. Raske, president of the Greater New York Hospital Association. "But they're here now. And they're going to have a profound influence on redrafting the map of New York health care."

Emerging as hospitals' most promising source of new patients are clinics like Columbia-Presbyterian Eastside, which, in health care jargon, are called "centers," lest potential patients confuse these gleaming outposts with conventional clinics that cater to the poor and uninsured. To attract middle-class patients wary of leaving their protected blocks, the city's huge hospitals are branching out to ethnic enclaves, upscale New York neighborhoods, affluent suburban communities, and even distant American expatriate communities in Eastern Europe.

Four months ago, Columbia-Presbyterian created a satellite in Moscow and more centers are planned for Warsaw, Prague, St. Petersburg, Budapest and possibly Beijing.

"Our feeling is that there will be no hospitals in the future," said Dr. William T. Speck, president of Columbia-Presbyterian. "And probably, in the next 10 or 20 years most of the activity will take place in a center or maybe even in homes."

Hospital executives contend that satellites, which typically have no beds and no provision for round-the-clock care, are cheaper to operate than highly specialized hospitals, which provide all the incidental services of a hotel. Babies, for instance, can be delivered at alternative sites for half a hospital's $9,000 fee, Dr. Speck said.

Not surprisingly, Columbia-Presbyterian is planning a birthing center just a block away from its Madison Avenue location.

Source: "Vying for Patients, Hospitals Think Location, Location," Doreen Carvajal, The New York Times Company.

Among the questions that should be considered are the following:

1. How can sales, market share, and profit be optimized for the entire set of locations? Solutions might include some combination of upgrading facilities, expanding some sites, adding new outlets, and closing or changing the locations of some outlets.
2. What are the potential sales to be realized from each potential solution?
3. Where should outlets be located to maximize market share, sales, and profits without negatively impacting other outlets? This can be a key cause of friction between the operator of a franchise store and the franchising company.
4. What probable effects would there be on market share, sales, and profits if a competitor located nearby?

Table 8.2 briefly compares service/retail site selection criteria with manufacturing criteria.

TABLE 8.2
A comparison of service/retail considerations and manufacturing considerations

Manufacturing/Distribution	Service/Retail
Cost focus	**Revenue focus**
Transportation modes/costs	Demographics: age, income, education
Energy availability/costs	Population/drawing area
Labor cost/availability/skills	Competition
Building/leasing costs	Traffic volume/patterns
	Customer access/parking

GLOBAL LOCATIONS

Recent trends in locating facilities, particularly manufacturing facilities, reflect a combination of competitive and technological factors. One trend has been that of foreign producers, especially automotive firms, to locate plants in the United States. The United States represents a tremendous market for cars, trucks, and recreational vehicles. By locating in the United States, these firms can shorten delivery time and reduce delivery costs. Furthermore, they can avoid any future tariffs or quotas that might be applied to imports.

A development that affects location decisions was the passage of GATT in 1994. One of its provisions was the reduction and elimination of various tariffs. Consequently, location within the borders of a country to escape tariffs is now much less of an issue.

An ethical issue has been the use of "sweatshops," which employ workers at low wages in poor working conditions. Consumer protests have caused a number of companies to cease this practice.

Another trend is just-in-time manufacturing techniques (see Chapter 14), which encourage suppliers to locate near their customers to reduce supplier lead times. For this reason, some U.S. firms are reconsidering decisions to locate offshore. Moreover, in light manufacturing (e.g., electronics), low-cost labor is becoming less important than nearness to markets; users of electronics components want suppliers that are close to their manufacturing facilities. One offshoot of this is the possibility that the future will see a trend toward smaller factories located close to markets. In some industries, small, automated **microfactories** with narrow product focuses will be located near major markets to reduce response time.

microfactory Small factory with a narrow product focus, located near major markets.

It is likely that advances in information technology will enhance the ability of manufacturing firms to gather, track, and distribute information that links purchasing, marketing, and distribution with design, engineering, and manufacturing. This will reduce the need for these functions to be located close together, thereby permitting a strategy of locating production facilities near major markets.

Global Strategy: GM Is Building Plants in Developing Nations to Woo New Markets

READING

Rebecca Blumenstein

www.gm.com

ROSARIO, Argentina—On the outskirts of this city more than 6,000 miles from Detroit, bulldozers have been running around the clock moving the fertile topsoil to make way for a General Motors Corp. auto-assembly plant of tomorrow.

The state-of-the-art plant, on a remote road in what had been a remote part of the automotive world, is at the center of GM's aggressive shift away from its roots in North America to the developing world. GM is quietly building so many plants in so many corners of the world that the No. 1 automaker has decided to save money by building essentially the same plant in Argentina, Poland, China and Thailand—simultaneously.

This "four-plant strategy" is GM's biggest international expansion, costing at least $2.2 billion. The company has designed the plants to look so much alike that engineers may mistake which country they are in. And the assembly lines are being set up so that a glitch in a robot in Thailand, rather than turning into an expensive engineering problem that requires an expert for each machine at each plant, may well be solved by a quick call to Rosario or to Shanghai, China.

Expandable and Efficient

But the significance of GM's new plants extends much further. They are being built to be easily expandable as demand in developing markets grows. And they are being laid out in a giant U-shape so that suppliers can cart in an increasing array of already assembled parts to cut GM's costs, something GM can't do in the U.S. because of union resistance.

The new factories illustrate, more than anything else, how the nature of multinational corporations is changing as today's marketplace turns global. Just a few years ago, GM's South American plants were churning out Chevy Chevettes that hadn't been produced in the U.S. for years. The auto industry viewed the world largely as a dumping ground for obsolete technology and outdated models.

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Now, the industry is seeking future growth by concentrating its investments in the developing world and turning it into a showcase for the latest in technology and lean manufacturing. And GM is pursuing that global strategy more vigorously than any of its rivals, though every other major auto maker sees the need to tap into emerging markets, and some have a substantial foreign presence. Nobody, however, is building plants on the scale of GM, which recently announced plans for a fifth and even more advanced new plant, in southern Brazil.

The entire Rosario plant is designed to be lean. Its total cost, at $350 million, is one of the lowest for a new GM plant; $1 billion had been the rule-of-thumb price tag for a new assembly plant of any size. Moreover, the investment here includes a high-tech stamping machine that will press metal parts more quickly than any other GM press and an engine plant that will deliver to the assembly line engines with air conditioning, transmission and belts already installed.

Workers will do many tasks, a key principle of lean manufacturing, and will be assigned to teams working autonomously. Every worker will be responsible for an entire process in the assembly operation, including even the cleaning and basic maintenance of machines. In Japan, that is a common approach, but it is inconceivable in a GM plant in the U.S. because of union work rules, which allow only specified categories of skilled workers to repair and maintain machines.

Although the four plants are designed to be as similar as possible, they do have differences, ranging from efforts to protect machines from rusting in Thailand's humid climate to China's poor transportation system. There, Mr. Stevens says, "We are going to have things delivered to our Shanghai plant by bicycle."

Questions

1. Briefly describe GM's four-plant strategy.
2. What are some signs of GM's shift in global thinking?
3. List the lean manufacturing elements of the Rosario plant.
4. What are some nonlabor local conditions that had to be taken into consideration in designing individual plants?

Source: "Global Strategy: GM Is Building Plants in Developing Nations to Woo New Markets," Rebecca Blumenstein *The Wall Street Journal* Copyright © 1997 Dow Jones & Company, Inc. Used with permission.

Two other factors are causing companies to locate manufacturing facilities in countries that contain their markets (e.g., Japanese auto companies establishing factories in the United States). One is to counter negative sentiments such as "not made in this country." Thus, Japanese factories in the United States produce cars made by U.S. workers. The second factor relates to currency fluctuations and devaluations. These changes can have a significant impact on demand and, hence, on profits. Changes in currency value alter the price of foreign goods, but not the price of goods produced within a country. For instance, if the value of a country's currency falls relative to that of other countries, prices within the country don't change, but foreign-produced goods become more expensive. If demand is elastic, then demand for those foreign goods will fall. Furthermore, currency changes may result in increased costs of parts supplied by foreign producers. By locating and selling within a country, and buying from suppliers in that country, manufacturers can avoid the impact of currency changes.

