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, and they impact a wide range of activities and capabilities.

This chapter is about process selection and facility layout (i.e., the arrangement of the workplace). 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. Different process types have different capacity ranges, and once a process type is functioning, changing it can be difficult, time consuming, and costly. Obviously, long-term forecasts as well as an organization's mission and goals are important in developing a process strategy.

Process selection has operational and supply chain implications. Operational implications include equipment and labor requirements, operations costs, and both the ability to meet demand and the ability to respond to variations in demand. Supply chain implications relate to the volume and variety of inputs and outputs and the degree of flexibility that is required.

Technology is often a factor in process selection and layout. Three aspects of technology can be factors: product technology, processing technology, and information technology.

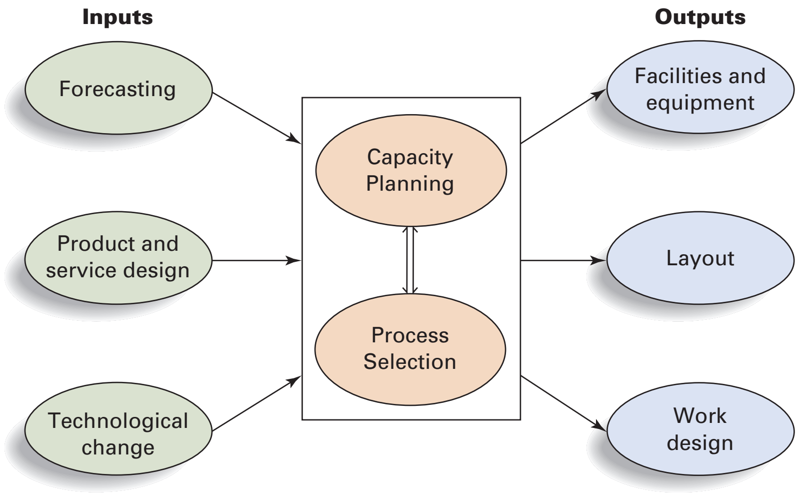
Process selection and facility layout are closely tied, and for that reason, these two topics are presented in a single chapter. The first part of the chapter covers the basic options for processing work. This is followed by a discussion of how processes and layout are linked. The remainder of the chapter is devoted to layout design.

6.1 INTRODUCTION

LO6.1 Explain the strategic importance of process selection and the influence it has on the organization and its supply chain.

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

FIGURE 6.1
Process selection and capacity planning influence system design



of where process selection and capacity planning fit into system design. Forecasts, product and service design, and technological considerations all influence capacity planning and process selection. Moreover, capacity and process selection are interrelated, and are often done in concert. They, in turn, affect facility and equipment choices, layout, and work 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.

6.2 PROCESS SELECTION

LO6.2 Name the two main factors that influence process selection.

Process choice is demand driven. The two key questions in process selection are:

1. How much variety will the process need to be able to handle?
2. How much volume will the process need to be able to handle?

Answers to these questions will serve as a guide to selecting an appropriate process. Usually, volume and variety are *inversely* related; a higher level of one means a lower level of the other. However, the need for flexibility of personnel and equipment is *directly* related to the level of variety the process will need to handle: the lower the variety, the less the need for flexibility, while the higher the variety, the greater the need for flexibility.

There is another aspect of variety that is important. Variety means either having separate operations for each product or service, with a steady demand for each, or being willing to live with some idle time, or to get equipment ready every time there is the need to change the product being produced or the service being provided.

Process Types

There are five basic process types: job shop, batch, repetitive, continuous, and project.

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

A job shop process: A midwestern hospital medical team performs a diagnostic procedure involving a cardiac catheterization.

A batch process: Menu items are prepared in batches, in the kitchen of the Spago Restaurant in the Forum at Caesar's Palace, Las Vegas, Nevada.

A repetitive process: Motorcycles on an assembly line with parts added in a sequential order.

A continuous process: An oil refinery performs a continuous process, mixing and separating crude oil into gas, fuel oil, chemicals, and many other products.

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 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 carwash. Other examples of service include cafeteria lines and ticket collectors at sports events and concerts. Also, *mass customization* is an option.

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 these four process types in the form of a matrix, with an example for each process type. 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, too, 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, because that would result in either higher than necessary costs or lost opportunities.

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

TABLE 6.1
Types of processing

LO6.3 Compare the four basic processing types.

	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; easy to add or change products or services	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

	High variety	Moderate variety	Low variety	Very low variety
Low or very low volume	**Job Shop** repair shop emergency room			
Moderate volume		**Batch** commercial bakery classroom lecture		
High volume			**Repetitive** assembly line automatic car wash	
Very high volume				**Continuous Flow** petroleum refining water treatment

FIGURE 6.2
Volume and variety influence process choice

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.

All of these process types (job shop, batch, repetitive, and continuous) are typically ongoing operations. However, some situations are not ongoing but instead are of limited duration. In such instances, the work is often organized as a *project.*

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.

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-standardized 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

Process type also impacts supply chain requirements. Repetitive and continuous processes require steady inputs of high-volume goods and services. Delivery reliability in terms of quality and timing is essential. Job shop and batch processing may mean that suppliers have to be able to deal with varying order quantities and timing of orders. In some instances seasonality is a factor, so suppliers must be able to handle periodic large demand.

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.

Morton Salt

OPERATIONS TOUR

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 buildup, 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 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

