3

FLOW, SPACE, AND ACTIVITY RELATIONSHIPS

3.1 INTRODUCTION

In determining the requirements of a facility, three important considerations are flow, space, and activity relationships. **Flow** depends on lot sizes, unit load sizes, material handling equipment and strategies, layout arrangement, and building configuration. **Space** is a function of lot sizes, storage system, production equipment type and size, layout arrangement, building configuration, housekeeping and organization policies, material handling equipment, and office, cafeteria, and restroom design. **Activity relationships** are defined by material or personnel flow, environmental considerations, organizational structure, continuous improvement methodology (teamwork activities), control issues, and process requirements.

As indicated in previous chapters, facilities planning is an iterative process. The facilities planning team or the facilities planner needs to interact not only with product, process, and schedule designers but also with top management to identify alternative issues and strategies to consider in the analysis (i.e., lot sizes, storage-handling strategies, office design, organizational structure, environmental policy).

The facilities planner also needs to continually investigate the impact of modern manufacturing approaches on flow, space, and activity relationships. For example, concepts like decentralized storage, multiple receiving docks, deliveries to points of use, decentralized management and support functions, quality at the source, cellular manufacturing, lean organizational structures, and small lot purchasing and production could challenge traditional activity relationships and reduce flow and space requirements.

Some of the traditional activity relationships to be challenged are centralized offices, a centralized storage area, a single receiving area, and a centralized rework area. Flow requirements are reduced with external and internal deliveries to points of use, storage of inventories in decentralized storage areas close to points of use, movement of material controlled by pull strategies with kanbans, and manufacturing cells. Less space is required for inventories; production, storage, and handling equipment; offices; parking lots; and cafeterias.

Different procedures, forms, and tables to determine flow, space, and activity relationships are covered in this chapter. Additionally, layout types are explained in Section 3.2 (including a consideration of cellular manufacturing), the logistics system is described in Section 3.3, and visual management is covered in Section 3.7. Activity relationships are considered in Section 3.3. Sections 3.4 through 3.6 address flow relationships. Space relationships are the subject of Section 3.7.

3.2 DEPARTMENTAL PLANNING

To facilitate the consideration of flow, space, and activity relationships, it is helpful to introduce the subject of departmental planning. At this point in the facilities planning process, we are not so concerned with organizational entities. Rather, we are interested in forming **planning departments.** Planning departments can involve production, support, administrative, and service areas (called production, support, administrative, and service planning departments).

Production planning departments are collections of workstations to be grouped together during the facilities layout process. The formulation of organizational units should parallel the formation of planning departments. If for some reason the placement of workstations violates certain organizational objectives, then modifications should be made to the layout.

As a general rule, planning departments may be determined by combining workstations that perform "like" functions. The difficulty with this general rule is the definition of the term "like." "Like" could refer to workstations performing operations on similar products or components or to workstations performing similar processes.

Depending on product volume-variety, production planning departments can also be classified as product, fixed materials location, product family (or group technology), and process planning departments (see Figure 3.1). As examples of production planning departments that consist of a combination of workstations performing operations on similar products or components, consider engine block production line departments, aircraft fuselage assembly departments, and uniform flat sheet metal departments. As described in Chapter 6, these are referred to as product planning departments because they are formed by combining workstations that produce similar products or components. **Product planning departments** may be further subdivided by the characteristics of the products being produced.

Suppose a large, stable demand for a standardized product, like an engine block, is to be met by production. In such a situation, the workstations should be combined into a planning department so that all workstations required to produce the product are combined. The resulting product planning department may be referred to as **production line department.**

Next, suppose a low, sporadic demand exists for a product that is very large and awkward to move, for example, an aircraft fuselage. The workstations should

