Layout Strategies

CHAPTER 9

CHAPTER OUTLINE

Alaska Airlines

Alaska Airlines

10 OM STRATEGY DECISIONS

- Design of Goods and Services
- Managing Quality
- Process Strategy
- Location Strategies
- *Layout Strategies*
- Human Resources
- Supply-Chain Management
- Inventory Management
- Scheduling
- Maintenance

GLOBAL COMPANY PROFILE
McDonald's

McDonald's Looks for Competitive Advantage Through Layout

In its over half-century of existence, McDonald's has revolutionized the restaurant industry by inventing the limited-menu fast-food restaurant. It has also made seven major innovations. The first, the introduction of *indoor seating* (1950s), was a layout issue, as was the second, *drive-through windows* (1970s). The third, adding *breakfasts* to the menu (1980s), was a product strategy. The fourth, *adding play areas* (late 1980s), was again a layout decision.

In the 1990s, McDonald's completed its fifth innovation, a radically new *redesign of the kitchens* in its 14,000 North American outlets to facilitate a mass customization process. Dubbed the "Made by You" kitchen system, sandwiches were assembled to order with the revamped layout.

In 2004, the chain began the rollout of its sixth innovation, a new food ordering layout: the *self-service kiosk*. Self-service kiosks have been infiltrating the service sector since the introduction of ATMs in 1985 (there are over 1.5 million ATMs in banking). Alaska Airlines was the first airline to provide self-service airport check-in, in 1996. Most passengers of the major airlines now check themselves in for flights. Kiosks take up less space than an employee and reduce waiting line time.

Now, McDonald's is working on its seventh innovation, and not surprisingly, it also deals with restaurant layout. The company, on an unprecedented scale, is redesigning all 30,000 eateries around the globe to take on a *21st-century look*. The dining area will be separated into three sections with distinct personalities: (1) the "linger" zone focuses on young adults and offers

Rick Wilking/Corbis

McDonald's finds that kiosks reduce both space requirements and waiting; order taking is faster. An added benefit is that customers like them. Also, kiosks are reliable—they don't call in sick. And, most important, sales are up 10%–15% (an average of $1) when a customer orders from a kiosk, which consistently recommends the larger size and other extras.

Nancy Siesel/The New York Times/Redux

The redesigned kitchen of a McDonald's in Manhattan. The more efficient layout requires less labor, reduces waste, and provides faster service. A graphic of this "assembly line" is shown in Figure 9.11.

comfortable furniture and Wi-Fi connections; (2) the "grab and go" zone features tall counters, bar stools, and flat-screen TVs; and (3) the "flexible" zone has colorful family booths, flexible seating, and kid-oriented music. The cost per outlet: a whopping \$300,000–\$400,000 renovation fee.

As McDonald's has discovered, facility layout is indeed a source of competitive advantage.

ZUMA Press, Inc./Alamy

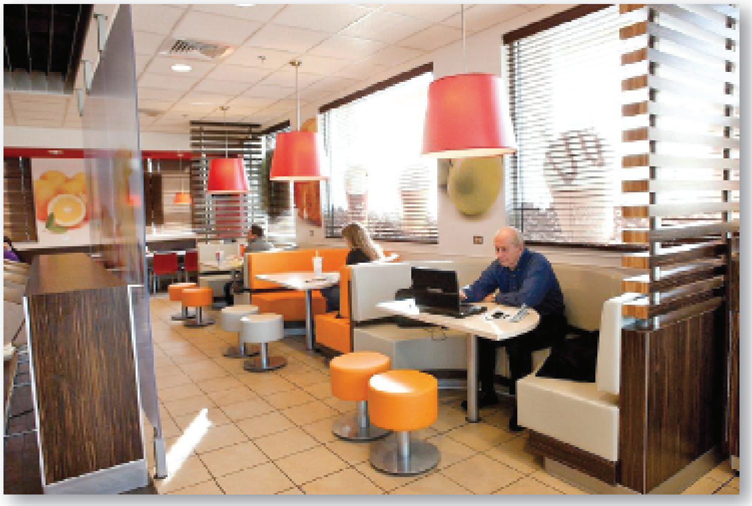
Flexible Zone

This area is geared for family and larger groups, with movable tables and chairs.

McDonald's Corporation

Grab & Go Zone

This section has tall counters with bar stools for customers who eat alone. Flat-screen TVs keep them company.



McDonald's Corporation

Linger Zone

Cozy booths, plus Wi-Fi connections, make these areas attractive to those who want to hang out and socialize.

LEARNING OBJECTIVES

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The Strategic Importance of Layout Decisions

Layout is one of the key decisions that determines the long-run efficiency of operations. Layout has strategic implications because it establishes an organization's competitive priorities in regard to capacity, processes, flexibility, and cost, as well as quality of work life, customer contact, and image. An effective layout can help an organization achieve a strategy that supports differentiation, low cost, or response. Benetton, for example, supports a *differentiation* strategy by heavy investment in warehouse layouts that contribute to fast, accurate sorting and shipping to its 5,000 outlets. Walmart store layouts support a strategy of *low cost*, as do its warehouse layouts. Hallmark's office layouts, where many professionals operate with open communication in work cells, support *rapid development* of greeting cards. *The objective of layout strategy is to develop an effective and efficient layout that will meet the firm's competitive requirements*. These firms have done so.

In all cases, layout design must consider how to achieve the following:

- Higher utilization of space, equipment, and people
- Improved flow of information, materials, and people
- Improved employee morale and safer working conditions
- Improved customer/client interaction
- Flexibility (whatever the layout is now, it will need to change)

In our increasingly short-life-cycle, mass-customized world, layout designs need to be viewed as dynamic.This means considering small, movable, and flexible equipment. Store displays need to be movable, office desks and partitions modular, and warehouse racks prefabricated. To make quick and easy changes in product models and in production rates, operations managers must design flexibility into layouts. To obtain flexibility in layout, managers cross-train their workers, maintain equipment, keep investments low, place workstations close together, and use small, movable equipment. In some cases, equipment on wheels is appropriate, in anticipation of the next change in product, process, or volume.

Types of Layout

Layout decisions include the best placement of machines (in production settings), offices and desks (in office settings), or service centers (in settings such as hospitals or department stores). An effective layout facilitates the flow of materials, people, and information within and between areas. To achieve these objectives, a variety of approaches has been developed. We will discuss seven of them in this chapter:

1. *Office layout:* Positions workers, their equipment, and spaces/offices to provide for movement of information.
2. *Retail layout:* Allocates display space and responds to customer behavior.
3. *Warehouse layout:* Addresses trade-offs between space and material handling.
4. *Fixed-position layout:* Addresses the layout requirements of large, bulky projects such as ships and buildings.

TABLE 9.1 Layout Strategies

	OBJECTIVES	EXAMPLES
Office	Locate workers requiring frequent contact close to one another	Allstate Insurance Microsoft Corp.
Retail	Expose customer to high-margin items	Kroger's Supermarket Walgreens Bloomingdale's
Warehouse (storage)	Balance low-cost storage with low cost material handling	Federal-Mogul's warehouse The Gap's distribution center
Project (fixed position)	Move material to the limited storage areas around the site	Ingall Ship Building Corp. Trump Plaza Pittsburgh Airport
Job shop (process oriented)	Manage varied material flow for each product	Arnold Palmer Hospital Hard Rock Cafe Olive Garden
Work cell (product families)	Identify a product family, build teams, cross-train team members	Hallmark Cards Wheeled Coach Ambulances
Repetitive/continuous (product oriented)	Equalize the task time at each workstation	Sony's TV assembly line Toyota Scion

5. *Process-oriented layout:* Deals with low-volume, high-variety production (also called "job shop," or intermittent production).
6. *Work-cell layout:* Arranges machinery and equipment to focus on production of a single product or group of related products.
7. *Product-oriented layout:* Seeks the best personnel and machine utilization in repetitive or continuous production.

Examples for each of these classes of layouts are noted in Table 9.1.

Because only a few of these seven classes can be modeled mathematically, layout and design of physical facilities are still something of an art. However, we do know that a good layout requires determining the following:

- *Material handling equipment:* Managers must decide about equipment to be used, including conveyors, cranes, automated storage and retrieval systems, and automatic carts to deliver and store material.
- *Capacity and space requirements:* Only when personnel, machines, and equipment requirements are known can managers proceed with layout and provide space for each component. In the case of office work, operations managers must make judgments about the space requirements for each employee. They must also consider allowances for requirements that address safety, noise, dust, fumes, temperature, and space around equipment and machines.
- *Environment and aesthetics:* Layout concerns often require decisions about windows, planters, and height of partitions to facilitate air flow, reduce noise, and provide privacy.
- *Flows of information:* Communication is important to any organization and must be facilitated by the layout. This issue may require decisions about proximity, as well as decisions about open spaces versus half-height dividers versus private offices.
- *Cost of moving between various work areas:* There may be unique considerations related to moving materials or to the importance of having certain areas next to each other. For example, moving molten steel is more difficult than moving cold steel.

Office Layout

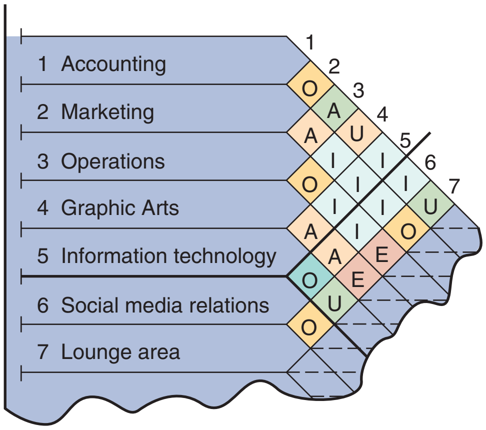
Office layouts require the grouping of workers, their equipment, and spaces to provide for comfort, safety, and movement of information. The main distinction of office layouts is the importance placed on the flow of information. Office layouts are in constant flux as the technological changes sweeping society alter the way offices function.

Office layout
The grouping of workers, their equipment, and spaces/offices to provide for comfort, safety, and movement of information.

Figure 9.1

Office Relationship Chart

The Muther Grid for a software firm.



Code	CLOSENESS
A	Absolutely necessary
E	Especially important
I	Important
O	Ordinary OK
U	Unimportant
X	Not desirable

LO 9.1 *Discuss* important issues in office layout

Even though the movement of information is increasingly electronic, analysis of office layouts still requires a task-based approach. Managers therefore examine both electronic and conventional communication patterns, separation needs, and other conditions affecting employee effectiveness. A useful tool for such an analysis is the *relationship chart* (also called a Muther Grid) shown in Figure 9.1. This chart, prepared for a software firm, indicates that operations must be near accounting and marketing, but it does not need to be near the graphic arts staff.

On the other hand, some layout considerations are universal (many of which apply to factories as well as to offices). They have to do with working conditions, teamwork, authority, and status. Should offices be private or open cubicles, have low file cabinets to foster informal communication or high cabinets to reduce noise and contribute to privacy?

Workspace can inspire informal and productive encounters if it balances three physical and social aspects[1]:

- *Proximity:* Spaces should naturally bring people together.
- *Privacy:* People must be able to control access to their conversations.
- *Permission:* The culture should signal that nonwork interactions are encouraged.

As a final comment on office layout, we note two major trends. First, technology, such as smart phones, scanners, the Internet, laptop computers, and tablets, allows increasing layout flexibility by moving information electronically and allowing employees to work offsite. Second, modern firms create dynamic needs for space and services.

Here are two examples:

- When Deloitte & Touche found that 30% to 40% of desks were empty at any given time, the firm developed its "hoteling programs." Consultants lost their permanent offices; anyone who plans to be in the building (rather than out with clients) books an office through a "concierge," who hangs that consultant's name on the door for the day and stocks the space with requested supplies.
- Cisco Systems cut rent and workplace service costs by 37% and saw productivity benefits of $2.4 billion per year by reducing square footage, reconfiguring space, creating movable, everything-on-wheels offices, and designing "get away from it all" innovation areas.

Retail Layout

Retail layout
An approach that addresses flow, allocates space, and responds to customer behavior.

Retail layouts are based on the idea that sales and profitability vary directly with customer exposure to products. Thus, most retail operations managers try to expose customers to as many products as possible. Studies do show that the greater the rate of exposure, the greater the sales and the higher the return on investment. The operations manager can change

Here are five versions of the office layout.

Everett Collection

Managers and architects have pondered how to design an office to encourage productivity for more than 100 years. In the early 20th century, large offices resembled factories (see the photo of the Jack Lemmon film *The Apartment*, where clerical workers sat in long rows, often performing repetitive tasks).

Starting in the 1960s, layouts changed to foster teamwork where managers and support staff sat together, and groupings were geared toward specific tasks.

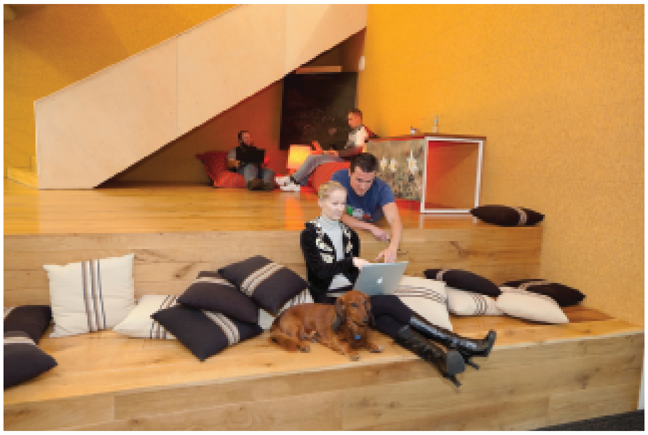
Courtesy of Herman Miller, Inc.

Chad McDermott/Fotolia

With computers, more individual work was possible and the “Cube Farm” era became ubiquitous through the ’80s and ’90s. An office full of high-walled cubicles offered both an open environment and personal office space.

By the turn of the century, looking for innovation and creativity to recruit and inspire college grads, technology firms created the “fun” office. Bright, casual, open office spaces, with amenities such as beanbag chairs, foosball tables, and coffee bars became the fad.

Monkey Business/Fotolia



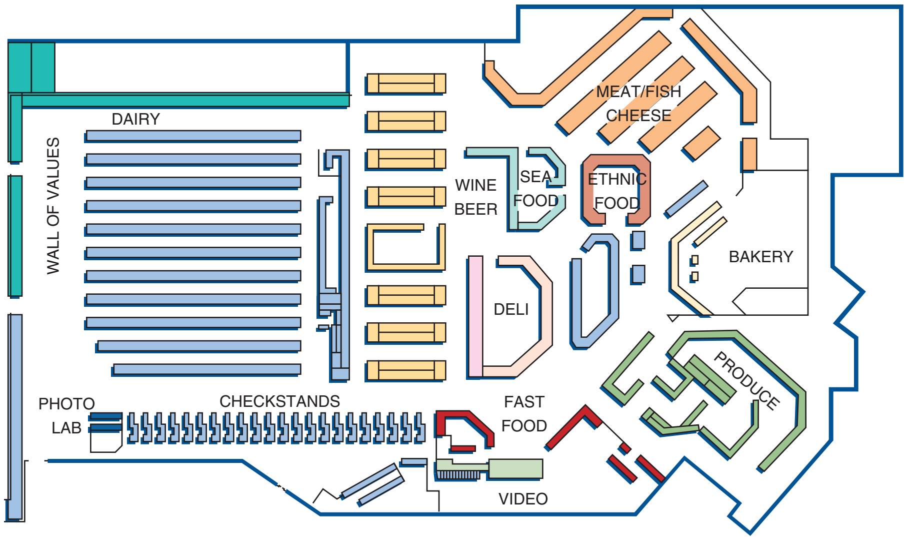
Amruth/Agencja Fotograficzna Caro/Alamy

The buzzwords today are serendipity and collaboration, as companies design office space to engineer encounters between employees. Steve Jobs designed his Pixar headquarters with the cafeteria and bathrooms in a central atrium away from work areas to encourage intermingling and collaboration. Skype achieves similar goals with open lounges.

Sources: Wall Street Journal (April 28, 2014); *USA Today* (Feb. 28, 2013); and *Harvard Business Review* (Oct. 2014).

Figure 9.2

Store Layout with Dairy and Bakery, High-Draw Items, in Different Areas of the Store



exposure with store arrangement and the allocation of space to various products within that arrangement.