The trend toward globalization for some organizations has meant having facilities, personnel, and operations around the world. This has created new challenges for managing scattered and distant operations. Added to that are the ongoing social unrest, political instability, and terrorist acts that have caused many organizations to be very cautious about locating in, or even traveling to, certain counties or regions. Nonetheless, the benefits of globalization, coupled with advanced communications capabilities and other technologies, make globalization worth considering.

The growth in multinational operations over the past several decades is evidence of the importance of foreign locations. Some firms are attracted to foreign locations because of nearby deposits of aluminum, copper, timber, oil, or other natural resources. Other firms view foreign locations as a way to expand their markets, and still others are attracted by ample supplies of labor. Some countries may offer financial incentives to companies to create jobs for their people. Developing countries may establish tariffs to protect their young industries from outside competition, which may also reduce the amount of "foreign" competition a firm must face if it locates in such a country. Until the North American Free Trade Agreement eliminated restrictions, the Fisher-Price Toy Company factory in Matamoros, Mexico, was not allowed to sell in Mexico the Muppet toys it makes. U.S. companies with factories in Mexico could import raw materials duty-free, but they were required to export all of their output.

Many developing countries offer an abundant supply of cheap labor. For example, a considerable amount of the clothes sold in the United States bear labels indicating they were made in Korea, China, or Taiwan. In some instances, it is less expensive to ship raw materials or semifinished goods to foreign countries for fabrication and assembly, and then ship them to their final destinations, than it is to produce them in the United States. However, the final cost per unit is the most important factor. In some cases, the low cost of labor in a foreign country can be negated by low productivity and shipping costs.

High production costs in Germany have contributed to a number of German companies locating some of their production facilities in lower-cost countries. Among them are industrial products giant Siemens, A.G. (a semiconductor plant in Britain), drug makers Bayer, A.G. (a plant in Texas) and Hoechst, A.G. (a plant in China), and automakers Mercedes (plants in Spain, France, and Alabama) and BMW (a plant in Spartansburg, South Carolina).

A firm contemplating a foreign location must carefully weigh the potential benefits against the potential problems. A major factor is the stability of a country's government and its attitude toward American firms. Import restrictions can pose problems with bringing in equipment and spare parts.

Some of the problems of a foreign location can be caused by language and cultural differences between the United States and the host country. U.S. firms often find it necessary to use U.S. technical personnel but find it difficult to convince workers to move to a foreign country; workers may have to leave their families behind or else subject them to sub-standard housing or educational systems. Companies are now exerting additional efforts to reduce these obstacles. Some provide housing allowances and have schools for U.S. children. They are also improving their efforts to see that the employees they send abroad are familiar with local customs and have a reasonable facility with the language of the host country.

One factor that has negatively impacted the bottom line of some U.S. firms operating plants in foreign countries is the level of corruption present, erasing some of the envisioned benefits of lower labor or transportation costs.

Not-So-Clear Choices: Should You Export, or Manufacture Overseas?

READING

Russ Banham

When the board-games company Bob Moog created in 1985 sought growth through global expansion 2 years later, Moog faced the usual two options: export the product or manufacture it overseas for local distribution. Moog chose the latter.

"We decided for a number of reasons to manufacture our board game, '20 Questions,' in Holland for distribution throughout Europe," said Moog, president of University Games Corp. of Burlingame, CA.

Recently the company expanded into Australia. Unlike the European ventures, however, Moog decided that it was more economical to import its products into Australia from the U.S. manufacturing facility because "anticipated initial sales in Australia just did not warrant a manufacturing operation there at this juncture," Moog said. "If sales pick up down the line, we may then examine local manufacturing."

Moog's dual strategy is not unique. One of the toughest questions a company confronts when pondering an international sales strategy is: to export, or not to export?

While exporting is often the least risky method of selling overseas, it frequently involves significant transportation, logistics, and tax-related costs that may make it uneconomical when compared with foreign manufacturing.

On the other hand, foreign manufacturing, while potentially a more competitive way of entering an overseas market has its own bugaboos. Political instability, fluctuating market conditions, and the huge capital costs to set up an overseas manufacturing operation are daunting challenges. Determining the best way to go often involves solving a perplexing conundrum. "It boils down to a trade-off between classic cost-and-time considerations and eco-political factors," said Richard Powers, president of Insight Inc., a provider of management support systems based in Bend, OR.

With exporting, a company must evaluate the various modes of transportation that would be involved in getting the goods there, and how this relates to the cycle time of putting the product in the marketplace. Some products are time-sensitive; others are less so.

On the other hand, if a company determines that an overseas manufacturing operation best meets its needs, it must examine the eco-political factors involved, such as tariff and

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duty drawbacks and international tax issues. "It may be less expensive, given these factors, for a company to incur the logistics costs of exporting than to risk the eco-political costs," Powers explained.

Trade-Offs and Traps

In addition to weighing these trade-offs, there are other related factors affecting the decision to either export or locate a plant overseas. To compete in their market, for example, some countries require that some form of local infrastructure be in place.

"Sometimes you run into government contracts where the only way to distribute a product in that country is to have it made locally," said Fred Ehrsam, vice president at Bain & Co., a Boston-based strategy consulting firm. "In China, for instance, you pretty much have to build something there in order to enter that market."

Certain products also dictate the international sales strategy to be taken. "If your company makes drinking glasses, you'll want to manufacture them in whatever country you plan to sell them," observed Scott Setrakian, a director in the San Francisco office of Mercer Management Consulting. "Drinking glasses, generally speaking, are pretty cheap to make and expensive to ship."

Political instability is another guiding force in a company's decision-making process. "If you want to sell in Russia, you're facing political instability as your biggest single operating risk," noted John Koopman, a principal in Mercer's Toronto office. "In Western Europe, this is not an issue. In Asia, there's a little risk, but in Russia it's a given." Other factors include time, the distance to the market, and price. Certain products require short lead times and, thus may best be delivered via a locally manufactured plant. "This is where you get into issues like transportation costs, tariffs and duties, labor expenses, and how much it costs to build a plant," Ehrsam explained.

The maturity of a company's product affects this decision. A product expected to require design changes, for example, may not fit well with foreign manufacturing plans. "It's pretty hard to implement changes to a product when the product is fairly far removed from the product development and engineering people," Ehrsam continued. "Tactically, you want to be moving products offshore that are relatively stable."

Another factor is the skill of the labor force in the market being considered. "You have to question whether or not the labor pool—no matter how low-cost—can be trained to do the things you need," Ehrsam added.

Many companies enter a foreign market by first exporting there, but with an eye toward building overseas in the future. "Exporting will give you a feel for the product and its market potential," Powers said. "Instead of jumping in the lake head first, exporting allows you to get your toes wet. It may cost more, but you're able to hedge your risks."

But CPC International favors full-scale overseas manufacturing to either foreign product assembly or exporting. "We rely on exporting chiefly as a means of entering a new marketplace," said Gale Griffin, vice president at the Englewood Cliffs, NJ–based food company. "We then like to move from an exporting environment into local manufacturing."

CPC manufactures much well-known food brands as Hellmann's Mayonnaise and the Knorr's line of soups. Altogether, the company manufactures in 62 of the 110 countries in which it markets its products.

CPC uses local personnel and managers almost exclusively when operating overseas. "We look for people who understand the markets and can compete very effectively within them," Griffin said. "They help you understand local government regulations, which can be tricky. We also let our local managers do their own marketing, figuring they know their own markets and how to compete there better than Englewood Cliffs does."

Mexx also sought out qualified locals to be its eyes and ears in a foreign market. "Such an individual can help develop the link between your business and the local marketplace," Koopman said. "Without this understanding of the local market, the risk of failure is tremendous."

Local relationships give local distributors and buyers peace of mind that they're dealing with a local company, he added. "You want to make the local buyer in France think he is dealing with a French company," Koopman said. "They want to feel they're dealing with the decision-maker, not some emissary from New York in another time zone."

