Chapter 7 Facility Layout

Basic Layouts

There are three basic types of layouts: process, product, and fixed-position; and three hybrid layouts: cellular layouts, flexible manufacturing systems, and mixed-model assembly lines. We discuss basic layouts in this section and hybrid layouts later in the chapter.

Process Layouts

Process layouts, also known as *functional layouts,* group similar activities together in departments or work centers according to the process or function they perform. For example, in a machine shop, all drills would be located in one work center, lathes in another work center, and milling machines in still another work center. In a department store, women's clothes, men's clothes, children's clothes, cosmetics, and shoes are located in separate departments. A process layout is characteristic of intermittent operations, service shops, job shops, or batch production, which serve different customers with different needs. The volume of each customer's order is low, and the sequence of operations required to complete a customer's order can vary considerably.

The equipment in a process layout is general purpose, and the workers are skilled at operating the equipment in their particular department. The advantage of this layout is flexibility. The disadvantage is inefficiency. Jobs or customers do not flow through the system in an orderly manner, backtracking is common, movement from department to department can take a considerable amount of time, and queues tend to develop. In addition, each new arrival may require that an operation be set up differently for its particular processing requirements. Although workers can operate a number of machines or perform a number of different tasks in a single department, their workload often fluctuates--from queues of jobs or customers waiting to be processed to idle time between jobs or customers. Figure 7.1 (a) and Figure 7.1 (b) shows a schematic diagram of process layouts in services and manufacturing.

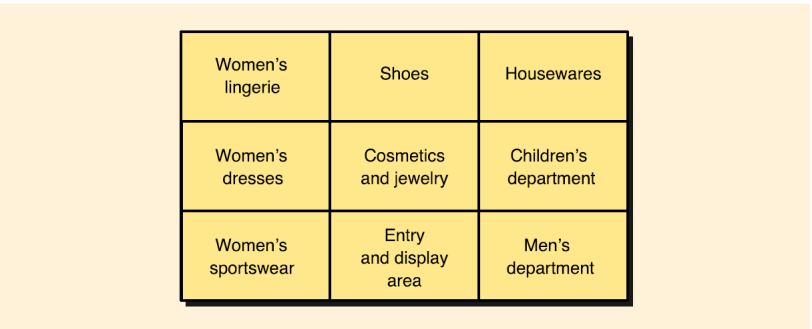


FIGURE 7.1(a) A process layout in services

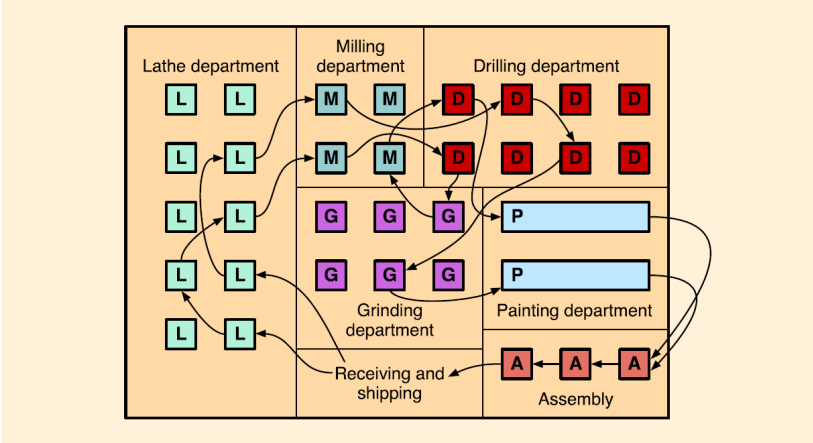


FIGURE 7.1(b) A process layout in manufacturing

Material storage and movement are directly affected by the type of layout. Storage space in a process layout is large to accommodate the large amount of in-process inventory. The factory may look like a warehouse, with work centers strewn between storage aisles. In-process inventory is high because material moves from work center to work center in batches waiting to be processed. Finished goods inventory, on the other hand, is low because the goods are being made for a particular customer and are shipped out to that customer upon completion.

Process layouts in manufacturing firms require flexible material handling equipment (such as forklifts) that can follow multiple paths, move in any direction, and carry large loads of in-process goods. A *forklift* moving pallets of material from work center to work center needs wide aisles to accommodate heavy loads and two-way movement. Scheduling of forklifts is typically controlled by radio dispatch and varies from day to day and hour to hour. Routes have to be determined and priorities given to different loads competing for pickup.

Process layouts in service firms require large aisles for customers to move back and forth and ample display space to accommodate different customer preferences.

The major layout concern for a process layout is where to locate the departments or machine centers in relation to each other. Although each job or customer potentially has a different route through the facility, some paths will be more common than others. Past information on customer orders and projections of customer orders can be used to develop patterns of flow through the shop.

Product Layouts

Product layouts, better known as *assembly lines,* arrange activities in a line according to the sequence of operations that need to be performed to assemble a particular product. Each product or has its own "line" specifically designed to meet its requirements. The flow of work is orderly and efficient, moving from one workstation to another down the assembly line until a finished product comes off the end of the line. Since the line is set up for one type of product or service, special machines can be purchased to match a product's specific processing requirements. Product layouts are suitable for mass production or repetitive operations in which demand is stable and volume is high. The product or service is a standard one made for a general market, not for a particular customer. Because of the high level of demand, product layouts are more automated than process layouts, and the role of the worker is different. Workers perform narrowly defined assembly tasks that do not demand as high a

wage rate as those of the more versatile workers in a process layout.

The advantage of the product layout is its efficiency and ease of use. The disadvantage is its inflexibility. Significant changes in product design may require that a new assembly line be built and new equipment be purchased. This is what happened to U.S. automakers when demand shifted to smaller cars. The factories that could efficiently produce six-cylinder engines could not be adapted to produce four-cylinder engines. A similar inflexibility occurs when demand volume slows. The fixed cost of a product layout (mostly for equipment) allocated over fewer units can send the price of a product soaring.

The major concern in a product layout is balancing the assembly line so that no one workstation becomes a bottleneck and holds up the flow of work through the line. Figure 7.2 shows the product flow in a product layout. Contrast this with the flow of products through the process layout shown in Figure 7.1 (b).

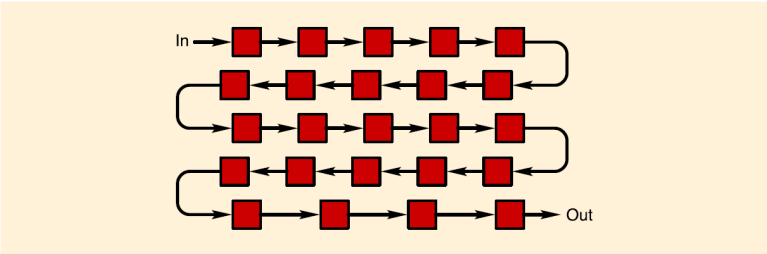


FIGURE 7.2 A Product Layout

A product layout needs material moved in one direction along the assembly line and always in the same pattern. Conveyors are the most common material handling equipment for product layouts. Conveyors can be *paced* (automatically set to control the speed of work) or *unpaced* (stopped and started by the workers according to their pace). Assembly work can be performed *online* (i.e., on the conveyor) or *offline* (at a workstation serviced by the conveyor).