Five ideas are helpful for determining the overall arrangement of many stores:

1. Locate the high-draw items around the periphery of the store. Thus, we tend to find dairy products on one side of a supermarket and bread and bakery products on another. An example of this tactic is shown in Figure 9.2.
2. Use prominent locations for high-impulse and high-margin items. Best Buy puts fast-growing, high-margin digital goods—such as cameras and printers—in the front and center of its stores.
3. Distribute what are known in the trade as "power items"—items that may dominate a purchasing trip—to both sides of an aisle, and disperse them to increase the viewing of other items.
4. Use end-aisle locations because they have a very high exposure rate.
5. Convey the mission of the store by carefully selecting the position of the lead-off department. For instance, if prepared foods are part of a supermarket's mission, position the bakery and deli up front to appeal to convenience-oriented customers. Walmart's push to increase sales of clothes means those departments are in broad view upon entering a store.

STUDENT TIP The goal in a retail layout is to maximize profit per square foot of store space.

LO 9.2 *Define* the objectives of retail layout

Once the overall layout of a retail store has been decided, products need to be arranged for sale. Many considerations go into this arrangement. However, the main *objective of retail layout is to maximize profitability per square foot of floor space* (or, in some stores, on linear foot of shelf space). Big-ticket, or expensive, items may yield greater dollar sales, but the profit per square foot may be lower. Computer programs are available to assist managers in evaluating the profitability of various merchandising plans for hundreds of categories: this technique is known as category management.

An additional, and somewhat controversial, issue in retail layout is called slotting. **Slotting fees** are fees manufacturers pay to get their goods on the shelf in a retail store or supermarket chain. The result of massive new-product introductions, retailers can now demand up to $25,000 to place an item in their chain. During the last decade, marketplace economics, consolidations, and technology have provided retailers with this leverage. The competition for shelf space is advanced by POS systems and scanner technology, which improve supply-chain management and inventory control. Many small firms question the legality and ethics of slotting fees, claiming the fees stifle new products, limit their ability to expand, and cost consumers money. Walmart is one of the few major retailers that does not demand slotting fees, removing a barrier to entry. (See the *Ethical Dilemma* at the end of this chapter.)

Slotting fees
Fees manufacturers pay to get shelf space for their products.

Servicescapes

Although a major goal of retail layout is to maximize profit through product exposure, there are other aspects of the service that managers consider. The term **servicescape** describes the physical surroundings in which the service is delivered and how the surroundings have a humanistic effect on customers and employees. To provide a good service layout, a firm considers three elements:

Servicescape
The physical surroundings in which a service takes place, and how they affect customers and employees.

1. *Ambient conditions*, which are background characteristics such as lighting, sound, smell, and temperature. All these affect workers *and* customers and can affect how much is spent and how long a person stays in the building.
2. *Spatial layout and functionality*, which involve customer circulation path planning, aisle characteristics (such as width, direction, angle, and shelf spacing), and product grouping.
3. *Signs, symbols, and artifacts*, which are characteristics of building design that carry social significance (such as carpeted areas of a department store that encourage shoppers to slow down and browse).

Examples of each of these three elements of servicescape are:

- *Ambient conditions:* Fine-dining restaurants with linen tablecloths and candlelit atmosphere; Mrs. Field's Cookie bakery smells permeating the shopping mall; leather chairs at Starbucks.
- *Layout/functionality:* Kroger's long aisles and high shelves; Best Buy's wide center aisle.
- *Signs, symbols, and artifacts:* Walmart's greeter at the door; Hard Rock Cafe's wall of guitars; Disneyland's entrance looking like hometown heaven.

Warehouse and Storage Layouts

Warehouse layout
A design that attempts to minimize total cost by addressing trade-offs between space and material handling.

LO 9.3 *Discuss* modern warehouse management and terms such as ASRS, cross-docking, and random stocking

The objective of **warehouse layout** *is to find the optimum trade-off between handling cost and costs associated with warehouse space*. Consequently, management's task is to maximize the utilization of the total "cube" of the warehouse—that is, utilize its full volume while maintaining low material handling costs. We define *material handling costs* as all the costs related to the transaction. This consists of incoming transport, storage, and outgoing transport of the materials to be warehoused. These costs include equipment, people, material, supervision, insurance, and depreciation. Effective warehouse layouts do, of course, also minimize the damage and spoilage of material within the warehouse.

imageBROKER/Alamy

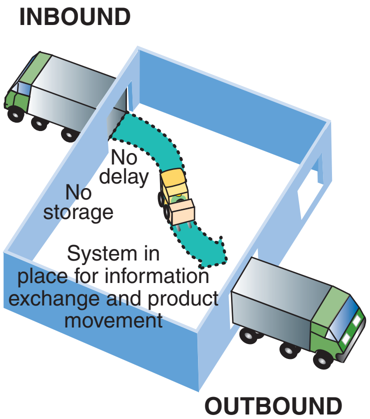
A critical element contributing to the bottom line at Hard Rock Cafe is the layout of each cafe's retail shop space. The retail space, from 600 to 1,300 square feet in size, is laid out in conjunction with the restaurant area to create the maximum traffic flow before and after eating. The payoffs for cafes like this one in London are huge. Almost half of a cafe's annual sales are generated from these small shops, which have very high retail sales per square foot.

STUDENT TIP
In warehouse layout, we want to maximize use of the whole building—from floor to ceiling.

Management minimizes the sum of the resources spent on finding and moving material plus the deterioration and damage to the material itself. The variety of items stored and the number of items "picked" has direct bearing on the optimum layout. A warehouse storing a few unique items lends itself to higher density than a warehouse storing a variety of items. Modern warehouse management is, in many instances, an automated procedure using *automated storage and retrieval systems* (ASRSs).

The Stop & Shop grocery chain, with 350 supermarkets in New England, has recently completed the largest ASRS in the world. The 1.3-million-square-foot distribution center in Freetown, Massachusetts, employs 77 rotating-fork automated storage and retrieval machines. These 77 ASRS machines each access 11,500 pick slots on 90 aisles—a total of 64,000 pallets of food.

An important component of warehouse layout is the relationship between the receiving/unloading area and the shipping/loading area. Facility design depends on the type of supplies unloaded, what they are unloaded from (trucks, rail cars, barges, and so on), and where they are unloaded. In some companies, the receiving and shipping facilities, or *docks*, as they are called, are even in the same area; sometimes they are receiving docks in the morning and shipping docks in the afternoon.



Cross-Docking

Cross-docking
Avoiding the placement of materials or supplies in storage by processing them as they are received for shipment.

Cross-docking means to avoid placing materials or supplies in storage by processing them as they are received. In a manufacturing facility, product is received directly by the assembly line. In a distribution center, labeled and presorted loads arrive at the shipping dock for immediate rerouting, thereby avoiding formal receiving, stocking/storing, and order-selection activities. Because these activities add no value to the product, their elimination is 100% cost savings. Walmart, an early advocate of cross-docking, uses the technique as a major component of its continuing low-cost strategy. With cross-docking, Walmart reduces distribution costs and speeds restocking of stores, thereby improving customer service. Although cross-docking reduces product handling, inventory, and facility costs, it requires both (1) tight scheduling and (2) accurate inbound product identification.

Random Stocking

Random stocking
Used in warehousing to locate stock wherever there is an open location.

Automatic identification systems (AISs), usually in the form of bar codes, allow accurate and rapid item identification. When automatic identification systems are combined with effective management information systems, operations managers know the quantity and location of every unit. This information can be used with human operators or with automatic storage and retrieval systems to load units anywhere in the warehouse—randomly. Accurate inventory quantities and locations mean the potential utilization of the whole facility because space does not need to be reserved for certain stock-keeping units (SKUs) or part families. Computerized **random stocking** systems often include the following tasks:

1. Maintaining a list of "open" locations
2. Maintaining accurate records of existing inventory and its locations
3. Sequencing items to minimize the travel time required to "pick" orders
4. Combining orders to reduce picking time
5. Assigning certain items or classes of items, such as high-usage items, to particular warehouse areas so that the total distance traveled within the warehouse is minimized

Random stocking systems can increase facility utilization and decrease labor cost, but they require accurate records.


Andrew Hetherington/Redux

At Ikea's distribution center in Almhult, Sweden, pallets are stacked and retrieved through a fully automated process.

Customizing

Customizing
Using warehousing to add value to a product through component modification, repair, labeling, and packaging.

Although we expect warehouses to store as little product as possible and hold it for as short a time as possible, we are now asking warehouses to customize products. Warehouses can be places where value is added through **customizing**. Warehouse customization is a particularly useful way to generate competitive advantage in markets where products have multiple configurations. For instance, a warehouse can be a place where computer components are put together, software loaded, and repairs made. Warehouses may also provide customized labeling and packaging for retailers so items arrive ready for display.

Increasingly, this type of work goes on adjacent to major airports, in facilities such as the FedEx terminal in Memphis. Adding value at warehouses adjacent to major airports also facilitates overnight delivery. For example, if your computer has failed, the replacement may be sent to you from such a warehouse for delivery the next morning. When your old machine arrives back at the warehouse, it is repaired and sent to someone else. These value-added activities at "quasi-warehouses" contribute to strategies of differentiation, low cost, and rapid response.

Fixed-Position Layout

Fixed-position layout
A system that addresses the layout requirements of stationary projects.

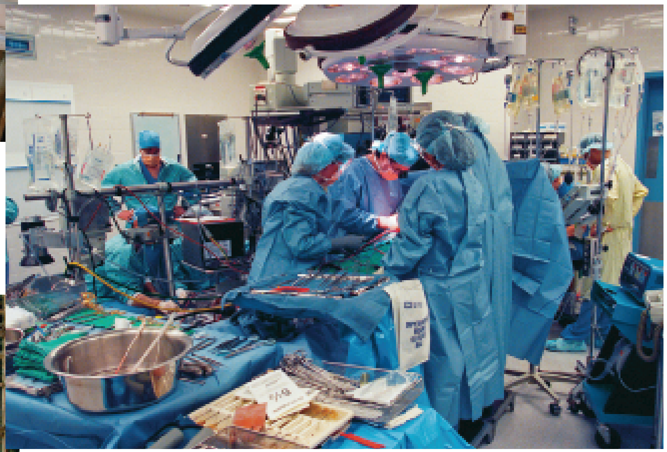
In a **fixed-position layout**, the project remains in one place, and workers and equipment come to that one work area. Examples of this type of project are a ship, a highway, a bridge, a house, and an operating table in a hospital operating room.

The techniques for addressing the fixed-position layout are complicated by three factors. First, there is limited space at virtually all sites. Second, at different stages of a project, different materials are needed; therefore, different items become critical as the project develops. Third, the volume of materials needed is dynamic. For example, the rate of use of steel panels for the hull of a ship changes as the project progresses.

Here are three versions of the fixed-position layout.

Craig Ruttle/AP Images

A house built via traditional fixed-position layout would be constructed onsite, with equipment, materials, and workers brought to the site. Then a "meeting of the trades" would assign space for various time periods. However, the home pictured here can be built at a much lower cost. The house is built in two movable modules in a factory. Scaffolding and hoists make the job easier, quicker, and cheaper, and the indoor work environment aids labor productivity.



Dick Blume/The Image Works

A service example of a fixed-position layout is an operating room; the patient remains stationary on the table, and medical personnel and equipment are brought to the site.

Tim Altevogt/Reuters/Corbis

In shipbuilding, there is limited space next to the fixed-position layout. Shipyards call these loading areas platens, and they are assigned for various time periods to each contractor.

LO 9.4 *Identify* when fixed-position layouts are appropriate

Because problems with fixed-position layouts are so difficult to solve well onsite, an alternative strategy is to complete as much of the project as possible offsite. This approach is used in the shipbuilding industry when standard units—say, pipe-holding brackets—are assembled on a nearby assembly line (a product-oriented facility). In an attempt to add efficiency to shipbuilding, Ingall Ship Building Corporation has moved toward product-oriented production when sections of a ship (modules) are similar or when it has a contract to build the same section of several similar ships. Also, as the first photo on this page shows, many home builders are moving from a fixed-position layout strategy to one that is more product oriented. About one-third of all new homes in the U.S. are built this way. In addition, many houses that are built onsite (fixed position) have the majority of components such as doors, windows, fixtures, trusses, stairs, and wallboard built as modules in more efficient offsite processes.

Process-Oriented Layout

Process-oriented layout

A layout that deals with low-volume, high-variety production in which like machines and equipment are grouped together.

A **process-oriented layout** can simultaneously handle a wide variety of products or services. This is the traditional way to support a product differentiation strategy. It is most efficient when making products with different requirements or when handling customers, patients, or clients with different needs. A process-oriented layout is typically the low-volume, high-variety strategy discussed in Chapter 7. In this job-shop environment, each product or each small group of products undergoes a different sequence of operations. A product or small order is produced

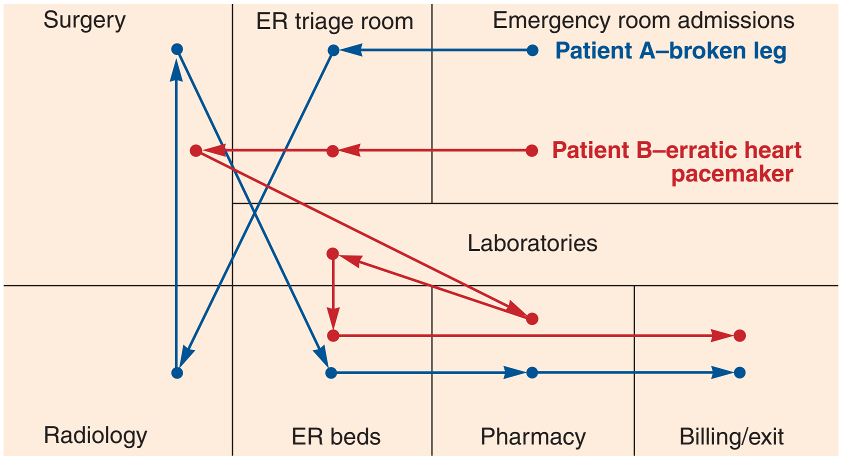


Figure 9.3

An Emergency Room Process Layout Showing the Routing of Two Patients

STUDENT TIP

Patient A (broken leg) proceeds (blue arrow) to ER triage, to radiology, to surgery, to a bed, to pharmacy, to billing. Patient B (pacemaker problem) moves (red arrow) to ER triage, to surgery, to pharmacy, to lab, to a bed, to billing.

VIDEO 9.1
Laying Out Arnold Palmer Hospital's New Facility

by moving it from one department to another in the sequence required for that product. A good example of the process-oriented layout is a hospital or clinic. Figure 9.3 illustrates the process for two patients, A and B, at an emergency clinic in Chicago. An inflow of patients, each with his or her own needs, requires routing through admissions, laboratories, operating rooms, radiology, pharmacies, nursing beds, and so on. Equipment, skills, and supervision are organized around these processes.

A big advantage of process-oriented layout is its flexibility in equipment and labor assignments. The breakdown of one machine, for example, need not halt an entire process; work can be transferred to other machines in the department. Process-oriented layout is also especially good for handling the manufacture of parts in small batches, or **job lots**, and for the production of a wide variety of parts in different sizes or forms.

Job lots
Groups or batches of parts processed together.

The disadvantages of process-oriented layout come from the general-purpose use of the equipment. Orders take more time to move through the system because of difficult scheduling, changing setups, and unique material handling. In addition, general-purpose equipment requires high labor skills, and work-in-process inventories are higher because of imbalances in the production process. High labor-skill needs also increase the required level of training and experience, and high work-in-process levels increase capital investment.

LO 9.5 *Explain* how to achieve a good process-oriented facility layout

When designing a process layout, the most common tactic is to arrange departments or work centers so as to minimize the costs of material handling. In other words, departments with large flows of parts or people between them should be placed next to one another. Material handling costs in this approach depend on (1) the number of loads (or people) to be moved between two departments during some period of time and (2) the distance-related costs of moving loads (or people) between departments. Cost is assumed to be a function of distance between departments. The objective can be expressed as follows:

$$\text{Minimize cost} = \sum_{i=1}^{n}\sum_{j=1}^{n} X_{ij}C_{ij} \tag{9-1}$$

where n = total number of work centers or departments
i, j = individual departments
X_{ij} = number of loads moved from department i to department j
C_{ij} = cost to move a load between department i and department j

Process-oriented facilities (and fixed-position layouts as well) try to minimize loads, or trips, multiplied by distance-related costs. The term C_{ij} combines distance and other costs into one factor. We thereby assume not only that the difficulty of movement is equal but also that the pickup and setdown costs are constant. Although they are not always constant, for simplicity's sake we summarize these data (that is, distance, difficulty, and pickup and setdown costs) in this one variable, cost. The best way to understand the steps involved in designing a process layout is to look at an example.

