

*technical note five*  
**FACILITY LAYOUT**

187	Basic Production Layout Formats	<p><i>Process layout defined</i>  <i>Product layout defined</i>  <i>Group technology (cellular) layout defined</i>  <i>Fixed-position layout defined</i></p>
188	Process Layout Computerized layout techniques—CRAFT Systematic layout planning	<p><i>CRAFT defined</i>  <i>Systematic layout planning (SLP) defined</i></p>
193	Product Layout Assembly lines Assembly-line balancing Splitting tasks Flexible and U-shaped line layouts Mixed-model line balancing Current thoughts on assembly lines	<p><i>Workstation cycle time defined</i>  <i>Assembly-line balancing defined</i>  <i>Precedence relationship defined</i></p>
200	Group Technology (Cellular) Layout Developing a GT layout Virtual GT cells	
202	Fixed-Position Layout	
203	Retail Service Layout Servicescapes Ambient conditions Spatial layout and functionality Signs, symbols, and artifacts	
206	Office Layout	
207	Conclusion	
215	Case: Soteriou's Souvlaki	
216	Case: State Automobile License Renewals	

*technical note*



PLANET EARTH ORBITING THE ASSEMBLY LINE IN A GLOBE FACTORY. THE GLOBES ARE MOVING THROUGH THE FACTORY USING A TRANSPORT SYSTEM SUSPENDED FROM THE CEILING OF THE FACTORY.

Layout decisions entail determining the placement of departments, work groups within the departments, workstations, machines, and stock-holding points within a production facility. The objective is to arrange these elements in a way that ensures a smooth work flow (in a factory) or a particular traffic pattern (in a service organization). In general, the inputs to the layout decision are as follows:

- 1 Specification of the objectives and corresponding criteria to be used to evaluate the design. The amount of space required, and the distance that must be traveled between elements in the layout, are common basic criteria.
- 2 Estimates of product or service demand on the system.
- 3 Processing requirements in terms of number of operations and amount of flow between the elements in the layout.
- 4 Space requirements for the elements in the layout.
- 5 Space availability within the facility itself, or if this is a new facility, possible building configurations.

In our treatment of layout, we examine how layouts are developed under various formats (or work-flow structures). Our emphasis is on quantitative techniques, but we also show examples of how qualitative factors are important in the design of the layout. Both manufacturing and service facilities are covered in this technical note.

## BASIC PRODUCTION LAYOUT FORMATS

● ● ● The formats by which departments are arranged in a facility are defined by the general pattern of work flow; there are three basic types (process layout, product layout, and fixed-position layout) and one hybrid type (group technology or cellular layout).

A **process layout** (also called a *job-shop* or *functional layout*) is a format in which similar equipment or functions are grouped together, such as all lathes in one area and all stamping machines in another. A part being worked on then travels, according to the established sequence of operations, from area to area, where the proper machines are located for each operation. This type of layout is typical of hospitals, for example, where areas are dedicated to particular types of medical care, such as maternity wards and intensive care units.

A **product layout** (also called a *flow-shop layout*) is one in which equipment or work processes are arranged according to the progressive steps by which the product is made. The path for each part is, in effect, a straight line. Production lines for shoes, chemical plants, and car washes are all product layouts.



Vol. I  
"The Manufacturing  
Process"

Process layout



Product layout

### Group technology (cellular) layout

A **group technology (cellular) layout** groups dissimilar machines into work centers (or cells) to work on products that have similar shapes and processing requirements. A group technology (GT) layout is similar to a process layout in that cells are designed to perform a specific set of processes, and it is similar to a product layout in that the cells are dedicated to a limited range of products. (*Group technology* also refers to the parts classification and coding system used to specify machine types that go into a cell.)

### Fixed-position layout

In a **fixed-position layout**, the product (by virtue of its bulk or weight) remains at one location. Manufacturing equipment is moved to the product rather than vice versa. Construction sites and movie lots are examples of this format.

Many manufacturing facilities present a combination of two layout types. For example, a given production area may be laid out by process, while another area may be laid out by product. It is also common to find an entire plant arranged according to product layout—for example, a parts fabrication area followed by a subassembly area, with a final assembly area at the end of the process. Different types of layouts may be used in each area, with a process layout used in fabrication, group technology in subassembly, and a product layout used in final assembly.

## PROCESS LAYOUT

● ● ● The most common approach to developing a process layout is to arrange departments consisting of like processes in a way that optimizes their relative placement. For example, the departments in a low-volume toy factory might consist of the shipping and receiving department, the plastic molding and stamping department, the metal forming department, the sewing department, and the painting department. Parts for the toys are fabricated in these departments and then sent to assembly departments where they are put together. In many installations, optimal placement often means placing departments with large amounts of interdepartment traffic adjacent to one another.



Suppose that we want to arrange the eight departments of a toy factory to minimize the interdepartmental material handling cost. Initially, let us make the simplifying assumption that all departments have the same amount of space (say, 40 feet by 40 feet) and that the building is 80 feet wide and 160 feet long (and thus compatible with the department dimensions). The first things we would want to know are the nature of the flow between departments and how the material is transported. If the company has another factory that makes similar products, information about flow patterns might be abstracted from the records. On the other hand, if this is a new product line, such information would have to come from routing sheets or from estimates by knowledgeable personnel such as process or industrial engineers. Of course, these data, regardless of their source, will have to be modified to reflect the nature of future orders over the projected life of the proposed layout.

Let us assume that this information is available. We find that all material is transported in a standard-size crate by forklift truck, one crate to a truck (which constitutes one “load”). Now suppose that transportation costs are \$1 to move a load between adjacent departments and \$1 extra for each department in between. The expected loads between departments for the first year of operation are tabulated in Exhibit TN5.1; available plant space is depicted in Exhibit TN5.2. Note that in our example, diagonal moves are permitted so that departments 2 and 3, and 3 and 6, are considered adjacent.

Given this information, our first step is to illustrate the interdepartmental flow by a model, such as Exhibit TN5.3. This provides the basic layout pattern, which we will try to improve.

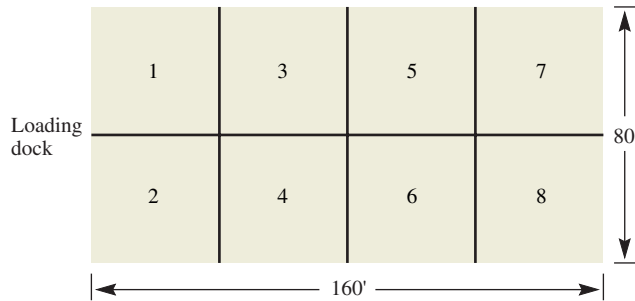
The second step is to determine the cost of this layout by multiplying the material handling cost by the number of loads moved between each pair of departments. Exhibit TN5.4 presents this information, which is derived as follows: The annual material handling cost between Departments 1 and 2 is \$175 ( $\$1 \times 175$  moves), \$60 between Departments 1 and 5 ( $\$2 \times 30$  moves), \$60 between Departments 1 and 7 ( $\$3 \times 20$  moves), \$240 between diagonal Departments 2 and 7 ( $\$3 \times 80$ ), and so forth. (The “distances” are taken from Exhibit TN5.2 or TN5.3, not Exhibit TN5.4.)

EXHIBIT TN5.1

Flow between Departments (Number of Moves)								Department	Activity	
	1	2	3	4	5	6	7	8		
1		175	50	0	30	200	20	25	1	Shipping and receiving
2			0	100	75	90	80	90	2	Plastic molding and stamping
3				17	88	125	99	180	3	Metal forming
4					20	5	0	25	4	Sewing department
5						0	180	187	5	Small toy assembly
6							374	103	6	Large toy assembly
7								7	7	Painting
8									8	Mechanism assembly

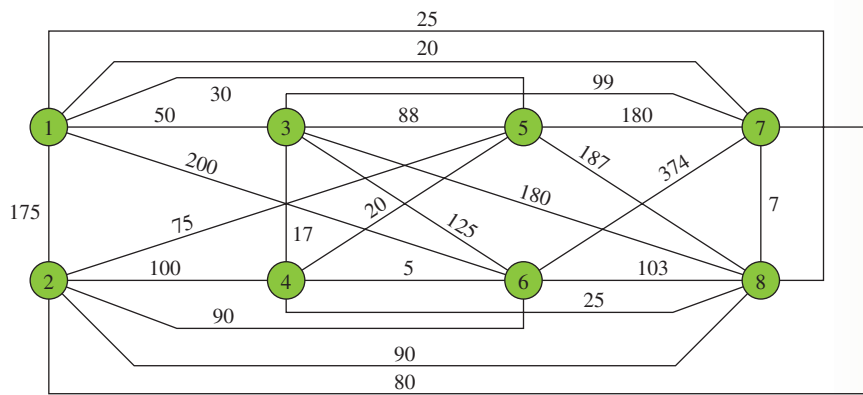
Interdepartmental Flow

EXHIBIT TN5.2



Building Dimensions and Departments

EXHIBIT TN5.3



Interdepartmental Flow Graph with Number of Annual Movements

EXHIBIT TN5.4

\$	1	2	3	4	5	6	7	8
1		175	50	0	60	400	60	75
2			0	100	150	180	240	270
3				17	88	125	198	360
4					20	5	0	50
5						0	180	187
6							374	103
7								7
8								

Cost Matrix—First Solution

Total cost: \$3,474

The third step is a search for departmental changes that will reduce costs. On the basis of the graph and the cost matrix, it seems desirable to place Departments 1 and 6 closer together to reduce their high move-distance costs. However, this requires shifting several other departments, thereby affecting their move-distance costs and the total cost of the second solution. Exhibit TN5.5 shows the revised layout resulting from relocating Department 6 and an adjacent department. (Department 4 is arbitrarily selected for this purpose.) The revised cost matrix for the exchange, showing the cost changes, is given in Exhibit TN5.6. Note the total cost is \$262 *greater* than in the initial solution. Clearly, doubling the distance between Departments 6 and 7 accounted for the major part of the cost increase. This points out the fact that, even in a small problem, it is rarely easy to decide the correct “obvious move” on the basis of casual inspection.



Thus far, we have shown only one exchange among a large number of potential exchanges; in fact, for an eight-department problem, there are 8! (or 40,320) possible arrangements. Therefore, the procedure we have employed would have only a remote possibility of achieving an optimal combination in a reasonable number of tries. Nor does our problem stop here.

Suppose that we *do* arrive at a good solution solely on the basis of material handling cost, such as that shown in Exhibit TN5.7 (whose total cost is \$3,550). We would note, first of all, that our shipping and receiving department is near the center of the factory—an arrangement that probably would not be acceptable. The sewing department is next to the painting department, introducing the hazard that lint, thread, and cloth particles might drift onto painted items. Further, small toy assembly and large toy assembly are located at opposite ends of the plant, which would increase travel time for assemblers (who very likely would be needed in both departments at various times of the day) and for supervisors (who might otherwise supervise both departments simultaneously). Often factors other than material handling cost need to be considered in finalizing a layout.

EXHIBIT TN5.5

Revised Interdepartmental Flow Chart (Only interdepartmental flow with effect on cost is depicted.)