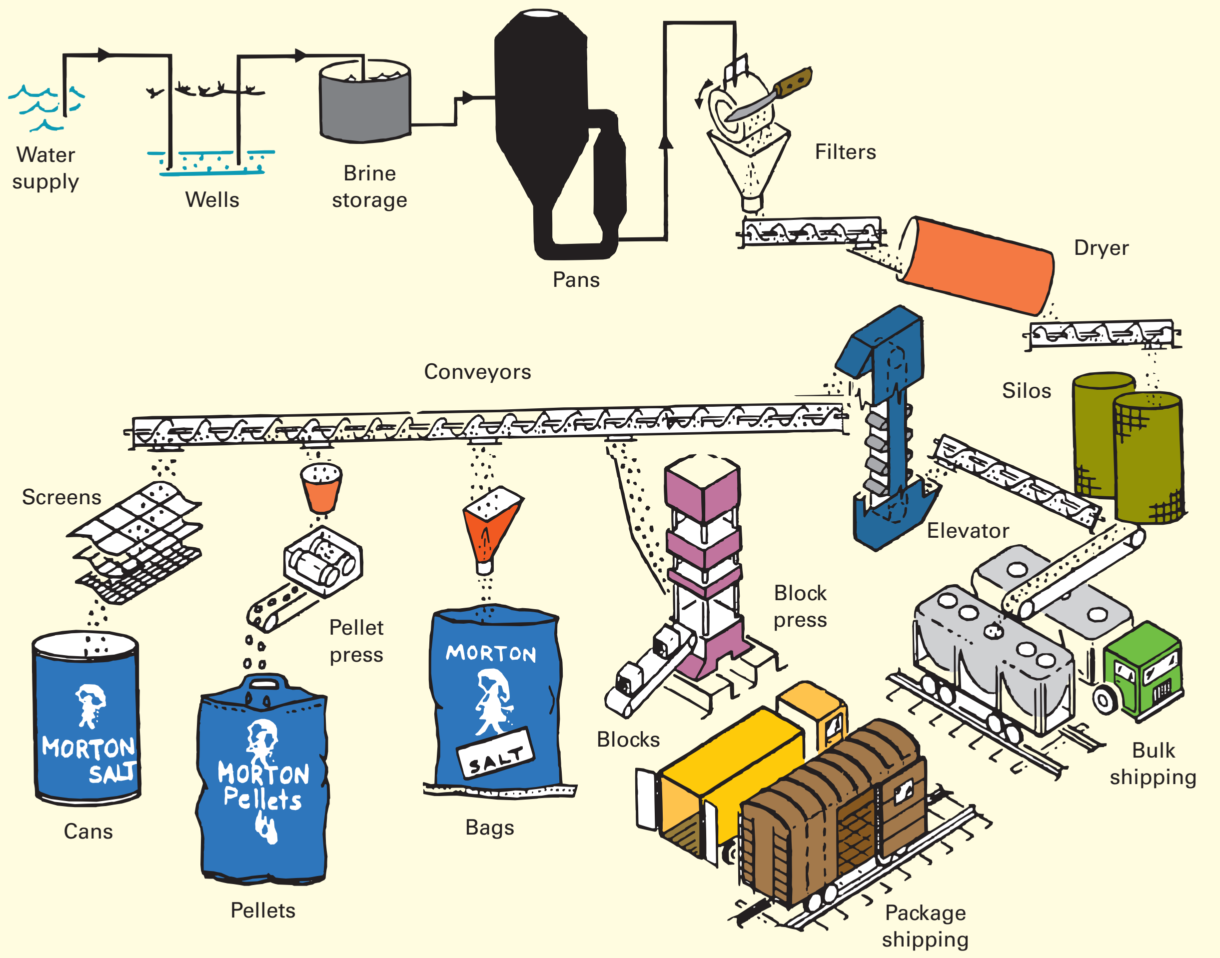
Annual round can production averages roughly 3.8 million cans. Approximately 70 percent of the output is for the Morton label, and the rest is for private label. There are two parallel, high-speed production lines. The two lines share common processes at the beginning of the lines, and then branch out 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)



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 plastic 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?

Product and Service Profiling

Process selection can involve substantial investment in equipment and have a very specific influence on the layout of facilities, which also require heavy investment. Moreover, mismatches between operations capabilities and market demand and pricing or cost strategies can have a significant negative impact on the ability of the organization to compete or, in government agencies, to effectively service clients. Therefore, it is highly desirable to assess the degree of correlation between various process choices and market conditions *before* making process choices in order to achieve an appropriate matching.

Product or service profiling Linking key product or service requirements to process capabilities.

Product or service profiling can be used to avoid any inconsistencies by identifying key product or service dimensions and then selecting appropriate processes. Key dimensions often relate to the range of products or services that will be processed, expected order sizes, pricing strategies, expected frequency of schedule changes, and order-winning requirements.

Sustainable Production of Goods and Services

Business organizations are facing increasing pressure from a variety of sources to operate sustainable production processes. According to the Lowell Center for Sustainable Production (http://sustainableproduction.org), "Sustainable Production is the creation of goods and services using processes and systems that are: non-polluting; conserving of energy and natural resources; economically efficient; safe and healthful for workers, communities, and consumers; and socially and creatively rewarding for all working people." To achieve this, the Lowell Center advocates designing and operating processes in ways that:

- "wastes and ecologically incompatible byproducts are reduced, eliminated or recycled on-site;
- chemical substances or physical agents and conditions that present hazards to human health or the environment are eliminated;
- energy and materials are conserved, and the forms of energy and materials used are most appropriate for the desired ends; and
- work spaces are designed to minimize or eliminate chemical, ergonomic and physical hazard."

To achieve these goals, business organizations must focus on a number of factors that include energy use and efficiency, CO_2 (carbon footprint) and toxic emissions, waste generation, lighting, heating, cooling, ventilation, noise and vibration, and worker health and safety.

Lean Process Design

Lean process design is guided by general principles that are discussed more fully in a later chapter. One principle of particular interest here is waste reduction, which relates to sustainability objectives. Lean design also focuses on variance reduction in workload over the entire process to achieve level production and thereby improve process flow. Successful lean design results in reduced inventory and floor space; quicker response times and shorter lead times; reduced defects, rework, and scrap; and increased productivity. Lean design is often translated into practice using cellular layouts, which are discussed later in this chapter.

Lean process design has broad applications in seemingly diverse areas such as health care delivery systems, manufacturing, construction projects, and process reengineering.

LO6.4 Explain the need for management of technology.

6.3 TECHNOLOGY

Technological innovation The discovery and development of new or improved products, services, or processes for producing or providing them.

Technology The application of scientific discoveries to the development and improvement of products and services and operations processes.

Technology and technological innovation often have a major influence on business processes. **Technological innovation** refers to the discovery and development of new or improved products, services, or processes for producing or providing them. **Technology** refers to applications of scientific discoveries to the development and improvement of goods and services and/or the processes that produce or provide them. It can involve such factors as knowledge, materials, methods, and equipment. The term *high technology* refers to the most advanced and developed equipment and methods.

Process technology and information technology can have a major impact on costs, productivity, and competitiveness. *Process technology* includes methods, procedures, and equipment used to produce goods and provide services. This not only involves processes within an organization, it also extends to supply chain processes. *Information technology (IT)* is the science and use of computers and other electronic equipment to store, process, and send information. IT is heavily ingrained in today's business operations. This includes electronic data processing, the use of bar codes and radio frequency tags to identify and track goods, devices used to obtain point-of-sale information, data transmission, the Internet, e-commerce, e-mail, and more.

With radio frequency (RFID) tags, items can be tracked during production and in inventory. For outbound goods, readers at a packing station can verify that the proper items and quantities were picked before shipping the goods to a customer or a distribution center. In a hospital setting, RFID tags can be used in several ways. One is to facilitate keeping accurate track of hospital garments, automating the process by which clean garments are inventoried and disbursed. An RFID tag can be worn by each hospital employee. The tag contains a unique ID number which is associated with each wearer. When an employee comes to the counter to pick up garments, the employee's tag is scanned and software generates data regarding garment, type, size, location on racks, and availability for that employee. The garments are then picked from the specified racks, their RFID tag is read by a nearby scanner and processed, and the database is automatically updated.

Technological innovation in processing technology can produce tremendous benefits for organizations by increasing quality, lowering costs, increasing productivity, and expanding processing capabilities. Among the examples are laser technology used in surgery and laser measuring devices, advances in medical diagnostic equipment, high-speed Internet connections, high-definition television, online banking, information retrieval systems, and high-speed search engines. Processing technologies often come through acquisition rather than through internal efforts of an organization.

While process technology can have enormous benefits, it also carries substantial risk unless a significant effort is made to fully understand both the downside and the upside of a particular technology. It is essential to understand what the technology will and won't do. Also, there are economic considerations (initial cost, space, cash flow, maintenance, consultants), integration considerations (cost, time, resources), and human considerations (training, safety, job loss).

Automation

An increasingly asked 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.