Example 1

DESIGNING A PROCESS LAYOUT

Walters Company management wants to arrange the six departments of its factory in a way that will minimize interdepartmental material-handling costs. They make an initial assumption (to simplify the problem) that each department is 20 × 20 feet and that the building is 60 feet long and 40 feet wide.

APPROACH AND SOLUTION ▶ The process layout procedure that they follow involves six steps:

Step 1: *Construct a "from–to matrix"* showing the flow of parts or materials from department to department (see Figure 9.4).

Figure **9.4**

Interdepartmental Flow of Parts

STUDENT TIP The high flows between 1 and 3 and between 3 and 6 are immediately apparent. Departments 1, 3, and 6, therefore, should be close together.

Number of loads per week

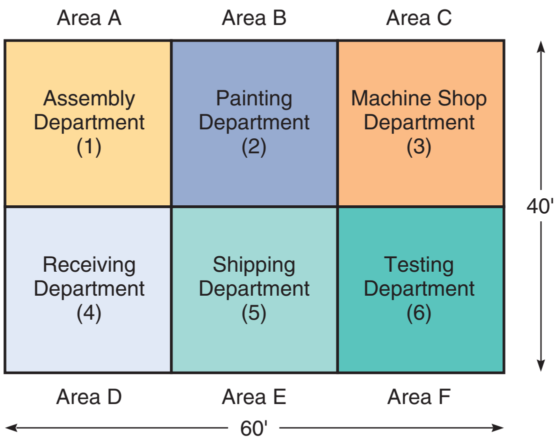
Department	Assembly (1)	Painting (2)	Machine Shop (3)	Receiving (4)	Shipping (5)	Testing (6)
Assembly (1)		50	100	0	0	20
Painting (2)			30	50	10	0
Machine Shop (3)				20	0	100
Receiving (4)					50	0
Shipping (5)						0
Testing (6)						

Step 2: *Determine the space requirements* for each department. (Figure 9.5 shows available plant space.)

Figure **9.5**

Building Dimensions and One Possible Department Layout

STUDENT TIP Think of this as a starting, initial, layout. Our goal is to improve it, if possible.

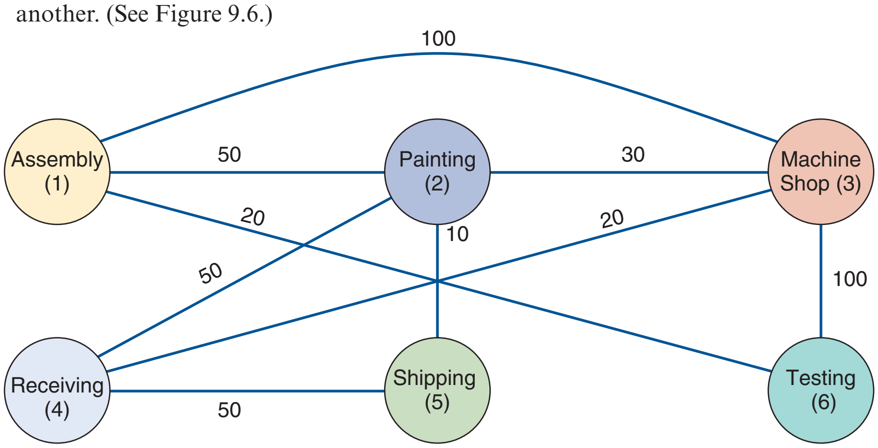


Step 3: *Develop an initial schematic diagram* showing the sequence of departments through which parts must move. Try to place departments with a heavy flow of materials or parts next to one another. (See Figure 9.6.)

Figure **9.6**

Interdepartmental Flow Graph Showing Number of Weekly Loads

STUDENT TIP This shows that 100 loads also move weekly between Assembly and the Machine Shop. We will probably want to move these two departments closer to one another to minimize the flow of parts through the factory.



Step 4: *Determine the cost of this layout* by using the material-handling cost equation:

$$\text{Cost} = \sum_{i=1}^{n}\sum_{j=1}^{n} X_{ij}C_{ij}$$

For this problem, Walters Company assumes that a forklift carries all interdepartmental loads. The cost of moving one load between adjacent departments is estimated to be $1. Moving a load between nonadjacent departments costs $2. Looking at Figures 9.4 and 9.5, we thus see that the handling cost between departments 1 and 2 is $50 ($1 × 50 loads), $200 between departments 1 and 3 ($2 × 100 loads), $40 between departments 1 and 6 ($2 × 20 loads), and so on. Work areas that are diagonal to one another, such as 2 and 4, are treated as adjacent. The total cost for the layout shown in Figure 9.6 is:

$$\begin{aligned}\text{Cost} = {} & \underset{(1\text{ and }2)}{\$50} + \underset{(1\text{ and }3)}{\$200} + \underset{(1\text{ and }6)}{\$40} + \underset{(2\text{ and }3)}{\$30} + \underset{(2\text{ and }4)}{\$50} \\ & + \underset{(2\text{ and }5)}{\$10} + \underset{(3\text{ and }4)}{\$40} + \underset{(3\text{ and }6)}{\$100} + \underset{(4\text{ and }5)}{\$50} \\ = {} & \$570\end{aligned}$$

Step 5: By trial and error (or by a more sophisticated computer program approach that we discuss shortly), *try to improve the layout* pictured in Figure 9.5 to establish a better arrangement of departments.

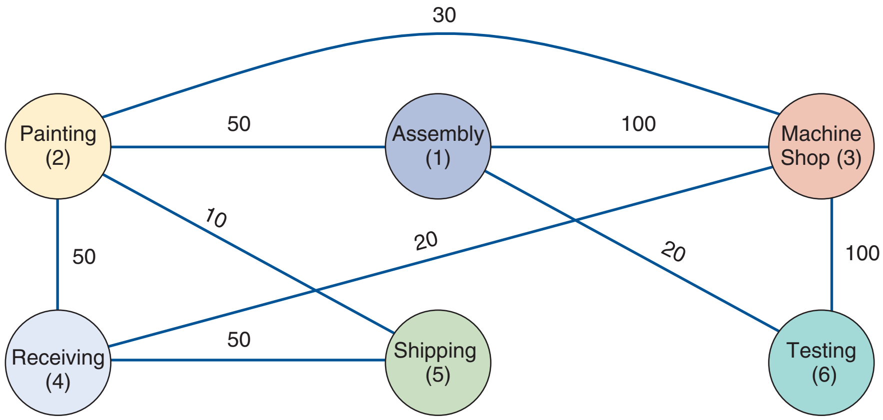
By looking at both the flow graph (Figure 9.6) and the cost calculations, we see that placing departments 1 and 3 closer together appears desirable. They currently are nonadjacent, and the high volume of flow between them causes a large handling expense. Looking the situation over, we need to check the effect of shifting departments and possibly raising, instead of lowering, overall costs.

One possibility is to switch departments 1 and 2. This exchange produces a second departmental flow graph (Figure 9.7), which shows a reduction in cost to $480, a savings in material handling of $90:

$$\begin{aligned}\text{Cost} = {} & \underset{(1\text{ and }2)}{\$50} + \underset{(1\text{ and }3)}{\$100} + \underset{(1\text{ and }6)}{\$20} + \underset{(2\text{ and }3)}{\$60} + \underset{(2\text{ and }4)}{\$50} \\ & + \underset{(2\text{ and }5)}{\$10} + \underset{(3\text{ and }4)}{\$40} + \underset{(3\text{ and }6)}{\$100} + \underset{(4\text{ and }5)}{\$50} \\ = {} & \$480\end{aligned}$$

Figure 9.7

Second Interdepartmental Flow Graph



STUDENT TIP

Notice how Assembly and Machine Shop are now adjacent. Testing stayed close to the Machine Shop also.

Suppose Walters Company is satisfied with the cost figure of $480 and the flow graph of Figure 9.7. The problem may not be solved yet. Often, a sixth step is necessary:

Step 6: *Prepare a detailed plan* arranging the departments to fit the shape of the building and its nonmovable areas (such as the loading dock, washrooms, and stairways). Often this step involves ensuring that the final plan can be accommodated by the electrical system, floor loads, aesthetics, and other factors.

In the case of Walters Company, space requirements are a simple matter (see Figure 9.8).

Figure 9.8

A Feasible Layout for Walters Company

Area A	Area B	Area C
Painting Department (2)	Assembly Department (1)	Machine Shop Department (3)
Receiving Department (4)	Shipping Department (5)	Testing Department (6)
Area D	Area E	Area F

STUDENT TIP

Here we see the departments moved to areas A–F to try to improve the flow.

INSIGHT ▶ This switch of departments is only one of a large number of possible changes. For a six-department problem, there are actually 720 (or $6! = 6 \times 5 \times 4 \times 3 \times 2 \times 1$) potential arrangements! In layout problems, we may not find the optimal solution and may have to be satisfied with a "reasonable" one.

LEARNING EXERCISE ▶ Can you improve on the layout in Figures 9.7 and 9.8? [Answer: Yes, it can be lowered to $430 by placing Shipping in area A, Painting in area B, Assembly in area C, Receiving in area D (no change), Machine Shop in area E, and Testing in area F (no change).]

RELATED PROBLEMS ▶ 9.1–9.9 (9.10 is available in MyOMLab)

EXCEL OM Data File **Ch09Ex1.xls** can be found in MyOMLab.

ACTIVE MODEL 9.1 Example 1 is further illustrated in Active Model 9.1 in MyOMLab.

Computer Software for Process-Oriented Layouts

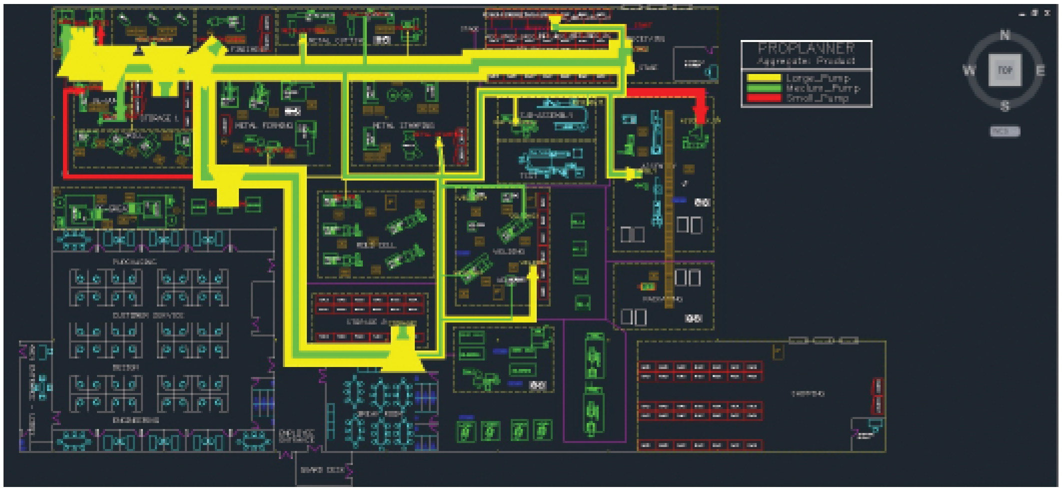
The graphic approach in Example 1 is fine for small problems. It does not, however, suffice for larger problems. When 20 departments are involved in a layout problem, more than 600 *trillion* different department configurations are possible. Fortunately, computer programs have been written to handle large layouts. These programs (see the Flow Path Calculator graphic on the next page) often add sophistication with flowcharts, multiple-story capability, storage and container placement, material volumes, time analysis, and cost comparisons. These programs tend to be interactive—that is, require participation by the user. And most only claim to provide "good," not "optimal," solutions.

Siemens Corp. software such as this allows operations managers to quickly place factory equipment for a full three-dimensional view of the layout. Such presentations provide added insight into the issues of facility layout in terms of process, material handling, efficiency, and safety. (Images created with Tecnomatix Plant Simulation software, courtesy of Siemens PLM Software)

Julian Stratenschulte/picture-alliance/dpa/AP Images

Proplanner Software for Process-Oriented Layouts

Working with computer-aided design software, analysts with the click of a mouse can use Proplanner's Flow Path Calculator to generate material flow diagrams and calculate material handling distances, time, and cost. Variable-width flow lines, color-coded by product, part, or material handling method, allow users to identify how layouts should be arranged and where to eliminate excessive material handling.



Work Cells

A **work cell** reorganizes people and machines that would ordinarily be dispersed in various departments into a group so that they can focus on making a single product or a group of related products (Figure 9.9). Cellular work arrangements are used when volume warrants a special arrangement of machinery and equipment. These work cells are reconfigured as product designs change or volume fluctuates. The advantages of work cells are:

Work cell
An arrangement of machines and personnel that focuses on making a single product or family of related products.

1. *Reduced work-in-process inventory* because the work cell is set up to provide one-piece flow from machine to machine.
2. *Less floor space* required because less space is needed between machines to accommodate work-in-process inventory.
3. *Reduced raw material and finished goods inventories* because less work-in-process allows more rapid movement of materials through the work cell.
4. *Reduced direct labor cost* because of improved communication among employees, better material flow, and improved scheduling.
5. *Heightened sense of employee participation* in the organization and the product: employees accept the added responsibility of product quality because it is directly associated with them and their work cell.
6. *Increased equipment and machinery utilization* because of better scheduling and faster material flow.
7. *Reduced investment in machinery and equipment* because good utilization reduces the number of machines and the amount of equipment and tooling.

LO 9.6 *Define* work cell and the requirements of a work cell

Requirements of Work Cells

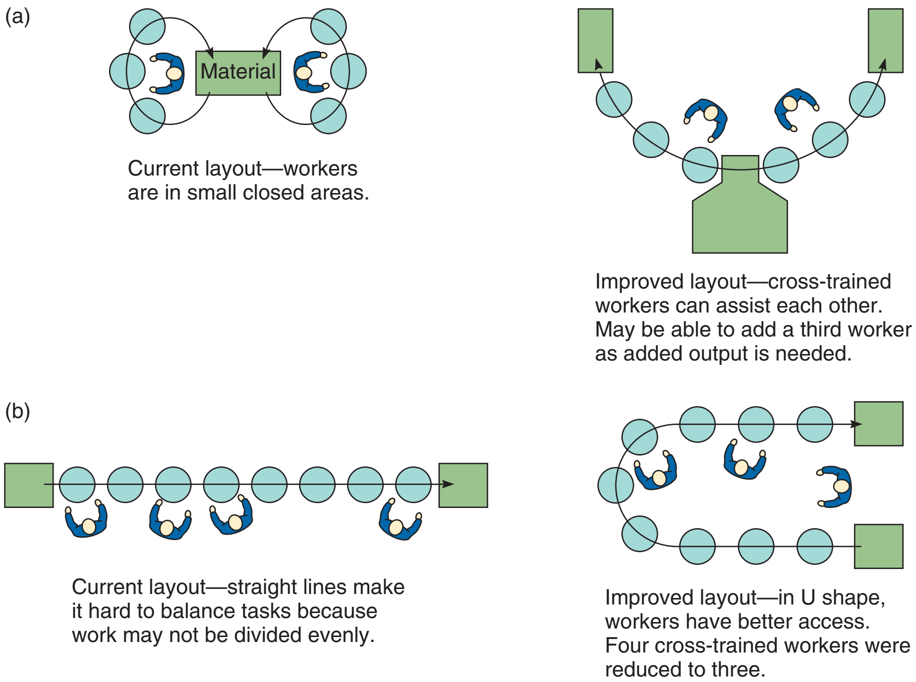
The requirements of cellular production include:

- Identification of families of products, often through the use of group technology codes or equivalents
- A high level of training, flexibility, and empowerment of employees
- Being self-contained, with its own equipment and resources
- Testing (poka-yoke) at each station in the cell

Figure 9.9

Improving Layouts by Moving to the Work Cell Concept

Note in both (a) and (b) that U-shaped work cells can reduce material and employee movement. The U shape may also reduce space requirements, enhance communication, cut the number of workers, and make inspection easier.



STUDENT TIP
Using work cells is a big step toward manufacturing efficiency. They can make jobs more interesting, save space, and cut inventory.