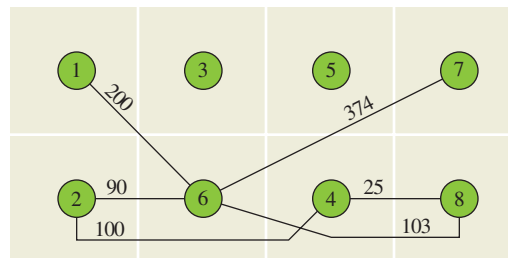


EXHIBIT TN5.6

Cost Matrix—Second Solution

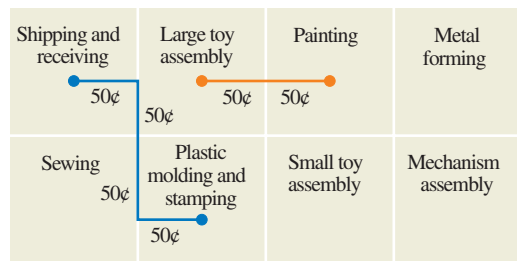
	1	2	3	4	5	6	7	8	Net cost change
1	175	50	0	60	(200)	60	75		-\$200
2		0	(200)	150	(90)	240	270		+ 10
3			17	88	125	198	360		
4				20	5	0	(25)		- 25
5					0	180	187		
6						(748)	(206)		+\$374, + \$103
7							7		
8									
									+ \$262
									Total cost: \$3,736

EXHIBIT TN5.7

Small toy assembly 5	Mechanism assembly 8	Shipping and receiving 1	Large toy assembly 6
Metal forming 3	Plastic molding and stamping 2	Sewing 4	Painting 7

A Feasible Layout

EXHIBIT TN5.8



CRAFT Solution to Toy Factory Layout

Material handling cost between departments      1 and 2 =  $\$2 \times 175 = \$350$   
 6 and 7 =  $\$1 \times 374 = \$374$

## COMPUTERIZED LAYOUT TECHNIQUES—CRAFT

A number of computerized layout programs have been developed since the 1970s to help devise good process layouts. Of these, the most widely applied is the Computerized Relative Allocation of Facilities Technique (**CRAFT**).<sup>1</sup>

CRAFT

The CRAFT method follows the same basic idea that we developed in the layout of the toy factory, but with some significant operational differences. Like the toy factory example, it requires a load matrix and a distance matrix as initial inputs, but in addition, it requires a cost per unit distance traveled, say, \$.10 per foot moved. (Remember, we made the simplifying assumption that cost doubled when material had to jump one department, tripled when it had to jump two departments, and so forth.) With these inputs and an initial layout in the program, CRAFT then tries to improve the relative placement of the departments as measured by total material handling cost for the layout. (Material handling cost between departments = Number of loads  $\times$  Rectilinear distance between department centroids  $\times$  Cost per unit distance.) It makes improvements by exchanging pairs of departments iteratively until no further cost reductions are possible. That is, the program calculates the effect on total cost of exchanging departments; if this yields a reduction, the exchange is made, which constitutes an iteration. As we saw in the manual method, the departments are part of a material flow network, so even a simple pairwise exchange generally will affect flow patterns among many other departments.

### EXAMPLE TN5.1: Applying Craft to the Toy Factory

This example shows how CRAFT is applied to the toy factory problem defined in Exhibits TN5.4–TN5.7.

#### SOLUTION

A CRAFT layout solution to the toy factory problem is shown in Exhibit TN5.8. It provides a higher-cost layout than the manual one (\$3,497 versus \$3,244). Note, however, that these costs are not precisely comparable because CRAFT uses rectilinear distances as opposed to Euclidean (straight-line)

distances, and links centroids of departments instead of “entrances.” Because we were not given cost per unit distances in this example, CRAFT simply broke the stated \$1-per-unit cost of movement between departments into 50¢ segments. Exhibit TN5.8 shows two example calculations of the CRAFT movement costs. (Having square departments in the toy factory makes this calculation method a reasonable one for example purposes.) Also note that we fixed the location of the shipping and receiving department in the CRAFT solution so that it would be adjacent to the loading dock. ●

Distinguishing features of CRAFT and issues relating to it are as follows:

- 1 It is a heuristic program. It uses a simple rule of thumb in making evaluations: “Compare two departments at a time and exchange them if it reduces the total cost of the layout.” This type of rule is obviously necessary to analyze even a modest-size layout.
- 2 It does not guarantee an optimal solution.
- 3 CRAFT is biased by its starting conditions: where you start (that is, the initial layout) will determine the final layout.
- 4 Starting with a reasonably good solution is more likely to yield a lower-cost final solution, but it does not always. This means that a good strategy for using CRAFT is to generate a variety of different starting layouts to expose the program to different pairwise exchanges.
- 5 It can handle up to 40 departments and rarely exceeds 10 iterations in arriving at a solution.
- 6 CRAFT departments consist of combinations of square modules (typically representing floor areas 10 feet by 10 feet). This permits multiple departmental configurations, but often results in strange departmental shapes that have to be modified manually to obtain a realistic layout.
- 7 A modified version called SPACECRAFT has been developed to handle multistory layout problems.<sup>2</sup>
- 8 CRAFT assumes the existence of variable-path material handling equipment such as forklift trucks. Therefore, when computerized fixed-path equipment is employed, CRAFT’s applicability is greatly reduced.

## SYSTEMATIC LAYOUT PLANNING

### Systematic layout planning (SLP)

In certain types of layout problems, numerical flow of items between departments either is impractical to obtain or does not reveal the qualitative factors that may be crucial to the placement decision. In these situations, the venerable technique known as **systematic layout planning (SLP)** can be used.<sup>3</sup> It involves developing a relationship chart showing the degree of importance of having each department located adjacent to every other department. From this chart, an activity relationship diagram, similar to the flow graph used for illustrating material handling between departments, is developed. The activity relationship diagram is then adjusted by trial and error until a satisfactory adjacency pattern is obtained. This pattern, in turn, is modified department by department to meet building space limitations. Exhibit TN5.9 illustrates the technique with a simple five-department problem involving laying out a floor of a department store.

The SLP approach has been quantified for ease of evaluating alternative layouts. This entails assigning numerical weights to the closeness preferences and then trying different layout arrangements. The layout with the highest total closeness score is selected. For example, weights of 16 for “A,” 8 for “E,” 4 for “I,” 2 for “O,” 0 for “U,” and –80 for “X” could be assigned. The choice of this weight structure is rather ad hoc, but the logic is that the most undesirable preference weighting (–80 for “X”) is five times worse than the most desirable weighting of 16 for “A.” Applying this weighting scheme using the software gives a score of 40 to the final layout in Exhibit TN5.9. (The score is the summation of the preference scores for each pair—in this case, 10 pairs. Exchanges may be made randomly, by user choice, or by pairs in this software program.)

EXHIBIT TN5.9

Systematic Layout Planning for a Floor of a Department Store

A. Relationship Chart (based on Tables B and C)

From	To				Area (sq. ft.)
	2	3	4	5	
1. Credit department	I 6	U	E 4	U	100
2. Toy department		U	I 1	A 1,6	400
3. Wine department			U	X 1	300
4. Camera department				X 1	100
5. Candy department					100

Letter Closeness rating  
Number Reason for rating

B.

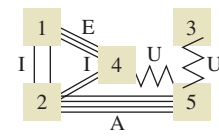
CODE	REASON*
1	Type of customer
2	Ease of supervision
3	Common personnel
4	Contact necessary
5	Share same space
6	Psychology

\*Others may be used.

C.

VALUE	CLOSENESS	LINE CODE*	NUMERICAL WEIGHTS
A	Absolutely necessary		16
E	Especially important		8
I	Important		4
O	Ordinary closeness OK		2
U	Unimportant		0
X	Undesirable	^/^^	-80

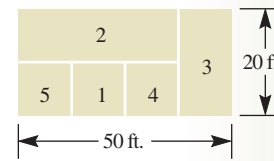
\*Used for example purposes only.



Initial relationship diagram (based on Tables A and C)



Initial layout based on relationship diagram (ignoring space and building constraints)



Final layout adjusted by square footage and building size

PRODUCT LAYOUT

The basic difference between product layout and process layout is the pattern of work flow. As we have seen in process layout, the pattern can be highly variable because material for any given job may have to be routed to the same processing department several times during its production cycle. In product layout, equipment or departments are dedicated to a particular product line, duplicate equipment is employed to avoid backtracking, and a straight-line flow of material movement is achievable. Adopting a product layout makes sense when the batch size of a given product or part is large relative to the number of different products or parts produced.



Vol. II  
"Layout Improvements and Equipment Strategies."

ASSEMBLY LINES

Assembly lines are a special case of product layout. In a general sense, the term *assembly line* refers to progressive assembly linked by some material handling device. The usual assumption is that some form of pacing is present and the allowable processing time is equivalent for all workstations. Within this broad definition, there are important differences among line types. A few of these are material handling devices (belt or roller conveyor, overhead crane); line configuration (U-shape, straight, branching); pacing (mechanical, human); product mix (one product or multiple products); workstation characteristics (workers may sit, stand, walk with the line, or ride the line); and length of the line (few or many).



## WHAT'S IT LIKE WORKING ON AN ASSEMBLY LINE?

Ben Hamper, the infamous “Rivethead” working for General Motors, describes his new job on the Chevy Suburban assembly line with the following:

*The whistle blew and the Rivet Line began to crawl. I took a seat up on the workbench and watched the guy I was replacing tackle his duties. He'd grab one end of a long rail and, with the help of the worker up the line from him, flip it over on its back. CLAAAANNNNNNGGGG! He then raced back to the bench and grabbed a four-wheel-drive spring casting and a muffler hanger. He would rivet the pieces onto the rail. With that completed, he'd jostle the rail back into an upright position and grab a cross member off the overhanging feeder line that curled above the bench. Reaching up with his spare arm, he'd grab a different rivet gun while fidgeting to get the cross member firmly planted so that it aligned with the proper set of holes. He then inserted the rivets and began squashing the*

*cross member into place. Just watching this guy go at it made my head hurt.*

*“How about takin' a stab at it?” the guy asked me after a while. “You're not gonna get the feel of the job sittin' up there on the bench.”*

*I politely declined. I didn't want to learn any portion of this monster maze before it was absolutely necessary. Once the bossman thought you had a reasonable grasp of the setup, he was likely to step in and turn you loose on your own. I needed to keep delaying in order to give Art some time to reel me back up to Cab Shop.*

*“Well, you've got three days,” the guy replied. “After that, this baby's all yours.”*

EXCERPT FROM B. HAMPER'S *RIVETHEAD: TALES FROM THE ASSEMBLY LINE* (NEW YORK: WARNER BOOKS, 1992), P. 90.

workers). For worker insight, see the box titled “What's It Like Working on an Assembly Line?”

The range of products partially or completely assembled on lines includes toys, appliances, autos, planes, guns, garden equipment, clothing, and a wide variety of electronic components. In fact, it is probably safe to say that virtually any product that has multiple parts and is produced in large volume uses assembly lines to some degree. Clearly, lines are an important technology; to really understand their managerial requirements, we should have some familiarity with how a line is balanced.

## ASSEMBLY-LINE BALANCING

Though primarily a scheduling issue, assembly-line balancing often has implications for layout. This would occur when, for balance purposes, workstation size or the number used would have to be physically modified.

The most common assembly line is a moving conveyor that passes a series of workstations in a uniform time interval called the **workstation cycle time** (which is also the time between successive units coming off the end of the line). At each workstation, work is performed on a product either by adding parts or by completing assembly operations. The work performed at each station is made up of many bits of work, termed *tasks*, *elements*, and *work units*. Such tasks are described by motion–time analysis. Generally, they are groupings that cannot be subdivided on the assembly line without paying a penalty in extra motions.