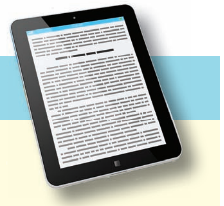
Automated services are becoming increasingly important. Examples range from automated teller machines (ATMs) to automated heating and air conditioning and include automated inspection, automated storage and retrieval systems, package sorting, mail processing, e-mail, online banking, and E-Z pass.

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, 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).

Both manufacturing and service organizations are increasing their use of automation as a way to reduce costs, increase productivity, and improve quality and consistency.

Foxconn Shifts Its Focus to Automation

READING



Foxconn operates a network of factories across the Chinese mainland, employing 1.2 million people, that makes products for tech companies that include Apple, Hewlett Packard, and Dell. The electronics manufacturing giant has been on a steady course for a while to replace manpower with robotic systems.

"Foxconn (has) vowed to install up to 1 million robots in its factories over the next three years, which analysts suggested was in part to address long-time scandals such as high suicide rates among employees and exploitation of workers."

Foreign manufacturers in China are also viewing upgrades as vital to their operations in the country. In fact, numerous multinational companies have recognized the long-term benefits of replacing human labor with robots.

Questions

1. As Foxconn cuts jobs as it shifts to greater use of automation, jobs will be created in other companies. In what types of companies would you expect to see jobs created?
2. Many companies outsourced their manufacturing activities to Foxconn due to its low labor costs. Does Foxconn's shift to automation make it likely that some of those companies will reconsider outsourcing in favor of shifting to automation? What are some reasons for staying with Foxconn, and what are some reasons that favor shifting to their own automated processes?

Source: Based on "Foxconn halts recruitment as focus shifts to automation," He Wei in Shanghai, *China Daily,* February 2, 2013, p. 9.

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 to 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. Automation has important implications not only for cost and flexibility, but also for the fit with overall strategic priorities. If the decision is made to automate, care must be taken to remove waste from the system prior to automating, to avoid building the waste into the automated system. Table 6.3 has a list of questions for organizations that are considering automation.

Generally speaking, there are three kinds of automation: fixed, programmable, and flexible.

Fixed automation is the least flexible. 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 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.

TABLE 6.3
Automation questions

1. What level of automation is appropriate? (Some operations are more suited to being automated than others, so partial automation can be an option.)
2. How would automation affect the flexibility of an operation system?
3. How can automation projects be justified?
4. How should changes be managed?
5. What are the risks of automating?
6. What are some of the likely effects of implementing automation on market share, costs, quality, customer satisfaction, labor relations, and ongoing operations?

Computer numerical control (CNC) refers to a computer that reads instructions and drives a machine tool. CNC machines are controlled directly from files created by CAM software packages. With increased automation of manufacturing processes with CNC machining, considerable improvements in consistency and quality have been achieved. CNC automation reduces the frequency of errors and provides operators with time to perform additional tasks. The intelligence of CNC controllers has dramatically increased job shop cell production. Some machines might even make 1,000 parts on a weekend with no operator, checking each part with lasers and sensors.

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 that tell the machine the details of the operations to be performed. The instructions are stored on a device such as 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 often 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).*

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.

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. 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. Below are robots that can recognize objects and make certain simple decisions.

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.

Tmsuk's receptionist robot is used for medical purposes. These robots can guide a hospital visitor to a nearby elevator. If a human touches the panel on the robot's body or speaks to it, the robot can display or print directions.

In practice, flexible automation is used in several different formats.

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 when 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"

At the Ford Motor plant in Michigan, in the final assembly area, flexibility means that the build sequence is the same, regardless of model, on one or more platforms. This allows for efficient use of people and equipment.

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, 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.

6.4 PROCESS 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 and equipment are 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: Demand variety or uncertainty exists about demand. The second reason can be overcome through improved forecasting.

6.5 STRATEGIC RESOURCE ORGANIZATION: 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.

LO6.5 List some reasons for redesign of layouts.

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 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 basic objective of layout design is to facilitate a smooth flow of work, material, and information through the system. Supporting objectives generally involve the following:

1. To facilitate attainment of product or service quality.
2. To use workers and space efficiently.
3. To avoid bottlenecks.
4. To minimize material handling costs.
5. To eliminate unnecessary movements of workers or materials.
6. To minimize production time or customer service time.
7. To design for safety.

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. These include cellular layouts and flexible manufacturing systems.

LO6.6 Describe product layouts and their main advantages and disadvantages.

Repetitive Processing: Product Layouts

Product layout Layout that uses standardized processing operations to achieve smooth, rapid, high-volume flow.

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

[1]Based on "Airport Checkpoints Moved to Help Speed Travelers on Their Way," *Minneapolis–St. Paul Star Tribune,* January 13, 1995, p. 1B.

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 6.3. 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 6.4 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.

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 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.

Repetitive processing can be machine paced (e.g., automatic car wash, automobile assembly), worker paced (e.g., fast-food restaurants such as McDonald's, Burger King), or even customer paced (e.g., cafeteria line).

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.

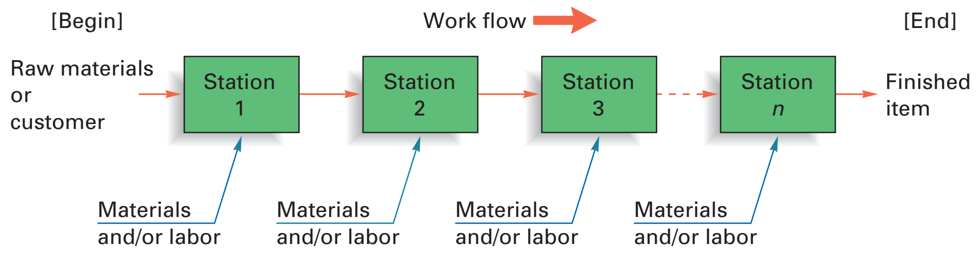


FIGURE 6.3
A flow line for production or service

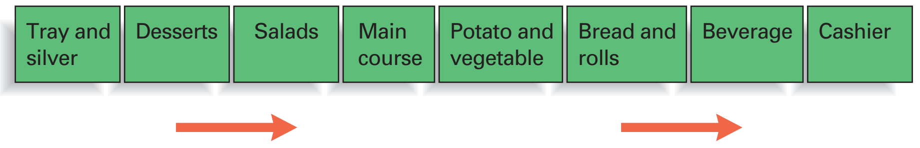


FIGURE 6.4
Cafeteria line

Workers assemble "Wizard of Oz" pinball machines at Jersey Jack Pinball.

3. Labor specialization, which 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. The establishment of routing and scheduling in the initial design of the system. These activities do not require much attention once the system is operating.
7. Fairly routine accounting, purchasing, and inventory control.

The primary disadvantages of product layouts include the following:

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.
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 6.5) 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

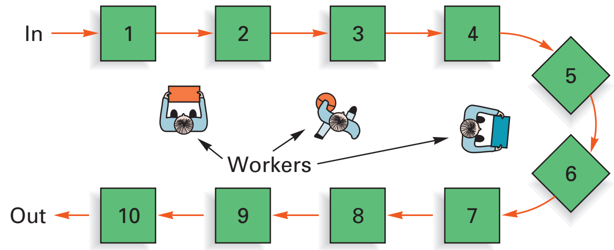


FIGURE 6.5
A U-shaped production line

teamwork. Flexibility in work assignments is increased because workers can handle not only adjacent stations but also 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

LO6.7 Describe process layouts and their main advantages and disadvantages.