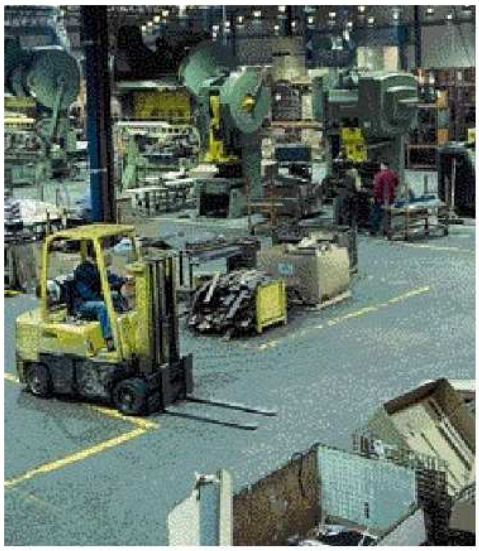
Aisles are narrow because material is moved only one way, it is not moved very far, and the conveyor is an integral part of the assembly process, usually with workstations on either side. Scheduling of the conveyors, once they are installed, is simple--the only variable is how fast they should operate.

Storage space along an assembly line is quite small because in-process inventory is consumed in the assembly of the product as it moves down the assembly line. Finished goods, however, may require a separate warehouse for storage before they are shipped to dealers or stores to be sold.

Product and process layouts look different, use different material handling methods, and have different layout concerns. Table 7.1 summarizes the differences between product and process layouts.

TABLE 7.1 A Comparison of Product and Process Layouts

	Product Layout	*Process Layout*
1. Description	Sequential arrangement of activities	Functional grouping of activities
2. Type of process	Continuous, mass production, mainly assembly	Intermittent, job shop, batch production, mainly fabrication
3. Product	Standardized, made to stock	Varied, made to order
4. Demand	Stable	Fluctuating
5. Volume	High	Low
6. Equipment	Special purpose	General purpose
7. Workers	Limited skills	Varied skills
8. Inventory	Low in-process, high finished goods	High in-process, low finished goods
9. Storage space	Small	Large
10. Material handling	Fixed path (conveyor)	Variable path (forklift)
11. Aisles	Narrow	Wide
12. Scheduling	Part of balancing	Dynamic
13. Layout decision	Line balancing	Machine location
14. Goal	Equalize work at each station	Minimize material handling cost
15. Advantage	Efficiency	Flexibility



The photo on the left shows a process layout: a forklift moves pallets of material from department to department in a stamping factory that makes automotive molding. The photo on the right shows a product layout: partially completed units move by conveyor from one workstation to the next on an electronics assembly line.

Fixed-Position Layouts

Fixed-position layouts are typical of projects in which the product produced is too fragile, bulky, or heavy to move. Ships, houses, and aircraft are examples. In this layout, the product remains stationary for the entire manufacturing cycle. Equipment, workers, materials, and

other resources are brought to the production site. Equipment utilization is low because it is often less costly to leave equipment idle at a location where it will be needed again in a few days, than to move it back and forth. Frequently, the equipment is leased or subcontracted, because it is used for limited periods of time. The workers called to the work site are highly skilled at performing the special tasks they are requested to do. For instance, pipefitters may be needed at one stage of production, and electricians or plumbers at another. The wage rate for these workers is much higher than minimum wage. Thus, if we were to look at the cost breakdown for fixed-position layouts, the fixed cost would be relatively low (equipment may not be owned by the company), whereas the variable costs would be high (due to high labor rates and the cost of leasing and moving equipment).

The size and complexity of aircraft production requires a fixed-position layout. Construction takes place in stages at fixed locations. Rather than move the aircraft itself, crews of workers gather around each unit with their tools and equipment and move from site to site to complete their tasks. Notice the modular offices, and the various carts and bins with wheels for easy movement.

Because the fixed-position layout is specialized, we concentrate on the product and process layouts and their variations for the remainder of this chapter. In the sections that follow, we examine some quantitative approaches for designing product and process layouts.

Pause and Reflect

7-2. What type of layout would be appropriate for a grocery store? home construction? electronics assembly? a university?

7-3. What are the fixed and variable cost trade-offs among product, process, and fixed-position layouts? Draw a cost/volume graph to illustrate your answer.

7-4. Visit a local McDonald's, Burger King, and Taco Bell (or similar establishments). How do their layouts differ? Which appears to be most efficient? Why?

Designing Process Layouts

In designing a process layout, we want to minimize material handling costs, which are a function of the amount of material moved times the distance it is moved. This implies that departments that incur the most interdepartment movement should be located closest to each other, and those that do not interact should be located further away. Two techniques used to design process layouts, block diagramming and relationship diagramming, are based on logic and the visual representation of data.

Block Diagramming

We begin with data on historical or predicted movement of material between departments in the existing or proposed facility. This information is typically provided in the form of a from/to chart, or *load summary chart.* The chart gives the average number of **unit loads** transported between the departments over a given period of time. A unit load can be a single unit, a pallet of material, a bin of material, or a crate of material--however material is normally moved from location to location. In automobile manufacturing, a single car represents a unit load. For a ball-bearing producer, a unit load might consist of a bin of 100 or 1,000 ball bearings, depending on their size.

The next step in designing the layout is to calculate the *composite movements* between departments and rank them from most movement to least movement. Composite movement, represented by a two-headed arrow, refers to the back-and-forth movement between each pair of departments.

Finally, trial layouts are placed on a grid that graphically represents the relative distances between departments in the form of uniform blocks. The objective is to assign each department to a block on the grid so that *nonadjacent loads* are minimized. The term *nonadjacent* is defined as a distance farther than the next block, either horizontally, vertically, or diagonally. The trial layouts are scored on the basis of the number of nonadjacent loads. Ideally, the optimum layout would have zero nonadjacent loads. In practice, this is rarely possible, and the process of trying different layout configurations to reduce the number of nonadjacent loads continues until an acceptable layout is found.