The total work to be performed at a workstation is equal to the sum of the tasks assigned to that workstation. The **assembly-line balancing** problem is one of assigning all tasks to a series of workstations so that each workstation has no more than can be done in the workstation cycle time, and so that the unassigned (that is, idle) time across all workstations is minimized. The problem is complicated by the relationships among tasks imposed by product design and process technologies. This is called the **precedence relationship**, which specifies the order in which tasks must be performed in the assembly process.

The steps in balancing an assembly line are straightforward:

- 1 Specify the sequential relationships among tasks using a precedence diagram. The diagram consists of circles and arrows. Circles represent individual tasks; arrows indicate the order of task performance.

Workstation cycle time

Assembly-line balancing

Precedence relationship



- 2 Determine the required workstation cycle time ( $C$ ), using the formula

$$C = \frac{\text{Production time per day}}{\text{Required output per day (in units)}}$$

- 3 Determine the theoretical minimum number of workstations ( $N_t$ ) required to satisfy the workstation cycle time constraint using the formula (note that this must be rounded up to the next highest integer).

$$N_t = \frac{\text{Sum of task times } (T)}{\text{Cycle time } (C)}$$

- 4 Select a primary rule by which tasks are to be assigned to workstations, and a secondary rule to break ties.
- 5 Assign tasks, one at a time, to the first workstation until the sum of the task times is equal to the workstation cycle time, or no other tasks are feasible because of time or sequence restrictions. Repeat the process for Workstation 2, Workstation 3, and so on until all tasks are assigned.
- 6 Evaluate the efficiency of the balance derived using the formula<sup>4</sup>

$$\text{Efficiency} = \frac{\text{Sum of task times } (T)}{\text{Actual number of workstations } (N_a) \times \text{Workstation cycle time } (C)}$$

- 7 If efficiency is unsatisfactory, rebalance using a different decision rule.

#### EXAMPLE TN5.2: Assembly-Line Balancing

The Model J Wagon is to be assembled on a conveyor belt. Five hundred wagons are required per day. Production time per day is 420 minutes, and the assembly steps and times for the wagon are given in Exhibit TN5.10. Assignment: Find the balance that minimizes the number of workstations, subject to cycle time and precedence constraints.

#### SOLUTION

- 1 Draw a precedence diagram. Exhibit TN5.11 illustrates the sequential relationships identified in Exhibit TN5.10. (The length of the arrows has no meaning.)

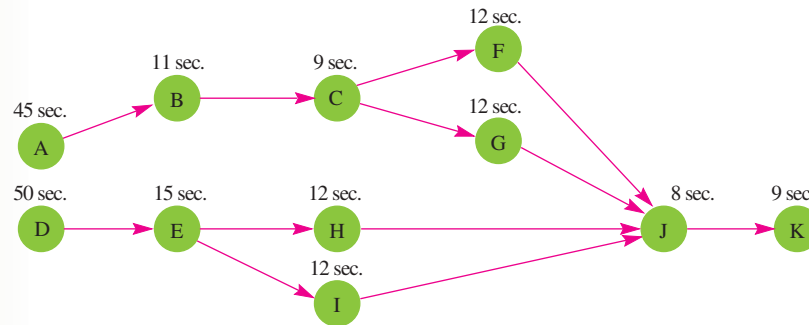
TASK	TASK TIME (IN SECONDS)	DESCRIPTION	TASKS THAT MUST PRECEDE
A	45	Position rear axle support and hand fasten four screws to nuts.	—
B	11	Insert rear axle.	A
C	9	Tighten rear axle support screws to nuts.	B
D	50	Position front axle assembly and hand fasten with four screws to nuts.	—
E	15	Tighten front axle assembly screws.	D
F	12	Position rear wheel #1 and fasten hubcap.	C
G	12	Position rear wheel #2 and fasten hubcap.	C
H	12	Position front wheel #1 and fasten hubcap.	E
I	12	Position front wheel #2 and fasten hubcap.	E
J	8	Position wagon handle shaft on front axle assembly and hand fasten bolt and nut.	F, G, H, I
K	9	Tighten bolt and nut.	J

EXHIBIT TN5.10

Assembly Steps and Times for Model J Wagon

## EXHIBIT TN5.11

## Precedence Graph for Model J Wagon



- 2 Determine workstation cycle time. Here we have to convert to seconds because our task times are in seconds.

$$C = \frac{\text{Production time per day}}{\text{Output per day}} = \frac{60 \text{ sec.} \times 420 \text{ min.}}{500 \text{ wagons}} = \frac{25,200}{500} = 50.4$$

- 3 Determine the theoretical minimum number of workstations required (the actual number may be greater):

$$N_t = \frac{T}{C} = \frac{195 \text{ seconds}}{50.4 \text{ seconds}} = 3.87 = 4 \text{ (rounded up)}$$

- 4 Select assignment rules. Research has demonstrated that some rules are better than others for certain problem structures. In general, the strategy is to use a rule assigning tasks that either have many followers or are of long duration because they effectively limit the balance achievable. In this case, we use the following as our primary rule:
- a. Prioritize tasks in order of the largest number of following tasks.

TASK	NUMBER OF FOLLOWING TASKS
A	6
B or D	5
C or E	4
F, G, H, or I	2
J	1
K	0

Our secondary rule, to be invoked where ties exist from our primary rule, is

b. Prioritize tasks in order of longest task time (shown in Exhibit TN5.12). Note that D should be assigned before B, and E assigned before C due to this tiebreaking rule.

- 5 Make task assignments to form Workstation 1, Workstation 2, and so forth until all tasks are assigned. The actual assignment is given in Exhibit TN5.12A and is shown graphically in Exhibit TN5.12B. It is important to meet precedence and cycle time requirements as the assignments are made.
- 6 Calculate the efficiency. This is shown in Exhibit TN5.12C.
- 7 Evaluate the solution. An efficiency of 77 percent indicates an imbalance or idle time of 23 percent ( $1.0 - .77$ ) across the entire line. From Exhibit TN5.12A we can see that there are 57 total seconds of idle time, and the “choice” job is at Workstation 5.

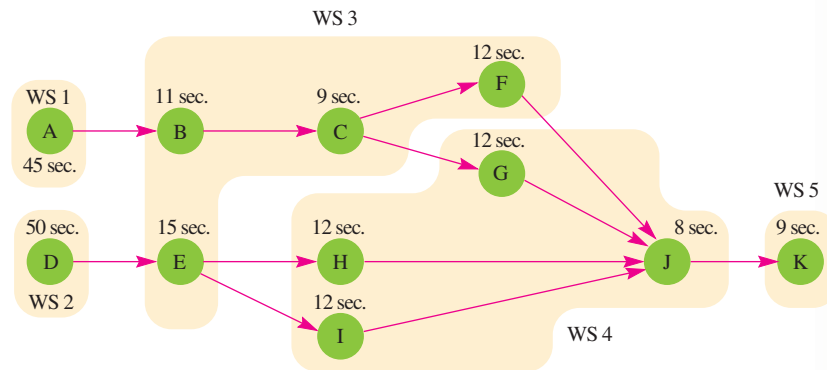
Is a better balance possible? In this case, yes. Try balancing the line with rule *b* and breaking ties with rule *a*. (This will give you a feasible four-station balance.) ●

EXHIBIT TN5.12

	TASK	TASK TIME (IN SECONDS)	REMAINING UNASSIGNED TIME (IN SECONDS)	FEASIBLE REMAINING TASKS	TASK WITH MOST FOLLOWERS	TASK WITH LONGEST OPERATION TIME
Station 1	A	45	5.4 idle	None		
Station 2	D	50	0.4 idle	None		
Station 3	B	11	39.4	C, E	C, E	E
	E	15	24.4	C, H, I	C	
	C	9	15.4	F, G, H, I	F, G, H, I	F, G, H, I
	F*	12	3.4 idle	None		
Station 4	G	12	38.4	H, I	H, I	H, I
	H*	12	26.4	I		
	I	12	14.4	J		
	J	8	6.4 idle	None		
Station 5	K	9	41.4 idle	None		

A. Balance Made According to Largest-Number-of-Following-Tasks Rule

\*Denotes task arbitrarily selected where there is a tie between longest operation times.



B. Precedence Graph for Model J Wagon

$$\text{Efficiency} = \frac{T}{N_s C} = \frac{195}{(5)(50.4)} = .77, \text{ or } 77\%$$

C. Efficiency Calculation

### SPLITTING TASKS

Often the longest required task time forms the shortest workstation cycle time for the production line. This task time is the lower time bound unless it is possible to split the task into two or more workstations.

Consider the following illustration: Suppose that an assembly line contains the following task times in seconds: 40, 30, 15, 25, 20, 18, 15. The line runs for  $7\frac{1}{2}$  hours per day and demand for output is 750 per day.

The workstation cycle time required to produce 750 per day is 36 seconds ( $[7\frac{1}{2} \text{ hours} \times 60 \text{ minutes} \times 60 \text{ seconds}] / 750$ ). Our problem is that we have one task that takes 40 seconds. How do we deal with this task?

There are several ways that we may be able to accommodate the 40-second task in a 36-second cycle. Possibilities are

- 1 **Split the task.** Can we split the task so that complete units are processed in two workstations?
- 2 **Share the task.** Can the task somehow be shared so an adjacent workstation does part of the work? This differs from the split task in the first option because the adjacent station acts to assist, not to do some units containing the entire task.
- 3 **Use parallel workstations.** It may be necessary to assign the task to two workstations that would operate in parallel.
- 4 **Use a more skilled worker.** Because this task exceeds the workstation cycle time by just 11 percent, a faster worker may be able to meet the 36-second time.

- 5 **Work overtime.** Producing at a rate of one every 40 seconds would create 675 per day, 75 short of the needed 750. The amount of overtime required to produce the additional 75 is 50 minutes ( $75 \times 40 \text{ seconds}/60 \text{ seconds}$ ).
- 6 **Redesign.** It may be possible to redesign the product to reduce the task time slightly.

Other possibilities to reduce the task time include an equipment upgrade, a roaming helper to support the line, a change of materials, and multiskilled workers to operate the line as a team rather than as independent workers.

### FLEXIBLE AND U-SHAPED LINE LAYOUTS

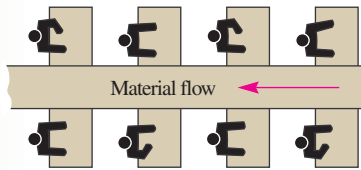
As we saw in the preceding example, assembly-line balances frequently result in unequal workstation times. Flexible line layouts such as those shown in Exhibit TN5.13 are a common way of dealing with this problem. In our toy company example, the U-shaped line with work sharing at the bottom of the figure could help resolve the imbalance.

### MIXED-MODEL LINE BALANCING

This approach is used by JIT manufacturers such as Toyota. Its objective is to meet the demand for a variety of products and to avoid building high inventories. Mixed-model line balancing involves scheduling several different models to be produced over a given day or week on the same line in a cyclical fashion.

EXHIBIT TN5.13

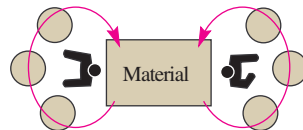
#### Flexible Line Layouts



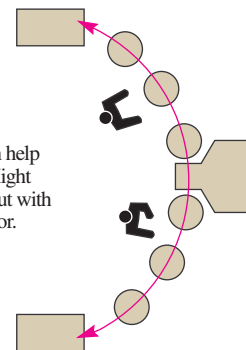
Bad: Operators caged. No chance to trade elements of work between them. (Subassembly line layout common in American plants.)