Finding someone qualified to fill these shoes is as easy as calling an executive search firm or accessing the Internet. "There are many qualified people looking to represent all kinds of companies on the Net," Powers noted.

Powers' company, Insight, offers a computer software model that can help companies find the right overseas representatives. Called the Global Supply Chain Model, the software guides companies through the maze of decisions required to develop an international sales strategy, from how many plants [are] needed to satisfy global markets to the best means to source products. The software costs $30,000, excluding consulting services. The task of finding a local rep should not be taken lightly, especially when it concerns finding someone to manage an overseas plant. "Having a plant manager who can create a culture from the ground up with the right discipline and values to develop a solid team of people is crucial to the success of the endeavor," Ehrsam said. "I've seen the best prepared and executed strategies succeed or fall to pieces on the basis of that one individual."

Best-Laid Plans

While some elements making up an international sales strategy can be predicted with a degree of certainty, others—like currency exchange values—are capricious at best. "At Mexx, we planned twice to enter the Italian market," Koopman recalled. "In both cases, one week before we were set to

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launch our clothing line there, the Italian lira was devalued 20 percent—meaning our prices would increase by 20 percent. Both times we were forced to cancel our plans." Another unpredictable element is regulation. "A company may decide to set up shop in, say, Malaysia, because it considers the tariffs to be too high to export there successfully," Ehrsam said. "Next thing you know, the government of Malaysia decides to lower its tariffs significantly. Suddenly, you realize it may have been cheaper to export there rather than incur the huge capital costs of a plant."

Technology obsolescence and improvements in logistics play similar, unpredictable roles. A company may spend hundreds of thousands of dollars building a foreign facility weeks before a new automated manufacturing system renders its technology a buggy in an age of automobiles.

Moreover, a new way of moving goods faster, more efficiently and less expensively may materialize, reversing the status quo and making exporting a more cost-effective means of reaching a marketplace.

Ultimately, no matter which way a company chooses to enter a foreign market, it needs a pair of fleet feet. "It's very important, especially with new economies, to get in as early as possible," Griffin counseled. "You want to establish market leadership for your brand, and the fact is, the first one there often has the best chance."

Questions

1. What advantages and disadvantages does exporting have?
2. What advantages and disadvantages does foreign manufacturing have?
3. What are the advantages of employing local personnel and managers when operating overseas?
4. What relevance do currency exchange rates have for foreign trade?
5. What other factors might be relevant?

Source: "Not-So-Clear Choices: Should You Export, or Manufacture Overseas?" Russ Banham, *International Business,* November/December 1997, pp. 23–25. Copyright © 1997 Russ Banham. Used with permission.

Table 8.3 provides a checklist of potential issues for decisions on foreign locations.

TABLE 8.3
Factors relating to foreign locations

Foreign government	*a.* Policies on foreign ownership of production facilities
	Local content requirements
	Import restrictions
	Currency restrictions
	Environment regulations
	Local product standards
	b. Stability issues
Cultural differences	Living circumstances for foreign workers and their dependents
	Religious holidays/traditions
Customer preferences	Possible "buy locally" sentiment
Labor	Level of training and education of workers
	Work practices
	Possible regulations limiting number of foreign employees
	Language differences
Resources	Availability and quality of raw materials, energy, transportation

EVALUATING LOCATION ALTERNATIVES

There are a number of techniques that are helpful in evaluating location alternatives: locational cost-profit-volume analysis, factor rating, and the center of gravity method.

Locational Cost-Profit-Volume Analysis

The economic comparison of location alternatives is facilitated by the use of cost-profit-volume analysis. The analysis can be done numerically or graphically. The graphical approach will be demonstrated here because it enhances understanding of the concept and indicates the ranges over which one of the alternatives is superior to the others.

The procedure for **locational cost-profit-volume analysis** involves these steps:

locational cost-profit-volume analysis Technique for evaluating location choices in economic terms.

1. Determine the fixed and variable costs associated with each location alternative.
2. Plot the total-cost lines for all location alternatives on the same graph.
3. Determine which location will have the lowest total cost for the expected level of output. Alternatively, determine which location will have the highest profit.

This method assumes the following:

1. Fixed costs are constant for the range of probable output.
2. Variable costs are linear for the range of probable output.
3. The required level of output can be closely estimated.
4. Only one product is involved.

For a cost analysis, compute the total cost for each location:

$$\text{Total cost} = \text{FC} + v \times Q \tag{8–1}$$

where

FC = Fixed cost
v = Variable cost per unit
Q = Quantity or volume of output

EXAMPLE 1

Fixed and variable costs for four potential plant locations are shown below:

Location	Fixed Cost per Year	Variable Cost per Unit
A.........	$250,000	$11
B.........	100,000	30
C.........	150,000	20
D.........	200,000	35

a. Plot the total-cost lines for these locations on a single graph.

b. Identify the range of output for which each alternative is superior (i.e., has the lowest total cost).

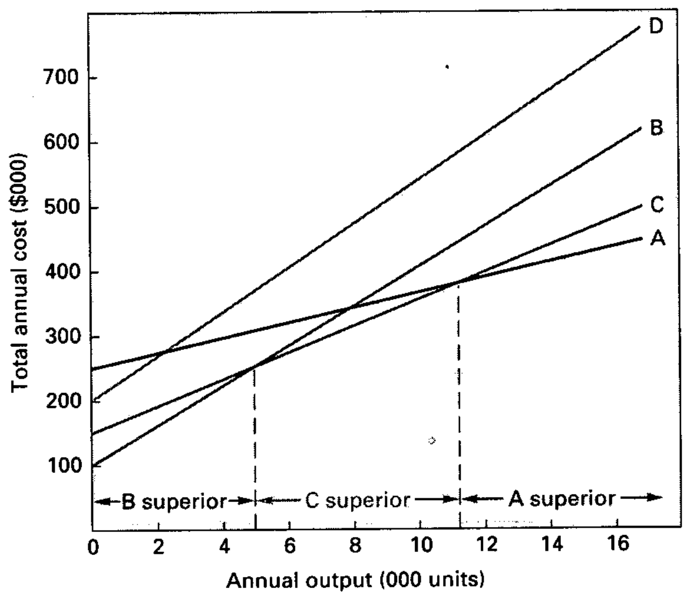
c. If expected output at the selected location is to be 8,000 units per year, which location would provide the lowest total cost?

SOLUTION

a. To plot the total-cost lines, select an output that is approximately equal to the expected output level (e.g., 10,000 units per year). Compute the total cost for each location at that level:

	Fixed Cost	+	Variable Cost	=	Total Cost
A......	$250,000	+	$11(10,000)	=	$360,000
B......	100,000	+	30(10,000)	=	400,000
C......	150,000	+	20(10,000)	=	350,000
D......	200,000	+	35(10,000)	=	550,000

Plot each location's fixed cost (at Output = 0) and the total cost at 10,000 units; and connect the two points with a straight line. (See the accompanying graph.)



b. The *approximate* ranges for which the various alternatives will yield the lowest costs are shown on the graph. Note that location D is never superior. The *exact* ranges can be determined by finding the output level at which lines B and C and lines C and A cross. To do this, set their total cost equations equal and solve for Q, the break-even output level. Thus, for B and C:

$$\underset{(B)}{\$100{,}000 + \$30Q} = \underset{(C)}{\$150{,}000 + \$20Q}$$

Solving, you find $Q = 5{,}000$ units per year.

For C and A:

$$\underset{(C)}{\$150{,}000 + \$20Q} = \underset{(A)}{\$250{,}000 + \$11Q}$$

Solving, $Q = 11{,}111$ units per year.

c. From the graph, you can see that for 8,000 units per year, location C provides the lowest total cost.

For a profit analysis, compute the total profit for each location:

$$\text{Total profit} = Q(R - v) - \text{FC} \qquad (8\text{–}2)$$

where

R = Revenue per unit

Solved Problem 2 at the end of the chapter illustrates profit analysis.