Work cells have at least five advantages over assembly lines and focused process facilities: (1) because tasks are grouped, inspection is often immediate; (2) fewer workers are needed; (3) workers can reach more of the work area; (4) the work area can be more efficiently balanced; and (5) communication is enhanced. Work cells are sometimes organized in a U shape, as shown on the right side of Figure 9.9. The shape of the cell is secondary to the process flow. The focus should be on a flow that optimizes people, material, and communication.

Why did Canon's copier factories in Japan switch from assembly lines to work cells? First, the move freed up 12 miles of conveyor-belt space, at 54 plants, saving $280 million in real estate costs. Second, the cells enabled Canon to change its product mix more quickly, to accommodate short life cycles. And third, morale increased because workers can now assemble a whole copier, not just one part. Some of Canon's fastest workers are so admired that they have become TV celebrities!

Staffing and Balancing Work Cells

Once the work cell has the appropriate equipment located in the proper sequence, the next task is to staff and balance the cell. Efficient production in a work cell requires appropriate staffing.

Takt time
Pace of production to meet customer demands.

This involves two steps. First, determine the **takt time**,[2] which is the pace (frequency) of production units necessary (time per unit) to meet customer orders:

$$\text{Takt time} = \text{Total work time available}/\text{Units required to satisfy customer demand} \quad (9\text{-}2)$$

Second, determine the number of operators required. This requires dividing the total operation time in the work cell by the takt time:

$$\text{Workers required} = \text{Total operation time required}/\text{Takt time} \quad (9\text{-}3)$$

Example 2 considers these two steps when staffing work cells.

Example 2

STAFFING WORK CELLS

Stephen Hall's company in Dayton makes auto mirrors. The major customer is the Honda plant nearby. Honda expects 600 mirrors delivered daily, and the work cell producing the mirrors is scheduled for 8 hours. Hall wants to determine the takt time and the number of workers required.

APPROACH ▶ Hall uses Equations (9-2) and (9-3) and develops a work balance chart to help determine the time for each operation in the work cell, as well as total time.

SOLUTION ▶

$$\text{Takt time} = (8 \text{ hours} \times 60 \text{ minutes})/600 \text{ units} = 480/600 = .8 \text{ minute} = 48 \text{ seconds}$$

Therefore, the customer requirement is one mirror every 48 seconds.

The *work balance chart* in Figure 9.10 shows that 5 operations are necessary, for a total operation time of 140 seconds:

$$\begin{aligned}\text{Workers required} &= \text{Total operation time required}/\text{Takt time}\\ &= (50 + 45 + 10 + 20 + 15)/48\\ &= 140/48 = 2.92\end{aligned}$$

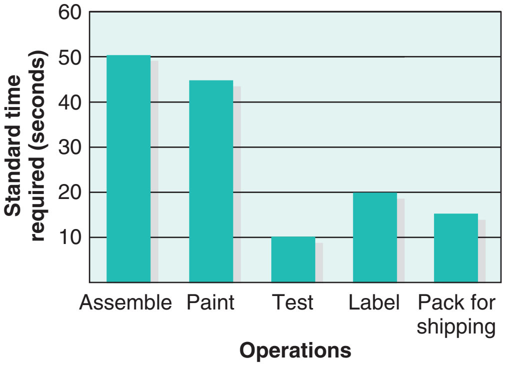


Figure 9.10

Work Balance Chart for Mirror Production

INSIGHT ▶ To produce one unit every 48 seconds will require 2.92 people. With three operators this work cell will be producing one unit each 46.67 seconds (140 seconds/3 employees = 46.67) and 617 units per day (480 minutes available × 60 seconds/46.67 seconds for each unit = 617).

LEARNING EXERCISE ▶ If testing time is expanded to 20 seconds, what is the staffing requirement? [Answer: 3.125 employees.]

RELATED PROBLEM ▶ 9.11

A *work balance chart* (like the one in Example 2) is also valuable for evaluating the operation times in work cells. Some consideration must be given to determining the bottleneck operation. Bottleneck operations can constrain the flow through the cell. Imbalance in a work cell is seldom an issue if the operation is manual, as cell members by definition are part of a cross-trained team. Consequently, the inherent flexibility of work cells typically overcomes modest imbalance issues within a cell. However, if the imbalance is a machine constraint, then an adjustment in machinery, process, or operations may be necessary. In such situations the use of traditional assembly-line-balancing analysis, the topic of our next section, may be helpful.

The success of work cells is not limited to manufacturing. Kansas City's Hallmark, which has over half the U.S. greeting card market and produces some 40,000 different cards, has modified the offices into a cellular design. In the past, its 700 creative professionals would take up to 2 years to develop a new card. Hallmark's decision to create work cells consisting of artists, writers, lithographers, merchandisers, and accountants, all located in the same area, has resulted in card preparation in a fraction of the time that the old layout required. Work cells have also yielded higher performance and better service for the American Red Cross blood donation process.

The Focused Work Center and the Focused Factory

Focused work center

A permanent or semipermanent product-oriented arrangement of machines and personnel.

Focused factory

A facility designed to produce similar products or components.

When a firm has *identified a family of similar products that have a large and stable demand*, it may organize a focused work center. A **focused work center** (also called a "plant within a plant") moves production to a large work cell that remains part of the present facility. For example, bumpers and dashboards in Toyota's Texas plant are produced in a focused work center, and the Levi's departments in JCPenney are managed and run in a stand-alone boutique setting.

If the focused work center is in a separate facility, it is often called a **focused factory**. For example, separate plants that produce seat belts, fuel tanks, and exhaust systems for Toyota are focused factories. A fast-food restaurant is also a focused factory—most are easily reconfigured for adjustments to product mix and volume. Burger King changes the number of personnel and task assignments rather than moving machines and equipment. In this manner, Burger King balances the assembly line to meet changing production demands. In effect, the "layout" changes numerous times each day.

The term *focused factories* may also refer to facilities that are focused in ways other than by product line or layout. For instance, facilities may focus on their core competence, such as low cost, quality, new product introduction, or flexibility.

Focused facilities in both manufacturing and services appear to be better able to stay in tune with their customers, to produce quality products, and to operate at higher margins. This is true whether they are auto manufacturers like Toyota; restaurants like McDonald's and Burger King; or a hospital like Arnold Palmer.

Repetitive and Product-Oriented Layout

Product-oriented layouts are organized around products or families of similar high-volume, low-variety products. Repetitive production and continuous production, which are discussed in Chapter 7, use product layouts. The assumptions are that:

LO 9.7 *Define* product-oriented layout

1. Volume is adequate for high equipment utilization
2. Product demand is stable enough to justify high investment in specialized equipment
3. Product is standardized or approaching a phase of its life cycle that justifies investment in specialized equipment
4. Supplies of raw materials and components are adequate and of uniform quality (adequately standardized) to ensure that they will work with the specialized equipment

Fabrication line

A machine-paced, product-oriented facility for building components.

Assembly line

An approach that puts fabricated parts together at a series of workstations; used in repetitive processes.

Two types of a product-oriented layout are fabrication and assembly lines. The **fabrication line** builds components, such as automobile tires or metal parts for a refrigerator, on a series of machines, while an **assembly line** puts the fabricated parts together at a series of workstations. However, both are repetitive processes, and in both cases, the line must be "balanced"; that is, the time spent to perform work on one machine must equal or "balance" the time spent to perform work on the next machine in the fabrication line, just as the time spent at one workstation by one assembly-line employee must "balance" the time spent at the next workstation by the next employee. The same issues arise when designing the "disassembly lines" of slaughterhouses and automobile recyclers.

Assembly-line balancing

Obtaining output at each workstation on a production line so delay is minimized.

A well-balanced assembly line has the advantage of high personnel and facility utilization and equity among employees' workloads. Some union contracts require that workloads be nearly equal among those on the same assembly line. The term most often used to describe this process is **assembly-line balancing**. Indeed, the *objective of the product-oriented layout is to minimize imbalance in the fabrication or assembly line*.

The main advantages of product-oriented layout are:

1. The low variable cost per unit usually associated with high-volume, standardized products
2. Low material-handling costs
3. Reduced work-in-process inventories
4. Easier training and supervision
5. Rapid throughput

The disadvantages of product layout are:

1. The high volume required because of the large investment needed to establish the process
2. Work stoppage at any one point can tie up the whole operation
3. The process flexibility necessary for a variety of products and production rates can be a challenge

Because the problems of fabrication lines and assembly lines are similar, we focus our discussion on assembly lines. On an assembly line, the product typically moves via automated means, such as a conveyor, through a series of workstations until completed. This is the way fast-food hamburgers are made (see Figure 9.11), automobiles and some planes (see the photo of the Boeing 737 on the next page) are assembled, and television sets and ovens are produced. Product-oriented layouts use more automated and specially designed equipment than do process layouts.

VIDEO 9.2
Facility Layout at Wheeled Coach Ambulances

Assembly-Line Balancing

Line balancing is usually undertaken to minimize imbalance between machines or personnel while meeting a required output from the line. To produce at a specified rate, management must know the tools, equipment, and work methods used. Then the time requirements for each assembly task (e.g., drilling a hole, tightening a nut, or spray-painting a part) must be determined. Management also needs to know the *precedence relationship* among the activities—that is, the sequence in which various tasks must be performed. Example 3 shows how to turn these task data into a precedence diagram.

LO 9.8 *Explain* how to balance production flow in a repetitive or product-oriented facility

Elapsed time	0:00	0:11	0:31	0:45		1:30
Task time (seconds)		11	20	14	0	45
Task	1. Order	2. Bun toasting	3. Assembly with condiments	4. Wrapping of patty with bun	5. Order picked up immediately to keep it fresh	6. Customer service (order and payment)

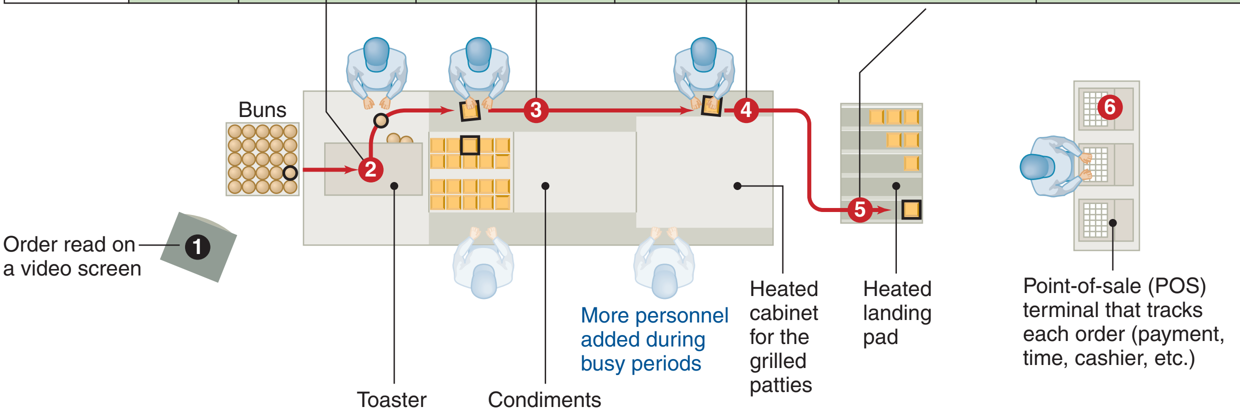


Figure **9.11**

McDonald's Hamburger Assembly Line

The Boeing 737, the world's most popular commercial airplane, is produced on a moving production line, traveling at 2 inches a minute through the final assembly process. The moving line, one of several lean manufacturing innovations at the Renton, Washington, facility, has enhanced quality, reduced flow time, slashed inventory levels, and cut space requirements. Final assembly is only 11 days—a time savings of 50%—and inventory is down more than 55%.

Example 3

DEVELOPING A PRECEDENCE DIAGRAM FOR AN ASSEMBLY LINE

Boeing wants to develop a precedence diagram for an electrostatic wing component that requires a total assembly time of 65 minutes.

APPROACH ▶ Staff gather tasks, assembly times, and sequence requirements for the component in Table 9.2.

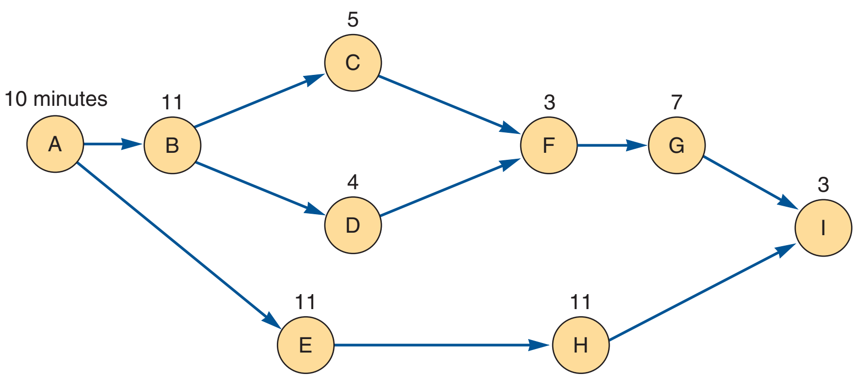
TABLE 9.2 Precedence Data for Wing Component

TASK	ASSEMBLY TIME (MINUTES)	TASK MUST FOLLOW TASK LISTED BELOW	
A	10	—	This means that tasks B and E cannot be done until task A has been completed.
B	11	A	
C	5	B	
D	4	B	
E	11	A	
F	3	C, D	
G	7	F	
H	11	E	
I	3	G, H	
	Total time 65		

SOLUTION ▶ Figure 9.12 shows the precedence diagram.

Figure **9.12**

Precedence Diagram



INSIGHT ▶ The diagram helps structure an assembly line and workstations, and it makes it easier to visualize the sequence of tasks.

LEARNING EXERCISE ▶ If task D had a second preceding task (C), how would Figure 9.12 change? [Answer: There would also be an arrow pointing from C to D.]

RELATED PROBLEMS ▶ 9.13a, 9.15a, 9.16a, 9.17a, 9.20a (9.25a,d, 9.26a, 9.27 are available in MyOMLab)

Once we have constructed a precedence chart summarizing the sequences and performance times, we turn to the job of grouping tasks into job stations so that we can meet the specified production rate. This process involves three steps:

1. Take the units required (demand or production rate) per day and divide them into the productive time available per day (in minutes or seconds). This operation gives us what is called the **cycle time**[3]—namely, the maximum time allowed at each workstation if the production rate is to be achieved:

$$\text{Cycle time} = \frac{\text{Production time available per day}}{\text{Units required per day}} \tag{9-4}$$

2. Calculate the theoretical minimum number of workstations. This is the total task-duration time (the time it takes to make the product) divided by the cycle time. Fractions are rounded to the next higher whole number:

$$\text{Minimum number of workstations} = \frac{\sum_{i=1}^{n} \text{Time for task } i}{\text{Cycle time}} \tag{9-5}$$

   where n is the number of assembly tasks.

3. Balance the line by assigning specific assembly tasks to each workstation. An efficient balance is one that will complete the required assembly, follow the specified sequence, and keep the idle time at each workstation to a minimum. A formal procedure for doing this is the following:
   a. Identify a master list of tasks.
   b. Eliminate those tasks that have been assigned.
   c. Eliminate those tasks whose precedence relationship has not been satisfied.
   d. Eliminate those tasks for which inadequate time is available at the workstation.
   e. Use one of the line-balancing "heuristics" described in Table 9.3. The five choices are (1) longest task time, (2) most following tasks, (3) ranked positional weight, (4) shortest task time, and (5) least number of following tasks. You may wish to test several of these **heuristics** to see which generates the "best" solution—that is, the smallest number of workstations and highest efficiency. Remember, however, that although heuristics provide solutions, they do not guarantee an optimal solution.

Cycle time
The maximum time that a product is allowed at each workstation.

Heuristic
Problem solving using procedures and rules rather than mathematical optimization.

TABLE 9.3 Layout Heuristics That May Be Used to Assign Tasks to Workstations in Assembly-Line Balancing

1. *Longest task (operation) time*	From the available tasks, choose the task with the largest (longest) time.
2. *Most following tasks*	From the available tasks, choose the task with the largest number of following tasks.
3. *Ranked positional weight*	From the available tasks, choose the task for which the sum of the times for each following task is longest. (In Example 4 we see that the ranked positional weight of task C = 5(C) + 3(F) + 7(G) + 3(I) = 18, whereas the ranked positional weight of task D = 4(D) + 3(F) + 7(G) + 3(I) = 17; therefore, C would be chosen first, using this heuristic.)
4. *Shortest task (operations) time*	From the available tasks, choose the task with the shortest task time.
5. *Least number of following tasks*	From the available tasks, choose the task with the least number of subsequent tasks.