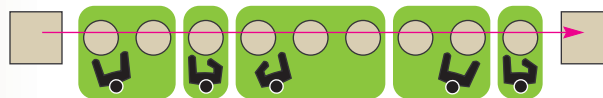
Better: Operators can trade elements of work. Can add and subtract operators. Trained ones can nearly self-balance at different output rates.



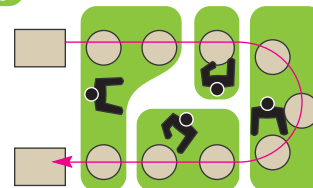
Bad: Operators birdcaged. No chance to increase output with a third operator.



Better: Operators can help each other. Might increase output with a third operator.



Bad: Straight line difficult to balance.



Better: One of several advantages of U-line is better operator access. Here, five operators were reduced to four.

SOURCE: R. W. HALL, *ATTAINING MANUFACTURING EXCELLENCE* (HOMEWOOD, IL: DOW JONES-IRWIN, 1987), P. 125.



THIS HONDA ASSEMBLY LINE ALLOWS TECHNICIANS THE FLEXIBILITY TO TRADE WORK ELEMENTS, AND ALLOWS MANAGEMENT TO ADD OR SUBTRACT OPERATORS AS NECESSARY.

**EXAMPLE TN5.3: Mixed Model Line Balancing**

To illustrate how this is done, suppose our toy company has a fabrication line to bore holes in its Model J wagon frame and its Model K wagon frame. The time required to bore the holes is different for each wagon type.

Assume that the final assembly line downstream requires equal numbers of Model J and Model K wagon frames. Assume also that we want to develop a cycle time for the fabrication line that is balanced for the production of equal numbers of J and K frames. Of course, we could produce Model J frames for several days and then produce Model K frames until an equal number of frames have been produced. However, this would build up unnecessary work-in-process inventory.

If we want to reduce the amount of in-process inventory, we could develop a cycle mix that greatly reduces inventory buildup while keeping within the restrictions of equal numbers of J and K wagon frames.

Process times: 6 minutes per J and 4 minutes per K.

The day consists of 480 minutes (8 hours × 60 minutes).

**SOLUTION**

$$6J + 4K = 480$$

Because equal numbers of J and K are to be produced (or  $J = K$ ), produce 48J and 48K per day, or 6J and 6K per hour.

The following shows one balance of J and K frames.

	Balanced Mixed-Model Sequence					
Model sequence	J J	K K K	J J	J J	K K K	Repeats 8 times per day
Operation time	6 6	4 4 4	6 6	6 6	4 4 4	
Minicycle time	12	12	12	12	12	
Total cycle time	60					

This line is balanced at 6 frames of each type per hour with a minicycle time of 12 minutes.

Another balance is J K K J K J, with times of 6, 4, 4, 6, 4, 6. This balance produces 3J and 3K every 30 minutes with a minicycle time of 10 minutes (JK, KJ, KJ). ●

The simplicity of mixed-model balancing (under conditions of a level production schedule) is seen in Yasuhiro Mondon's description of Toyota Motor Corporation's operations:

Final assembly lines of Toyota are mixed product lines. The production per day is averaged by taking the number of vehicles in the monthly production schedule classified by specifications, and dividing by the number of working days.

In regard to the production sequence during each day, the cycle time of each different specification vehicle is calculated. To have all specification vehicles appear at their own cycle time, different specification vehicles are ordered to follow each other.<sup>5</sup>

### CURRENT THOUGHTS ON ASSEMBLY LINES

It is true that the widespread use of assembly-line methods in manufacturing has dramatically increased output rates. Historically, the focus has almost always been on full utilization of human labor—that is, to design assembly lines minimizing human idle time. Equipment and facility utilization stood in the background as much less important. Past research has tried to find optimal solutions as if the problem stood in a never-changing world.

Newer views of assembly lines take a broader perspective. The intentions are to incorporate greater flexibility in products produced on the line, more variability in workstations (such as size and number of workers), improved reliability (through routine preventive maintenance), and high-quality output (through improved tooling and training). The Breakthrough Box on Dell Computer describes how a combination of assembly lines and manufacturing cells (the topic of the next section) can be used when product demand changes quickly.

## GROUP TECHNOLOGY (CELLULAR) LAYOUT

Vol. IV

"The Vision Light System  
at Federal Signal."



● ● ● Group technology (or cellular) layout allocates dissimilar machines into cells to work on products that have similar shapes and processing requirements. Group technology (GT) layouts are now widely used in metal fabricating, computer chip manufacture, and assembly work. The overall objective is to gain the benefits of product layout in job-shop kinds of production. These benefits include

- 1 **Better human relations.** Cells consist of a few workers who form a small work team; a team turns out complete units of work.
- 2 **Improved operator expertise.** Workers see only a limited number of different parts in a finite production cycle, so repetition means quick learning.
- 3 **Less in-process inventory and material handling.** A cell combines several production stages, so fewer parts travel through the shop.
- 4 **Faster production setup.** Fewer jobs mean reduced tooling and hence faster tooling changes.

### DEVELOPING A GT LAYOUT

Shifting from process layout to a GT cellular layout entails three steps:

- 1 Grouping parts into families that follow a common sequence of steps. This step requires developing and maintaining a computerized parts classification and coding system. This is often a major expense with such systems, although many companies have developed shortcut procedures for identifying parts families.
- 2 Identifying dominant flow patterns of parts families as a basis for location or relocation of processes.
- 3 Physically grouping machines and processes into cells. Often there will be parts that cannot be associated with a family and specialized machinery that cannot be placed

## BREAKTHROUGH

### DELL COMPUTER'S SERVER PLANT USES CELLS

The one-person build cells that populate the heart of the plant enhance flexibility—a critical element of Dell Computer's direct build-to-order model. Assisted by Web-based online work instructions, an experienced operator in a standard cell can assemble any of the 10 basic server platforms in various configurations.

"With the old-style progressive-build approach, you pretty much batched your build every day," notes Mark Lozano, senior production control manager. "You couldn't change what was



going down the line. But here, you can build whatever you want when you want. In one cell we can have a high-end machine following a low-end machine. That kind of flexibility allows us a much shorter cycle time for all of our platforms."

Server components begin their journey through the plant at one of two locations. In one area, motherboards are prepped and installed into the computer chassis. In the second, a kitting area, other components are pulled from storage racks with the aid of a computerized "pick to light" system and placed into totes. From there, intelligent conveyors—linked to a manufacturing execution system—deliver the materials to an open build cell using a pull process.

In the cell the operator does the rest, including putting in the screws. "The next person who can open it up is the customer," says Kris Vorm, director of server engineering. No downstream quality inspector examines the innards of the unit, unless subsequent electronic tests indicate a pesky quality problem. Under a buddy system, a builder will ask another operator to make a visual inspection before he or she screws the cover onto the box. Next stop is the extended test rack, where detailed diagnostics are conducted prior to downloading and testing the operating system and application software—all based on customer specifications.

ADAPTED FROM J. H. SHERIDAN, "DELL COMPUTER'S SERVER PLANT EMPHASIZES VELOCITY AND FLEXIBILITY, WHILE BALANCING SUPPLY AND DEMAND," *INDUSTRY WEEK*, OCTOBER 18, 1999, PP. 46–48.

in any one cell because of its general use. These unattached parts and machinery are placed in a "remainder cell."

Exhibit TN5.14 illustrates the cell development process followed by Rockwell's Telecommunication Division, maker of wave-guide parts. Part A shows the original process-oriented layout; part B, the planned relocation of process based on parts-family production requirements; and part C, an enlarged layout of the cell designed to perform all but the finishing operation. According to Schonberger, cellular organization was practical here because (1) distinct parts families existed; (2) there were several of each type of machine, so taking a machine out of a cluster did not rob the cluster of all its capacity, leaving no way to produce other products; and (3) the work centers were easily movable stand-alone machine tools—heavy, but anchored to the floor rather simply. He adds that these three features represent general guidelines for deciding where cells make sense.<sup>6</sup>

### VIRTUAL GT CELLS

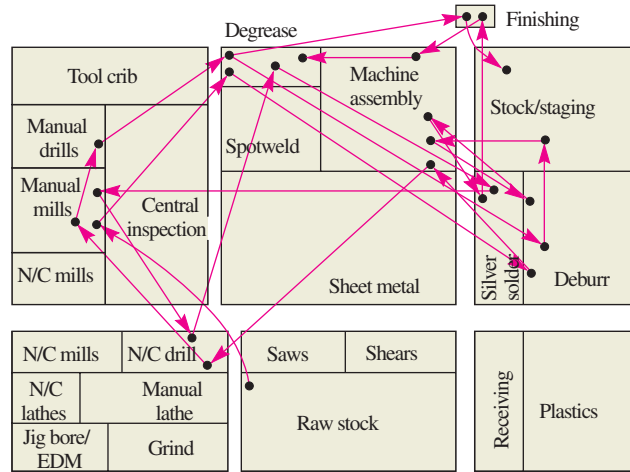
When equipment is not easily movable, many companies dedicate a given machine out of a set of identical machines in a process layout. A virtual GT cell for, say, a two-month production run for the job might consist of Drill 1 in the drills area, Mill 3 in the mill area, and Assembly Area 1 in the machine assembly area. To approximate a GT flow, all work on the particular part family would be done only on these specific machines.



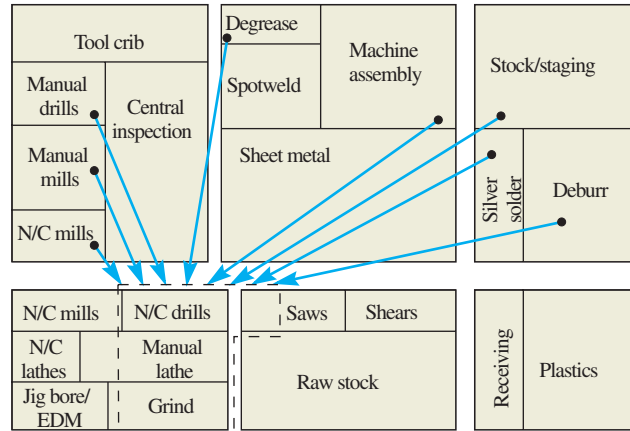
EXHIBIT TN5.14

Developing a Cell to Produce Wave-Guide Parts

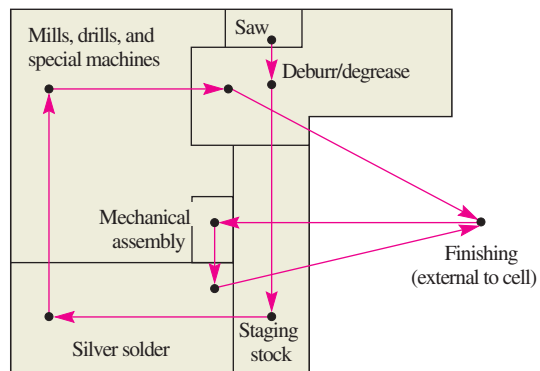
A. Old Plant Organization



B. Planned Relocation of Processes



C. Cell



SOURCE: REPRINTED WITH PERMISSION OF THE FREE PRESS, A DIVISION OF SIMON AND SCHUSTER ADULT PUBLISHING GROUP, FROM *WORLD CLASS MANUFACTURING* BY R. J. SCHONBERGER, COPYRIGHT © 1986 BY SCHONBERGER & ASSOCIATES, INC.