Process layouts (functional 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 6.6 illustrates the departmental arrangement typical of a process layout.

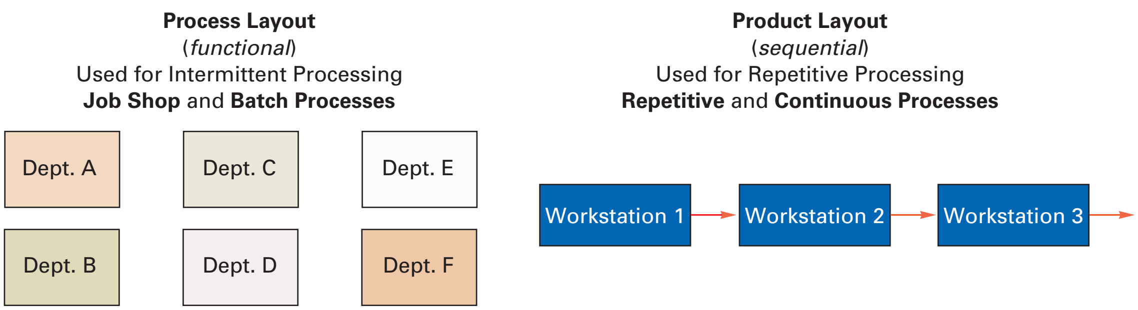
Process layouts Layouts that can handle varied processing requirements.

Intermittent processing Nonrepetitive processing.

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

FIGURE 6.6 Comparison of process and product layouts



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 and capacity mismatches. 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 the following:

1. The systems can handle a variety of processing requirements.
2. The 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 the following:

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.

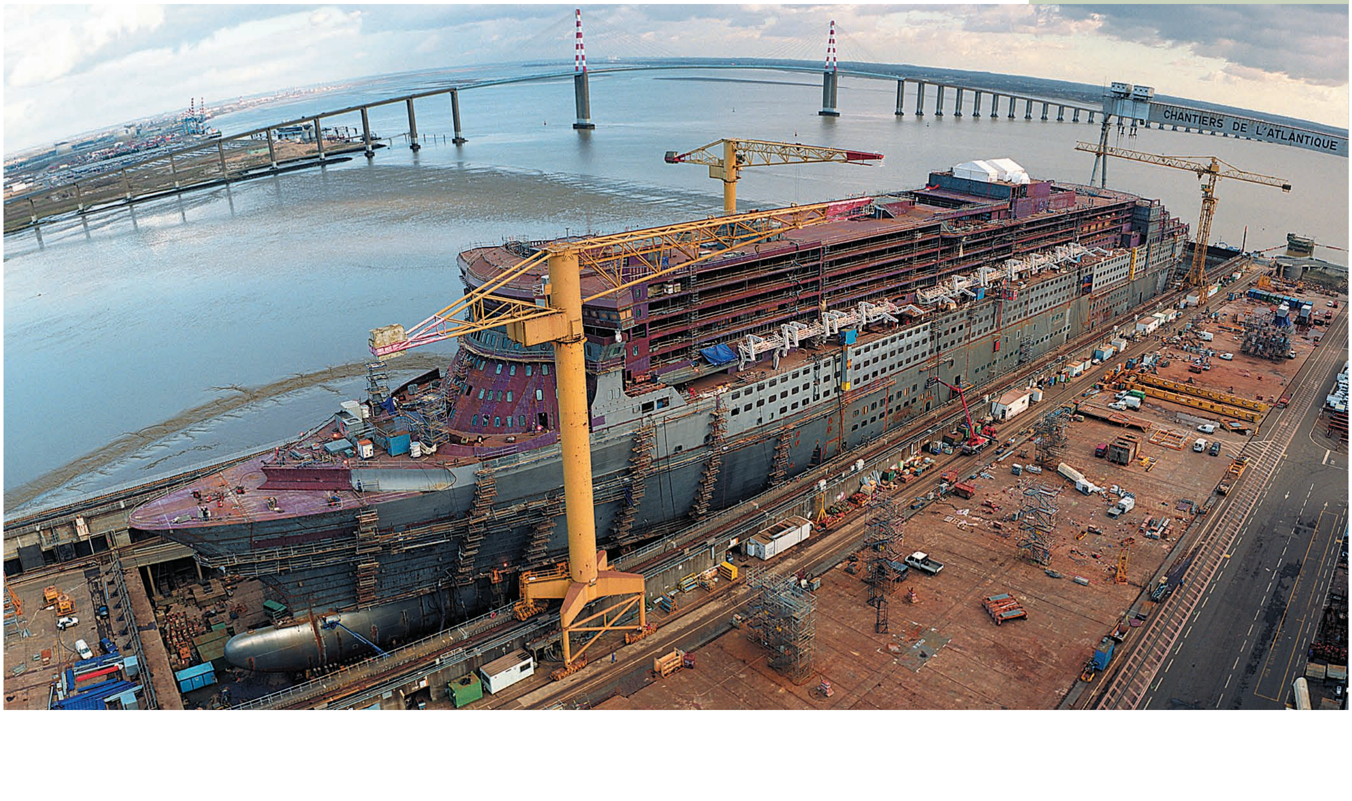
Fixed-position layouts are widely used in farming, firefighting, road building, home building, remodeling and repair, and drilling for oil. In each case, compelling reasons bring workers, materials, and equipment to the "product's" location instead of the other way around.

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, yet we find that 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, 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.

The Queen Mary 2 *when 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 is 147.6 feet wide. Its capacity is 2,620 passengers and 1,253 officers and crew.*



Cellular Layouts

Cellular production Layout in which workstations are grouped into a cell that can process items that have similar processing requirements.

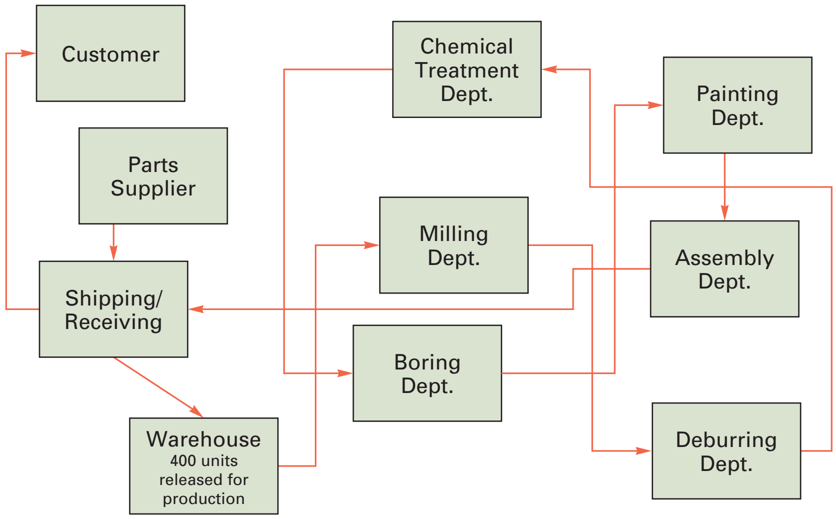
Cellular Production. **Cellular production** is a type of layout in which workstations are grouped into what is referred to as a *cell.* Groupings are determined by the operations needed to perform work for a set of similar items, or *part families,* that require similar processing. The cells become, in effect, miniature versions of product layouts. The cells may have no conveyorized movement of parts between machines, or they may have a flow line connected by a conveyor (automatic transfer). 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 manufacturing enables companies to produce a variety of products with as little waste as possible. A cell layout provides a smooth flow of work through the process with minimal transport or delay. Benefits frequently associated with cellular manufacturing include minimal work in process, reduced space requirements and lead times, productivity and quality improvement, and increased flexibility.