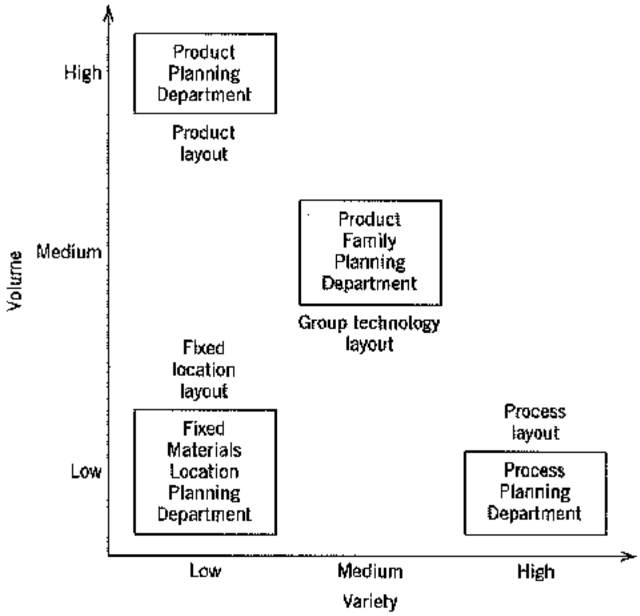


Figure 3.1 Volume-variety layout classification.

be combined into a planning department that includes all workstations required to produce the product and the staging area. This type of product planning department may be referred to as a **fixed materials location department.**

A third type of product planning department may be identified when there exists a medium demand for a medium number of similar components. Similar components form a family of components that, in group technology terminology, may be produced via a "group" of workstations. The combination of the group of workstations results in a product planning department that may be referred to as a **product family department.**

Examples of planning departments based on the combination of workstations containing "similar" processes are metal cutting departments, gear cutting departments, and hobbing departments. Such planning departments are referred to as **process departments** because they are formed by combining workstations that perform "similar" processes.

The difficulty in defining process departments is in the interpretation of the word "similar." For example, in a facility specializing in the production of gears, gear hobbing, gear shaping, and shaft turning might not be considered similar and each might be grouped into their own planning departments. However, in a facility producing mechanical switching mechanisms, these same processes might be grouped into two, not three, planning departments: a gear cutting department, containing similar gear hobbing and shaping processes, and a turning department. Even more extreme, in a furniture facility, all metalworking might take place in a metalworking planning department. Therefore, the same three processes might be seen to be similar and grouped into a single process planning department. The determination of which workstations are to be considered similar depends on not only the workstations but also the relationships among workstations and between workstations and the overall facility.

Most facilities consist of a mixture of product and process planning departments. For example, in a facility consisting of mainly process planning departments producing a large variety of rather unrelated products, the detailed placement of individual workstations within a process department might be based on a product planning department philosophy. (As an illustration, all painting activities might be grouped together in a painting process department. However, the layout of the painting department can consist of a painting line designed on the basis of a product planning department philosophy). Conversely, in a facility consisting mainly of product planning departments producing a few, high-volume, standard products, it would not be surprising to find several "specialized" components produced in process planning departments.

A systematic approach should be used in combining workstations into departments. Each product and component should be evaluated and the best approach determined for combining workstations into planning departments. Table 3.1 summarizes the bases for combining workstations into planning departments.

Support, administrative, and service planning departments include offices and areas for storage, quality control, maintenance, administrative processes, cafeterias, restrooms, lockers, and so on. Traditionally, support, administrative, and service planning departments have been treated as "process" departments (similar activities performed within a certain area).

Organizations using modern manufacturing approaches are combining production, support, administrative, and service planning departments to create integrated production-support-administrative-service planning departments. For example, a manufacturing cell dedicated to the production of a family of parts and with dedicated support and administrative personnel and services (e.g., maintenance, quality, materi-

Table 3.1 ***Procedural Guide for Combining Workstations in Planning Departments***

If the Product Is	The Type of Planning Department Should Be	And the Method of Combining Workstations into Planning Departments Should Be
Standardized and has a large stable demand.	Production line, product department.	Combine all workstations required to produce the product.
Physically large, awkward to move, and has a low sporadic demand	Fixed materials location, product department	Combine all workstations required to produce the product with the area required for staging the product
Capable of being grouped into families of similar parts that may be produced by a group of workstations	Product family, product department	Combine all workstations required to produce the family of products
None of the above	Process department	Combine identical work stations into initial planning departments and attempt to combine similar initial planning departments without obscuring important interrelationships within departments

als, engineering, tooling, purchasing, management, vending machines, restrooms, lockers) could be an integrated planning department.