## FIXED-POSITION LAYOUT

● ● ● Fixed-position layout is characterized by a relatively low number of production units in comparison with process and product layout formats. In developing a fixed-position layout, visualize the product as the hub of a wheel with materials and equipment arranged concentrically around the production point in their order of use and movement difficulty. Thus, in building custom yachts, for example, rivets that are used throughout construction would be placed close to or in the hull; heavy engine parts, which must travel to the hull only once, would be placed at a more distant location; and cranes would be set up close to the hull because of their constant use.

In fixed-position layout, a high degree of task ordering is common, and to the extent that this precedence determines production stages, a fixed-position layout might be developed by arranging materials according to their technological priority. This procedure would be expected in making a layout for a large machine tool, such as a stamping machine, where manufacture follows a rigid sequence; assembly is performed from the ground up, with parts being added to the base in almost a building-block fashion.

As far as quantitative layout techniques are concerned, there is little in the literature devoted to fixed-position formats, even though they have been utilized for thousands of years. In certain situations, however, it may be possible to specify objective criteria and develop a fixed-position layout through quantitative means. For instance, if the material handling cost is significant and the construction site permits more or less straight-line material movement, the CRAFT process layout technique might be advantageously employed.

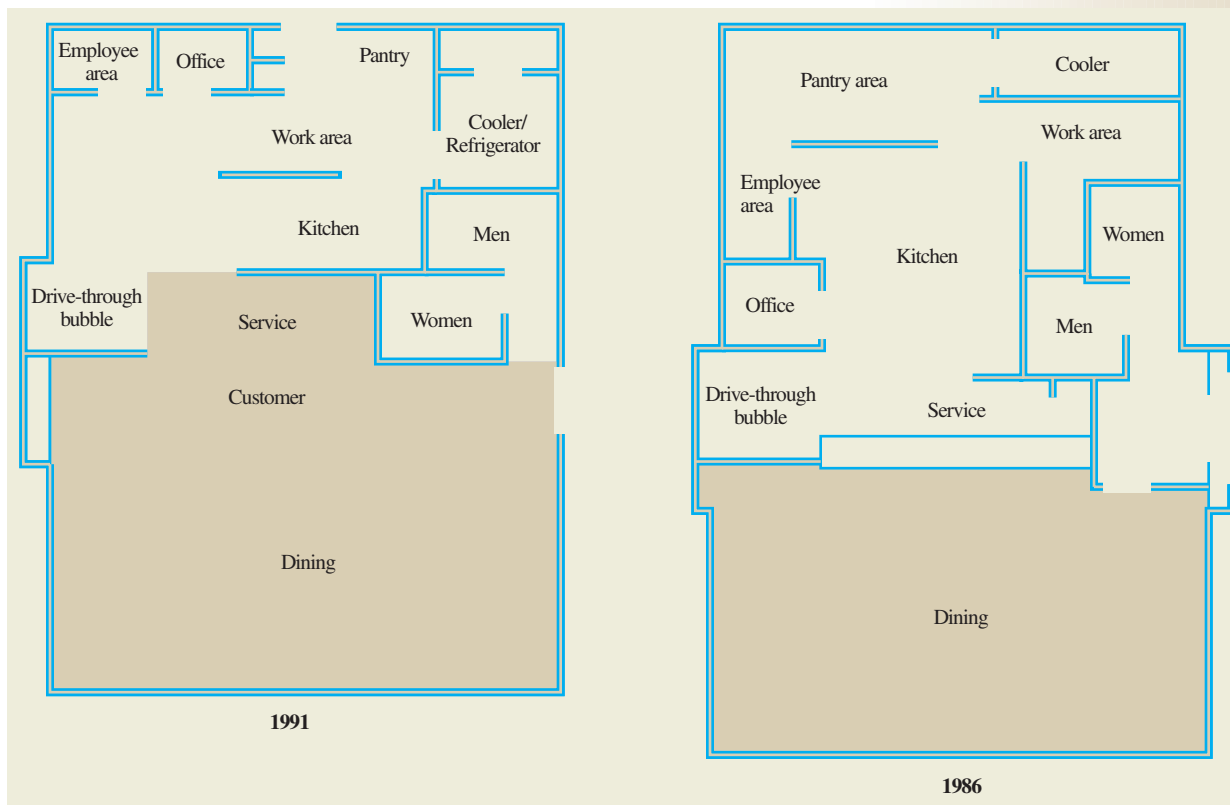
## RETAIL SERVICE LAYOUT

● ● ● The objective of a *retail service layout* (as is found in stores, banks, and restaurants) is to maximize net profit per square foot of store space. A company that has been very successful in leveraging every inch of its layout space to achieve this objective is Taco Bell Restaurants. Exhibit TN5.15 illustrates Taco Bell store layouts used in 1986 and from 1991 to the present. The nature of the layout changes reflects actions required to support the company's value strategy of speed and low prices. Key operational modifications include elimination of many on-site food preparation steps, which simultaneously increased the speed of service while reducing the amount of working space needed. For example, the



Taco Bell Restaurant Floor Plans

EXHIBIT TN5.15



SOURCE: COURTESY OF TACO BELL CORP., LOS ANGELES, CA.

chopping and bagging of lettuce and the precooking and seasoning of meats, beans, and hard tortilla products are now done at central kitchens or by suppliers. The restaurant kitchens are now heating and assembly units only. In addition to such outsourcing, changes were made in queue structures, such as moving from a single line running parallel to the counter, to a double line running perpendicular to it. This improved product flow facilitated serving drive-through windows, increased capacity, and allowed customers to see assembly workers' faces (as opposed to just their backs, as was the case before).

## SERVICESCAPES

As previously noted, the broad objective of layout in retail services is generally to maximize net profit per square foot of floor space. Operationally, this goal is often translated into such criteria as "minimize handling cost" or "maximize product exposure." However, as Sommers and Kernan observed more than 30 years ago, employing these and similar criteria in service layout planning "results in stores that look like warehouses and requires shoppers to approach the task like order pickers or display case stockers."<sup>7</sup> There are other, more humanistic aspects of the service that must also be considered in the layout.

Bitner coined the term *servicescape* to refer to the physical surroundings in which the service takes place and how these surroundings affect customers and employees. An understanding of the servicescape is necessary to create a good layout for the service firm (or the service-related portions of the manufacturing firm). The servicescape has three elements that must be considered: the ambient conditions; the spatial layout and functionality; and the signs, symbols, and artifacts.<sup>8</sup>

## AMBIENT CONDITIONS

The term *ambient conditions* refers to background characteristics such as the noise level, music, lighting, temperature, and scent that can affect employee performance and morale as well as customers' perceptions of the service, how long they stay, and how much money they spend. Although many of these characteristics are influenced primarily by the design of the building (such as the placement of light fixtures, acoustic tiles, and exhaust fans), the layout within a building can also have an effect. Areas near food preparation will smell like food, lighting in a hallway outside a theater must be dim, tables near a stage will be noisy, and locations near an entrance will be drafty.

## SPATIAL LAYOUT AND FUNCTIONALITY

Two aspects of the *spatial layout and functionality* are especially important: planning the circulation path of the customers and grouping the merchandise. The goal of circulation planning is to provide a path for the customers that exposes them to as much of the merchandise as possible while placing any needed services along this path in the sequence they will be needed. For example, the photo shows a bank reception area placed where the customer will encounter it immediately upon entering the bank. Aisle characteristics are of particular importance. Aside from determining the number of aisles to be provided, decisions must be made as to the width of the aisles because this is a direct function of expected or desired traffic. Aisle width can also affect the direction of flow through the service. Stew Leonard's Dairy Store in Norwalk, Connecticut, is designed so that it is virtually impossible to turn around a shopping cart once you have entered the shopping flow path. Focal points that catch the customers' attention in the layout can also be used to draw the customers in the desired direction. The famous blue light at Kmart is an example. Another is shown in the photo.

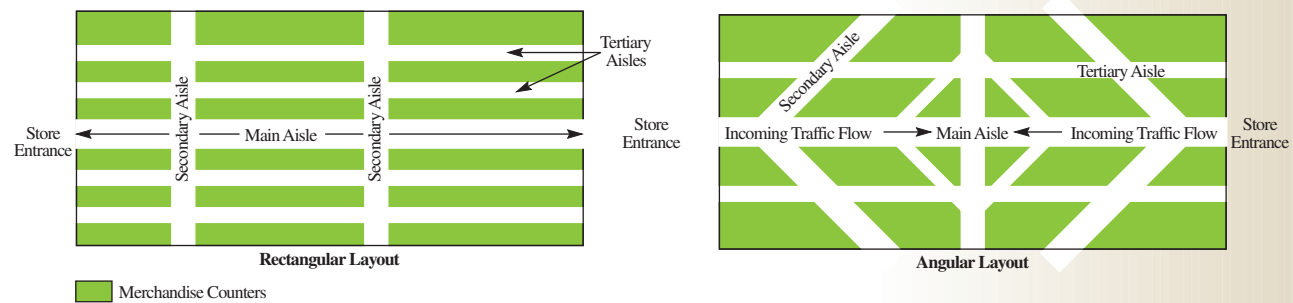
To enhance shoppers' view of merchandise as they proceed down a main aisle, secondary and tertiary aisles may be set at an angle. Consider the two layouts in Exhibit TN5.16. The rectangular layout would probably require less expensive fixtures and contain more display space. If storage considerations are important to the store management, this would be the more desirable layout. On the other hand, the angular layout provides the shopper with a



STEW LEONARD'S DESIGNS ITS STORES TO MOVE CUSTOMERS ALONG A SHOPPING FLOW PATH. ENTERTAINING CHARACTERS SCATTERED THROUGHOUT THE STORE ARE ALSO USED TO CATCH CUSTOMERS' ATTENTION AND DRAW THEM INTO VARIOUS AREAS IN THE STORE.

### Alternative Store Layouts

EXHIBIT TN5.16



much clearer view of the merchandise and, other things being equal, presents a more desirable selling environment.

It is common practice now to base merchandise groupings on the shopper's view of related items, as opposed to the physical characteristics of the products or shelf space and servicing requirements. This grouping-by-association philosophy is seen in boutiques in department stores and gourmet sections in supermarkets.

Special mention is in order for a few guidelines derived from marketing research and relating to circulation planning and merchandise grouping:

- 1 People in supermarkets tend to follow a perimeter pattern in their shopping behavior. Placing high-profit items along the walls of a store will enhance their probability of purchase.
- 2 Sale merchandise placed at the end of an aisle in supermarkets almost always sells better than the same sale items placed in the interior portion of an aisle.
- 3 Credit and other nonselling departments that require customers to wait for the completion of their services should be placed either on upper floors or in "dead" areas.
- 4 In department stores, locations nearest the store entrances and adjacent to front-window displays are most valuable in terms of sales potential.

## BREAKTHROUGH

### IN NEW DRUG LABS, “PORCHES” AND “HUDDLE ZONES”

“The myths of innovation are always stories about solitary, heroic individuals working on their own who have these sudden leaps of insight. In fact, it’s usually much messier than that,” Pfizer’s Dr. Milne says. “Innovation actually thrives on exchange. It is very social, and you want an environment that speaks to that.”