Example 4 illustrates a simple line-balancing procedure.

Example 4

BALANCING THE ASSEMBLY LINE

On the basis of the precedence diagram and activity times given in Example 3, Boeing determines that there are 480 productive minutes of work available per day. Furthermore, the production schedule requires that 40 units of the wing component be completed as output from the assembly line each day. It now wants to group the tasks into workstations.

APPROACH ▶ Following the three steps above, we compute the cycle time using Equation (9-4) and minimum number of workstations using Equation (9-5), and we assign tasks to workstations—in this case using the *most following tasks* heuristic.

SOLUTION ▶

$$\text{Cycle time (in minutes)} = \frac{480 \text{ minutes}}{40 \text{ units}}$$

$$= 12 \text{ minutes/unit}$$

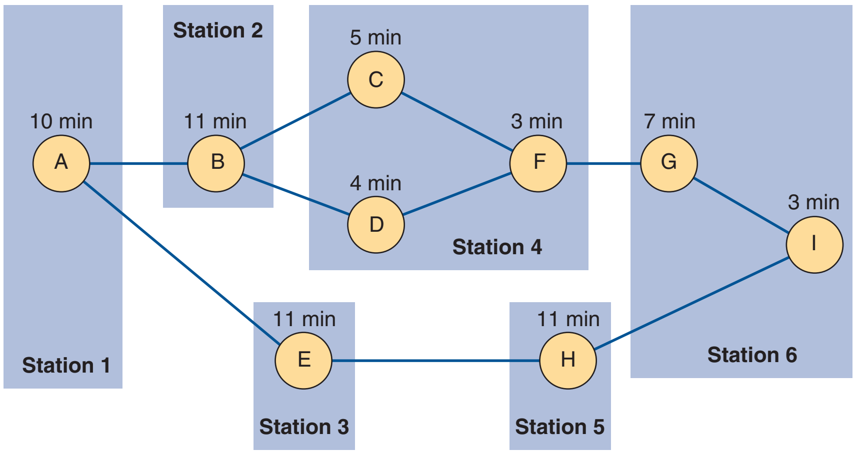
$$\text{Minimum number of workstations} = \frac{\text{Total task time}}{\text{Cycle time}} = \frac{65}{12}$$

$$= 5.42, \text{ or } 6 \text{ stations}$$

Figure 9.13 shows one solution that does not violate the sequence requirements and that groups tasks into six one-person stations. To obtain this solution, activities with the most following tasks were moved into workstations to use as much of the available cycle time of 12 minutes as possible. The first workstation consumes 10 minutes and has an idle time of 2 minutes.

Figure **9.13**

A Six-Station Solution to the Line-Balancing Problem



STUDENT TIP Tasks C, D, and F can be grouped together in one workstation, provided that the physical facilities and skill levels meet the work requirements.

INSIGHT ▶ This is a reasonably well-balanced assembly line. The second and third workstations use 11 minutes. The fourth workstation groups three small tasks and balances perfectly at 12 minutes. The fifth has 1 minute of idle time, and the sixth (consisting of tasks G and I) has 2 minutes of idle time per cycle. Total idle time for this solution is 7 minutes per cycle.

LEARNING EXERCISE ▶ If task I required 6 minutes (instead of 3 minutes), how would this change the solution? [Answer: The cycle time would not change, and the *theoretical* minimum number of workstations would still be 6 (rounded up from 5.67), but it would take 7 stations to balance the line.]

RELATED PROBLEMS ▶ 9.12–9.24 (9.25–9.27 are available in MyOMLab)

EXCEL OM Data File **Ch09Ex4.xls** can be found in MyOMLab.

There are two measures of effectiveness of a balance assignment. The first measure computes the *efficiency* of a line balance by dividing the total task times by the product of the number of workstations required times the assigned (actual) cycle time of the *longest* workstation:

$$\text{Efficiency} = \frac{\sum \text{Task times}}{(\textit{Actual}\text{ number of workstations}) \times (\text{Largest assigned cycle time})} \quad (9\text{-}6)$$

Operations managers compare different levels of efficiency for various numbers of workstations. In this way, a firm can determine the sensitivity of the line to changes in the production rate and workstation assignments.

The second measure computes the *idle time* for the line.

$$\text{Idle time} = (\text{Actual number of workstations} \times \text{Largest assigned cycle time}) - \sum \text{Task times} \quad (9\text{-}7)$$

Example 5

DETERMINING LINE EFFICIENCY

Boeing needs to calculate the efficiency for Example 4.

APPROACH ▶ Equation (9-6) is applied.

SOLUTION ▶

$$\text{Efficiency} = \frac{65 \text{ minutes}}{(6 \text{ stations}) \times (12 \text{ minutes})} = \frac{65}{72} = 90.3\%$$

Note that opening a seventh workstation, for whatever reason, would decrease the efficiency of the balance to 77.4% (assuming that at least one of the workstations still required 12 minutes):

$$\text{Efficiency} = \frac{65 \text{ minutes}}{(7 \text{ stations}) \times (12 \text{ minutes})} = 77.4\%$$

INSIGHT ▶ Increasing efficiency may require that some tasks be divided into smaller elements and reassigned to other tasks. This facilitates a better balance between workstations and means higher efficiency. Note that we can also compute efficiency as 1 − (% Idle time), that is, [1 − (Idle time)/(Total time in workstations)].

LEARNING EXERCISE ▶ What is the efficiency if an eighth workstation is opened? [Answer: Efficiency = 67.7%.]

RELATED PROBLEMS ▶ 9.13f, 9.14c, 9.15f, 9.17c, 9.18b, 9.19b, 9.20e,g (9.25e, 9.26c, 9.27 are available in MyOMLab)

Large-scale line-balancing problems, like large process-layout problems, are often solved by computers. Computer programs such as Assembly Line Pro, Proplanner, Timer Pro, Flexible Line Balancing, and Promodel are available to handle the assignment of workstations on assembly lines with numerous work activities. Such software evaluates the thousands, or even millions, of possible workstation combinations much more efficiently than could ever be done by hand.

Summary

Layouts make a substantial difference in operating efficiency. The seven layout situations discussed in this chapter are (1) office, (2) retail, (3) warehouse, (4) fixed position, (5) process oriented, (6) work cells, and (7) product oriented. A variety of techniques have been developed to solve these layout problems. Office layouts often seek to maximize information flows, retail firms focus on product exposure, and warehouses attempt to optimize the trade-off between storage space and material handling cost.

The fixed-position layout problem attempts to minimize material handling costs within the constraint of limited space at the site. Process layouts minimize travel distances times the number of trips. Product layouts focus on reducing waste and the imbalance in an assembly line. Work cells are the result of identifying a family of products that justify a special configuration of machinery and equipment that reduces material travel and adjusts imbalances with cross-trained personnel.

Often, the issues in a layout problem are so wide-ranging that finding an optimal solution is not possible. For this reason, layout decisions, although the subject of substantial research effort, remain something of an art.

Key Terms

Office layout (p. 409)
Retail layout (p. 410)
Slotting fees (p. 412)
Servicescape (p. 413)
Warehouse layout (p. 413)
Cross-docking (p. 414)
Random stocking (p. 415)
Customizing (p. 415)
Fixed-position layout (p. 415)
Process-oriented layout (p. 416)
Job lots (p. 417)
Work cell (p. 421)
Takt time (p. 422)
Focused work center (p. 424)
Focused factory (p. 424)
Fabrication line (p. 424)
Assembly line (p. 424)
Assembly-line balancing (p. 424)
Cycle time (p. 427)
Heuristic (p. 427)

Ethical Dilemma

Although buried by mass customization and a proliferation of new products of numerous sizes and variations, grocery chains continue to seek to maximize payoff from their layout. Their layout includes a marketable commodity—shelf space—and they charge for it. This charge is known as a *slotting fee*. Recent estimates are that food manufacturers now spend some 13% of sales on trade promotions, which is paid to grocers to get them to promote and discount the manufacturer's products. A portion of these fees is for slotting, but slotting fees drive up the manufacturer's cost. They also put the small company with a new product at a disadvantage because small companies with limited resources may be squeezed out of the marketplace. Slotting fees may also mean that customers may no longer be able to find the special local brand. How ethical are slotting fees?

Discussion Questions

1. What are the seven layout strategies presented in this chapter?
2. What are the three factors that complicate a fixed-position layout?
3. How is process layout applied to supermarkets layout? What are the advantages and disadvantages of this type of layout for customers?
4. How would an analyst obtain data and determine the number of trips in:
   (a) a hospital?
   (b) a machine shop?
   (c) an auto-repair shop?
5. What are the advantages and disadvantages of product layout?
6. What are the four assumptions (or preconditions) of establishing layout for high-volume, low-variety products?
7. What are the alternative forms of work cells discussed in this textbook?
8. What are the advantages and disadvantages of work cells?
9. What are the main requirements of work cells?
10. What are the two major trends influencing office layout?
11. What are the key factors which should be considered in designing the hospital layout?
12. What layout innovations have you noticed recently in retail establishments?
13. What are the variables that a manager can manipulate in a retail layout?
14. Study the distribution of different sections and services across several floors inmulti-storeydepartment stores. Explain the rationale behindthe location of different departments/sections in thesetypes of stores.
15. How does Automatic Identificatoin work in a warehousing system?
16. What information is necessary for random stocking to work?
17. Explain the concept of cross-docking.
18. What is a heuristic? Name several that can be used in assembly-line balancing.

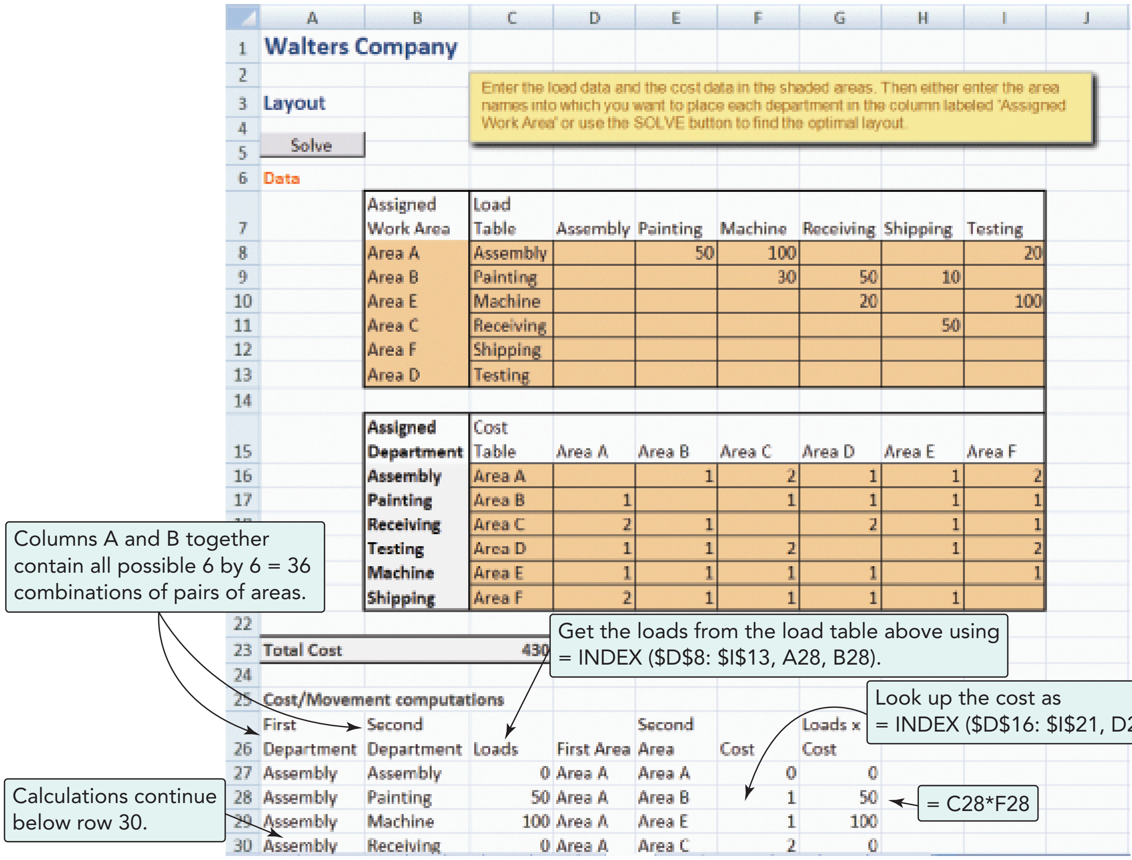
Using Software to Solve Layout Problems

In addition to the many commercial software packages available for addressing layout problems, Excel OM and POM for Windows, both of which accompany this text, contain modules for the process problem and the assembly-line-balancing problem.

USING EXCEL OM

Excel OM can assist in evaluating a series of department work assignments like the one we saw for the Walters Company in Example 1. The layout module can generate an optimal solution by enumeration or by computing the "total movement" cost for each layout you wish to examine. As such, it provides a speedy calculator for each flow–distance pairing.

Program 9.1 illustrates our inputs in the top two tables. We first enter department flows, then provide distances between work areas. Entering area assignments on a trial-and-error basis in the upper left of the top table generates movement computations at the bottom of the screen. Total movement is recalculated each time we try a new area assignment. It turns out that the assignment shown is optimal at 430 feet of movement.



Walters Company

Layout

Solve

Data

Enter the load data and the cost data in the shaded areas. Then either enter the area names into which you want to place each department in the column labeled 'Assigned Work Area' or use the SOLVE button to find the optimal layout.

Assigned Work Area	Load Table	Assembly	Painting	Machine	Receiving	Shipping	Testing
Area A	Assembly		50	100			20
Area B	Painting			30	50	10	
Area E	Machine				20		100
Area C	Receiving					50	
Area F	Shipping						
Area D	Testing						

Assigned Department	Cost Table	Area A	Area B	Area C	Area D	Area E	Area F
Assembly	Area A		1	2	1	1	2
Painting	Area B	1		1	1	1	1
Receiving	Area C	2	1		2	1	1
Testing	Area D	1	1	2		1	2
Machine	Area E	1	1	1	1		1
Shipping	Area F	2	1	1	1	1	

Total Cost 430

Cost/Movement computations

First Department	Second Department	Loads	First Area	Second Area	Cost	Loads x Cost
Assembly	Assembly	0	Area A	Area A	0	0
Assembly	Painting	50	Area A	Area B	1	50
Assembly	Machine	100	Area A	Area E	1	100
Assembly	Receiving	0	Area A	Area C	2	0

Program 9.1

Using Excel OM's Process Layout Module to Solve the Walters Company Problem in Example 1

USING POM FOR WINDOWS

The POM for Windows facility layout module can be used to place up to 10 departments in 10 rooms to minimize the total distance traveled as a function of the distances between the rooms and the flow between departments. The program exchanges departments until no exchange will reduce the total amount of movement, meaning an optimal solution has been reached.

The POM for Windows and Excel OM modules for line balancing can handle a line with up to 99 tasks, each with up to six immediate predecessors. In this program, cycle time can be entered as either (1) *given*, if known, or (2) the *demand* rate can be entered with time available as shown. All five "heuristic rules" are used: (1) longest operation (task) time, (2) most following tasks, (3) ranked positional weight, (4) shortest operation (task) time, and (5) least number of following tasks. No one rule can guarantee an optimal solution, but POM for Windows displays the number of stations needed for each rule.

Appendix IV discusses further details regarding POM for Windows.

Solved Problems

Virtual Office Hours help is available in MyOMLab.

SOLVED PROBLEM 9.1

Aero Maintenance is a small aircraft engine maintenance facility located in Wichita, Kansas. Its new administrator, Ann Daniel, decides to improve material flow in the facility, using the process layout method she studied at Wichita State University. The current layout of Aero Maintenance's eight departments is shown in Figure 9.14.

The only physical restriction perceived by Daniel is the need to keep the entrance in its current location. All other departments can be moved to a different work area (each 10 feet square) if layout analysis indicates a move would be beneficial.