Many companies train their operators in most of the support, administrative, and management functions so that they can become autonomous. In these cases, the operators (called technicians or associates) plus a facilitator-coordinator can manage the operation of the manufacturing cell with minimum external support.

Activity relationships and flow and space requirements in a facility with self-managing teams will be totally different than in a facility with traditional production, support, and administrative planning departments (less material, personnel, tooling, and paperwork flow requirements and less space needs).

Many companies using modern manufacturing approaches are converting their facilities to combinations of product and product family (group technology) planning departments. Group technology layouts are combined with *just-in-time* (JIT) concepts in cellular manufacturing arrangements. A more detailed explanation of group technology and cellular manufacturing follows.

Manufacturing Cells

Product family or group technology departments aggregate medium volume-variety parts into families based on similar manufacturing operations or design attributes. Machines required to manufacture the part family are grouped together to form a "cell."

Cellular manufacturing [1, 2, 3, 10, 31, 46] involves the use of *manufacturing cells.* The manufacturing cells can be formed in a variety of ways, with the most popular involving grouping of machines, employees, materials, tooling, and material handling and storage equipment to produce families of parts. Cellular manufacturing became quite popular in the late 1900s and is often associated with just-in-time (JIT) [19, 39, 40, 45], total quality management (TQM) [8, 13, 21, 22, 23, 24, 32, 38, 52, 53, 54], and lean manufacturing concepts and techniques [37, 51, 55]. (For additional information on lean manufacturing, explore the Web site for the Lean Enterprise Institute, http://www.lean.org/.)

Successful implementation of manufacturing cells requires addressing selection, design, operation, and control issues. Selection refers to the identification of machine and part types for a particular cell. Cell design refers to layout and production and material handling requirements. Operation of a cell involves determining lot sizes, scheduling, number of operators, type of operators, and type of production control (push vs. pull). Finally, control of a cell refers to the methods used to measure the performance of the cell.

Several approaches have been proposed to address selection issues of manufacturing cells. The most popular approaches are classification and coding, production flow analysis, clustering techniques, heuristic procedures, and mathematical models [1, 2, 5, 7, 14, 16, 17, 25, 26, 28, 30, 31, 44, 46, 58].

Classification is the grouping of parts into classes or part families based on design attributes and coding is the representation of these attributes by assigning numbers or symbols to them.

Production flow analysis [5] is a procedure for forming part families by analyzing the operation sequences and the production routing of a part or component through the plant.

Clustering methodologies are used to group parts together so they can be processed as a family [7, 14, 16, 20, 26, 28, 31, 46, 58]. This methodology lists parts and machines in rows and columns, and interchanges them based on some criterion like similarity coefficients. For example, the *direct clustering algorithm* (DCA) [7] forms clustered groups based on sequentially moving rows and columns to the top and left.

Several heuristic procedures have been developed for the formation of cells [2, 17, 20, 25, 46]. One developed by Ballakur and Steudel [2] assigns machines to cells based on work load factors and assigns parts to cells based on the percentage of operations of a part processed within a cell.

Several other mathematical models have also been developed [1, 30, 46, 47]. One proposed by Al-Qattan [1] to form machine cells and families of parts is based on the branch and bound method.

Singh and Rajamani [46] present a wide range of algorithms for forming manufacturing cells. Among those they consider are bond energy (BEA), rank-order clustering (ROC and ROC2), modified rank-order clustering (MODROC), direct clustering (DCA), cluster identification (CIA), single linkage clustering (SLC), and linear cell clustering (LCC) algorithms. In addition, they consider the use of mathematical programming approaches, including formulating the cell formation problem as a p-median covering problem, an assignment problem, a quadratic assignment problem, and a nonlinear optimization problem. Although of less practical interest, they also show how simulated annealing, genetic algorithms, and neural networks can be used to address the problem of cell formation.

It is important to note that the formation of cells is seldom the responsibility of the facilities planner. Instead, it is typically performed by the manufacturing engineer in conjunction with the production planner. Cell formation, inventory control, demand forecasting, assembly line balancing, and a host of other subjects are of great interest and significance to facilities planning. However, they are seldom (if ever) found in the domain of the facilities planner. For that reason, at most, we mention them briefly, if at all.