The layout solution in grid 2 represents the relative position of each department. The next step in the layout design is to add information about the space required for each department. Recommendations for workspace around machines can be requested from equipment vendors or found in safety regulations or operating manuals. In some cases, vendors provide templates of equipment layouts, with work areas included. Workspace allocations for workers can be specified as part of job design, recommended by professional groups, or agreed upon through union negotiations. A **block diagram** can be created by blocking in the work areas around the departments on the grid. The *final block diagram* adjusts the block diagram for the desired or proposed shape of the building. Standard building shapes include rectangles, L shapes, T shapes, and U shapes.

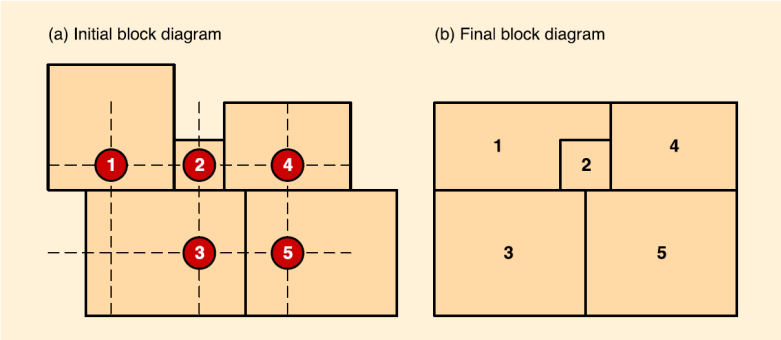


FIGURE 7.3 Block Diagrams

Figure 7.3(a) shows an initial block diagram for Example 7.1, and Figure 7.3(b) shows a final block diagram. Notice that the space requirements vary considerably from department to department, but the relative location of departments has been retained from the grid.

Relationship Diagramming

The preceding solution procedure is appropriate for designing process layouts when quantitative data are available. However, in situations for which quantitative data are difficult to obtain or do not adequately address the layout problem, the load summary chart can be replaced with subjective input from analysts or managers. Richard Muther developed a format for displaying manager preferences for departmental locations, known as **Muther's grid**.[2] The preference information is coded into six categories associated with the five vowels, *A, E, I, O,* and *U,* plus the letter *X.* As shown in Figure 7.4, the vowels match the first letter of the closeness rating for locating two departments next to each other. The diamond-shaped grid is read similar to mileage charts on a road map. For example, reading down the highlighted row in Figure 7.4, it is *okay* if the offices are located next to production, *absolutely necessary* that the stockroom be located next to production, *important* that shipping and receiving be located next to production, *especially important* that the locker room be located next to production, and *absolutely necessary* that the toolroom be located next to production.

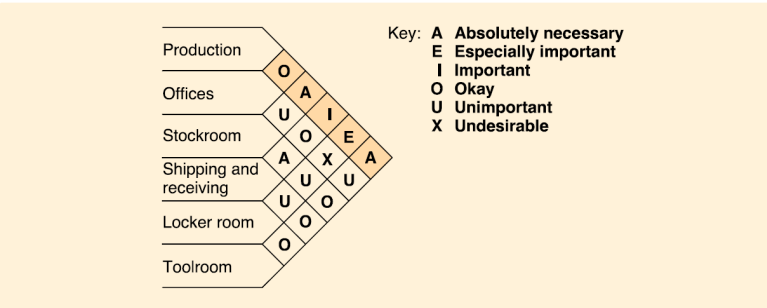


FIGURE 7.4 Muther's Grid

The information from Muther's grid can be used to construct a **relationship diagram** that evaluates existing or proposed layouts. Consider the relationship diagram shown in Figure 7.5(a). A schematic diagram of the six departments from Figure 7.5 is given in a 2 ∞ 3 grid. Lines of different thicknesses are drawn from department to department. The thickest lines (three, four, or five strands) identify the closeness ratings with the highest priority--that is, for which departments it is *important, especially important,* or *absolutely necessary* that they be located next to each other. The priority diminishes with line thickness. *Undesirable* closeness ratings are marked with a zigzagged line. Visually, the best solution would show short heavy lines and no zigzagged lines (undesirable locations are noted only if they are adjacent). Thin

lines (one or two strands, representing *unimportant* or *okay)* can be of any length and for that reason are sometimes eliminated from the analysis. An alternate form of relationship diagramming uses colors instead of line thickness to visualize closeness ratings.

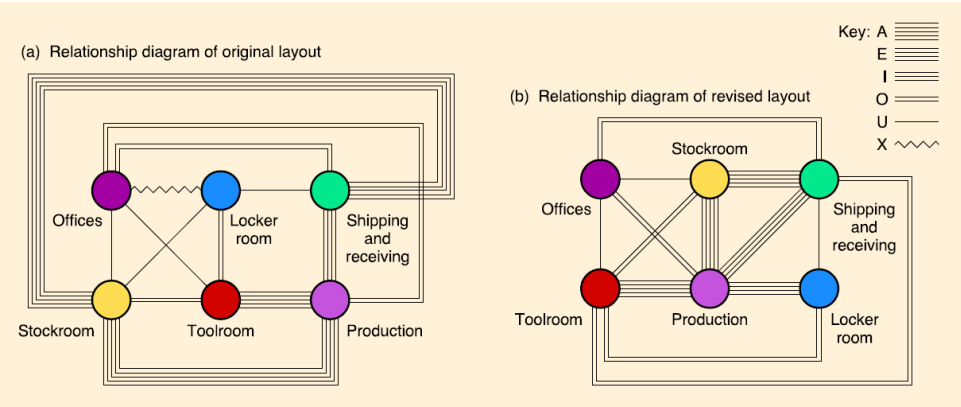


FIGURE 7.5 Relationship Diagrams

From Figure 7.5(a), it is obvious that production and shipping and receiving are located too far from the stockroom and that the offices and locker room are located too close to one another. Figure 7.5(b) shows a revised layout, and evaluates the layout with a relationship diagram. The revised layout appears to satisfy the preferences expressed in Muther's grid. The heavy lines are short and within the perimeter of the grid. The lengthy lines are thin, and there are no zigzagged lines.

Computerized Layout Solutions

The diagrams just discussed help formulate ideas for the arrangement of departments in a process layout, but they can be cumbersome for large problems. Fortunately, several computer packages are available for designing process layouts. The best known is CRAFT (Computerized Relative Allocation of Facilities Technique) and CORELAP (Computerized Relationship Layout Planning). CRAFT takes a load summary chart and block diagram as input and then makes pairwise exchanges of departments until no improvements in cost or nonadjacency score can be found. The output is a revised block diagram after each iteration for a rectangular-shaped building, which may or may not be optimal. CRAFT is sensitive to the initial block diagram used; that is, different block diagrams as input will result in different layouts as outputs. For this reason, CRAFT is often used to improve upon existing layouts or to enhance the best manual attempts at designing a layout.

CORELAP uses nonquantitative input and relationship diagramming to produce a feasible layout for up to forty-five departments and different building shapes. It attempts to create an acceptable layout from the beginning by locating department pairs with A ratings first, then those with E ratings, and so on.