Where the expected level of output is close to the middle of the range over which one alternative is superior, the choice is readily apparent. If the expected level of output is very close to the edge of a range, it means that the two alternatives will yield comparable annual costs, so management would be indifferent in choosing between the two *in terms of total cost.* However, it is important to recognize that, in most situations, other factors besides cost must also be considered. Later in this section, a general scheme for including a broad range of factors is described. First, let's consider another kind of cost often considered in location decisions: transportation costs.

The Transportation Model

Transportation costs sometimes play an important role in location decisions. These can stem from the movement of either raw materials or finished goods. If a facility will be the sole source or destination of shipments, the company can include the transportation costs in a locational cost-volume analysis by incorporating the transportation cost per unit being shipped into the variable cost per unit. (If raw materials are involved, the transportation cost must be converted into cost per unit of *output* in order to correspond to other variable costs.)

When a problem involves shipment of goods from multiple sending points to multiple receiving points, and a new location (sending or receiving point) is to be added to the system, the company should undertake a separate analysis of transportation. In such instances the *transportation model* of linear programming is very helpful. It is a special-purpose algorithm used to determine the minimum transportation cost that would result if a potential new location were to be added to an existing system. It also can be used if a *number* of new facilities are to be added or if an entire new system is being developed. The model is used to analyze each of the configurations considered, and it reveals the minimum costs each would provide. This information can then be included in the evaluation of location alternatives. Solved Problem 1 illustrates how results of a transportation analysis can be combined with the results of a locational cost-volume analysis. See also the chapter supplement.

Factor Rating

Factor rating is a technique that can be applied to a wide range of decisions ranging from personal (buying a car, deciding where to live) to professional (choosing a career, choosing among job offers). Here it is used for location analysis.

A typical location decision involves both qualitative and quantitative inputs, which tend to vary from situation to situation depending on the needs of each organization. **Factor rating** is a general approach that is useful for evaluating a given alternative and comparing alternatives. The value of factor rating is that it provides a rational basis for evaluation and facilitates comparison among alternatives by establishing a *composite* value for each alternative that summarizes all related factors. Factor rating enables decision makers to incorporate their personal opinions and quantitative information in the decision process.

factor rating General approach to evaluating locations that includes quantitative and qualitative inputs.

The following procedure is used to develop a factor rating:

1. Determine which factors are relevant (e.g., location of market, water supply, parking facilities, revenue potential).
2. Assign a weight to each factor that indicates its relative importance compared with all other factors. Typically, weights sum to 1.00.
3. Decide on a common scale for all factors (e.g., 0 to 100).
4. Score each location alternative.
5. Multiply the factor weight by the score for each factor, and sum the results for each location alternative.
6. Choose the alternative that has the highest composite score.

This procedure is illustrated in the next example.

EXAMPLE 2

A photo-processing company intends to open a new branch store. The table below contains information on two potential locations. Which is the better alternative?

SOLUTION

Factor	Weight	SCORES (OUT OF 100) Alt. 1	Alt. 2	WEIGHTED SCORES Alternative 1	Alternative 2
Proximity to existing store	.10	100	60	.10(100) = 10.0	.10(60) = 6.0
Traffic volume	.05	80	80	.05(80) = 4.0	.05(80) = 4.0
Rental costs	.40	70	90	.40(70) = 28.0	.40(90) = 36.0
Size	.10	86	92	.10(86) = 8.6	.10(92) = 9.2
Layout	.20	40	70	.20(40) = 8.0	.20(70) = 14.0
Operating costs	.15	80	90	.15(80) = 12.0	.15(90) = 13.5
	1.00			70.6	82.7

Alternative 2 is better because it has the higher composite score.

In some cases, managers may prefer to establish minimum *thresholds* for composite scores. If an alternative fails to meet that minimum, they can reject it without further consideration. If none of the alternatives meets the minimum, this means that either additional alternatives must be identified and evaluated or the minimum threshold must be reevaluated.

The Center of Gravity Method

center of gravity method Method for locating a distribution center that minimizes distribution cost.

IOM

The **center of gravity method** is a method to determine the location of a distribution center that will minimize distribution costs. It treats distribution cost as a linear function of the distance and the quantity shipped. The quantity to be shipped to each destination is assumed to be fixed (i.e., will not change over time). An acceptable variation is that quantities are allowed to change, as long as their relative amounts remain the same (e.g., seasonal variations).

The method includes the use of a map that shows the locations of destinations. The map must be accurate and drawn to scale. A coordinate system is overlaid on the map to determine relative locations. The location of the 0,0 point of the coordinate system, and its scale, is unimportant. Once the coordinate system is in place, you can determine the coordinates of each destination. (See Figure 8.1, parts a and b.)

If the quantities to be shipped to every location are *equal,* you can obtain the coordinates of the center of gravity (i.e., the location of the distribution center) by finding the average of the x coordinates and the average of the y coordinates (see Figure 8.1). These averages can be easily determined using the following formulas:

$$\bar{x} = \frac{\sum x_i}{n} \qquad (8\text{–}3)$$

$$\bar{y} = \frac{\sum y_i}{n}$$

where

x_i = x coordinate of destination i

y_i = y coordinate of destination i

n = number of destinations

When the number of units to be shipped is not the same for all destinations (usually the case), a *weighted average* must be used to determine the center of gravity, with the weights being the *quantities* to be shipped.

The appropriate formulas are

$$\bar{x} = \frac{\sum x_i Q_i}{\sum Q_i} \qquad (8\text{–}4)$$

$$\bar{y} = \frac{\sum y_i Q_i}{\sum Q_i}$$

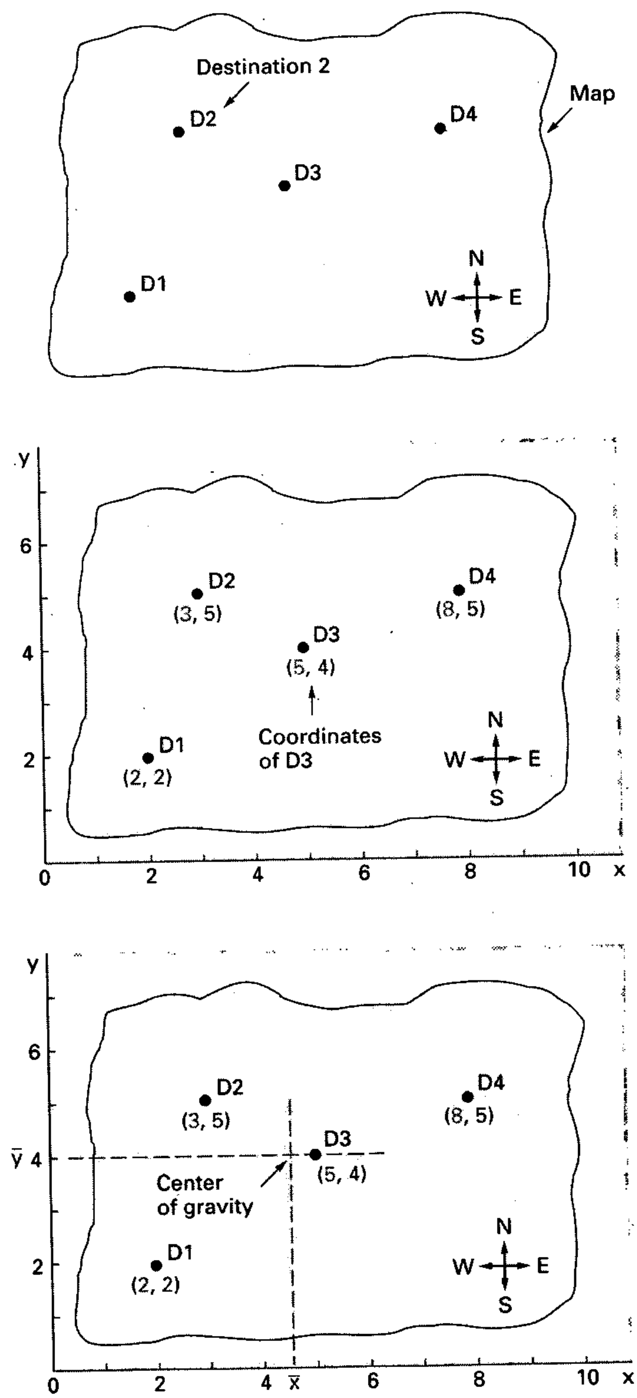
FIGURE 8.1

Center of gravity method
a. Map showing destinations.
b. Add a coordinate system.
c. Center of gravity.

a. Map showing destinations.

b. Add a coordinate system.

c. Center of gravity.