Because cellular manufacturing is increasing in importance and application and because it can significantly impact the facilities layout, we have chosen to introduce the subject through the following examples. For illustrative purposes, we will limit our treatment to the use of the direct clustering algorithm developed by Chan and Milner [7]. The DCA methodology is based on a machine-part matrix in which 1 indicates that the part requires processing by the indicated machine; a blank indicates the machine is not used for the particular part. The DCA methodology consists of the following steps:

Step 1. Order the rows and columns. Sum the 1s in each column and in each row of the machine-part matrix. Order the rows (top to bottom) in descending order of the number of 1s in the rows and order the columns (left to right) in ascending order of the number of 1s in each. Where ties exist, break the ties in descending numerical sequence.

Step 2. Sort the columns. Beginning with the first row of the matrix, shift to the left of the matrix all columns having a 1 in the first row. Continue the process row-by-row until no further opportunity exists for shifting columns.

Step 3. Sort the rows. Column-by-column, beginning with the leftmost column, shift rows upward when opportunities exist to form blocks of 1s. (It

	Machine #					
Part #	1	2	3	4	5	# of 1s
1	1		1			2
2	1					1
3		1		1	1	3
4	1		1			2
5		1				1
6				1	1	2
# of 1s	3	2	2	2	2	

Figure 3.2 Machine-part matrix for Example 3.1.

should be noted that performing the column and row sortation is facilitated by using spreadsheets, such as Excel.)

Step 4. Form cells. Look for opportunities to form cells such that all processing for each part occurs in a single cell.

Example 3.1

Consider the machine-part matrix shown in Figure 3.2 for a situation involving 6 parts to be processed; 5 machines are required. As noted above, the entries in the matrix indicate the machine-part combination that is required; for example, part 1 requires machining by machines 1 and 3.

Applying step 1 of the direct clustering algorithm, as shown in Figure 3.3, the rows are ranked in descending order of the number of 1s and ties are broken in descending numerical sequence. The row-ordered sequence of the part numbers is {3, 6, 4, 1, 5, 2}. Likewise, the columns are arranged in ascending order of the number of 1s, with ties broken in descending numerical order; the resulting column-ordered sequence of the machine numbers is {5, 4, 3, 2, 1}. The ordered machine-part matrix is shown in Figure 3.3.

Step 2 involves sorting the columns to move toward the left all columns having a 1 in the first row, which represents part 3. Since the columns for machines 5 and 4 are already located to the left of the matrix, only the column for machine 2 can be shifted. That is the only column shift required for this example. The resulting column-sorted machine-part matrix is depicted in Figure 3.4.

Step 3 consists of sorting the rows by moving upward rows having a 1 in the first column that are not already located as far toward the top of the matrix as possible. Since

	Machine #					
Part #	5	4	3	2	1	# of 1s
3	1	1		1		3
6	1	1				2
4			1		1	2
1			1		1	2
5				1		1
2					1	1
# of 1s	2	2	2	2	3	

Figure 3.3 Ordered machine-part matrix.

	Machine #					
Part #	5	4	2	3	1	# of 1s
3	1	1	1			3
6	1	1				2
4				1	1	2
1				1	1	2
5			1			1
2					1	1
# of 1s	2	2	2	2	3	

Figure 3.4 Column-sorted machine-part matrix.

Part # \ Machine #	5	4	2	3	1	# of 1s
3	1	1	1			3
6	1	1				2
5			1			1
4				1	1	2
1				1	1	2
2					1	1
# of 1s	2	2	2	2	3	

Figure 3.5 Row-sorted machine-part matrix.

Part # \ Machine #	5	4	2	3	1
3	1	1	1		
6	1	1			
5			1		
4				1	1
1				1	1
2					1

Figure 3.6 Formation of two cells.

none can be shifted further for either machines 5 or 4, the first row to be moved is that for part 5, based on its processing requirement with machine 2. The resulting row-sorted machine-part matrix is shown in Figure 3.5.