Simulation software for layout analysis, such as PROMODEL and EXTEND provide visual feedback and allow the user to quickly test a variety of scenarios. Three-D modeling and CAD-integrated layout analysis are available in VisFactory and similar software. All these computer packages are basically trial-and-error approaches to layout design that provide good, but not necessarily optimal, process layouts.

Service Layouts

Most service organizations use process layouts. This makes sense because of the variability in customer requests for service. Service layouts are designed in much the same way as process layouts in manufacturing firms, but the objectives may differ. For example, instead of minimizing the flow of materials through the system, services may seek to minimize the flow of customers or the flow of paperwork. In retail establishments, the objective is usually related to maximizing profit per unit of display space. If sales vary directly with customer exposure, then an effective layout would expose the customer to as many goods as possible. This means instead of minimizing a customer's flow, it would be more beneficial to maximize it (to a certain point). Grocery stores take this approach when they locate milk on one end of the store and bread on the other, forcing the customer to travel through aisles of merchandise that might prompt additional purchases.

Service layouts must be attractive as well as functional. In the photo on the left, modular office units without permanent walls allow maximum flexibility, save space, and encourage communication. In the photo on the right, Fuddruckers restaurant creates an atmosphere of quality and freshness by allowing customers to prepare their own salads and hamburger fixings at spacious salad bars overflowing with extras. Customers get exactly what they want faster than if a waiter had processed the order. Who makes the best hamburgers? Fuddruckers and you!

Another aspect of service layout is the allocation of shelf space to various products. Industry-specific recommendations are available for layout and display decisions. Computerized versions, such as SLIM (Store Labor and Inventory Management) and COSMOS (Computerized Optimization and Simulation Modeling for Operating Supermarkets), consider shelf space, demand rates, profitability, and stockout probabilities in layout design. Finally, service layouts are often visible to the customer, so they must be aesthetically pleasing as well as functional.

Pause and Reflect

7-5. What is the difference between block diagramming and relationship diagramming?

7-6. How do service layouts differ from manufacturing layouts?

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[2] R. Muther, *Systematic Layout Planning* (Boston: Industrial Education Institute, 1961).

Designing Product Layouts

A product layout arranges machines or workers in a line according to the operations that need to be performed to assemble a particular product. From this description, it would seem the layout could be determined simply by following the order of assembly as contained in the bill of material for the product. To some extent, this is true. Precedence requirements specifying which operations must precede others, which can be done concurrently and which must wait until later are an important input to the product layout decision. But there are other factors that make the decision more complicated.

Product layouts or assembly lines are used for high-volume production. To attain the required output rate as efficiently as possible, jobs are broken down into their smallest indivisible portions, called *work elements.* Work elements are so small that they cannot be performed by more than one worker or at more than one workstation. But it is common for one worker to perform several work elements as the product passes through his or her workstation. Part of the layout decision is concerned with grouping these work elements into workstations so products flow through the assembly line smoothly. A *workstation* is any area along the assembly line that requires at least one worker or one machine. If each workstation on the assembly line takes the same amount of time to perform the work elements that have been assigned, then products will move successively from workstation to workstation with no need for a product to wait or a worker to be idle. The process of equalizing the amount of work at each workstation is called **line balancing**.

Line Balancing

Assembly line balancing operates under two constraints, precedence requirements and cycle time restrictions.

Precedence requirements are physical restrictions on the *order* in which operations are performed on the assembly line. For example, we would not ask a worker to package a product before all the components were attached, even if he or she had the time to do so before passing the product to the next worker on the line. To facilitate line balancing, precedence requirements are often expressed in the form of a precedence diagram. The *precedence diagram* is a network, with work elements represented by circles or nodes and precedence relationships represented by directed line segments connecting the nodes. We will construct a precedence diagram later in Example 7.2.

Cycle time, the other restriction on line balancing, refers to the maximum amount of time the product is allowed to spend at each workstation if the targeted production rate is to be reached. *Desired cycle time* is calculated by dividing the time available for production by the number of units scheduled to be produced:

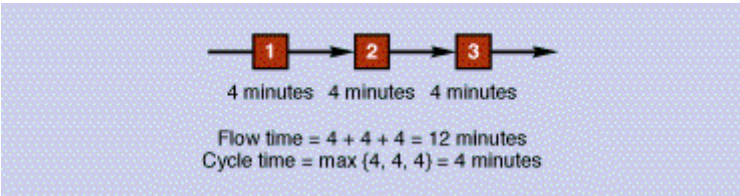
$$C_d = \frac{\text{production time available}}{\text{desired units of output}}$$

Suppose a company wanted to produce 120 units in an eight-hour day. The cycle time necessary to achieve that production quota, is

$$C_d = \frac{(8 \text{ hours} \times 60 \text{ minutes / hour})}{(120 \text{ units})}$$

$$= \frac{480}{120} = 4 \text{ minutes}$$

Cycle time can also be viewed as the time between completed items rolling off the assembly line. Consider the three-station assembly line shown here.



It takes 12 minutes (i.e., 4 + 4 + 4) for each item to pass completely through all three stations of the assembly line. The time required to complete an item is referred to as its *flow time,* or *lead time.* However, the assembly line does not work on only one item at a time. When fully operational, the line will be processing three items at a time, one at each workstation, in various stages of assembly. Every 4 minutes a new item enters the line at workstation 1, an item is passed from workstation 1 to workstation 2, another item is passed from workstation 2 to workstation 3, and a completed item leaves the assembly line. Thus, a completed item rolls off the assembly line every 4 minutes. This 4-minute interval is the actual cycle time of the line.

The actual cycle time, C_a, is the maximum workstation time on the line. It differs from the desired cycle time when the production quota does not match the maximum output attainable by the system. Sometimes the production quota cannot be achieved because the time required for one work element is too large. To correct the situation, the quota can be revised downward or parallel stations can be set up for the bottleneck element.

Line balancing is basically a trial and error process. We group elements into work stations recognizing time and precedence constraints. For simple problems, we can evaluate all feasible groupings of elements. For more complicated problems, we need to know when to stop trying different workstation configurations. The *efficiency* of the line can provide one type of guideline; the *theoretical minimum number of workstations* provides another. The formulas for efficiency, E, and minimum number of workstations, N, are

$$E = \frac{\sum_{i=1}^{j} t_i}{nC_a} \qquad N = \frac{\sum_{i=1}^{j} t_i}{C_d}$$

where

t_i = completion time for element i

j = number of work elements

n = actual number of workstations

C_a = actual cycle time

C_d = desired cycle time

The total idle time of the line, called **balance delay**, is calculated as (1 – efficiency). Efficiency and balance delay are usually expressed as percentages. In practice, it may be difficult to attain the theoretical number of workstations or 100 percent efficiency.