Which is why Dr. Milne and his colleagues junked Pfizer’s standard lab model of two parallel hallways—in effect, human traffic lanes—with labs and offices opening off them. In the new buildings, the labs and offices encircle a central core so scientists can gather without being in the way of people

passing by. In another departure, office doors are angled into one another so scientists run into each other when leaving. Dr. Milne calls these spots “front porch” interactions.

Extending the togetherness theme, Pfizer groups five to seven scientists in “families,” and each family has its own open conference area called a “huddle zone.” With huge windows and sweeping views, these spots are the prettiest in the building. Pfizer’s “families” are grouped into a “tribe” of 70. Each tribe has its own larger gathering areas. All have coffee carts. Dr. Milne is particularly fond of coffee carts and the interaction they can create.

REPUBLICED WITH PERMISSION OF DOW JONES, INC., FROM *THE WALL STREET JOURNAL*, “IN NEW DRUG LABS, ‘PORCHES’ AND ‘HUDDLE ZONES,’” BY G. HARRIS, OCTOBER 6, 1999, P. B1; PERMISSION CONVEYED THROUGH THE COPYRIGHT CLEARANCE CENTER, INC.

## SIGNS, SYMBOLS, AND ARTIFACTS

*Signs, symbols, and artifacts* refer to the parts of the service that have social significance. As with the ambiance, these are often a characteristic of the design of the building, although the orientation, location, and size of many objects and areas can carry special meaning. As examples,

- In the old days, bank loan officers were easily identified because their desks were located on a raised section of the bank floor called the platform.
- A person seated at the desk closest to the entrance is usually in charge of greeting customers and directing them to their destination.
- In a department store, the tiled areas indicate the aisles for travel, while carpeted areas indicate departments for browsing.
- Some car salespeople have blackboards installed in their offices because a person writing on a blackboard symbolizes someone who should be listened to and trusted (such as a teacher).

As you might have gathered from these examples, the influence of behavioral factors makes the development of hard and fast rules for servicescape layout rather difficult. Suffice it to say that making the layout choice is not simply a matter of choosing between display space and ease of operation.

## OFFICE LAYOUT



● ● ● The trend in *office layout* is toward more open offices, with personal work spaces separated only by low divider walls. Companies have removed fixed walls to foster greater communication and teamwork. (See, for example, the Breakthrough Box titled “In New Drug Labs, ‘Porches’ and ‘Huddle Zones.’” Signs, symbols, and artifacts, as discussed in the section on service layout, are possibly even more important in office layout than in retailing. For instance, size and orientation of desks can indicate the importance or professionalism of the people behind them.

Central administration offices are often designed and laid out so as to convey the desired image of the company. For example, Scandinavian Airlines System’s (SAS) administrative

office complex outside Stockholm is a two-story collection of glass-walled pods that provide the feeling of the open communication and flat hierarchy (few levels of organization) that characterize the company's management philosophy.

Service-Master (the highly profitable janitorial management company) positions its "Know-How Room" at the center of its headquarters. This room contains all of the physical products, operations manuals, and pictorial displays of career paths and other symbols for the key knowledge essential to the business. "From this room, the rest of the company can be seen as a big apparatus to bring the knowledge of the marketplace to its employees and potential customers."<sup>9</sup>



## CONCLUSION

● ● ● Facility layout is where the rubber meets the road in the design and operation of a production system. A good factory (or office) layout can provide real competitive advantage by facilitating material and information flow processes. It can also enhance employees' work life. A good service layout can be an effective "stage" for playing out the service encounter. In conclusion, here are some marks of a good layout in these environments:

### MARKS OF A GOOD LAYOUT FOR MANUFACTURING AND BACK-OFFICE OPERATIONS

- 1 Straight-line flow pattern (or adaptation).
- 2 Backtracking kept to a minimum.
- 3 Production time predictable.
- 4 Little interstage storage of materials.
- 5 Open plant floors so everyone can see what is happening.
- 6 Bottleneck operations under control.
- 7 Workstations close together.
- 8 Orderly handling and storage of materials.
- 9 No unnecessary rehandling of materials.
- 10 Easily adjustable to changing conditions.

### MARKS OF A GOOD LAYOUT FOR FACE-TO-FACE SERVICES

- 1 Easily understood service flow pattern.
- 2 Adequate waiting facilities.
- 3 Easy communication with customers.
- 4 Easily maintained customer surveillance.
- 5 Clear exit and entry points with adequate checkout capabilities.
- 6 Departments and processes arranged so that customers see only what you want them to see.
- 7 Balance between waiting areas and service areas.
- 8 Minimum walking and material movement.
- 9 Lack of clutter.
- 10 High sales volume per square foot of facility.



## KEY TERMS

**Process layout** Also called a *job-shop* or *functional layout*; a format in which similar equipment or functions are grouped together.

**Product layout** Also called a *flow-shop layout*; equipment or work processes are arranged according to the progressive steps by which the product is made.

**Group technology (cellular) layout** Groups dissimilar machines into work centers (or cells) to work on products that have similar shapes and processing requirements.

**Fixed-position layout** The product remains at one location and equipment is moved to the product.

**CRAFT (Computerized Relative Allocation of Facilities Technique)** A method to help devise good process layouts. The technique is designed to minimize material handling costs in the facility and works by iteratively exchanging pairs of departments until no further cost reductions are possible.

**Systematic layout planning (SLP)** A technique for solving process layout problems when the use of numerical flow data between departments is not practical. The technique uses an activity relationship diagram that is adjusted by trial and error until a satisfactory adjacency pattern is obtained.

**Workstation cycle time** The time between successive units coming off the end of an assembly line.

**Assembly-line balancing** The problem of assigning all the tasks to a series of workstations so that each workstation has no more than can be done in the workstation cycle time, and so that idle time across all workstations is minimized.

**Precedence relationship** The order in which tasks must be performed in the assembly process.

## SOLVED PROBLEMS

### SOLVED PROBLEM 1

A university advising office has four rooms, each dedicated to specific problems: petitions (Room A), schedule advising (Room B), grade complaints (Room C), and student counseling (Room D). The office is 80 feet long and 20 feet wide. Each room is 20 feet by 20 feet. The present location of rooms is A, B, C, D—that is, a straight line. The load summary shows the number of contacts that each adviser in a room has with other advisers in the other rooms. Assume that all advisers are equal in this value.

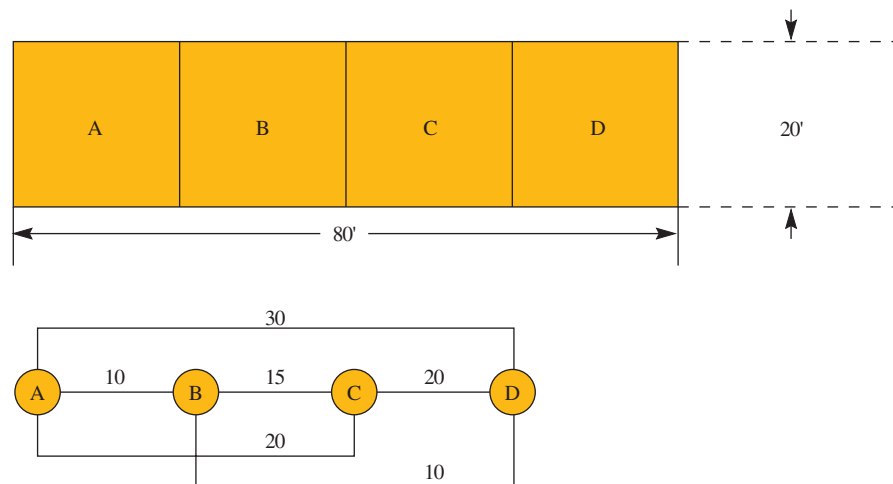
Load summary:  $AB = 10, AC = 20, AD = 30,$

$BC = 15, BD = 10, CD = 20.$

- Evaluate this layout according to the material handling cost method.
- Improve the layout by exchanging functions within rooms. Show your amount of improvement using the same method as in *a*.

#### Solution

*a.*



Using the material handling cost method shown in the toy company example, we obtain the following costs, assuming that every nonadjacency doubles the initial cost/unit distance:

$$AB = 10 \times 1 = 10$$

$$AC = 20 \times 2 = 40$$

$$AD = 30 \times 3 = 90$$

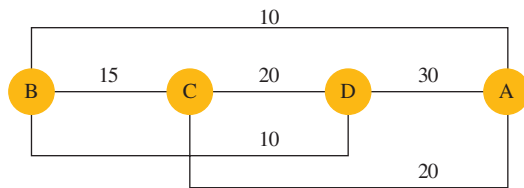
$$BC = 15 \times 1 = 15$$

$$BD = 10 \times 2 = 20$$

$$CD = 20 \times 1 = 20$$

$$\text{Current cost} = 195$$

b. A better layout would be *BCDA*.



$$\begin{aligned}
 AB &= 10 \times 3 = 30 \\
 AC &= 20 \times 2 = 40 \\
 AD &= 30 \times 1 = 30 \\
 BC &= 15 \times 1 = 15 \\
 BD &= 10 \times 2 = 20 \\
 CD &= 20 \times 1 = 20 \\
 \text{Improved cost} &= 155
 \end{aligned}$$

### SOLVED PROBLEM 2

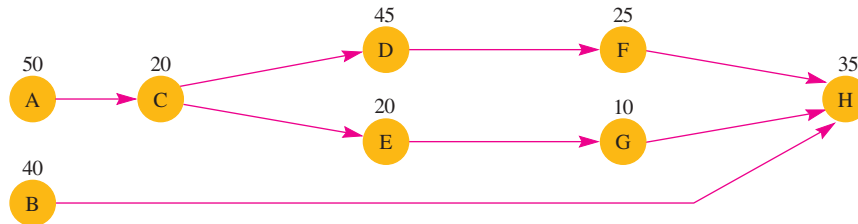
The following tasks must be performed on an assembly line in the sequence and times specified:

TASK	TASK TIME (SECONDS)	TASKS THAT MUST PRECEDE
A	50	—
B	40	—
C	20	A
D	45	C
E	20	C
F	25	D
G	10	E
H	35	B, F, G

- Draw the schematic diagram.
- What is the theoretical minimum number of stations required to meet a forecast demand of 400 units per 8-hour day?
- Use the longest-task-time rule and balance the line in the minimum number of stations to produce 400 units per day.

### Solution

a.



b. The theoretical minimum number of stations to meet  $D = 400$  is

$$N_t = \frac{T}{C} = \frac{245 \text{ seconds}}{\left( \frac{60 \text{ seconds} \times 480 \text{ minutes}}{400 \text{ units}} \right)} = \frac{245}{72} = 3.4 \text{ stations}$$

c.