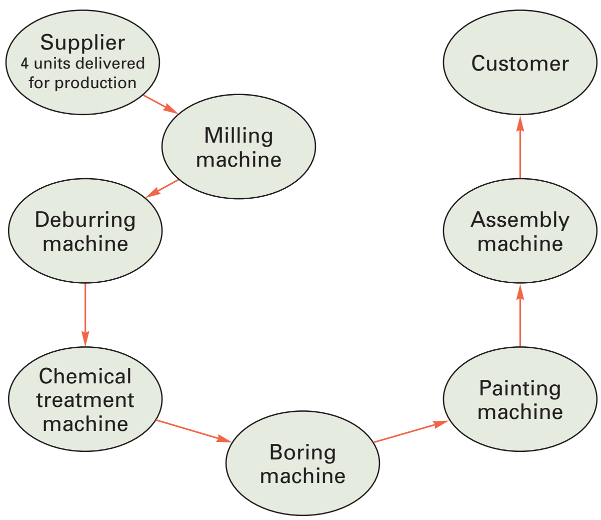
Figure 6.7 provides a comparison between a traditional process layout (6.7A) and a cellular layout (6.7B). To get a sense of the advantage of the cellular layout, trace the movement of an order in the traditional layout (6.7A) that is depicted by the path of the arrow. Begin on the

FIGURE 6.7
Comparison of process and cellular layouts

Source: Adapted from U.S. Environmental Protection Agency, "Lean Manufacturing and the Environment," www.epa.gov/innovation/lean/thinking/cellular.htm.



A. Example of an order processed in a traditional process layout.



B. The same example of an order processed in a cellular layout.

TABLE 6.4
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

bottom left at Shipping/Receiving, then follow the arrow to Warehouse, where a batch of raw material is released for production. Follow the path (shown by the arrows) that the batch takes as it moves through the system to Shipping/Receiving and then to the Customer. Now turn to Figure 6.7B. Note the simple path the order takes as it moves through the system.

Several techniques facilitate effective cellular layout design. Among them are the following two:

Single-minute exchange of die (SMED) enables an organization to quickly convert a machine or process to produce a different (but similar) product type. Thus, a single cell can produce a variety of products without the time-consuming equipment changeover associated with large batch processes, enabling the organization to quickly respond to changes in customer demand.

Right-sized equipment is often smaller than equipment used in traditional process layouts, and mobile, so that it can quickly be reconfigured into a different cellular layout in a different location.

Table 6.4 lists the benefits of cellular layouts compared to functional layouts.

The biggest challenges of implementing cellular manufacturing involve issues of equipment and layout and issues of workers and management. Equipment and layout issues relate to design and cost. The costs of work stoppages during implementation can be considerable, as can the costs of new or modified equipment and the rearrangement of the layout. The costs to implement cellular manufacturing must be weighed against the cost savings that can be expected from using cells. Also, the implementation of cell manufacturing often requires employee training and the redefinition of jobs. Each of the workers in each cell should ideally be able to complete the entire range of tasks required in that cell, and often this means being more multiskilled than they were previously. In addition, cells are often expected to be self-managing, and therefore workers will have to be able to work effectively in teams. Managers have to learn to be less involved than with more traditional work methods.

Group Technology. Effective cellular manufacturing must have groups of identified items with similar processing characteristics. This strategy for product and process design is known 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.

Group technology The grouping into part families of items with similar design or manufacturing 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

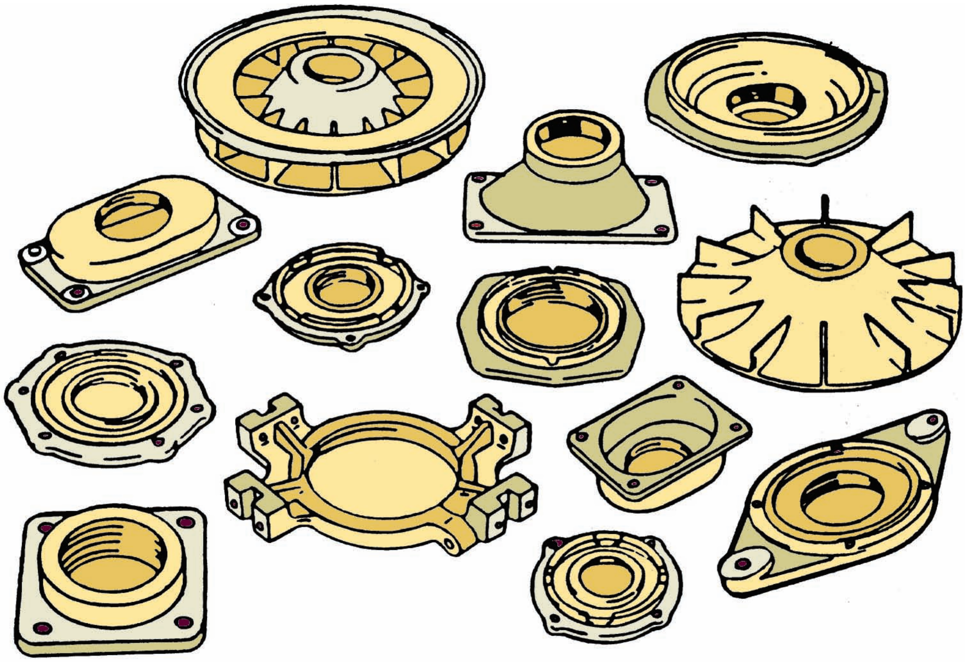


FIGURE 6.8
A group of parts with similar manufacturing process requirements but different design attributes

Source: Mikell P. Groover, *Automation, Production Systems, and Computer-Aided Manufacturing,* 3rd ed., © 2007, p. 508. Reprinted by permission of Pearson Education Inc., Upper Saddle River, NJ.

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, discussed earlier, are more fully automated versions of cellular manufacturing.

Service Layouts

As is the case with manufacturing, service layouts can often be categorized as product, process, or fixed-position layouts. In a fixed-position service layout (e.g., appliance repair, roofing, landscaping, home remodeling, copier service), materials, labor, and equipment are brought to the customer's residence or office. Process layouts are common in services due mainly to the high degree of variety in customer processing requirements. Examples include hospitals, supermarkets and department stores, vehicle repair centers, and banks. If the service is organized sequentially, with all customers or work following the same or similar sequence, as it is in a car wash or a cafeteria line, a product layout is used.