The line balancing process can be summarized as follows:

1. Draw and label a precedence diagram.
2. Calculate the desired cycle time required for the line.
3. Calculate the theoretical minimum number of workstations.
4. Group elements into workstations, recognizing cycle time and precedence constraints.
5. Calculate the efficiency of the line.
6. Determine if the theoretical minimum number of workstations or an acceptable efficiency level has been reached. If not, go back to step 4.

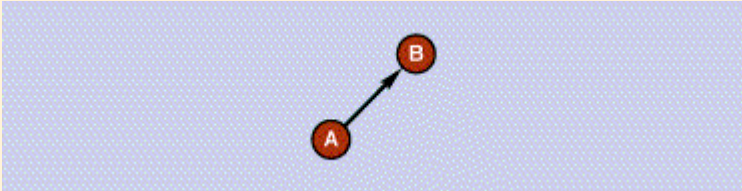
EXAMPLE 7.2 — Line Balancing

Real Fruit Snack Strips are made from a mixture of dried fruit, food coloring, preservatives, and glucose. The mixture is pressed out into a thin sheet, imprinted with various shapes, rolled, and packaged. The precedence and time requirements for each step in the assembly process are given below. To meet demand, Real Fruit needs to produce 6,000 fruit strips every 40-hour week. Design an assembly line with the fewest number of workstations that will achieve the production quota without violating precedence constraints.

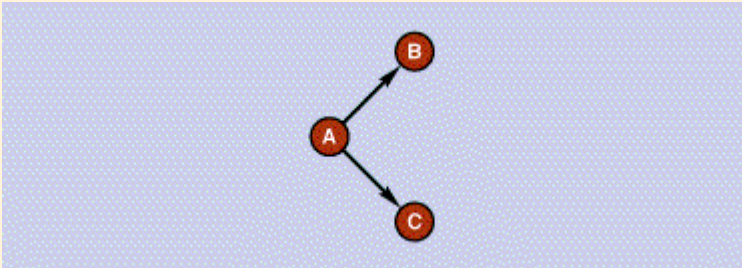
	Work Element	*Precedence*	*Time (min)*
A	Press out sheet of fruit	—	0.1
B	Cut into strips	A	0.2
C	Cutline fun shapes	A	0.4
D	Roll up and package	B, C	0.3

SOLUTION:

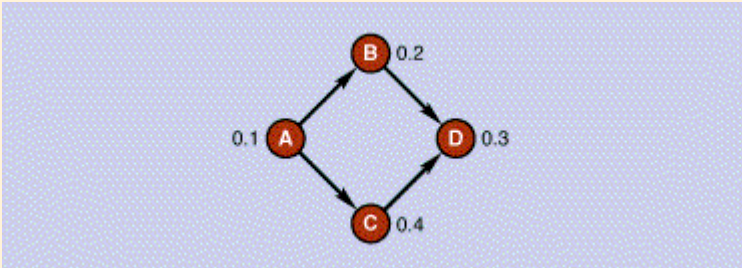
First, we draw a precedence diagram. Element A has no elements preceding it, so node A can be placed anywhere. Element A precedes element B, so the line segment that begins at node A must end at node B.



Element A precedes element C. Again, a line segment from node A must end at node C.



Elements B and C precede element D, so the line segments extending from nodes B and C must end at node D. The precedence diagram is completed by adding the time requirements beside each node.



Next, we calculate the desired cycle time and the theoretical minimum number of workstations:

$$C_d = \frac{40 \text{ hours} \times 60 \text{ minutes / hour}}{6,000 \text{ units}} = \frac{2,400}{6,000} = 0.4 \text{ minutes}$$

$$N = \frac{0.1 + 0.2 + 0.3 + 0.4}{0.4} = \frac{1.0}{0.4} = 2.5 \text{ workstations}$$

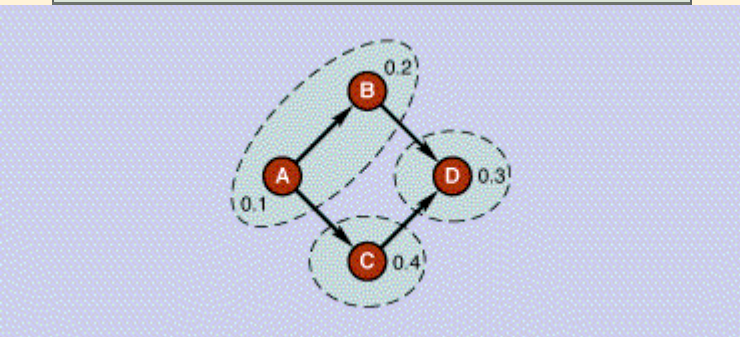
Since we cannot have half a workstation (or any portion of a workstation), we round up to 3 workstations.

We must group elements into workstations so that the sum of the element time at each workstation is less than or equal to the desired cycle time of 0.4 minutes.

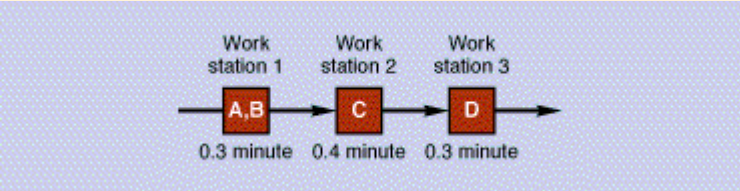
Examining the precedence diagram, let us begin with A since it is the only element that does not have a precedence. We assign A to workstation 1. B and C are now available for assignment. Cycle time is exceeded with A and C in the same workstation, so we assign B to workstation 1 and place C in a second workstation. No other element can be added to workstation 2, due to cycle time constraints. That leaves D for assignment to a third workstation. Elements grouped into workstations

are circled on the precedence diagram.

Workstation	Element	Remaining Time	Remaining Elements
1	A	0.3	B, C
	B	0.1	C, D
2	C	0.0	D
3	D	0.1	none



Our assembly line consists of three workstations, arranged as follows:



Since the theoretical minimum number of workstations was three, we know we have balanced the line as efficiently as possible.

The assembly line has an efficiency of

$$E = \frac{0.1 + 0.2 + 0.3 + 0.4}{3(0.4)} = \frac{1.0}{1.2} = 0.833 = 83.3 \text{ percent}$$

Computerized Line Balancing

Line balancing by hand becomes unwieldy as the problems grow in size. Fortunately, there are software packages that will balance large lines quickly. IBM's COMSOAL (Computer Method for Sequencing Operations for Assembly Lines) and GE's ASYBL (Assembly Line Configuration Program) can assign hundreds of work elements to workstations on an assembly line. These programs, and most that are commercially available, do not guarantee optimal solutions. They use various *heuristics,* or rules, to balance the line at an acceptable level of efficiency. The POM for Windows software lets the user select from five different heuristics: ranked positional weight, longest operation time, shortest operation time, most number of following tasks, and least number of following tasks. These heuristics specify the *order* in which work elements are considered for allocation to workstations. Elements are assigned to workstations in the order given until the cycle time is reached or until all tasks have been assigned.