	TASK	TASK TIME (SECONDS)	REMAINING UNASSIGNED TIME	FEASIBLE REMAINING TASK
Station 1	{ A	50	22	C
	{ C	20	2	None
Station 2	{ D	45	27	E, F
	{ F	25	2	None
Station 3	{ B	40	32	E
	{ E	20	12	G
	{ G	10	2	None
Station 4	H	35	37	None



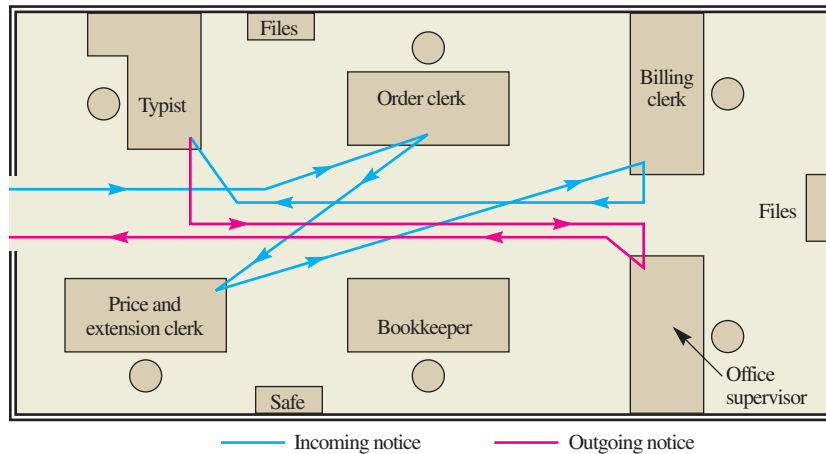
### REVIEW AND DISCUSSION QUESTIONS

- 1 What kind of layout is used in a physical fitness center?
- 2 What is the key difference between SLP and CRAFT?
- 3 What is the objective of assembly-line balancing? How would you deal with the situation where one worker, although trying hard, is 20 percent slower than the other 10 people on a line?
- 4 How do you determine the idle time percentage from a given assembly-line balance?
- 5 What information of particular importance do route sheets and process charts (discussed in Chapter 3) provide to the layout planner?
- 6 What is the essential requirement for mixed-model lines to be practical?
- 7 Why might it be difficult to develop a GT layout?
- 8 In what respects is facility layout a marketing problem in services? Give an example of a service system layout designed to maximize the amount of time the customer is in the system.
- 9 Consider a department store. Which departments probably should not be located near each other? Would any departments benefit from close proximity?
- 10 How would a flowchart help in planning the servicescape layout? What sorts of features would act as focal points or otherwise draw customers along certain paths through the service? In a supermarket, what departments should be located first along the customers' path? Which should be located last?

### PROBLEMS

1. See ISM.

- 1 The Cyprus Citrus Cooperative ships a high volume of individual orders for oranges to northern Europe. The paperwork for the shipping notices is done in the accompanying layout. Revise the layout to improve the flow and conserve space if possible.



2. See ISM. Output/day: 24B + 24D.  
 Process times: 12 min./B and  
 8 min./D. BB/DDD BB BB/DDD  
 repetitively.

- 2 An assembly line makes two models of trucks: a Buster and a Duster. Busters take 12 minutes each and Dusters take 8 minutes each. The daily output requirement is 24 of each per day. Develop a perfectly balanced mixed-model sequence to satisfy demand.
- 3 An assembly line is to operate eight hours per day with a desired output of 240 units per day. The following table contains information on this product's task times and precedence relationships:

3. a. See ISM.  
 b. 120 seconds.  
 c. See ISM.  
 d. 87.5%.

TASK	TASK TIME (SECONDS)	IMMEDIATE PREDECESSOR
A	60	—
B	80	A
C	20	A
D	50	A
E	90	B, C
F	30	C, D
G	30	E, F
H	60	G

- a. Draw the precedence diagram.
  - b. What is the workstation cycle time?
  - c. Balance this line using the longest task time.
  - d. What is the efficiency of your line balance?
- 4 The desired daily output for an assembly line is 360 units. This assembly line will operate 450 minutes per day. The following table contains information on this product's task times and precedence relationships:

TASK	TASK TIME (SECONDS)	IMMEDIATE PREDECESSOR
A	30	—
B	35	A
C	30	A
D	35	B
E	15	C
F	65	C
G	40	E, F
H	25	D, G

- 4. a. See ISM.
- b. 75 seconds.
- c. See ISM.
- d. 91.7%

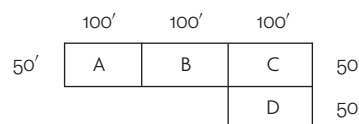
- a. Draw the precedence diagram.
  - b. What is the workstation cycle time?
  - c. Balance this line using the largest number of following tasks. Use the longest task time as a secondary criterion.
  - d. What is the efficiency of your line balance?
- 5 Some tasks and the order in which they must be performed according to their assembly requirements are shown in the following table. These are to be combined into workstations to create an assembly line. The assembly line operates  $7\frac{1}{2}$  hours per day. The output requirement is 1,000 units per day.

TASK	PRECEDING TASKS	TIME (SECONDS)	TASK	PRECEDING TASKS	TIME (SECONDS)
A	—	15	G	C	11
B	A	24	H	D	9
C	A	6	I	E	14
D	B	12	J	F, G	7
E	B	18	K	H, I	15
F	C	7	L	J, K	10

- 5. a. 27 seconds.
- b. 6 stations.
- c. 91.4%
- d. Work 45 minutes per day overtime.

- a. What is the workstation cycle time?
  - b. Balance the line using the longest task time based on the 1,000-unit forecast, stating which tasks would be done in each workstation.
  - c. For b, what is the efficiency of your line balance?
  - d. After production was started, Marketing realized that they understated demand and must increase output to 1,100 units. What action would you take? Be specific in quantitative terms, if appropriate.
- 6 An initial solution has been given to the following process layout problem. Given the flows described and a cost of \$2.00 per unit per foot, compute the total cost for the layout. Each location is 100 feet long and 50 feet wide as shown on the following figure. Use the centers of departments for distances and measure distance using metropolitan-rectilinear distance.

DEPARTMENT		A	B	C	D
A	0	10	25	55	
B		0	10	5	
C			0	15	
D				0	



- 6. \$44,500.

7. a. See ISM.  
 b. 90 seconds.  
 c. 4.56; therefore, 5 workstations.

Station	Tasks
1	a, d
2	g, j
3	c, b
4	e, h
5	f, i, k, l

See ISM.

e.  $\frac{410}{5 \times 90} = 91\%$

- f. Reduce cycle time to 81 seconds  
 (requires rebalancing line).

8. See ISM.

- 7 An assembly line is to be designed to operate  $7\frac{1}{2}$  hours per day and supply a steady demand of 300 units per day. Here are the tasks and their performance times:

TASK	PRECEDING TASKS	PERFORMANCE TIME (SECONDS)	TASK	PRECEDING TASKS	PERFORMANCE TIME (SECONDS)
a	—	70	g	d	60
b	—	40	h	e	50
c	—	45	i	f	15
d	a	10	j	g	25
e	b	30	k	h, i	20
f	c	20	l	j, k	25

- a. Draw the precedence diagram.  
 b. What is the workstation cycle time?  
 c. What is the theoretical minimum number of workstations?  
 d. Assign tasks to workstations using the longest operating time.  
 e. What is the efficiency of your line balance?  
 f. Suppose demand increases by 10 percent. How would you react to this? Assume that you can operate only  $7\frac{1}{2}$  hours per day.

- 8 S. L. P. Craft would like your help in developing a layout for a new outpatient clinic to be built in California. From analysis of another recently built clinic, she obtains the data shown in the following diagram. This includes the number of trips made by patients between departments on a typical day (shown above the diagonal line) and the numbered weights (defined in Exhibit TN5.9) between departments as specified by the new clinic's physicians (below the diagonal). The new building will be 60 feet by 20 feet.

- a. Develop an interdepartmental flow graph that minimizes patient travel.  
 b. Develop a "good" relationship diagram using systematic layout planning.  
 c. Choose either of the layouts obtained in a or b and sketch the departments to scale within the building.  
 d. Will this layout be satisfactory to the nursing staff? Explain.

DEPARTMENTS	2	3	4	5	6	AREA REQUIREMENT (SQ. FT.)
1 Reception	A 2	O 5	E 200	U 0	O 10	100
2 X-ray		E 10	I 300	U 0	O 8	100
3 Surgery			I 100	U 0	A 4	200
4 Examining rooms (5)				U 0	I 15	500
5 Lab					O 3	100
6 Nurses' station						100

9. a. 33.6 seconds.  
 b. 3.51; therefore, 4 workstations.  
 d. AB, DF, C, EG, H.  
 e. Efficiency = 70.2%  
 f. Reduce cycle time to 32 seconds  
 and work  $6\frac{2}{3}$  minutes overtime.  
 g. 1.89 hours overtime; may be better  
 to rebalance.

- 9 The following tasks are to be performed on an assembly line:

TASK	SECONDS	TASKS THAT MUST PRECEDE
A	20	—
B	7	A
C	20	B
D	22	B
E	15	C
F	10	D
G	16	E, F
H	8	G

The workday is seven hours long. Demand for completed product is 750 per day.

- a. Find the cycle time.
  - b. What is the theoretical number of workstations?
  - c. Draw the precedence diagram.
  - d. Balance the line using sequential restrictions and the longest-operating-time rule.
  - e. What is the efficiency of the line balanced as in d?
  - f. Suppose that demand rose from 750 to 800 units per day. What would you do? Show any amounts or calculations.
  - g. Suppose that demand rose from 750 to 1,000 units per day. What would you do? Show any amounts or calculations.
- 10 The Dorton University president has asked the OM department to assign eight biology professors (A, B, C, D, E, F, G, and H) to eight offices (numbered 1 to 8 in the diagram) in the new biology building.

10. a.  $8! = 40,320$ .

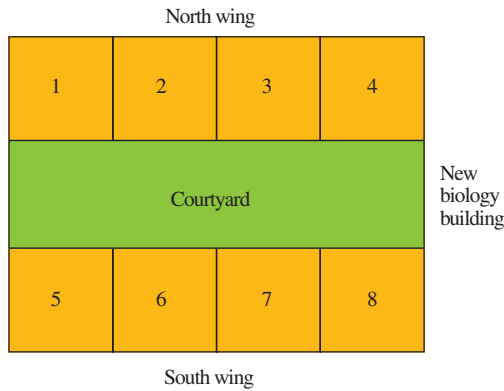
b. Layout I:

$$\text{TMHC} = 2(10) + 5(15) + 3(15) + 2(20) + 3(18) + 4(30) + 1(10) + 1(1) + 4(10) = 422$$

Layout II:

$$\text{TMHC} = 2(25) + 5(15) + 3(10) + 2(18) + 3(20) + 4(30) + 1(10) + 1(18) + 4(10) = 439$$

Layout I is optimal.



The following distances and two-way flows are given:

DISTANCES BETWEEN OFFICES (FEET)								TWO-WAY FLOWS (UNITS PER PERIOD)									
	1	2	3	4	5	6	7	8		A	B	C	D	E	F	G	H
1	—	10	20	30	15	18	25	34	A	—	2	0	0	5	0	0	0
2		—	10	20	18	15	18	25	B		—	0	0	0	3	0	2
3			—	10	25	18	15	18	C			—	0	0	0	0	3
4				—	34	25	18	15	D				—	4	0	0	0
5					—	10	20	30	E					—	1	0	0
6						—	10	20	F						—	1	0
7							—	10	G							—	4
8								—	H								—

- a. If there are no restrictions (constraints) on the assignment of professors to offices, how many alternative assignments are there to evaluate?
- b. The biology department has sent the following information and requests to the OM department:

Offices 1, 4, 5, and 8 are the only offices with windows.

A must be assigned Office 1.

D and E, the biology department co-chairpeople, must have windows.

H must be directly across the courtyard from D.

A, G, and H must be in the same wing.

F must *not* be next to D or G or directly across from G.

Find the optimal assignment of professors to offices that meets all the requests of the biology department and minimizes total material handling cost. You may use the path flow list as a computational aid.