IOM

where

Q_i = Quantity to be shipped to destination i

x_i = x coordinate of destination i

y_i = y coordinate of destination i

EXAMPLE 3

Determine the coordinates of the center of gravity for the problem that is depicted in Figure 8.1c. Assume that the shipments from the center of gravity to each of the four destinations will be equal quantities.

SOLUTION

The coordinates of the destinations can be obtained from Figure 8.1b:

Destination	x, y
D1	2, 2
D2	3, 5
D3	5, 4
D4	8, 5
	18 16

$$\bar{x} = \frac{\sum x_i}{n} = \frac{18}{4} = 4.5 \qquad \bar{y} = \frac{\sum y_i}{n} = \frac{16}{4} = 4$$

Hence, the center of gravity is at (4.5, 4), which places it just west of destination D3 (see Figure 8.1).

EXAMPLE 4

Suppose that the shipments for the problem depicted in Figure 8.1a are not all equal, but instead are the following:

Destination	x, y	Weekly Quantity
D1	2, 2	800
D2	3, 5	900
D3	5, 4	200
D4	8, 5	100
		2,000

Determine the center of gravity.

SOLUTION

Because the quantities to be shipped differ among destinations, you must use the weighted average formulas.

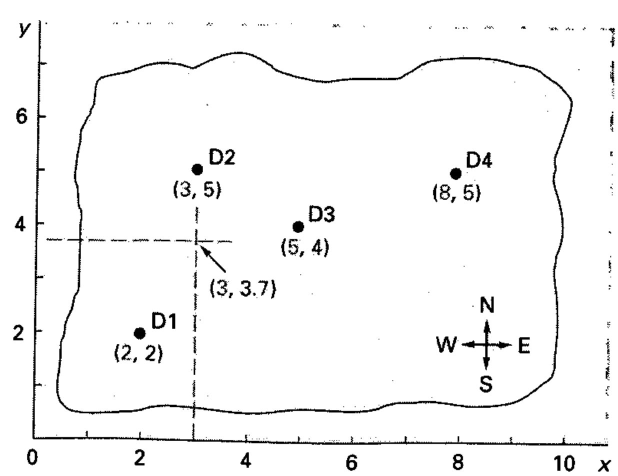
$$\bar{x} = \frac{\sum x_i Q_i}{\sum Q_i} = \frac{2(800) + 3(900) + 5(200) + 8(100)}{2{,}000} = \frac{6{,}100}{2{,}000} = 3.05 \text{ [round to 3]}$$

$$\bar{y} = \frac{\sum y_i Q_i}{\sum Q_i} = \frac{2(800) + 5(900) + 4(200) + 5(100)}{2{,}000} = \frac{7{,}400}{2{,}000} = 3.7$$

Hence, the coordinates of the center of gravity are approximately (3, 3.7). This would place it south of destination D2, which has coordinates of (3, 5). (See Figure 8.2.)

FIGURE 8.2

Center of gravity for Example 4



SUMMARY

Location decisions confront both new and existing organizations. Growth, market shifts, depletion of raw materials, and the introduction of new products and services are among the reasons organizations are concerned with location decisions. The importance of these decisions is underscored by the long-term commitment they typically involve and by their potential impact on the operating system.

The primary location options available to existing organizations are to expand an existing location, move to a new location, maintain existing facilities while adding another facility in a new location, or do nothing.

In practice, the major influences on location decisions are location of raw materials, labor supply, market considerations, community-related factors, site-related factors, and climate. Foreign locations may be attractive in terms of labor costs, abundance of raw materials, or as potential markets for a firm's products or services. Problems organizations sometimes encounter in foreign countries include language differences, cultural differences, bias, and political instability.

A common approach to narrowing the range of location alternatives is to first identify a country or region that seems to satisfy overall needs and then identify a number of community-site alternatives for more in-depth analysis. A variety of methods are used to evaluate location alternatives. Those described in the chapter include locational cost-profit-volume analysis, factor rating, and the center of gravity method. The transportation model was mentioned briefly; the chapter supplement contains a more complete description of that subject.

There are numerous commercial software packages available for location analysis. In addition to the models described, many packages employ linear programming or mixed integer programming algorithms. In addition, some software packages use heuristic approaches to obtain reasonable solutions to location problems.

KEY TERMS

center of gravity method, 366
factor rating, 365
geographical information system (GIS), 352
locational cost-profit-volume analysis, 363
microfactory, 358

SOLVED PROBLEMS

Problem 1

Cost analysis. A farm implements dealer is seeking a fourth warehouse location to complement three existing warehouses. There are three potential locations: Charlotte, N.C.; Atlanta, Ga.; and Columbia, S.C. Charlotte would involve a fixed cost of $4,000 per month and a variable cost of $4 per unit; Atlanta would involve a fixed cost of $3,500 per month and a variable cost of $5 per unit; and Columbia would involve a fixed cost of $5,000 per month and a variable cost of $6 per unit. Use of the Charlotte location would increase system transportation costs by $19,000 per month, Atlanta by $22,000 per month, and Columbia by $18,000 per month. Which location would result in the lowest total cost to handle 800 units per month?

Solution

Given: Volume = 800 units per month

	FC per Month	Variable Cost per Unit, *v*	Transportation Cost per Month
Charlotte	$4,000	$4	$19,000
Atlanta	3,500	5	22,000
Columbia	5,000	6	18,000

Monthly total cost = FC + VC + Transportation cost

Charlotte: $4,000 + $4 per unit × 800 units + $19,000 = $26,200

Atlanta: 3,500 + 5 per unit × 800 units + 22,000 = 29,500

Columbia: 5,000 + 6 per unit × 800 units + 18,000 = 27,800

Hence, Charlotte would have the lowest total cost for this monthly volume.

Problem 2

Profit analysis. A manufacturer of staplers is about to lose its lease, so it must move to another location. Two sites are currently under consideration. Fixed costs would be $8,000 per month at site A and $9,400 per month at site B. Variable costs are expected to be $5 per unit at site A and $4 per unit at site B. Monthly demand has been steady at 8,800 units for the last several years and is not expected to deviate from that amount in the foreseeable future. Assume staplers sell for $6 per unit. Determine which location would yield the higher profit under these conditions.

Solution

$$\text{Profit} = Q(R - v) - \text{FC}$$

Site	Revenue	FC	v	Monthly Profit
A......	$52,800	$8,000	$44,000	$ 800
B......	$52,800	$9,400	$35,200	$8,200

Hence, site B is expected to yield the higher monthly profit.

Problem 3

Factor rating. Determine which location has the highest factor rating given the following information:

		LOCATION	
Factor	**Weight**	**A**	**B**
Labor cost.........	.50	20	40
Material cost......	.30	10	30
Supplier base......	.20	50	10
	1.00		

Solution

Combining the weights with the location scores, we can see that location B has the higher score:

		LOCATION		WEIGHTED SCORES	
Factor	**Weight**	**A**	**B**	**A**	**B**
Labor cost.........	.50	20	40	.50(20) = 10	.50(40) = 20
Material cost......	.30	10	30	.30(10) = 3	.30(30) = 9
Supplier base......	.20	50	10	.20(50) = 10	.20(10) = 2
	1.00			23	31

DISCUSSION AND REVIEW QUESTIONS

1. In what ways can the location decision have an impact on the production system?
2. Respond to this statement: "The importance of the location decision is often vastly overrated; the fact that virtually every type of business is located in every section of the country means there should be no problem in finding a suitable location."
3. What community factors influence location decisions?
4. How are manufacturing and nonmanufacturing location decisions similar? Different?
5. What are the potential benefits of locating in foreign countries? Potential drawbacks?
6. What is factor rating, and how does it work?
7. Outline the general approach for developing location alternatives.
8. What are the basic assumptions in locational cost-profit-volume analysis?
9. Discuss recent trends in location and possible future strategies.