Pause and Reflect

7-7. What are the objectives of line balancing?

7-8. Describe several heuristic approaches to line balancing.

Hybrid Layouts

Hybrid layouts modify and/or combine some aspects of product and process layouts. We discuss three hybrid layouts: cellular layouts, flexible manufacturing systems, and mixed-model assembly lines.

Cellular Layouts

Cellular layouts attempt to combine the flexibility of a process layout with the efficiency of a product layout. Based on the concept of group technology (GT), dissimilar machines are grouped into work centers, called *cells,* to process parts with similar shapes or processing requirements. (Figure 7.6 shows a family of parts with similar shapes.) The cells are arranged in relation to each other so that material movement is minimized. Large machines that cannot be split among cells are located near to the cells that use them, that is, at their *point of use.*

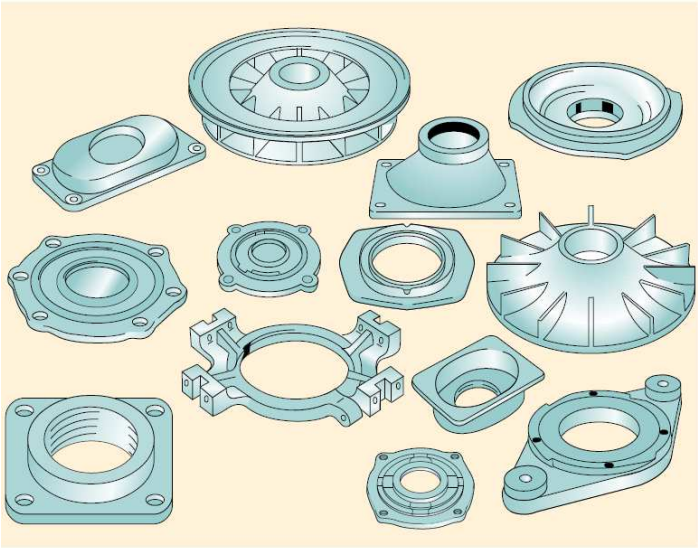


FIGURE 7.6 A Family of Similar Parts

Source: Adapted from Mikell P. Groover, *Automation, Production Systems, and Computer-Integrated Manufacturing.* ©1987. Reprinted by permission of Prentice Hall, Inc., Englewood Cliffs, New Jersey.

The layout of machines *within* each cell resembles a small assembly line. Thus, line-balancing procedures, with some adjustment, can be used to arrange the machines within the cell. The layout *between* cells is a process layout. Therefore, computer programs such as CRAFT can be used to locate cells and any leftover equipment in the facility.

Consider the process layout in Figure 7.7. Machines are grouped by function into four distinct departments. Component parts manufactured in the process layout section of the factory are later assembled into a finished product on the assembly line. The parts follow different flow

paths through the shop. Three representative routings, for parts A, B, and C, are shown in the figure. Notice the distance that each part must travel before completion and the irregularity of the part routings. A considerable amount of "paperwork" is needed to direct the flow of each individual part and to confirm that the right operation has been performed. Workers are skilled at operating the types of machines within a single department and typically can operate more than one machine at a time.

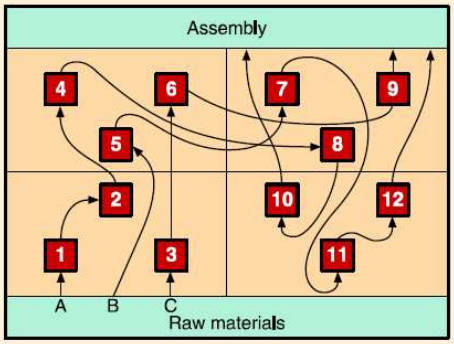


FIGURE 7.7 Original Process Layouts

Parts	Machines 1	2	3	4	5	6	7	8	9	10	11	12
A	×	×		×				×		×		
B					×		×				×	×
C			×			×			×			
D	×	×		×				×		×		
E					×	×						×
F	×			×				×				
G			×			×			×			×
H							×				×	×

FIGURE 7.8 Part Routing Matrix

Figure 7.8 gives the complete part routing matrix for the eight parts processed through the facility. In its current form, there is no apparent pattern to the routings. **Production flow analysis (PFA)** is a group technology technique that reorders part routing matrices to identify families of parts with similar processing requirements. The reordering process can be as simple as listing which parts have four machines in common, then which have three in common, two in common, and the like, or as sophisticated as pattern-recognition algorithms from the field of artificial intelligence. Figure 7.9 shows the results of reordering Figure 7.8. Now the part families and cell formations are clear. Cell 1, consisting of machines 1, 2, 4, 8, and 10, will process parts A, D, and F; Cell 2, consisting of machines 3, 6, and 9, will process products C and G; and Cell 3, consisting of machines 5, 7, 11, and 12, will process parts B, H, and E. A complete cellular layout showing the three cells feeding a final assembly line is given in Figure 7.10. The representative part flows for parts A, B, and C are much more direct than those in the process layout. There is no backtracking or crisscrossing of routes, and the parts travel a shorter distance to be processed. Notice that parts G and E cannot be completely processed within cells 2 and 3, to which they have been assigned. However, the two cells are located in such a fashion that the transfer of parts between the cells does not involve much extra movement.

Parts	Machines 1	2	4	8	10	3	6	9	5	7	11	12
A	×	×	×	×	×							
D	×	×	×	×	×							
F	×		×	×								
C						×	×	×				
G						×	×	×				×
B									×	×	×	×
H										×	×	×
E							×		×			×

Cell 1: Parts A, D, F
Machines 1, 2, 4, 8, 10

Cell 2: Parts C, G
Machines 3, 6, 9

Cell 3: Parts B, H, E
Machines 5, 7, 11, 12

FIGURE 7.9 Part Routing Matrix Reordered to Highlight Cells

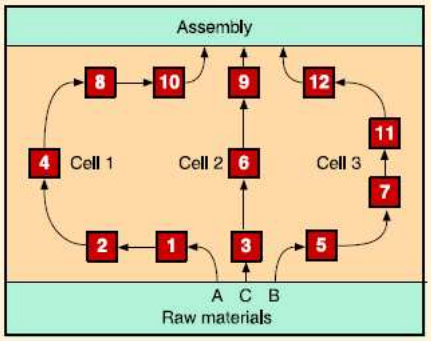


FIGURE 7.10 Revised Layout with Three Cells

The U shape of cells 1 and 3 is a popular arrangement for manufacturing cells because it facilitates the rotation of workers among several machines. Workers in a cellular layout typically operate more than one machine, as was true of the process layout. However, workers who are assigned to each cell must now be multifunctional--that is, skilled at operating many different kinds of machines, not just one type, as in the process layout. In addition, workers are assigned a *path* to follow among the machines that they operate, which may or may not coincide with the path the product follows through the cell. Figure 7.11 (on page 301 of your textbook) shows a U-shaped manufacturing cell including worker paths.