PATH	FLOW	PATH	FLOW	PATH	FLOW	PATH	FLOW	PATH	FLOW
A-B	2	B-C	0	C-D	0	D-E	4	E-F	1
A-C	0	B-D	0	C-E	0	D-F	0	E-G	0
A-D	0	B-E	0	C-F	0	D-G	0	E-H	0
A-E	5	B-F	3	C-G	0	D-H	0	F-G	1
A-F	0	B-G	0	C-H	3			F-H	0
A-G	0	B-H	2					G-H	4
A-H	0								

11. a.

1	2	3	4
8	7	6	5

b.

ADJACENCY	FLOW	DISTANCE	FLOW × DISTANCE
1-2	35	10	350
1-5	1	40	40
2-3	30	10	300
2-7	4	10	40
3-4	45	10	450
3-5	5	20	100
4-5	30	10	300
4-7	3	30	90
5-6	30	10	300
6-7	20	10	200
7-8	15	10	150
		Total	2,320

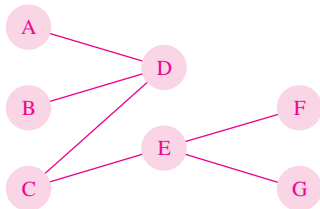
12. a. 30 seconds.

b. 100 percent efficient.

c. Duplicate station 3.

90 percent efficient.

13. a.



b. 4 minutes.

c. Station 1 (A and C).

Station 2 (E).

Station 3 (B and F).

Station 4 (D and G).

d.  $15/16 = .9375$ .

11 The flow of materials through eight departments is shown in the table below. Even though the table shows flows into and out of the different departments, assume that the direction of flow is not important. In addition, assume that the cost of moving material depends only on the distance moved.

	DEPARTMENTS							
	1	2	3	4	5	6	7	8
1	—	20						
2	15	—	25				4	
3		5	—	40	5			
4			5	—	10			
5	1			20	—	30		
6						—	20	
7				3			—	10
8							5	—

a. Construct a schematic layout where the departments are arranged on a 2 × 4 grid with each cell representing a 10 × 10-meter square area.

b. Evaluate your layout using a distance-times-flow measure. Assume that distance is measured rectilinearly (in this case departments that are directly adjacent are 10 meters apart and those that are diagonal to one another are 20 meters apart).

12 A firm uses a serial assembly system and needs answers to the following:

a. A desired output of 900 units per shift (7.5 hours) is desired for a new processing system. The system requires product to pass through four stations where the work content at each station is 30 seconds. What is the required cycle time for such a system?

b. How efficient is your system with the cycle time you calculated?

c. Station 3 changes and now requires 45 seconds to complete. What will need to be done to meet demand (assume only 7.5 hours are available)? What is the efficiency of the new system?

### ADVANCED PROBLEM

13 Francis Johnson's plant needs to design an efficient assembly line to make a new product. The assembly line needs to produce 15 units per hour and there is room for only four workstations. The tasks and the order in which they must be performed are shown in the following table. Tasks cannot be split, and it would be too expensive to duplicate any task.

TASK	TASK TIME (MINUTES)	IMMEDIATE PREDECESSOR
A	1	—
B	2	—
C	3	—
D	1	A, B, C
E	3	C
F	2	E
G	3	E

- a. Draw the precedence diagram.
- b. What is the workstation cycle time?
- c. Balance the line so that only four workstations are required. Use whatever method you feel is appropriate.
- d. What is the efficiency of your line balance?

## CASE: SOTERIOU'S SOUVLAKI

● ● ● Soteriou looks up from cleaning the floor—the lights are on. This means that the power has finally been hooked up, and soon his restaurant will reopen here in its new location.

Soteriou's Souvlaki is typical of many of the small dining establishments scattered around the perimeter of the university. Specializing in Greek cuisine—souvlaki (lamb kabobs), gyros, tiropita (cheese-filled pastries), and baklava (a honey and pistachio nut dessert)—the restaurant has been very popular with the student body.

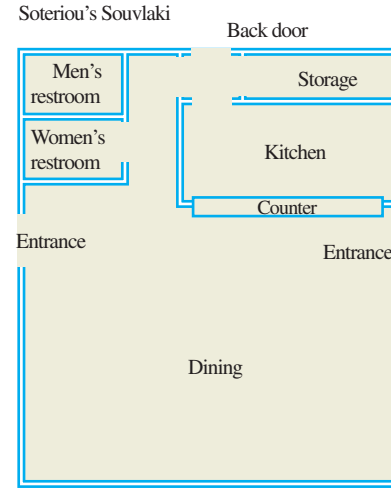
The operations are similar to those of most fast-food restaurants. Customers enter and queue near the register to place their orders and pay. Food is prepared and given to the customer over the main counter. Drinks are self-serve, and the tables are bused by the customers as they leave. The kitchen is normally run by Soteriou with help from an assistant working the cash register.

Until recently, Soteriou's had been located in a local food court, but earthquake damage, space constraints, and deteriorating sanitary conditions prompted him to move the restaurant to these new quarters. The new facility is a small, free-standing building, formerly a hamburger joint. Although the previous owners have removed all equipment and tables, the large fixed service counter remains, physically marking out the kitchen and dining areas. (See the accompanying figure.)

Aware of students' growing health consciousness (and possibly a little heady with the extra floor space in the new building), Soteriou has decided to add a self-service salad bar to the new restaurant. The salad bar will be much like those in other restaurants, but with a more Mediterranean flair.

The new kitchen does not appear to be much larger than the old one, though it is narrower. To prepare his Greek specialties in this new kitchen, Soteriou will need a grill/oven, a storage refrigerator, a preparation table (with hot and cold bins for the condiments, side dishes, and pita bread), a vertical spit broiler for the gyros meat, and a display case to hold the tiropitas, baklava, and cups for the self-serve drink machines.

The new dining area will include smoking and nonsmoking seating, the salad bar, self-serve drink machines, and an area for the



register queues. Of course, the location of the cash register will be important to both the kitchen and dining area layouts.

Leaning against the mop handle, Soteriou looks around the clean, empty floor. Eager to open the new location, he has already ordered all the necessary equipment, but where will he put it? Unfortunately, the equipment will be arriving tomorrow morning. Once it is placed by the delivery crew, it will be hard for Soteriou and his assistant to rearrange it by themselves.

### QUESTION

The matrices in Exhibits TN5.17 and TN5.18 show the importance of proximity for the kitchen equipment and dining area features. Use systematic layout planning (with numerical reference weightings) to develop a floor layout for the kitchen and the dining area of Soteriou's Souvlaki.

SOURCE: THIS CASE WAS PREPARED BY DOUGLAS STEWART. IT IS NOT INTENDED TO SHOW PROPER OR IMPROPER HANDLING OF FOOD.

### EXHIBIT TN5.17

	GRILL	PREP. TABLE	REFRIG.	VERTICAL BROILER	DISPLAY CASE
Cash register	X	A	X	U	A
Grill	—	A	A	U	E
Prep. table	—	—	I	A	U
Refrigerator	—	—	—	U	X
Vertical broiler	—	—	—	—	U
Display case	—	—	—	—	—

### The Kitchen

## EXHIBIT TN5.18

	NO SMOKING	SMOKING	DRINKS	SALAD BAR	WAITING AREA
<b>The Dining Area</b>					
Cash register	U	U	I	I	A
No smoking	—	X	E	E	U
Smoking	—	—	I	I	U
Drinks	—	—	—	U	U
Salad bar	—	—	—	—	X
Waiting area	—	—	—	—	—

## EXHIBIT TN5.19

	JOB	AVERAGE TIME TO PERFORM (SECONDS)
<b>State Automobile License Renewals Process Times</b>		
	1. Review renewal application for correctness	15
	2. Process and record payment	30
	3. Check file for violations and restrictions	60
	4. Conduct eye test	40
	5. Photograph applicant	20
	6. Issue temporary license	30

## CASE: STATE AUTOMOBILE LICENSE RENEWALS

Henry Coupe, manager of a metropolitan branch office of the state department of motor vehicles, attempted to perform an analysis of the driver's license renewal operations. Several steps were to be performed in the process. After examining the license renewal process, he identified the steps and associated times required to perform each step as shown in Exhibit TN5.19.

Coupe found that each step was assigned to a different person. Each application was a separate process in the sequence shown in the exhibit. Coupe determined that his office should be prepared to accommodate the maximum demand of processing 120 renewal applicants per hour.

He observed that the work was unevenly divided among the clerks, and that the clerk who was responsible for checking violations tended to shortcut her task to keep up with the other clerks. Long lines built up during the maximum demand periods.

Coupe also found that jobs 1, 2, 3, and 4 were handled by general clerks who were each paid \$12.00 per hour. Job 5 was performed by a photographer paid \$16 per hour. Job 6, the issuing of temporary licenses, was required by state policy to be handled by a uniformed motor vehicle officer. Officers were paid \$18 per hour, but they could be assigned to any job except photography.

A review of the jobs indicated that job 1, reviewing the application for correctness, had to be performed before any other step. Similarly, job 6, issuing the temporary license, could not be performed until all the other steps were completed. The branch offices were charged \$20 per hour for each camera to perform photography.

Coupe was under severe pressure to increase productivity and reduce costs, but he was also told by the regional director of the department of motor vehicles that he had better accommodate the demand for renewals. Otherwise, "heads would roll."

## QUESTIONS

- 1 What is the maximum number of applications per hour that can be handled by the present configuration of the process?
- 2 How many applications can be processed per hour if a second clerk is added to check for violations?
- 3 Assuming the addition of one more clerk, what is the maximum number of applications the process can handle?
- 4 How would you suggest modifying the process to accommodate 120 applications per hour?

SOURCE: P. R. OLSEN, W. E. SASSER, AND D. D. WYCKOFF, *MANAGEMENT OF SERVICE OPERATIONS: TEXT, CASES, AND READINGS*, pp. 95–96. © 1978. REPRINTED BY PERMISSION OF PRENTICE HALL, ENGLEWOOD CLIFFS, NEW JERSEY.

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## FOOTNOTES

- 1 For a discussion of CRAFT and other methods, see R. L. Francis and J. A. White, *Facility Layout and Location: An Analytical Approach* (Englewood Cliffs, NJ: Prentice Hall, 1974).
- 2 R. Johnson, "Spacecraft for Multi-Floor Layout Planning," *Management Science* 28, no. 4 (April 1982), pp. 407–17.
- 3 See R. Muther and J. D. Wheeler, "Simplified Systematic Layout Planning," *Factory* 120, nos. 8, 9, 10 (August, September, October 1962), pp. 68–77, 111–19, 101–13.
- 4 The workstation cycle time used in this calculation should be the actual cycle time used by the assembly line.
- 5 Y. Monden, *Toyota Production System: Practical Approach to Production Management* (Atlanta, GA: Industrial Engineering and Management Press, Institute of Industrial Engineers, 1983), p. 208.
- 6 R. J. Schonberger, *World Class Manufacturing* (New York: Free Press, 1986), p. 112.
- 7 M. S. Sommers and J. B. Kernan, "A Behavioral Approach to Planning, Layout and Display," *Journal of Retailing*, Winter 1965–66, pp. 21–27.
- 8 M. J. Bitner, "Servicescapes: The Impact of Physical Surroundings on Customers and Employees," *Journal of Marketing* 56 (April 1992), pp. 57–71.
- 9 R. Norman, *Service Management*, 2nd ed. (New York: John Wiley & Sons, 1991), p. 28.