TAKING STOCK

1. What trade-offs are involved in deciding to have a single large, centrally located facility instead of several smaller, dispersed facilities?
2. Who needs to be involved in facility location decisions?
3. Name several ways that technology has had an impact on location decisions.

CRITICAL THINKING EXERCISES

1. What are the potential advantages and disadvantages of locating a production facility in a foreign country instead of using a domestic location?
2. The owner of a fast-food franchise has exclusive rights to operate in a medium-size metropolitan area. The owner currently has a single outlet open, which has proved to be very popular, and there are often

waiting lines of customers. The owner is therefore considering opening one or more outlets in the area. What are the key factors that the owner should investigate before making a final decision? What trade-offs would there be in opening one additional site versus opening several additional sites?

PROBLEMS

1. A newly formed firm must decide on a plant location. There are two alternatives under consideration: locate near the major raw materials or locate near the major customers. Locating near the raw materials will result in lower fixed and variable costs than locating near the market, but the owners believe there would be a loss in sales volume because customers tend to favor local suppliers. Revenue per unit will be $185 in either case. Using the following information, determine which location would produce the greater profit.

Omaha: $8,000
K.C.: $256,000
Choose K.C.

	Omaha	Kansas City
Annual fixed costs ($ millions)........	$1.2	$1.4
Variable cost per unit................	$36	$47
Expected annual demand (units)......	8,000	12,000

2. The owner of Genuine Subs, Inc., hopes to expand the present operation by adding one new outlet. She has studied three locations. Each would have the same labor and materials costs (food, serving containers, napkins, etc.) of $1.76 cents per sandwich. Sandwiches sell for $2.65 each in all locations. Rent and equipment costs would be $5,000 per month for location A, $5,500 per month for location B, and $5,800 per month for location C.
   a. Determine the volume necessary at each location to realize a monthly profit of $10,000.
   b. If expected sales at A, B, and C are 21,000 per month, 22,000 per month, and 23,000 per month, respectively, which location would yield the greatest profits?

	A	B	C
a	16,854	17,416	17,753
b	$13,690	$14,080	$14,670

3. A small producer of machine tools wants to move to a larger building, and has identified two alternatives. Location A has annual fixed costs of $800,000 and variable costs of $14,000 per unit; location B has annual fixed costs of $920,000 and variable costs of $13,000 per unit. The finished items sell for $17,000 each.
   a. At what volume of output would the two locations have the same total cost?
   b. For what range of output would location A be superior? For what range would B be superior?

a. 120 units
b. A: 0 to 119
B: 121 or more

4. A company that produces pleasure boats has decided to expand one of its lines. Current facilities are insufficient to handle the increased workload, so the company is considering three alternatives, A (new location), B (subcontract), and C (expand existing facilities).
   Alternative A would involve substantial fixed costs but relatively low variable costs: fixed costs would be $250,000 per year, and variable costs would be $500 per boat. Subcontracting would involve a cost per boat of $2,500, and expansion would require an annual fixed cost of $50,000 and a variable cost of $1,000 per boat.
   a. Find the range of output for each alternative that would yield the lowest total cost.
   b. Which alternative would yield the lowest total cost for an expected annual volume of 150 boats?
   c. What other factors might be considered in choosing between expansion and subcontracting?

a. B: 0 to 33
C: 34 to 400
A: 400 or more
b. C
c. Subcontracting prices more precise; subcontracting provides another source of supply; expansion allows more control and flexibility.

5. Rework Problem 4*b* using this additional information: Expansion would result in an increase of $70,000 per year in transportation costs, subcontracting would result in an increase of $25,000 per year, and adding a new location would result in an increase of $4,000 per year.

A: $329,000
B: $400,000
C: $270,000
C is best

6. A firm that has recently experienced an enormous growth rate is seeking to lease a small plant in Memphis, Tenn.; Biloxi, Miss.; or Birmingham, Ala. Prepare an economic analysis of the three locations given the following information: Annual costs for building, equipment, and administration would be $40,000 for Memphis, $60,000 for Biloxi, and $100,000 for Birmingham. Labor and materials are expected to be $8 per unit in Memphis, $4 per unit in Biloxi, and $5 per unit in Birmingham. The Memphis location would increase system transportation costs by $50,000 per year, the Biloxi location by $60,000 per year, and the Birmingham location by $25,000 per year. Expected annual volume is 10,000 units.

	Total cost
Memphis	[illegible]
Biloxi	$160,000
Birmingham	[illegible]5,000

7. A retired auto mechanic hopes to open a rustproofing shop. Customers would be local new-car dealers. Two locations are being considered, one in the center of the city and one on the outskirts. The central city location would involve fixed monthly costs of $7,000 and labor, materials, and transportation costs of $30 per car. The outside location would have fixed monthly costs of $4,700 and labor, materials, and transportation costs of $40 per car. Dealer price at either location will be $90 per car.
   a. Which location will yield the greatest profit if monthly demand is (1) 200 cars? (2) 300 cars?
   b. At what volume of output will the two sites yield the same monthly profit?

a	City	Outside
P_{200}	$5,000	$5,300
P_{300}	$11,000	$10,300

b. 230 cars

H	L	M-H	M-H
H	L	M	M-H
L	H	L	M
L	H	L	L
L	H	L	L
L	M	L	L
L	M-H	M-H	M
M	H	M	M-H

8. For each of the four types of organizations shown, rate the importance of each factor in terms of making location decisions using L = low importance, M = moderate importance, and H = high importance.

Factor	Local Bank	Steel Mill	Food Warehouse	Public School
Convenience for customers	____	____	____	____
Attractiveness of building	____	____	____	____
Nearness to raw materials	____	____	____	____
Large amounts of power	____	____	____	____
Pollution controls	____	____	____	____
Labor cost and availability	____	____	____	____
Transportation costs	____	____	____	____
Construction costs	____	____	____	____

A: 87.02
B: 82.62
C: 80.90
A is best

9. Using the following factor ratings, determine which location alternative should be chosen on the basis of maximum composite score, A, B, or C.

Factor (100 points each)	Weight	LOCATION A	B	C
Convenient..........	.15	80	70	60
Parking facilities.....	.20	72	76	92
Display area.........	.18	88	90	90
Shopper traffic	.27	94	86	80
Operating costs......	.10	98	90	82
Neighborhood.......	.10	96	85	75
	1.00			

a. A: 39/7
B: 44/7
C: 44/7
B or C best
b. A: 53/9
B: 55/9
C: 54/9
B is best, A is worst

10. A manager has received an analysis of several cities being considered for a new office complex. The data (10 points maximum) are

Factor	LOCATION A	B	C
Business services	9	5	5
Community services	7	6	7
Real estate cost........	3	8	7
Construction costs	5	6	5
Cost of living...........	4	7	8
Taxes	5	5	4
Transportation	6	7	8

a. If the manager weights the factors equally, how would the locations stack up in terms of their composite factor rating scores?

b. If business services and construction costs are given weights that are double the weights of the other factors, how would the locations stack up?

$\bar{x} = 5, \bar{y} = 4$
Location optimal at (5, 4)

11. A toy manufacturer produces toys in five locations throughout the country. Raw materials (primarily barrels of powdered plastic) will be shipped from a new, centralized warehouse whose location is to be determined. The monthly quantities to be shipped to each location are the same. A coordinate system has been established, and the coordinates of each location have been determined as shown. Determine the coordinates of the centralized warehouse.

Location	(x, y)
A	3, 7
B	8, 2
C	4, 6.
D	4, 1
E	6, 4

12. A clothing manufacturer produces women's clothes at four locations in Mexico. Relative locations have been determined, as shown in the table below. The location of a central shipping point for bolts of cloth must now be determined. Weekly quantities to be shipped to each location are shown below. Determine the coordinates of the location that will minimize distribution costs.