When Lantech, Inc. of Louisville, Kentucky, reorganized its production facility into manufacturing cells, defects went down by half and customer orders were completed in 12 hours instead of five weeks. As shown in this photo, the cells are small (they are labeled X13, X18, and so on) and are located close together. That's so workers can move between cells if necessary, share information, and "see everything."

The advantages of cellular layouts are as follows:

- *Reduced material handling and transit time.* Material movement is more direct. Less distance is traveled between operations. Material does not accumulate or wait long periods of time to be moved. Within a cell, the worker is more likely to carry a partially finished item from machine to machine than wait for material handling equipment, as is characteristic of process layouts, where larger loads must be moved farther distances.
- *Reduced setup time.* Since similar parts are processed together, the adjustments required to set up a machine should not be that different from item to item. If it does not take that long to change over from one item to another, then the changeover can occur more frequently, and items can be produced and transferred in very small batches or lot sizes.
- *Reduced work-in-process inventory.* In a work cell, as with assembly lines, the flow of work is balanced so that no bottlenecks or significant buildup of material occurs between stations or machines. Less space is required for storage of in-process inventory between machines, and machines can be moved closer together, thereby saving transit time and increasing communication.
- *Better use of human resources.* Typically, a cell contains a small number of workers responsible for producing a completed part or product. The workers act as a self-managed team, in most cases more satisfied with the work that they do and more particular about the quality of their work. Labor in cellular manufacturing is a flexible resource. Workers in each cell are multifunctional and can be assigned to different routes within a cell or between cells as demand volume changes.
- *Easier to control.* Items in the same part family are processed in a similar manner through the work cell. There is a significant reduction in the paperwork necessary to document material travel, such as where an item should be routed next, if the right operation has been performed, and the current status of a job. With fewer jobs processed through a cell, smaller batch sizes, and less distance to travel between operations, the progress of a job can be verified *visually* rather than by mounds of paperwork.
- *Easier to automate.* Automation is expensive. Rarely can a company afford to automate an entire factory all at once. Cellular layouts can be automated one cell at a time. Figure 7.12 (on page 302 of your textbook) shows an automated cell with one robot in the center to load and unload material from several CNC machines and an incoming and outgoing conveyor. Automating a few workstations on an assembly line will make it difficult to balance the line and achieve the increases in productivity expected. Introducing automated equipment in a job shop has similar results, because the "islands of automation" speed up only certain processes and are not integrated into the complete processing of a part or product.

Several disadvantages of cellular layouts must also be considered:

- *Inadequate part families.* There must be enough similarity in the types of items processed to form distinct part families. Cellular manufacturing is appropriate for medium levels of product variety and volume. The formation of part families and the allocation of machines to cells is not always an easy task. Part families identified for design purposes may not be appropriate for manufacturing purposes.
- *Poorly balanced cells.* It is more difficult to balance the flow of work through a cell than a single-product assembly line, because items may follow different sequences

through the cell that require different machines or processing times. The sequence in which parts enter the cell can thus affect the length of time a worker or machine spends at a certain stage of processing. Poorly balanced cells can be very inefficient. It is also important to balance the workload among cells in the system, so that one cell is not overloaded while others are idle. This may be taken care of in the initial cellular layout, only to become a problem as changes occur in product designs or product mix. Several imbalances may require the reformation of cells around different part families, and the cost and disruption that implies.

- *Expanded training and scheduling of workers.* Training workers to do different tasks is expensive and time-consuming and requires the workers' consent. Initial union reaction to multifunctional workers was not positive. Today, many unions have agreed to participate in the flexible assignment of workers in exchange for greater job security. Although flexibility in worker assignment is one of the advantages of cellular layouts, the task of determining and adjusting worker paths within or between cells can be quite complex.
- *Increased capital investment.* In cellular manufacturing, multiple smaller machines are preferable to single large machines. Implementing a cellular layout can be economical if new machines are being purchased for a new facility, but it can be quite expensive and disruptive in existing production facilities where new layouts are required. Existing equipment may be too large to fit into cells or may be underutilized when placed in a single cell. Additional machines of the same type may have to be purchased for different cells. The cost and downtime required to move machines can also be high.

Cellular layouts have become popular in the past decade as the backbone of modern factories. Cells can differ considerably in size, in automation, and in the variety of parts processed. As small, interconnected layout units, cells are common in services, as well as manufacturing.

Flexible Manufacturing Systems

The idea of a **flexible manufacturing system (FMS)** was proposed in England in the 1960s with System 24 that could operate without human operators 24 hours a day under computer control. The emphasis from the beginning was on automation rather than the reorganization of work flow. Early FMSs were large and complex, consisting of dozens of CNC machines and sophisticated material handling systems. The systems were very automated, very expensive, and controlled by incredibly complex software. The FMS control computer operated the material handling system, maintained the library of CNC programs and downloaded them to the machines, scheduled the FMS, kept track of tool use and maintenance, and reported on the performance of the system.

There are not many industries that can afford the investment required for a traditional FMS as described. Fewer than 400 FMSs are in operation around the world today. Currently, the trend in flexible manufacturing is toward smaller versions of the traditional FMS, sometimes called *flexible manufacturing cells.* It is not unusual in today's terminology for two or more CNC machines to be considered a flexible cell and two or more cells, an FMS.

The only manual operations in LTV's FMS are performed at the load/unload stations in the center of the photograph. Blank stock to be machined is shown in the foreground. The items rotating on the carousel are different fixturing devices that the workers build up and tear down to hold the various blanks in place for machining. Automated guided vehicles transport items to and from machining centers and the load/unload stations. Notice the computers (in blue) at each machining center and the main control room in the rear. Nearly 1,200 CNC part programs and 900 verification programs for part geometry are contained in the system.