However, service layout requirements are somewhat different from manufacturing layout requirements. The degree of customer contact and the degree of customization are two key factors in service layout design. If contact and customization are both high, as in health care and personal care, the service environment is a job shop, usually with high labor content and flexible equipment, and a layout that supports this. If customization is high but contact low (e.g., picture framing, tailoring), the layout can be arranged to facilitate workers and equipment. If contact is high but customization is low (e.g., supermarkets, gas stations), self-service is a possibility, in which case layout must take into account ease of obtaining the service as well as customer safety. If the degree of contact and the need for customization are low, the core service and the customer can be separated, making it easier to achieve a high degree of efficiency in operations. Highly standardized services may lend themselves to automation (e.g., Web services, online banking, ATM machines).

Let's consider some of these 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.

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.

Kiosks benefit customers by speeding up tedious processes and reducing waiting time. At McDonald's, kiosks actually increase sales by an average of $1 over face-to-face purchases. Managers explain this by the kiosk's ability to prompt customers for more purchases by showing pictures of products they might want to buy.

A Safe Hospital Room of the Future

READING

No one expects a stay in a hospital room to be unsafe or having to endure disruptions in their care, although today, there is need for improvement in hospital room safety and patient care. The following are suggestions for an improved hospital room of the future.

1 **Double-sided linen closets** allow staff to restock supplies without disturbing the patient.

2 **Bar codes** increase safety by matching the right medicine to the right patient.

3 **A two-bin supply system** ensures that providers don't run out of critical supplies.

4 **A hand-washing station** in every room gives providers a place to wash their hands.

5 **A sliding glass door** doubles as a **whiteboard** for information exchanges.

6 **Hand bars** on all sides of the bathroom help patients navigate more safely.

7 **Bed alarms** alert nurses that a patient may be attempting to get out of bed unassisted.

8 **Disinfecting units** use ultra-violet light to kill germs.

9 **Checklists** give providers a set of proven rules for preventing infections.

10 **Vents** suck the air out of the room of sick patients, filter it and then release it from the building.

11 **"Smart" pumps** deliver fluids, nutrients and medicines to patients at precisely controlled rates.

12 **Kits for fall prevention** include color-coded nonslip socks, lap blanket and wristband.

13 Frequently touched surfaces, such as IV poles, bed rails and faucets, are made with **germ-resistant copper alloys,** which are naturally antimicrobial.

14 **Infrared technology** that lights up the sink reminds health care providers to wash their hands.

15 Beds with **translation technology** help staff speak with all patients.

16 **Real-time vital signs**—heart rate, blood pressure—can be monitored from computers outside the room. *—B.H.*

Questions

1. If you have experienced a hospital room, either as a patient or a visitor, which of these features was present in that room?
2. If you have experienced a hospital room, which of these features was missing, but would have been desirable additions?

Source: "Real Possibilities," *AARP The Magazine,* April/May 2013, p. 54.

Office Layouts. Office layouts are undergoing transformations as the flow of paperwork is replaced with the increasing use of electronic communications. This lessens the 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, which also facilitate communication among workers.

Restaurant Layouts. There are many different types of restaurants, ranging from food trucks to posh establishments. Many belong to chains, and some of those are franchises. That type of restaurant typically adheres to a floor plan established by the company. Independent restaurants and bars have their own floor plans. Some have what could be considered very good designs, while others do not. Ed Norman of MVP Services Group, Inc., in Dubuque, IA, offers this valuable observation: "The single most important element is process workflow. Food and non-food products should transition easily through the operation from the receiving door to the customer with all phases of storage, pre-preparation, cooking, holding, and service, unimpaired or minimized due to good design."

Hospital Layouts. Key elements of hospital layout design are patient care and safety, with easy access to critical resources such as X-ray, CAT scan, and MRI equipment. General layout of the hospital is one aspect of layout, while layout of patient rooms is another. The following reading illustrates a safe hospital room of the future.

Automation in Services. One way to improve productivity and reduce costs in services is to remove the customer from the process as much as possible. Automated services is one increasingly used alternative. For example, financial services use ATMs, automated call answering, online banking, and electronic funds transfers; retail stores use optical scanning to process sales; and the travel industry uses electronic reservation systems. Other examples of automated services include shipping, mail processing, communication, and health care services.

From self check-in at the airport to depositing a check from anywhere, automation speeds up service and reduces the need to stand in line.

Automating services means more-standardized services and less need to involve the customer directly. However, service standardization brings trade-offs. Generally, costs are reduced and productivity increases, but the lack of customization and the inability to deal with a real person raise the risk of customer dissatisfaction.

6.6 DESIGNING PRODUCT LAYOUTS: LINE BALANCING

LO6.8 Solve simple line-balancing problems.

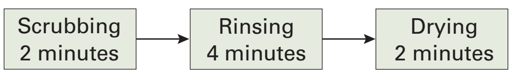
The goal of a product layout is to arrange workers or machines in the sequence that operations need to be performed. The sequence is referred to as a production line or an assembly line. These lines range from fairly short, with just a few operations, to long lines that have a large number of operations. Automobile assembly lines are examples of long lines. At the assembly line for Ford Mustangs, a Mustang travels about nine miles from start to finish!

Because it is difficult and costly to change a product layout that is inefficient, design is a critical issue. 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 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.



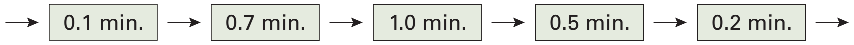
Line balancing involves assigning tasks to workstations. Usually, each workstation has one worker who handles all of the tasks at that station, although an option is to have several workers at a single workstation. For purposes of illustration, however, all of the examples and problems in this chapter 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, for example, 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?

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. Hence, the line's capacity is a function of its cycle time.

Cycle time The maximum time allowed at each workstation to complete its set of tasks on a unit.

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:



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:

$$\text{Output rate} = \frac{\text{Operating time per day}}{\text{Cycle time}} \tag{6–1}$$

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.

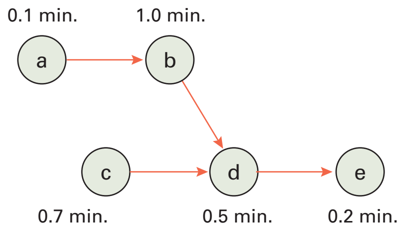
As a general rule, the cycle time is determined by the desired output; that is, a desired output rate is selected, and the cycle time is computed. If the cycle time does not fall between the maximum and minimum bounds, the desired output rate must be revised. We can compute the cycle time using this equation:

$$\text{Cycle time} = \frac{\text{Operating time per day}}{\text{Desired output rate}} \tag{6–2}$$

For example, suppose that the desired output rate is 480 units. Using Formula 6–2, the necessary cycle time is

$$\frac{\text{480 minutes per day}}{\text{480 units per day}} = \text{1.0 minute per unit}$$

FIGURE 6.9
A simple precedence diagram



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:

$$N_{\min} = \frac{\Sigma t}{\text{Cycle time}} \tag{6–3}$$

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 workstations.

Precedence diagram A diagram that shows elemental tasks and their precedence requirements.

A very useful tool in line balancing is a **precedence diagram.** Figure 6.9 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.

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.