First, Daniel analyzes records to determine the number of material movements among departments in an average month. These data are shown in Figure 9.15. Her objective, Daniel decides, is to lay out the departments so as to minimize the total movement (distance traveled) of material in the facility. She writes her objective as:

$$\text{Minimize material movement} = \sum_{i=1}^{8}\sum_{j=1}^{8} X_{ij}C_{ij}$$

where X_{ij} = number of material movements per month (loads or trips) moving from department i to department j

C_{ij} = distance in feet between departments i and j (which, in this case, is the equivalent of cost per load to move between departments)

Note that this is only a slight modification of the cost-objective equation shown earlier in the chapter.

Daniel assumes that adjacent departments, such as entrance (now in work area A) and receiving (now in work area B), have a walking distance of 10 feet. Diagonal departments are also considered adjacent and assigned a distance of 10 feet. Nonadjacent departments, such as the entrance and parts (now in area C) or the entrance and inspection (area G) are 20 feet apart, and nonadjacent rooms, such as entrance and metallurgy (area D), are 30 feet apart. (Hence, 10 feet is considered 10 units of cost, 20 feet is 20 units of cost, and 30 feet is 30 units of cost.)

Given the above information, redesign Aero Maintenance's layout to improve its material flow efficiency.

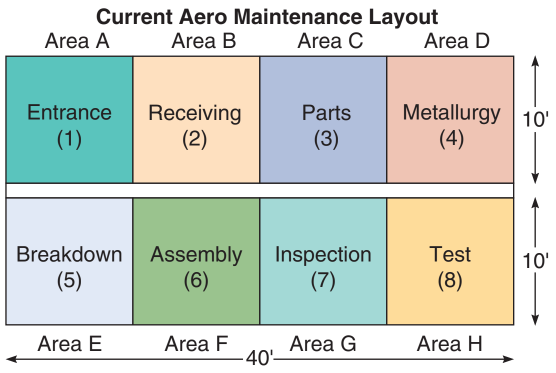


Figure 9.14

Aero Maintenance Layout

Figure 9.15

Number of Material Movements (Loads) Between Departments in 1 Month

Department	Entrance (1)	Receiving (2)	Parts (3)	Metallurgy (4)	Breakdown (5)	Assembly (6)	Inspection (7)	Test (8)
Entrance (1)		100	100	0	0	0	0	0
Receiving (2)			0	50	20	0	0	0
Parts (3)				30	30	0	0	0
Metallurgy (4)					20	0	0	20
Breakdown (5)						20	0	10
Assembly (6)							30	0
Inspection (7)								0
Test (8)								

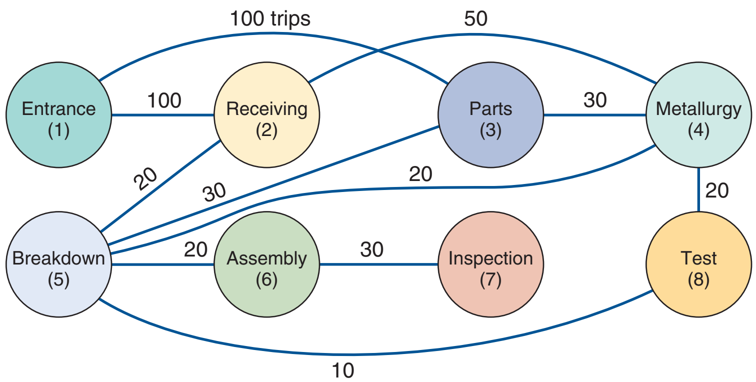
SOLUTION

First, establish Aero Maintenance's current layout, as shown in Figure 9.16. Then, by analyzing the current layout, compute material movement:

$$\begin{aligned}\text{Total movement} = {} & \underset{1\text{ to }2}{(100 \times 10')} + \underset{1\text{ to }3}{(100 \times 20')} + \underset{2\text{ to }4}{(50 \times 20')} + \underset{2\text{ to }5}{(20 \times 10')} \\ & + \underset{3\text{ to }4}{(30 \times 10')} + \underset{3\text{ to }5}{(30 \times 20')} + \underset{4\text{ to }5}{(20 \times 30')} + \underset{4\text{ to }8}{(20 \times 10')} \\ & + \underset{5\text{ to }6}{(20 \times 10')} + \underset{5\text{ to }8}{(10 \times 30')} + \underset{5\text{ to }7}{(30 \times 10')}\end{aligned}$$

$$= 1{,}000 + 2{,}000 + 1{,}000 + 200 + 300 + 600 + 600 + 200 + 200 + 300 + 300$$
$$= 6{,}700 \text{ feet}$$

Figure 9.16
Current Material Flow

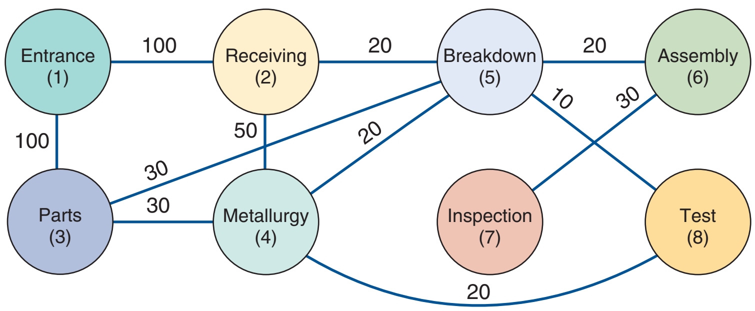


Propose a new layout that will reduce the current figure of 6,700 feet. Two useful changes, for example, are to switch departments 3 and 5 and to interchange departments 4 and 6. This change would result in the schematic shown in Figure 9.17:

$$\begin{aligned}
\text{Total movement} &= \underset{1\text{ to }2}{(100 \times 10')} + \underset{1\text{ to }3}{(100 \times 10')} + \underset{2\text{ to }4}{(50 \times 10')} + \underset{2\text{ to }5}{(20 \times 10')} \\
&\quad + \underset{3\text{ to }4}{(30 \times 10')} + \underset{3\text{ to }5}{(30 \times 20')} + \underset{4\text{ to }5}{(20 \times 10')} + \underset{4\text{ to }8}{(20 \times 20')} \\
&\quad + \underset{5\text{ to }6}{(20 \times 10')} + \underset{5\text{ to }8}{(10 \times 10')} + \underset{6\text{ to }7}{(30 \times 10')} \\
&= 1{,}000 + 1{,}000 + 500 + 200 + 300 + 600 + 200 \\
&\quad + 400 + 200 + 100 + 300 \\
&= 4{,}800 \text{ feet}
\end{aligned}$$

Do you see any room for further improvement?

Figure 9.17
Improved Layout



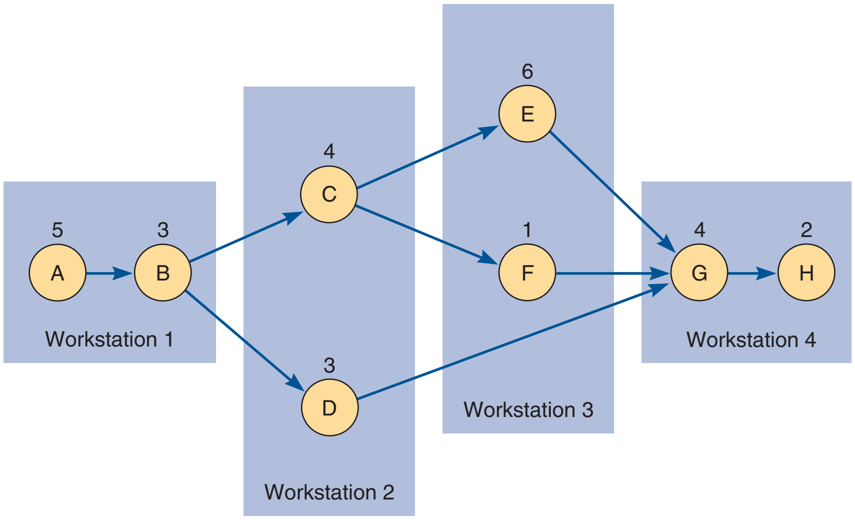
SOLVED PROBLEM 9.2

The assembly line whose activities are shown in Figure 9.18 has an 8-minute cycle time. Draw the precedence graph, and find the minimum possible number of one-person workstations. Then arrange the work activities into workstations so as to balance the line. What is the efficiency of your line balance?

TASK	PERFORMANCE TIME (MINUTES)	TASK MUST FOLLOW THIS TASK
A	5	—
B	3	A
C	4	B
D	3	B
E	6	C
F	1	C
G	4	D, E, F
H	2	G
	28	

Figure 9.18

Four-Station Solution to the Line-Balancing Problem



SOLUTION

The theoretical minimum number of workstations is:

$$\frac{\Sigma t_i}{\text{Cycle time}} = \frac{28 \text{ minutes}}{8 \text{ minutes}} = 3.5, \text{ or 4 stations}$$

The precedence graph and one good layout are shown in Figure 9.18:

$$\text{Efficiency} = \frac{\text{Total task time}}{(\text{Actual number of workstations}) \times (\text{Largest assigned cycle time})} = \frac{28}{(4)(8)} = 87.5\%$$

Problems

Note: **Px** means the problem may be solved with POM for Windows and/or Excel OM.

Problems 9.1–9.10 relate to Process-Oriented Layout

•• **9.1** Gordon Miller's job shop has four work areas, A, B, C, and D. Distances in feet between centers of the work areas are:

	A	B	C	D
A	—	4	9	7
B	—	—	6	8
C	—	—	—	10
D	—	—	—	—

Workpieces moved, in hundreds of workpieces per week, between pairs of work areas, are:

	A	B	C	D
A	—	8	7	4
B	—	—	3	2
C	—	—	—	6
D	—	—	—	—

It costs Gordon $1 to move 1 work piece 1 foot. What is the weekly total material handling cost of the layout? **Px**

•• **9.2** A Missouri job shop has four departments—machining (M), dipping in a chemical bath (D), finishing (F), and plating (P)—assigned to four work areas. The operations manager, Mary Marrs, has gathered the following data for this job shop as it is currently laid out (Plan A).

100s of Workpieces Moved Between Work Areas Each Year Plan A

	M	D	F	P
M	—	6	18	2
D	—	—	4	2
F	—	—	—	18
P	—	—	—	—

Distances Between Work Areas (Departments) in Feet

	M	D	F	P
M	—	20	12	8
D	—	—	6	10
F	—	—	—	4
P	—	—	—	—

It costs $0.50 to move 1 workpiece 1 foot in the job shop. Marrs's goal is to find a layout that has the lowest material handling cost.

a) Determine cost of the current layout, Plan A, from the data above.
b) One alternative is to switch those departments with the high loads, namely, finishing (F) and plating (P), which alters the

distance between them and machining (M) and dipping (D), as follows:

Distances Between Work Areas (Departments) in Feet Plan B

	M	D	F	P
M	—	20	8	12
D	—	—	10	6
F	—	—	—	4
P	—	—	—	—

What is the cost of *this* layout?

c) Marrs now wants you to evaluate Plan C, which also switches milling (M) and drilling (D), below.

Distance Between Work Areas (Departments) in Feet Plan C

	M	D	F	P
M	—	20	10	6
D	—	—	8	12
F	—	—	—	4
P	—	—	—	—

What is the cost of *this* layout?

d) Which layout is best from a cost perspective?

• **9.3** Three departments—milling (M), drilling (D), and sawing (S)—are assigned to three work areas in Victor Berardis's machine shop in Vent, Ohio. The number of workpieces moved per day and the distances between the centers of the work areas, in feet, follow.

Pieces Moved Between Work Areas Each Day

	M	D	S
M	—	23	32
D	—	—	20
S	—	—	—

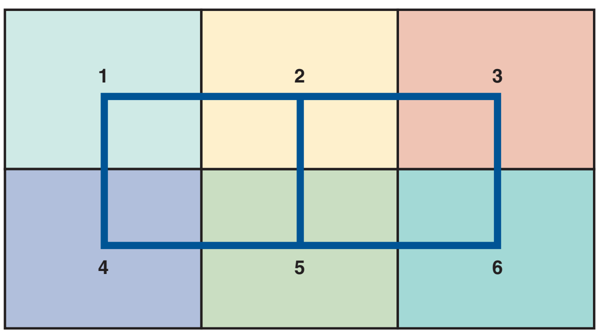
Distances Between Centers of Work Areas (Departments) in Feet

	M	D	S
M	—	10	5
D	—	—	8
S	—	—	—

It costs $2 to move 1 workpiece 1 foot.
What is the cost?

•• **9.4** Roy Creasey Enterprises, a machine shop, is planning to move to a new, larger location. The new building will be 60 feet long by 40 feet wide. Creasey envisions the building as having six distinct production areas, roughly equal in size. He feels strongly about safety and intends to have marked pathways throughout the building to facilitate the movement of people and materials. See the following building schematic.

Building Schematic (with work areas 1–6)



His foreman has completed a month-long study of the number of loads of material that have moved from one process to another in the current building. This information is contained in the following flow matrix.

Flow Matrix Between Production Processes

FROM \ TO	MATERIALS	WELDING	DRILLS	LATHES	GRINDERS	BENDERS
Materials	0	100	50	0	0	50
Welding	25	0	0	50	0	0
Drills	25	0	0	0	50	0
Lathes	0	25	0	0	20	0
Grinders	50	0	100	0	0	0
Benders	10	0	20	0	0	0

Finally, Creasey has developed the following matrix to indicate distances between the work areas shown in the building schematic.

Distance Between Work Areas

	1	2	3	4	5	6
1		20	40	20	40	60
2			20	40	20	40
3				60	40	20
4					20	40
5						20
6						

What is the appropriate layout of the new building?

•• **9.5** Adam Munson Manufacturing, in Gainesville, Florida, wants to arrange its four work centers so as to minimize interdepartmental parts handling costs. The flows and existing facility layout are shown in Figure 9.19. For example, to move a part from Work Center A to Work Center C is a 60-foot movement distance. It is 90 feet from A to D.

Parts Moved Between Work Centers

	A	B	C	D
A	—	450	550	50
B	350	—	200	0
C	0	0	—	750
D	0	0	0	—

Existing Layout

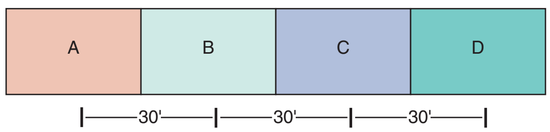


Figure **9.19**

Munson Manufacturing

a) What is the "load × distance," or "movement cost," of the layout shown?

b) Provide an improved layout and compute its movement cost.

• • • **9.6** You have just been hired as the director of operations for Reid Chocolates, a purveyor of exceptionally fine candies. Reid Chocolates has two kitchen layouts under consideration for its recipe making and testing department. The strategy is to provide the best kitchen layout possible so that food scientists can devote their time and energy to product improvement, not wasted effort in the kitchen. You have been asked to evaluate these two kitchen layouts and to prepare a recommendation for your boss, Mr. Reid, so that he can proceed to place the contract for building the kitchens. [See Figure 9.20(a), and Figure 9.20(b).] PX

Number of trips between work centers:

From: \ To:		Refrigerator 1	Counter 2	Sink 3	Storage 4	Stove 5
Refrig.	1	0	8	13	0	0
Counter	2	5	0	3	3	8
Sink	3	3	12	0	4	0
Storage	4	3	0	0	0	5
Stove	5	0	8	4	10	0

Figure 9.20(a)

Layout Options

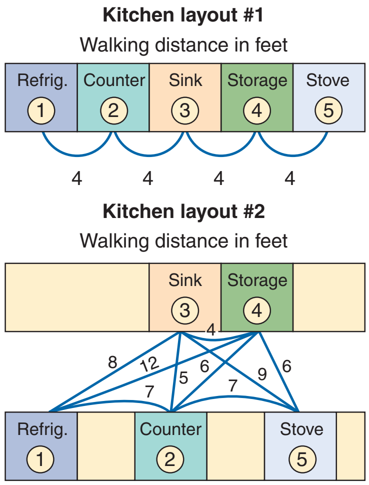
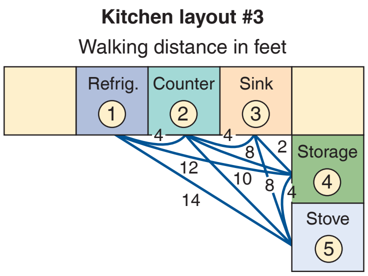
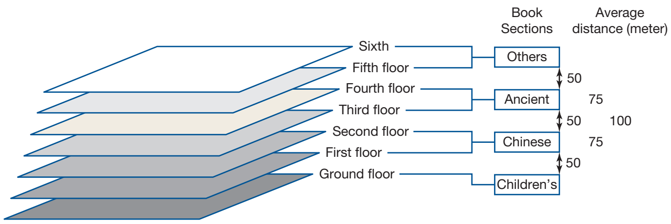


Figure 9.20(b)

• • • **9.7** Reid Chocolates (see Problem 9.6) is considering a third layout, as shown below. Evaluate its effectiveness in trip-distance feet. PX



• • • **9.8** The National Library of China[1] consists of four major sections, each distributed in different floors, in a seven storey building). A study shows that the average total distance moved by the visitors per day among different sections of the library is around 1500km. A new layout is being proposed as follows to reduce the moves.