$\bar{x} = 6, \bar{y} = 7$
Location optimal at (6, 7)

Location	(x, y)	Weekly Quantity
A	5, 7	15
B	6, 9	20
C	3, 9	25
D	9, 4	30

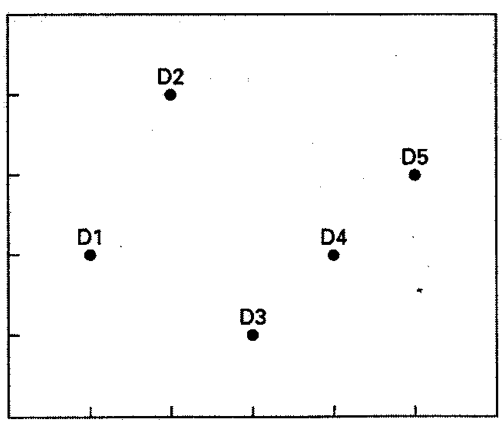
13. A company that handles hazardous waste wants to minimize the shipping cost for shipments to a disposal center from five receiving stations it operates. Given the locations of the receiving stations and the volumes to be shipped daily, determine the location of the disposal center.

$\bar{x} = 5.97, \bar{y} = 5.95$
Optimal location is (6, 6)

Location of Processing Station, (x, y)	Volume, Tons per Day
10, 5	26
4, 1	9
4, 7	25
2, 6	30
8, 7	40

14. Determine the center of gravity for the destinations shown on the following map. Monthly shipments will be the quantities listed in the table.

Destination	Quantity
D1	900
D2	300
D3	700
D4	600
D5	800



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Supplement to

CHAPTER 8

The Transportation Model

LEARNING OBJECTIVES

After completing this supplement, you should be able to:

1. Describe the nature of a transportation problem.
2. Set up transportation problems in the general linear programming format.
3. Interpret computer solutions.

SUPPLEMENT OUTLINE

Note: The CD that accompanies this book contains a module that provides detailed instruction on the transportation method.

The transportation problem involves finding the lowest-cost plan for distributing stocks of goods or *supplies* from multiple origins to multiple destinations that *demand* the goods. For instance, a firm might have three factories, all of which are capable of producing identical units of the same product, and four warehouses that stock or demand those products, as depicted in Figure 8S.1. The *transportation model* can be used to determine how to allocate the supplies available from the various factories to the warehouses that stock or demand those goods, in such a way that total shipping cost is minimized (i.e., the optimal shipping plan). Usually, analysis of the problem will produce a shipping plan that pertains to a certain period of time (day, week), although once the plan is established, it will generally not change unless one or more of the parameters of the problem (supply, demand, unit shipping cost) changes.

INTRODUCTION

Although Figure 8S.1 illustrates the nature of the transportation problem, in real life managers must often deal with allocation problems that are considerably larger in scope. A beer maker may have four or five breweries and hundreds or even thousands of distributors, and an automobile manufacturer may have eight assembly plants scattered throughout the United States and Canada and thousands of dealers that must be supplied with those cars. In such cases, the ability to identify the optimal distribution plan makes the transportation model very important.

The shipping (supply) points can be factories, warehouses, departments, or any other place from which goods are sent. Destinations can be factories, warehouses, departments, or other points that receive goods. The information needed to use the model consists of the following:

1. A list of the origins and each one's capacity or supply quantity per period.
2. A list of the destinations and each one's demand per period.
3. The unit cost of shipping items from each origin to each destination.

This information is arranged into a *transportation table* (see Table 8S.1).

The transportation model is one of a class of linear programming models, so named because of the linear relationships among variables. In the transportation model, transportation costs are treated as a direct linear function of the number of units shipped.

Use of the transportation model implies that certain assumptions are satisfied. The major ones are

1. The items to be shipped are homogeneous (i.e., they are the same regardless of their source or destination).
2. Shipping cost per unit is the same regardless of the number of units shipped.
3. There is only one route or mode of transportation being used between each origin and each destination.

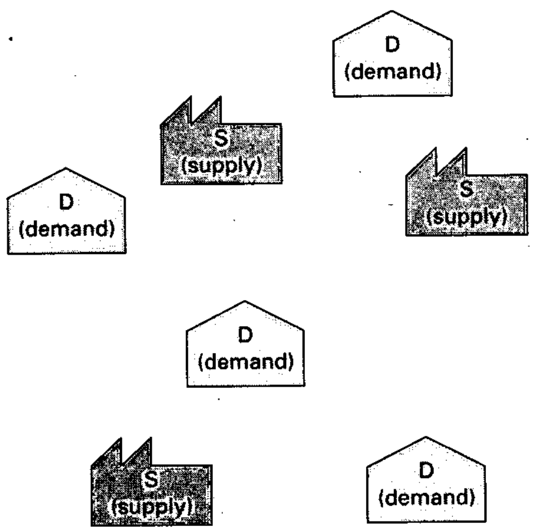


FIGURE 8S.1

The transportation problem involves determining a minimum-cost plan for shipping from multiple sources to multiple destinations

TABLE 8S.1

A transportation table

Cost to ship one unit from factory 1 to warehouse A.

Factory	Warehouse A	Warehouse B	Warehouse C	Warehouse D	Supply
1	4	7	7	1	100
2	12	3	8	8	200
3	8	10	16	5	150
Demand	80	90	120	160	450 / 450

Factory 1 can supply 100 units per period

Total supply capacity per period

Warehouse B can use 90 units per period

Total demand per period

IOM

LOCATION DECISIONS

The transportation model can be used to compare location alternatives in terms of their impact on the total distribution costs for a system. The procedure involves working through a separate problem for each location being considered and then comparing the resulting total costs.

If other costs, such as production costs, differ among locations, these can easily be included in the analysis, provided they can be determined on a per-unit basis. In this regard, note that merely adding or subtracting a constant to all cost values in any row or column will not affect the optimum solution; any additional costs should only be included if they have a varying effect within a row or column.

OTHER APPLICATIONS

We have seen how the transportation model can be used to minimize the costs associated with distributing goods, and we have seen how the model can be used for comparing location alternatives. The model is also used in a number of other ways. For example, in a slight variation of the model, profits can be used in place of costs. In such cases, each of the cell profits can be subtracted from the largest profit, and the remaining values (opportunity costs) can be treated in the same manner as shipping costs.

Some of the other uses of the model include production planning (see Chapter 12), problems involving assignment of personnel or jobs to certain departments or machines (see Chapter 15), capacity planning, and transshipment problems.[1]

The use of the transportation model for capacity planning parallels its use for location decisions. An organization can subject proposed capacity alternatives to transportation analysis to determine which one would generate the lowest total shipping cost. For example, it is perhaps intuitively obvious that a factory or warehouse that is close to its market—or has low transportation costs for some other reason—should probably have a larger capacity than other locations. Of course, many problems are not so simple, and they require actual use of the model.

COMPUTER SOLUTIONS

Although manual solution of transportation problems is fairly straightforward, computer solutions are generally preferred, particularly for moderate or large problems. Many software packages call for data input in the same tabular form used in this supplement. A more general approach is to format the problem as a standard linear programming model (i.e., specify the objective function and a set of constraints). That approach enables one to use the more general version of an LP package to solve a transportation problem. Let's consider this general approach.