EXAMPLE 1
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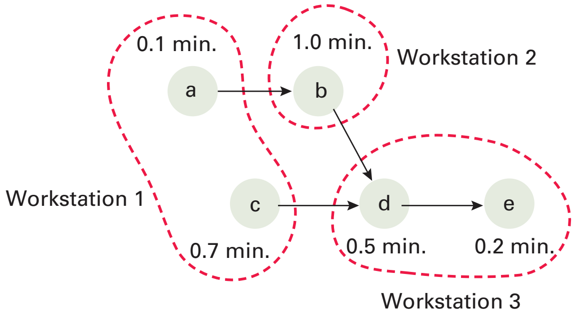
Arrange the tasks shown in Figure 6.9 into three workstations. Use a cycle time of 1.0 minute. Assign tasks in order of the greatest number of followers.

[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.

SOLUTION

1. Begin with task *a;* it has the most following tasks. Assign it to workstation 1.
2. Next, tasks *b* and *c* each have two following tasks, but only task *c* will fit in the time remaining at workstation 1, so assign task *c* to workstation 1.
3. Task *b* now has the most followers, but it will not fit at workstation 1, so assign it to workstation 2.
4. There is no time left at workstation 2, so we move on to workstation 3, assigning task *d* and then task *e* to that workstation.

Workstation	Time Remaining	Eligible	Assign Task	Revised Time Remaining	Station Idle Time
1	1.0	a, c	a	0.9	
	0.9	b, 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



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. When the calculated cycle time in Formula 6–2 and the actual bottleneck station time differ, the actual bottleneck station time should be used in all idle time, efficiency, and output (throughput) calculations. The actual bottleneck time dictates the actual pace of the line, whereas the calculated cycle time is just an upper limit on the amount of time that can be loaded into any station.

2. The **efficiency** of the line. This is computed as follows:

$$\text{Efficiency} = 100\% - \text{Percent idle time} \tag{6–5a}$$

Here, Efficiency = 100% − 16.7% = 83.3%. Alternatively, efficiency could be computed using Formula 6–5b:

$$\text{Efficiency} = \frac{N_{\text{actual}} \times \text{Cycle time} - \text{Idle time}}{N_{\text{actual}} \times \text{Cycle time}} \times 100 \tag{6–5b}$$

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

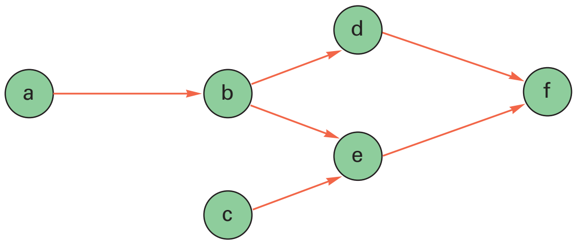
In balancing an assembly line, tasks are assigned *one at a time* to the line, starting at the first workstation. At each step, the unassigned tasks are checked to determine which are eligible for assignment. Next, the eligible tasks are checked to see which of them will fit in the workstation being 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

excel

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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.

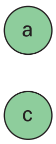
Task	Immediate Predecessor	Task Time (in minutes)
a	—	0.2
b	a	0.2
c	—	0.8
d	c	0.6
e	b	0.3
f	d, e	1.0
g	f	0.4
h	g	0.3
		$\Sigma t = 3.8$

5. Compute the resulting percent idle time and efficiency of the system.

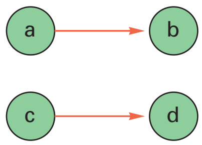
SOLUTION

1. Drawing a precedence diagram is a relatively straightforward task. Begin with activities with no predecessors. We see from the list that tasks *a* and *c* do not have predecessors. We build from here.

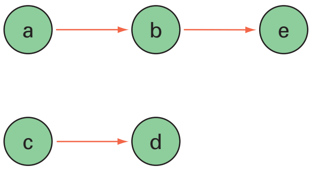
Step 1:



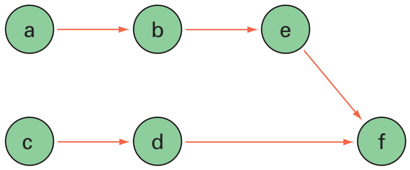
Step 2: Task *b* follows *a*, and *d* follows *c*.



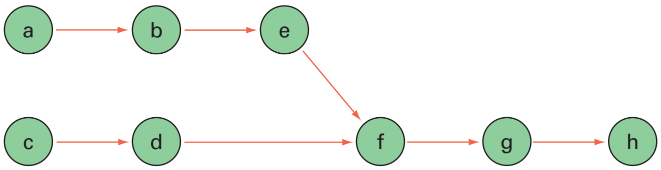
Step 3: Task *e* follows *b*.



Step 4: Task *f* follows *e*, and *d*.



Step 5: Task *g* follows *f*, and *h* follows *g*.



2. $$\text{Cycle time} = \frac{\text{Operating time}}{\text{Desired output rate}} = \frac{480 \text{ minutes per day}}{400 \text{ units per day}} = 1.2 \text{ minutes per cycle}$$

3. $$N_{\min} = \frac{\Sigma t}{\text{Cycle time}} = \frac{3.8 \text{ minutes per unit}}{1.2 \text{ minutes per cycle per station}} = 3.17 \text{ stations (round to 4)}$$

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.

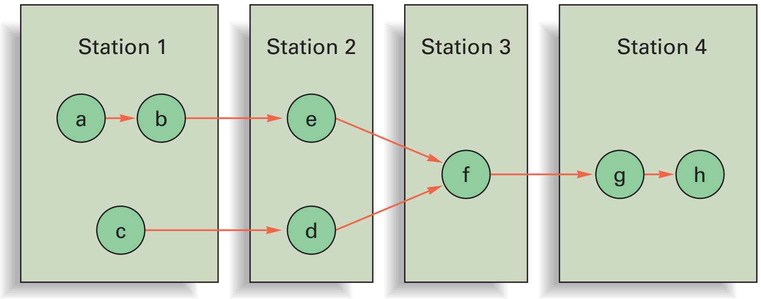
Station	Time Remaining	Eligible	Will Fit	Assign (task time)	Revised Time Remaining	Idle
1	1.2	a, c*	a, c*	a (0.2)	1.0	
	1.0	c, b**	c, b**	c (0.8)	0.2	
	0.2	b, d	b	b (0.2)	0.0	
	0	e, d	None	—		0.0
2	1.2	e, d	e, d	d (0.6)	0.6	
	0.6	e	e	e (0.3)	0.3	
	0.3***	f	None	—		0.3
3	1.2	f	f	f (1.0)	0.2	
	0.2	g	None	—		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. Percent idle time $= \dfrac{1.0 \text{ min.}}{4 \times 1.2 \text{ min.}} \times 100 = 20.83\%.$

Efficiency $= 100\% - 20.83\% = 79.17\%$

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 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.

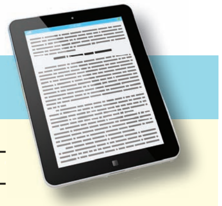
For these reasons, lines that involve human tasks are more of an ideal than a reality. In practice, lines are rarely perfectly balanced. However, this is not entirely bad, because some unbalance means that slack exists at points along the line, which can reduce the impact of brief stoppages at some workstations. Also, workstations that have slack can be used for new workers who may not be "up to speed."