Since some sections are in two different floors, there are intra-section distances to be considered too. The number of moves and distances are shown in the following tables.

Average Distances (meter)

	CHILDREN'S	CHINESE	ANCIENT	OTHERS
Children's	10	50	75	100
Chinese	50	20	50	75
Ancient	75	50	20	50
Others	100	75	50	20

Average number of moves/day

	CHILDREN'S	CHINESE	ANCIENT	OTHERS
Children's	2000	500	300	200
Chinese	700	4000	1500	1800
Ancient	500	1500	1500	1500
Others	300	2000	1200	2000

Could this new layout reduce the average total distance moved by the visitors per day?

• • **9.9** Six processes are to be laid out in six areas along a long corridor at Rita Gibson Accounting Services in Daytona Beach. The distance between adjacent work centers is 40 feet. The number of trips between work centers is given in the following table:

	TRIPS BETWEEN PROCESSES					
	TO					
FROM	A	B	C	D	E	F
A		18	25	73	12	54
B			96	23	31	45
C				41	22	20
D					19	57
E						48
F						

a) Assign the processes to the work areas in a way that minimizes the total flow, using a method that places processes with highest flow adjacent to each other.
b) What assignment minimizes the total traffic flow? PX

[1]www.nlc.cn/newen/newVisitUs/nlclg/irge/shaa/

Additional problem **9.10** *is available in* MyOMLab.

Problem 9.11 relates to Work Cells

•• **9.11** A Thai restaurant has experienced a significant increase in take away demand for its signature chicken curry. Due to the high demand, the head chef and the operations manager of the restaurant decided to dedicate a separate area in the kitchen, as a working cell, to fully focus on making take away chicken curry.

Daily demand is 240, and the restaurant serves take away food from 11 AM to 11 PM. The process of make chicken curry has five main steps:

(1) Preparation of the curry: 2 minutes
(2) Stir-frying the chicken: 3 minutes

(3) Preparation of the beans and rice: 1.5 minutes
(4) Serve the curry and rice in the take away container/box: 1 minute

Based on the above information,

a) Calculate the takt time.
b) Recommend the right number of employees for this working cell.
c) Which operations need special consideration?

Problems 9.12–9.27 relate to Repetitive and Product-Oriented Layout

• • **9.12** Stanford Rosenberg Computing wants to establish an assembly line for producing a new product, the Personal Digital Assistant (PDA). The tasks, task times, and immediate predecessors for the tasks are as follows:

TASK	TIME (sec)	IMMEDIATE PREDECESSORS
A	12	—
B	15	A
C	8	A
D	5	B, C
E	20	D

Rosenberg's goal is to produce 180 PDAs per hour.
a) What is the cycle time?
b) What is the theoretical minimum for the number of workstations that Rosenberg can achieve in this assembly line?
c) Can the theoretical minimum actually be reached when workstations are assigned? PX

• • • **9.13** Illinois Furniture, Inc., produces all types of office furniture. The "Executive Secretary" is a chair that has been designed using ergonomics to provide comfort during long work hours. The chair sells for \$130. There are 480 minutes available during the day, and the average daily demand has been 50 chairs. There are eight tasks:

TASK	PERFORMANCE TIME (min)	TASK MUST FOLLOW TASK LISTED BELOW
A	4	—
B	7	—
C	6	A, B
D	5	C
E	6	D
F	7	E
G	8	E
H	6	F, G

a) Draw a precedence diagram of this operation.
b) What is the cycle time for this operation?
c) What is the *theoretical* minimum number of workstations?
d) Assign tasks to workstations.
e) What is the idle time per cycle?
f) How much total idle time is present in an 8-hour shift?
g) What is the efficiency of the assembly line, given your answer in (d)? PX

• • **9.14** Sue Helms Appliances wants to establish an assembly line to manufacture its new product, the Micro Popcorn Popper. The goal is to produce five poppers per hour. The tasks, task times, and immediate predecessors for producing one Micro Popcorn Popper are as follows:

TASK	TIME (min)	IMMEDIATE PREDECESSORS
A	10	—
B	12	A
C	8	A, B
D	6	B, C
E	6	C
F	6	D, E

a) What is the *theoretical* minimum for the smallest number of workstations that Helms can achieve in this assembly line?
b) Graph the assembly line, and assign workers to workstations. Can you assign them with the theoretical minimum?
c) What is the efficiency of *your* assignment? PX

• • **9.15** The Action Toy Company has decided to manufacture a new train set, the production of which is broken into six steps. The demand for the train is 4,800 units per 40-hour workweek:

TASK	PERFORMANCE TIME (sec)	PREDECESSORS
A	20	None
B	30	A
C	15	A
D	15	A
E	10	B, C
F	30	D, E

a) Draw a precedence diagram of this operation.
b) Given the demand, what is the cycle time for this operation?
c) What is the *theoretical* minimum number of workstations?
d) Assign tasks to workstations.
e) How much total idle time is present each cycle?
f) What is the efficiency of the assembly line with five stations? With six stations? PX

•• **9.16** The following table details the tasks required for Indiana-based Frank Pianki Industries to manufacture a fully portable industrial vacuum cleaner. The times in the table are in minutes. Demand forecasts indicate a need to operate with a cycle time of 10 minutes.

ACTIVITY	ACTIVITY DESCRIPTION	IMMEDIATE PREDECESSORS	TIME
A	Attach wheels to tub	—	5
B	Attach motor to lid	—	1.5
C	Attach battery pack	B	3
D	Attach safety cutoff	C	4
E	Attach filters	B	3
F	Attach lid to tub	A, E	2
G	Assemble attachments	—	3
H	Function test	D, F, G	3.5
I	Final inspection	H	2
J	Packing	I	2

a) Draw the appropriate precedence diagram for this production line.
b) Assign tasks to workstations and determine how much idle time is present each cycle.
c) Discuss how this balance could be improved to 100%.
d) What is the *theoretical* minimum number of workstations? PX

•• **9.17** Tailwind, Inc., produces high-quality but expensive training shoes for runners. The Tailwind shoe, which sells for \$210, contains both gas- and liquid-filled compartments to provide more stability and better protection against knee, foot, and back injuries. Manufacturing the shoes requires 10 separate tasks. There are 400 minutes available for manufacturing the shoes in the plant each day. Daily demand is 60. The information for the tasks is as follows:

TASK	PERFORMANCE TIME (min)	TASK MUST FOLLOW TASK LISTED BELOW
A	1	—
B	3	A
C	2	B
D	4	B
E	1	C, D
F	3	A
G	2	F
H	5	G
I	1	E, H
J	3	I

a) Draw the precedence diagram.
b) Assign tasks to the minimum feasible number of workstations according to the “ranked positioned weight” decision rule.
c) What is the efficiency of the process you completed in (b)?
d) What is the idle time per cycle? PX

•• **9.18** The Mach 10 is a one-person sailboat manufactured by Creative Leisure. The final assembly plant is in Cupertino, California. The assembly area is available for production of the Mach 10 for 200 minutes per day. (The rest of the time it is busy making other products.) The daily demand is 60 boats. Given the information in the table,

a) Draw the precedence diagram and assign tasks using five workstations.
b) What is the efficiency of the assembly line, using your answer to (a)?
c) What is the *theoretical* minimum number of workstations?
d) What is the idle time per boat produced? PX

TASK	PERFORMANCE TIME (min)	TASK MUST FOLLOW TASK LISTED BELOW
A	1	—
B	1	A
C	2	A
D	1	C
E	3	C
F	1	C
G	1	D, E, F
H	2	B
I	1	G, H

Ivan Smuk/Shutterstock

•• **9.19** Because of the expected high demand for Mach 10, Creative Leisure has decided to increase manufacturing time available to produce the Mach 10 (see Problem 9.18).
a) If demand remained the same but 300 minutes were available each day on the assembly line, how many workstations would be needed?
b) What would be the efficiency of the new system, using the actual number of workstations from (a)?
c) What would be the impact on the system if 400 minutes were available? PX

••• **9.20** Dr. Lori Baker, operations manager at Nesa Electronics, prides herself on excellent assembly-line balancing. She has been told that the firm needs to complete 96 instruments per 24-hour day. The assembly-line activities are:

TASK	TIME (min)	PREDECESSORS
A	3	—
B	6	—
C	7	A
D	5	A, B
E	2	B
F	4	C
G	5	F
H	7	D, E
I	1	H
J	6	E
K	4	G, I, J
	50	

a) Draw the precedence diagram.
b) If the daily (24-hour) production rate is 96 units, what is the highest allowable cycle time?
c) If the cycle time after allowances is given as 10 minutes, what is the daily (24-hour) production rate?
d) With a 10-minute cycle time, what is the theoretical minimum number of stations with which the line can be balanced?
e) With a 10-minute cycle time and six workstations, what is the efficiency?
f) What is the total idle time per cycle with a 10-minute cycle time and six workstations?
g) What is the best workstation assignment you can make without exceeding a 10-minute cycle time, and what is its efficiency? PX

• • **9.21** Suppose production requirements in Solved Problem 9.2 (see page 396) increase and require a reduction in cycle time from 8 minutes to 7 minutes. Balance the line once again, using the new cycle time. Note that it is not possible to combine task times so as to group tasks into the minimum number of workstations. This condition occurs in actual balancing problems fairly often. PX

• • **9.22** New students who join the university, should visit certain departments in their first day, as part of the registration and induction process. Students are usually allocated to groups of ten, and their visits and their timings are as follows:

DEPARTMENT	DURATION FOR EACH GROUP (MINUTE)
Registration/Finance	60
IT	45
Library	90
Social Club	30
Sport Centre	30
Student Support Service	45
Medical Centre	45
Campus Services (banks, restaurant, etc.)	30

During the visit, at least one person from the university student support team should be with each team of students. The student support team has allocated the visit of every two departments to one person as follows: Deborah (Registration and IT), Gemma (Library and Social Club), Frank (Sport Centre and Student support service), and Raj (Medical centre and Campus services). The visits of the departments can be done in any sequence. Based on the current arrangements,
a) What is the cycle time
b) What is the throughput per hour
c) Total idle time in each cycle
d) Recommend a new task allocation with a shorter cycle time. Explain how it can improve the idle times and capacity of the visits.

• • • **9.23** Samuel Smith's company wants to establish an assembly line to manufacture its new product, the iStar phone. Samuel's goal is to produce 60 iStars per hour. Tasks, task times, and immediate predecessors are as follows:

TASK	TIME (sec)	IMMEDIATE PREDECESSORS	TASK	TIME (sec)	IMMEDIATE PREDECESSORS
A	40	—	F	25	C
B	30	A	G	15	C
C	50	A	H	20	D, E
D	40	B	I	18	F, G
E	6	B	J	30	H, I

a) What is the theoretical minimum for the number of workstations that Samuel can achieve in this assembly line?
b) Use the *most following tasks* heuristic to balance an assembly line for the iStar phone.
c) How many workstations are in your answer to (b)?
d) What is the efficiency of your answer to (b)? PX

• • • • **9.24** As the Cottrell Bicycle Co. of St. Louis completes plans for its new assembly line, it identifies 25 different tasks in the production process. VP of Operations Jonathan Cottrell now faces the job of balancing the line. He lists precedences and provides time estimates for each step based on work-sampling techniques. His goal is to produce 1,000 bicycles per standard 40-hour workweek.

TASK	TIME (sec)	PRECEDENCE TASKS	TASK	TIME (sec)	PRECEDENCE TASKS
K3	60	—	E3	109	F3
K4	24	K3	D6	53	F4
K9	27	K3	D7	72	F9, E2, E3
J1	66	K3	D8	78	E3, D6
J2	22	K3	D9	37	D6
J3	3	—	C1	78	F7
G4	79	K4, K9	B3	72	D7, D8, D9, C1
G5	29	K9, J1	B5	108	C1
F3	32	J2	B7	18	B3
F4	92	J2	A1	52	B5
F7	21	J3	A2	72	B5
F9	126	G4	A3	114	B7, A1, A2
E2	18	G5, F3			

a) Balance this operation, using various heuristics. Which is best and why?
b) What happens if the firm can change to a 41-hour workweek? PX

Additional problems **9.25–9.27** *are available in* MyOMLab.

CASE STUDIES

Reebok Royal CL production line in Vietnam[2]

Adidas shoe production facilities in Vietnam make a variety of sport, classic, football, tennis, and running shoes. The production line consists of five main stations to produce the shoes: Cutting, Pre-fit, Stitching, Stock-fitting and Assembly. The production system is manual-operations oriented. Therefore, utilization manpower plays a crucial role to manage the efficiency and productivity of the production system.

The production planning system uses the PPH (Pair/ Person/ Hour) indicator as the main KPI (key performance indicator) to evaluate its production lines' performances. Pair (i.e. pair of shoes) is the unit of the business output, and man-hour is considered as an input that is equal to one hour of work an employee performs in making pairs.

Reebok Royal CL model, as an example, has an output target of 960 units per day (there are 8 working hours per day), the Takt time for each station of the production is 30 seconds. The number of workers in each production station is provided in the table below:

WORK STATION	NUMBER OF WORKERS	WORK STATION TAKT TIME *(MIN)*	TARGET OUTPUT PER HOUR	TARGET OUTPUT PER DAY
Cutting	5	0.5	120	960
Pre-fit	6	0.5	120	960
Stitching	43	0.5	120	960
Stock-fitting	20	0.5	120	960
Assembly	34	0.5	120	960

[2] Adapted from: Thanh, N. T. (2014). *Improvement of efficiency for production line by applying line balancing and simulation: A case study in Adidas Company* (Doctoral dissertation, International University HCMC, Vietnam).

A time study and productivity review project can identify whether the output targets for this production line are achievable or not. Table below shows an example of operation time and average productivity of each work station.

WORK STATION	OPERATION TIME *(MIN)*
Cutting	3
Pre-fit	3.2
Stitching	24
Stock-fitting	12
Assembly	16

Based on the available information:

1. What is the throughput of each work station?
2. Can this production line meet the output target?
3. Given that all workers are trained and skilful to handle the activities in different work stations, what is the maximum throughout which can be expected from this production line.
4. How many extra workers are needed to meet the target output?

Laying Out Arnold Palmer Hospital's New Facility

Video Case

When Orlando's Arnold Palmer Hospital began plans to create a new 273-bed, 11-story hospital across the street from its existing facility, which was bursting at the seams in terms of capacity, a massive planning process began. The $100 million building, opened in 2006, was long overdue, according to Executive Director Kathy Swanson: "We started Arnold Palmer Hospital in 1989, with a mission to provide quality services for children and women in a comforting, family-friendly environment. Since then we have served well over 1.5 million women and children and now deliver more than 12,000 babies a year. By 2001, we simply ran out of room, and it was time for us to grow."

The new hospital's unique, circular pod design provides a maximally efficient layout in all areas of the hospital, creating a patient-centered environment. *Servicescape* design features include a serene environment created through the use of warm colors, private rooms with pull-down Murphy beds for family members, 14-foot ceilings, and natural lighting with oversized windows in patient rooms. But these radical new features did not come easily. "This pod concept with a central nursing area and pie-shaped rooms resulted from over 1,000 planning meetings of 35 user groups, extensive motion and time studies, and computer simulations of the daily movements of nurses," says Swanson.

In a traditional linear hospital layout, called the *racetrack* design, patient rooms line long hallways, and a nurse might walk 2.7 miles per day serving patient needs at Arnold Palmer. "Some nurses spent 30% of their time simply walking. With the nursing shortage and the high cost of health care professionals, efficiency is a major concern," added Swanson. With the nursing station in the center of 10- or 12-bed circular pods, no patient room is more than 14 feet from a station. The time savings are in the 20% range. Swanson pointed to Figures 9.21 and 9.22 as examples of the old and new walking and trip distances.*

"We have also totally redesigned our neonatal rooms," says Swanson. "In the old system, there were 16 neonatal beds in a large and often noisy rectangular room. The new building features semiprivate rooms for these tiny babies. The rooms are much improved, with added privacy and a quiet, simulated night atmosphere, in addition to pull-down beds for parents to use. Our research shows that babies improve and develop much more quickly with this layout design. Layout and environment indeed impact patient care!"