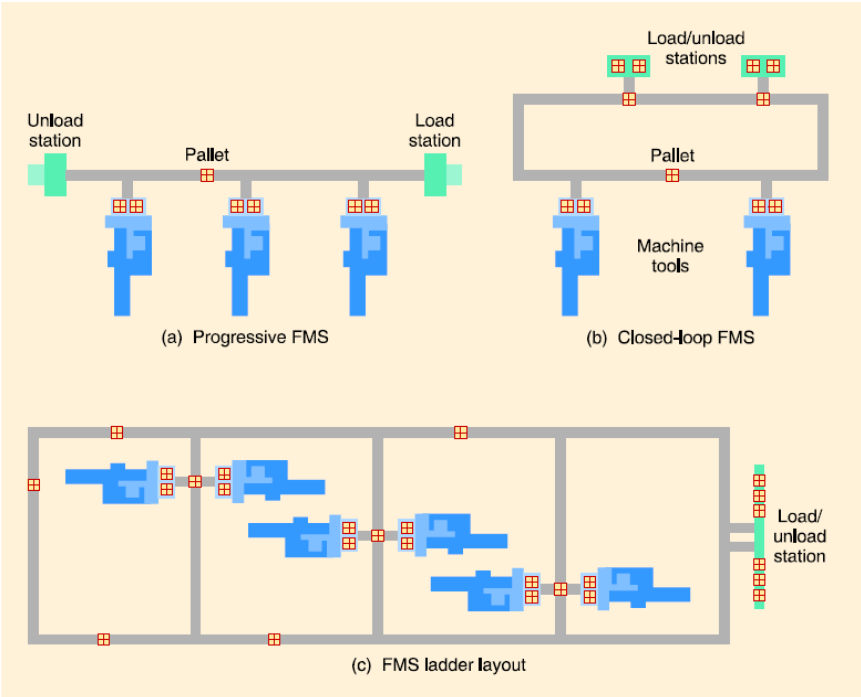


FIGURE 7.13 Alternative FMS Layouts

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Mixed-Model Assembly Lines

Traditional assembly lines, designed to process a single model or type of product, can be used to process more than one type of product, but not efficiently. Models of the same type are produced in long production runs, sometimes lasting for months, and then the line is shut down and changed over for the next model. The next model is also run for an extended time, producing perhaps half a year to a year's supply; then the line is shut down again and changed over for yet another model; and so on. The problem with this arrangement is the difficulty in responding to changes in customer demand. If a certain model is selling well and customers

want more of it, they have to wait until the next batch of that model is scheduled to be produced. On the other hand, if demand is disappointing for models that have already been produced, the manufacturer is stuck with unwanted inventory.

Recognizing that this mismatch of production and demand is a problem, some manufacturers concentrated on devising more sophisticated forecasting techniques. Others changed the manner in which the assembly line was laid out and operated so that it really became a **mixed-model assembly line**. First, they reduced the time needed to change over the line to produce different models. Then they trained their workers to perform a variety of tasks and allowed them to work at more than one workstation on the line, as needed. Finally, they changed the way in which the line was arranged and scheduled. The following factors are important in the design and operation of mixed-model assembly lines:

- *Line balancing:* In a mixed-model line, the time to complete a task can vary from model to model. Instead of using the completion times from one model to balance the line, a distribution of possible completion times from the array of models must be considered. In most cases, the expected value, or average, times are used in the balancing procedure. Otherwise, mixed-model lines are balanced in much the same way as single-model lines.
- *U-shaped lines.* To compensate for the different work requirements of assembling different models, it is necessary to have a flexible workforce and to arrange the line so that workers can assist one another as needed. Figure 7.15 shows how the efficiency of an assembly line can be improved when a U-shaped line is used.

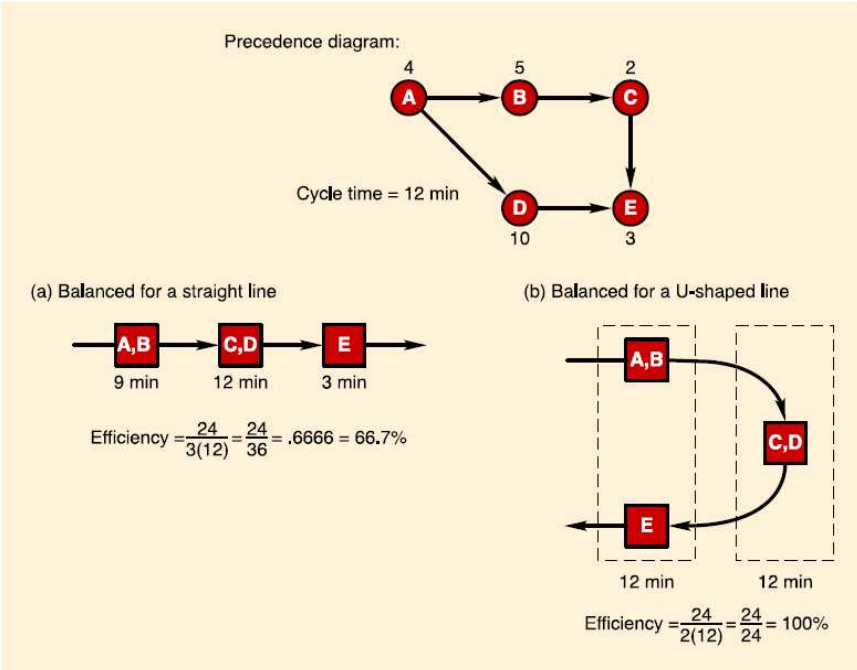

FIGURE 7.15 Balancing U-Shaped Lines

- *Flexible workforce.* Although worker paths are predetermined to fit within a set cycle time, the use of average time values in mixed-model lines will produce variations in worker performance. Hence, the lines are not run at a set speed. Items move through the line at the pace of the slowest operation. This is not to say that production quotas are not important. If the desired cycle time is exceeded at any station on the line, other workers are notified by flashing lights or sounding alarms so that they can come to the

aid of the troubled station. The assembly line is slowed or stopped until the work at the errant workstation is completed. This flexibility of workers helping other workers makes a tremendous difference in the ability of the line to adapt to the varied length of tasks inherent in a mixed-model line.

- *Model sequencing.* Since different models are produced on the same line, mixed-model scheduling involves an additional decision--the order, or sequence, of models to be run through the line. From a logical standpoint, it would be unwise to sequence two models back-to-back that require extra long processing times. It would make more sense to mix the assembling of models so that a short model (requiring less than the average time) followed a long one (requiring more than the average time). With this pattern, workers could "catch up" from one model to the next.

  Another objective in model sequencing is to spread out the production of different models as evenly as possible throughout the time period scheduled. This concept of *uniform production* will be discussed in Chapter 15, "Just-in-Time Systems."

Pause and Reflect

7-9. How are manufacturing cells formed? How does the role of the worker differ in cellular manufacturing?

7-10. How does a cellular layout combine a product and process layout?

7-11. Describe a flexible manufacturing system. How does it differ from a cellular layout?

7-12. How do mixed-model assembly lines differ from traditional assembly lines? What additional decisions are required?