Other Approaches

Companies use a number of other approaches 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.

BMW's Strategy: Flexibility

READING

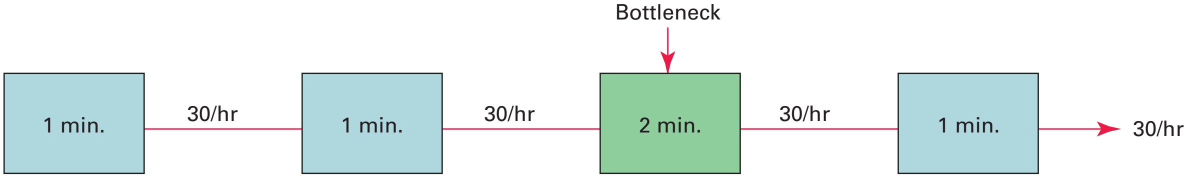


The assembly line in Dingolfing, Germany, where BMW assembles its 7-Series, has built-in flexibility that allows it to easily produce multiple models. Rival car producers typically configure their assembly lines to produce just a single model at a time. In order for them to produce a different model, the line must be shut down so that it can be changed over to be able to produce the different model. BMW's production flexibility enables its line to easily respond to market fluctuations while avoiding the costly changeovers that its rivals' more rigid lines require.

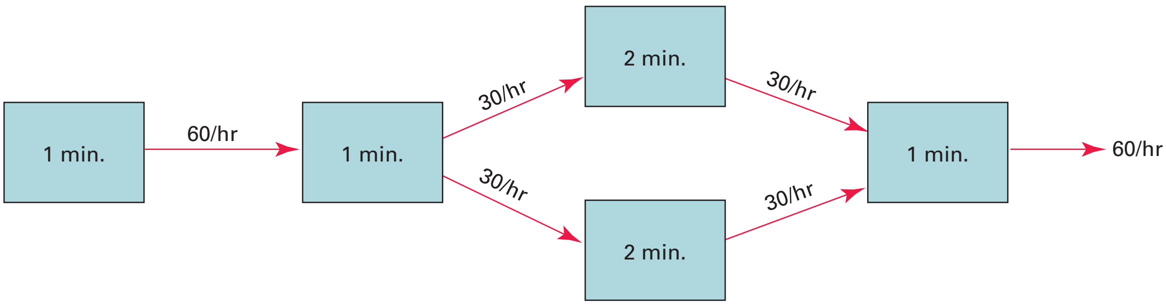
Source: Based on "Betting on the S," *The Wall Street Journal*, July 11, 2005, p. B1.

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:

$$\frac{60 \text{ minutes per hour}}{2 \text{ minutes per unit}} = 30 \text{ units per hour}$$



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 reading describes one such line.

[3]Adapted from Mikell P. Groover, *Automation, Production Systems, and Computer-Aided Manufacturing,* 2nd ed. © 1987. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

6.7 DESIGNING PROCESS LAYOUTS

LO6.9 Develop simple process layouts.

The main issue in designing process layouts concerns the relative positioning of the departments involved. As illustrated in Figure 6.10, 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.

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.

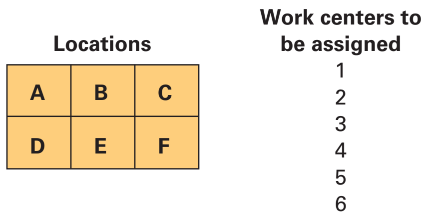


FIGURE 6.10
Work centers must be assigned to locations

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 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.

TABLE 6.5
Distance between locations (meters)

	LOCATION		
From \ To	A	B	C
A		20	40
B			30
C			

TABLE 6.6
Interdepartmental work flow (loads per day)

		DEPARTMENT		
From \ To		1	2	3
Dept.	1		30	170
	2			100
	3			

EXAMPLE 3

eXcel

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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 inter-location 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 6.11.

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	C	B: 30	100 × 30 = 3,000
			B: 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. 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

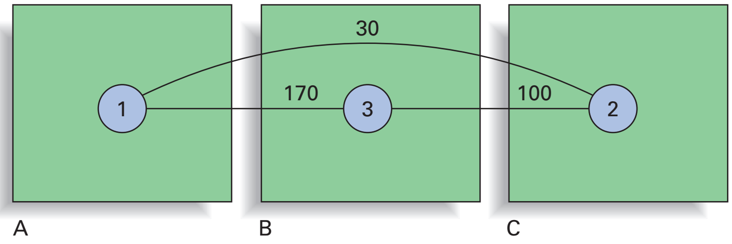
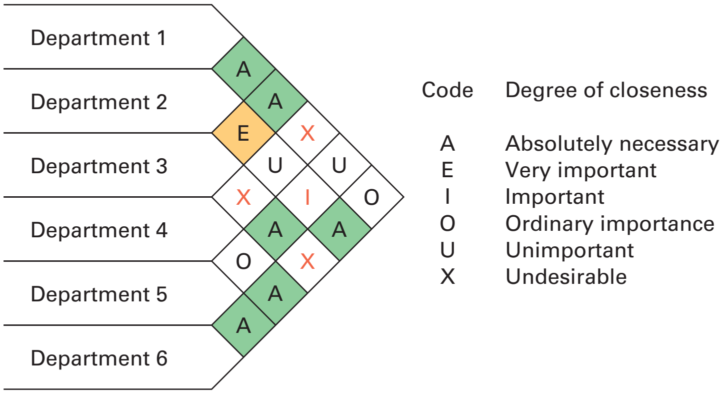


FIGURE 6.11
Interdepartmental work flows for assigned departments

[4]Richard Muther and John Wheeler, "Simplified Systematic Layout Planning," *Factory* 120, nos. 8, 9, and 10 (August, September, October 1962), pp. 68–77, 111–119, 101–113, respectively.

FIGURE 6.12
A Muther grid



information is then summarized in a grid like that shown in Figure 6.12. 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. They use same equipment or facilities.
2. They share the same personnel or records.
3. Required sequence of work flow.
4. Needed for ease of communication.
5. Would create unsafe or unpleasant conditions.
6. Similar work is performed.

EXAMPLE 4

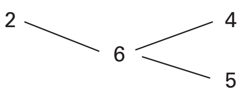
Assign the six departments in Figure 6.12 to a 2 × 3 set of locations using the heuristic rule: Assign critical departments first, because they are the most important.

SOLUTION

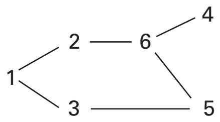
Critical pairs of departments are those with A or X ratings. Prepare a list of those by referring to the grid:

A Links	X Links
1–2	1–4
1–3	3–6
2–6	3–4
3–5	
4–6	
5–6	

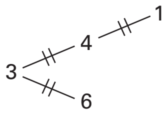
Next, form a cluster of A links, beginning with the department that appears most frequently in the A list (in this case, 6). For instance:



Take the remaining A links 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 X links:



Observe that, as it stands, the cluster of A links also satisfies the X separations. It is a fairly simple exercise to fit the cluster into a 2 × 3 arrangement:

1	2	6
3	5	4

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.

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. Except for projects, process selection is usually a function of the volume and variety needed.

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. Software is available for large or complex designs.

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.