*Layout and walking distances, including some of the numbers in Figures 9.21 and 9.22, have been simplified for purposes of this case.

Figure 9.21

Traditional Hospital Layout

Patient rooms are on two linear hallways with exterior windows. Supply rooms are on interior corridors. This layout is called a "racetrack" design.

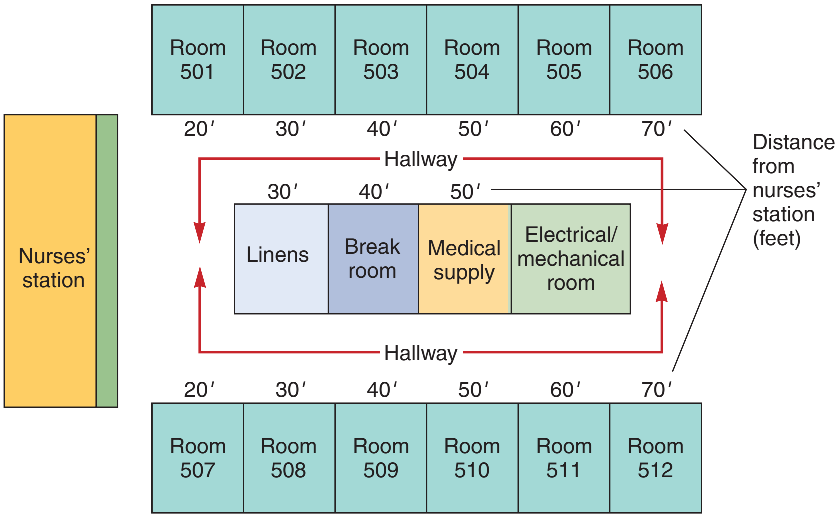
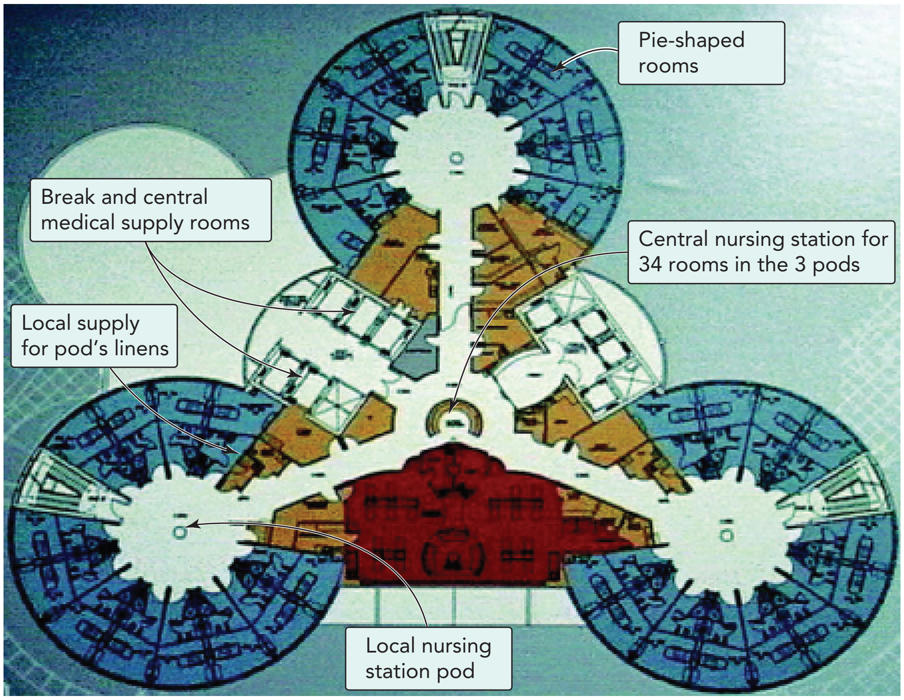


Figure 9.22

New Pod Design for Hospital Layout

Note that each room is 14 feet from the pod's *local* nursing station. The *break rooms* and the *central medical station* are each about 60 feet from the local nursing pod. Pod *linen supply* rooms are also 14 feet from the local nursing station.



Courtesy Arnold Palmer Medical Center

Discussion Questions*

1. Identify the many variables that a hospital needs to consider in layout design.
2. What are the advantages of the circular pod design over the traditional linear hallway layout found in most hospitals?
3. Figure 9.21 illustrates a sample linear hallway layout. During a period of random observation, nurse Thomas Smith's day includes 6 trips from the nursing station to each of the 12 patient rooms (back and forth), 20 trips to the medical supply room, 5 trips to the break room, and 12 trips to the linen supply room. What is his total distance traveled in miles?
4. Figure 9.22 illustrates an architect's drawing of Arnold Palmer Hospital's new circular pod system. If nurse Susan Jones's day includes 7 trips from the nursing pod to each of the 12 rooms (back and forth), 20 trips to central medical supply, 6 trips to the break room, and 12 trips to the pod linen supply, how many miles does she walk during her shift? What are the differences in the travel times between the two nurses for this random day?
5. The concept of *servicescapes* is discussed in this chapter. Describe why this is so important at Arnold Palmer Hospital, and give examples of its use in layout design.

6. As technology and costs change, hospitals continue to innovate. The reduced cost of computers means some hospitals have moved from a central computer at the nurse's station to computers in the room or on carts (see photo). What changes in overall hospital layout would these innovations suggest?

*You may wish to view the video that accompanies this case before addressing these questions.

Rubbermaid Healthcare.

Facility Layout at Wheeled Coach

Video Case

When President Bob Collins began his career at Wheeled Coach, the world's largest manufacturer of ambulances, there were only a handful of employees. Now the firm's Florida plant has a workforce of 350. The physical plant has also expanded, with offices, R&D, final assembly, and wiring, cabinetry, and upholstery work cells in one large building. Growth has forced the painting work cell into a separate building, aluminum fabrication and body installation into another, inspection and shipping into a fourth, and warehousing into yet another.

Like many other growing companies, Wheeled Coach was not able to design its facility from scratch. And although management realizes that material handling costs are a little higher than an ideal layout would provide, Collins is pleased with the way the facility has evolved and employees have adapted. The aluminum cutting work cell lies adjacent to body fabrication, which, in turn, is located next to the body-installation work cell. And while the vehicle must be driven across a street to one building for painting and then to another for final assembly, at least the ambulance is on wheels. Collins is also satisfied with the flexibility shown in the design of the work cells. Cell construction is flexible and can accommodate changes in product mix and volume. In addition, work cells are typically small and movable, with many work benches and staging racks borne on wheels so that they can be easily rearranged and products transported to the assembly line.

Assembly-line balancing is one key problem facing Wheeled Coach and every other repetitive manufacturer. Produced on a schedule calling for four 10-hour work days per week, once an ambulance is on one of the six final assembly lines, it *must* move forward each day to the next workstation. Balancing just enough workers and tasks at each of the seven workstations is a never-ending challenge. Too many workers end up running into each other; too few can't finish an ambulance in seven days. Constant shifting of design and mix and improved analysis has led to frequent changes.

Discussion Questions*

1. What analytical techniques are available to help a company like Wheeled Coach deal with layout problems?
2. What suggestions would you make to Bob Collins about his layout?
3. How would you measure the "efficiency" of this layout?

*You may wish to view the video that accompanies this case before addressing these questions.

- **Additional Case Study:** Visit MyOMLab for this free case study:
  Microfix, Inc.: This company needs to balance its PC manufacturing assembly line and deal with sensitivity analysis of time estimates.

Endnotes

1. Fayurd, A. L., and J. Weeks. "Who Moved My Cube?" *Harvard Business Review* (July–August, 2011): 102.
2. *Takt* is German for "time," "measure," or "beat" and is used in this context as the rate at which completed units must be produced to satisfy customer demand.
3. *Cycle time* is the maximum time allowed to accomplish a task or process step. Several process steps may be necessary to complete the product. *Takt time*, discussed earlier, is determined by the customer and is the speed at which completed units must be produced to satisfy customer demand.

Chapter 9 *Rapid* Review

Main Heading	Review Material	MyOMLab
THE STRATEGIC IMPORTANCE OF LAYOUT DECISIONS (p. 370)	Layout has numerous strategic implications because it establishes an organization's competitive priorities in regard to capacity, processes, flexibility, and cost, as well as quality of work life, customer contact, and image. *The objective of layout strategy is to develop an effective and efficient layout that will meet the firm's competitive requirements.*	Concept Questions: 1.1–1.4
TYPES OF LAYOUT (pp. 370–371)	Types of layout and examples of their typical objectives include: 1. *Office layout*: Locate workers requiring frequent contact close to one another. 2. *Retail layout*: Expose customers to high-margin items. 3. *Warehouse layout*: Balance low-cost storage with low-cost material handling. 4. *Fixed-position layout*: Move material to the limited storage areas around the site. 5. *Process-oriented layout*: Manage varied material flow for each product. 6. *Work-cell layout*: Identify a product family, build teams, and cross-train team members. 7. *Product-oriented layout*: Equalize the task time at each workstation.	Concept Questions: 2.1–2.4
OFFICE LAYOUT (pp. 371–372)	■ **Office layout**—The grouping of workers, their equipment, and spaces/offices to provide for comfort, safety, and movement of information. A *relationship chart* displays a "closeness value" between each pair of people and/or departments that need to be placed in the office layout.	Concept Questions: 3.1–3.4
RETAIL LAYOUT (pp. 372–375)	■ **Retail layout**—An approach that addresses flow, allocates space, and responds to customer behavior. Retail layouts are based on the idea that sales and profitability vary directly with customer exposure to products. The main *objective of retail layout is to maximize profitability per square foot of floor space* (or, in some stores, per linear foot of shelf space). ■ **Slotting fees**—Fees manufacturers pay to get shelf space for their products. ■ **Servicescape**—The physical surroundings in which a service takes place and how they affect customers and employees.	Concept Questions: 4.1–4.4
WAREHOUSE AND STORAGE LAYOUTS (pp. 375–377)	■ **Warehouse layout**—A design that attempts to minimize total cost by addressing trade-offs between space and material handling. The variety of items stored and the number of items "picked" has direct bearing on the optimal layout. Modern warehouse management is often an automated procedure using *automated storage and retrieval systems* (ASRSs). ■ **Cross-docking**—Avoiding the placement of materials or supplies in storage by processing them as they are received for shipment. Cross-docking requires both tight scheduling and accurate inbound product identification. ■ **Random stocking**—Used in warehousing to locate stock wherever there is an open location. ■ **Customizing**—Using warehousing to add value to a product through component modification, repair, labeling, and packaging.	Concept Questions: 5.1–5.4
FIXED-POSITION LAYOUT (pp. 377–378)	■ **Fixed-position layout**—A system that addresses the layout requirements of stationary projects. Fixed-position layouts involve three complications: (1) there is limited space at virtually all sites, (2) different materials are needed at different stages of a project, and (3) the volume of materials needed is dynamic.	Concept Questions: 6.1–6.4
PROCESS-ORIENTED LAYOUT (pp. 378–383)	■ **Process-oriented layout**—A layout that deals with low-volume, high-variety production in which like machines and equipment are grouped together. ■ **Job lots**—Groups or batches of parts processed together. $\text{Minimize cost} = \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij} C_{ij}$ (9-1)	Concept Questions: 7.1–7.4 Problems: 9.1–9.10 Virtual Office Hours for Solved Problem: 9.1 **VIDEO 9.1** Laying Out Arnold Palmer Hospital's New Facility **ACTIVE MODEL 9.1**

Main Heading	Review Material	MyOMLab
WORK CELLS (pp. 383–386)	■ **Work cell**—An arrangement of machines and personnel that focuses on making a single product or family of related products. ■ **Takt time**—Pace of production to meet customer demands. Takt time = Total work time available/ Units required to satisfy customer demand (9-2) Workers required = Total operation time required/Takt time (9-3) ■ **Focused work center**—A permanent or semipermanent product-oriented arrangement of machines and personnel. ■ **Focused factory**—A facility designed to produce similar products or components.	Concept Questions: 8.1–8.4 Problem: 9.11
REPETITIVE AND PRODUCT-ORIENTED LAYOUT (pp. 386–391)	■ **Fabrication line**—A machine-paced, product-oriented facility for building components. ■ **Assembly line**—An approach that puts fabricated parts together at a series of workstations; a repetitive process. ■ **Assembly-line balancing**—Obtaining output at each workstation on a production line in order to minimize delay. ■ **Cycle time**—The maximum time that a product is allowed at each workstation. Cycle time = Production time available per day ÷ Units required per day (9-4) Minimum number of workstations = $\sum_{i=1}^{n}$ Time for task i/(Cycle time) (9-5) ■ **Heuristic**—Problem solving using procedures and rules rather than mathematical optimization. Line-balancing heuristics include *longest task (operation) time, most following tasks, ranked positional weight, shortest task (operation) time,* and *least number of following tasks.* $\text{Efficiency} = \dfrac{\sum\text{Task times}}{(\textit{Actual}\text{ number of workstations}) \times (\text{Largest assigned cycle time})}$ (9-6) Idle time = (Actual number of workstations × Largest assigned cycle time) − ∑Task times (9-7)	Concept Questions: 9.1–9.4 Problems: 9.12–9.27 **VIDEO 9.2** Facility Layout at Wheeled Coach Ambulances Virtual Office Hours for Solved Problem: 9.2

Self Test

Before taking the self-test, refer to the learning objectives listed at the beginning of the chapter and the key terms listed at the end of the chapter.

LO 9.1 How are product oriented layout organised?
- **a)** Product-oriented layouts are organized around products or families of low-volume, low-variety products.
- **b)** Product-oriented layouts are organized around products or families of similar high-volume, low-variety products.
- **c)** Product-oriented layouts are organized around products or families of low-volume, high-variety products.
- **d)** Product-oriented layouts are organized around similar processes withlow-volume capacities.
- **e)** Product-oriented layouts are organized around working cells with high-variety products.

LO 9.2 Which of the following does *not* support the retail layout objective of maximizing customer exposure to products?
- **a)** Locate high-draw items around the periphery of the store.
- **b)** Use prominent locations for high-impulse and high-margin items.
- **c)** Maximize exposure to expensive items.
- **d)** Use end-aisle locations.
- **e)** Convey the store's mission with the careful positioning of the lead-off department.

LO 9.3 Which statement is NOT correct?
- **a)** Cross-docking tries to avoid placing materials in the storage area.
- **b)** Cross-docking reduces product handling
- **c)** Direct delivery of assembly parts to the assembly line is an example of cross-docking in manufacturing.
- **d)** Cross-docking increases facility costs
- **e)** Cross-docking reduces inventory

LO 9.4 A fixed-position layout:
- **a)** groups workers to provide for movement of information.
- **b)** addresses the layout requirements of large, bulky projects such as ships and buildings.
- **c)** seeks the best machine utilization in continuous production.
- **d)** allocates shelf space based on customer behavior.
- **e)** deals with low-volume, high-variety production.

LO 9.5 A process-oriented layout:
- **a)** groups workers to provide for movement of information.
- **b)** addresses the layout requirements of large, bulky projects such as ships and buildings.
- **c)** seeks the best machine utilization in continuous production.
- **d)** allocates shelf space based on customer behavior.
- **e)** deals with low-volume, high-variety production.

LO 9.6 For a focused work center or focused factory to be appropriate, the following three factors are required:
- **a)** ______________
- **b)** ______________
- **c)** ______________

LO 9.7 A good office layout can inspire informal and productive encounters by balancing three social and physical factors as follows:
- **a)** ______________
- **b)** ______________
- **c)** ______________

LO 9.8 In a sandwich production factory, making each ham and cheese sandwich consists of a number of activities which totally take 7 minutes. The production line for ham and cheese sandwich has five workers who work 12 hours a day. What is the maximum number of ham and cheese sandwiches they can make in this production line?
- **a)** 465
- **b)** 425
- **c)** 612
- **d)** 514
- **e)** 102

Answers: LO 9.1. b; LO 9.2. c; LO 9.3. d; LO 9.4. b; LO 9.5. e; LO 9.6. family of products, stable forecast (demand), volume; LO 9.7. Proximity, Privacy, and permission (for non-work interaction); LO 9.8. d.