The decision variables for a transportation model are the quantities to be shipped. Because each cell represents a potential transportation route, each must have a decision variable. We can use the symbol x_{1A} to represent the decision variable for cell 1-A, x_{1B} for cell 1-B, and so on. The objective function consists of the cell costs and these cell symbols:

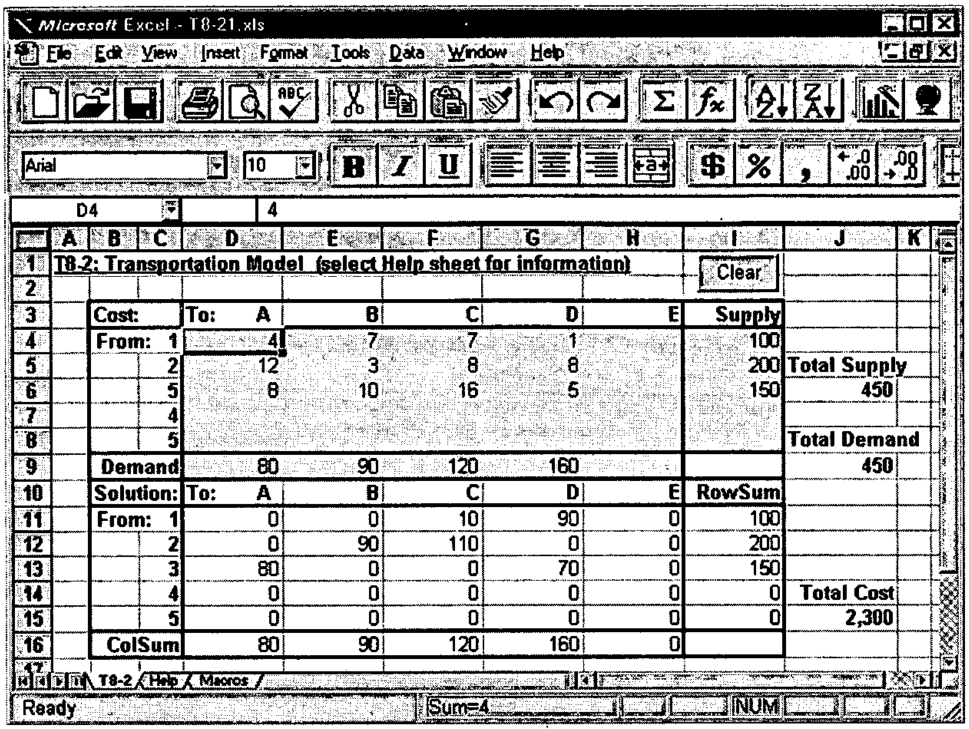
$$\text{Minimize } 4x_{1A} + 7x_{1B} + 7x_{1C} + 1x_{1D} + 12x_{2A} + 3x_{2B} + 8x_{2C} \\ + 8x_{2D} + 8x_{3A} + 10x_{3B} + 16x_{3C} + 5x_{3D}$$

Because the amounts allocated in any row or column must add to the row or column total, each row and column must have a constraint. Thus, we have

Supply (rows)

$$x_{1A} + x_{1B} + x_{1C} + x_{1D} = 100$$
$$x_{2A} + x_{2B} + x_{2C} + x_{2D} = 200$$
$$x_{3A} + x_{3B} + x_{3C} + x_{3D} = 150$$

[1]Transshipment relates to problems with major distribution centers that in turn redistribute to smaller market destinations. See, for example, W. J. Stevenson, *Introduction to Management Science,* 3rd ed. (Burr Ridge, IL: Richard D. Irwin, 1998).



	A	B C	D	E	F	G	H	I	J
1	T8-2: Transportation Model (select Help sheet for information)							Clear	
2									
3		Cost:	To: A	B	C	D	E	Supply	
4		From: 1	4	7	7	1		100	
5		2	12	3	8	8		200	Total Supply
6		5	8	10	16	5		150	450
7		4							
8		5							Total Demand
9		Demand	80	90	120	160			450
10		Solution:	To: A	B	C	D	E	RowSum	
11		From: 1	0	0	10	90	0	100	
12		2	0	90	110	0	0	200	
13		3	80	0	0	70	0	150	
14		4	0	0	0	0	0	0	Total Cost
15		5	0	0	0	0	0	0	2,300
16		ColSum	80	90	120	160	0		

FIGURE 8S.2
Excel template for Table 8S.1

Excel Tutorial

$$\begin{aligned} \text{Demand (columns)}\quad x_{1A} + x_{2A} + x_{3A} &= 80 \\ x_{1B} + x_{2B} + x_{3B} &= 90 \\ x_{1C} + x_{2C} + x_{3C} &= 120 \\ x_{1D} + x_{2D} + x_{3D} &= 160 \end{aligned}$$

We do not need a constraint for the total; the row and column constraints take care of this.

If supply and demand are not equal, add an extra (dummy) row or column with the necessary supply (demand) for equality to the table before writing the constraints.

Another approach to transportation problems is to use spreadsheet software. The Excel templates can also be used to solve transportation problems. Figure 8S.2 illustrates the Excel worksheet for the preceding problem.

PROBLEMS

1. Solve this LP problem using the transportation method. Find the optimal transportation plan and the minimum cost. Also, decide if there is an alternate solution. If there is one, identify it.

   $$\text{Minimize } 8x_{11} + 2x_{12} + 5x_{13} + 2x_{21} + x_{22} + 3x_{23} + 7x_{31} + 2x_{32} + 6x_{33}$$

   $$\begin{aligned} \text{Subject to}\quad x_{11} + x_{12} + x_{13} &= 90 \\ x_{21} + x_{22} + x_{23} &= 105 \\ x_{31} + x_{32} + x_{33} &= 105 \\ x_{11} + x_{21} + x_{31} &= 150 \\ x_{12} + x_{22} + x_{32} &= 75 \\ x_{13} + x_{23} + x_{33} &= 75 \\ \text{All variables} &\geq 0 \end{aligned}$$

2. A toy manufacturer wants to open a third warehouse that will supply three retail outlets. The new warehouse will supply 500 units of backyard playsets per week. Two locations are being studied, N1 and N2. Transportation costs for location N1 to stores A, B, and C are \$6, \$8, and \$7 per unit, respectively; for location N2, the costs are \$10, \$6, and \$4, respectively. The existing system is shown in the following table. Which location would result in the lower transportation costs for the system?

	A	B	C	Dummy
1		500		
2	400			
N1		100	350	50

TC = $6,750

	A	B	C	Dummy
1		500		
2	400			
N2		100	350	50

TC = $5.500

	A	B	C
1			210
2	140		
3	80	60	10
Tol.		160	

TC = $6,720

	A	B	C
1			210
2	60	80	
3		140	10
Cin.	160		

TC = $6,960

Location	TC
SCP	$10,080
FI	10,500
LH	10,380

From: Warehouse \ Store To:	A	B	C	Capacity (Units/week)
1	[8]	[3]	[7]	500
2	[5]	[10]	[9]	400
Demand (Units/week)	400	600	350	

3. A large firm is contemplating construction of a new manufacturing facility. The two leading locations are Toledo and Cincinnati. The new factory would have a supply capacity of 160 units per week. Transportation costs from each potential location and existing locations are shown in the following table. Determine which location would provide the lower transportation costs.

From Toledo to	Cost per Unit	From Cincinnati to	Cost per Unit
A........	$18	A...........	$ 7
B........	8	B...........	17
C........	13	C...........	13

	A	B	C	Supply (Units/week)
1	[10]	[14]	[10]	210
2	[12]	[17]	[20]	140
3	[11]	[11]	[12]	150
Demand (Units/week)	220	220	220	

4. A large retailer is planning to open a new store. Three locations in California are currently under consideration: South Coast Plaza (SCP), Fashion Island (FI), and Laguna Hills (LH). Transportation costs for the locations and costs, demands, and supplies for existing locations and warehouses (origins), are shown below. Each of the locations has a demand potential of 300 units per week. Which location would yield the lowest transportation costs for the system?

	TO		
From Warehouse	**SCP**	**FI**	**LH**
1	$ 4	$7	$5
2	11	6	5
3	5	5	6

	A	B	Supply (Units/week)
1	[15]	[9]	660
2	[10]	[7]	340
3	[14]	[18]	200
Demand (Units/week)	400	500	

BIBLIOGRAPHY AND FURTHER READING

Bierman, Harold, Charles P. Bonini, and Warren H. Hausman. *Quantitative Analysis for Business Decisions.* 8th ed. Homewood, IL: Richard D. Irwin, 1991.

Stevenson, William J. *Introduction to Management Science.* 3rd ed. Burr Ridge, IL: Richard D. Irwin, 1998.