In this case, as shown in Figure 3.6, the machines can be grouped into 2 cells, with parts 3, 5 and 6 being processed in a cell made up of machines 2, 4, and 5 and with parts 1, 2, and 4 being processed in a cell consisting of machines 1 and 3. Unfortunately, it is not always the case that cells can be formed without conflicts existing, as illustrated in Example 3.2.

Example 3.2

Consider the machine-part matrix shown in Figure 3.7. Applying the DCA methodology results in the ordered machine-part matrix shown in Figure 3.8. Notice that no further improvement will occur by performing step 2 or step 3. Also, notice that because machine 2 is needed for parts 3 and 5, a conflict exists; alternatively, we could say that because part 5 requires machines 2 and 3, a conflict exists. As shown in Figure 3.9a, two cells can be formed, one consisting of machines 4 and 5 and the other consisting of machines 1, 2, and 3, with the machining required for part 3 on machine 2 to be resolved. Alternatively, as shown in Figure 3.9b, machines 2, 4, and 5 can form a cell and machines 1 and 3 can form another cell; in this case, the machining of part 5 on machine 2 must be resolved. Finally, as shown in Figure 3.9c, the cellular formation as given in Figure 3.9b can be used, but with part 5 assigned to the cell consisting of machines 2, 4, and 5; as shown, the processing of part 5 on machine 3 would need to be resolved for this cellular formation.

Examining Figure 3.9a, a possible solution comes to mind. Depending on the facility, if machines 2 and 3 can be located relatively close to one another, albeit in

Part # \ Machine #	1	2	3	4	5	# of 1s
1	1		1			2
2	1					1
3		1		1	1	3
4	1		1			2
5		1	1			2
6				1	1	2
# of 1s	3	2	3	2	2	

Figure 3.7 Machine-part matrix.

Part # \ Machine #	5	4	2	3	1	# of 1s
3	1	1	1			3
6	1	1				2
5			1	1		1
4				1	1	2
1				1	1	2
2					1	1
# of 1s	2	2	2	2	3	

Figure 3.8 Ordered machine-part matrix.

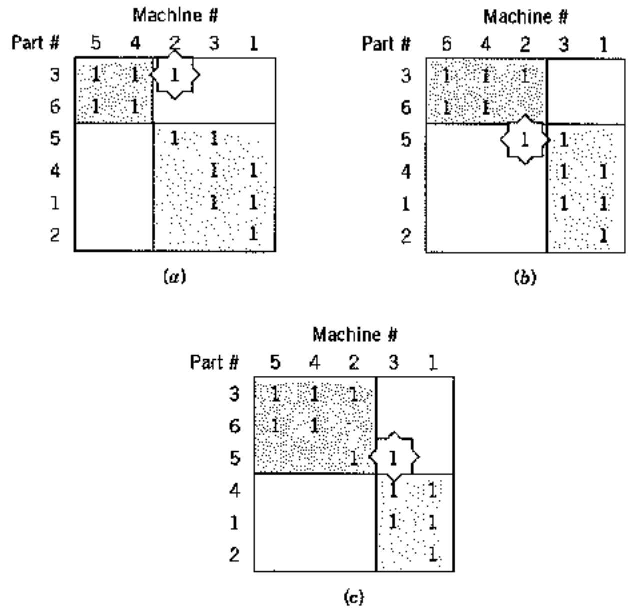


Figure 3.9 Formation of cells with "bottleneck" machine 2 or 3.

different cells, then part 5 could be processed by machines on the "boundaries" of the cells.

Another option is to duplicate machine 2 and place it in each cell, as shown in Figure 3.10a. Alternatively, as shown in Figure 3.10b, machine 3 could be duplicated and placed in each cell. The tradeoff between having a part travel to both cells versus having to duplicate a machine depends on many factors, not the least of which is the overall utilization of the machine to be duplicated. For example, if the processing requirements for parts 3 and 5 are such that multiple machines of type 2 are required, then the conflict involving the formation of cells disappears or is minimized; likewise, if the volume of processing required for part 5 fully utilizes machine 3, then providing another machine 3 to process parts 2 and 4 is a natural means of resolving the conflict.

The situation depicted in Example 3.2 points out a weakness of several of the cell formation algorithms. Namely, the simplest ones do not take into account machine utilization and the possibilities of multiple machines of a given type being required.

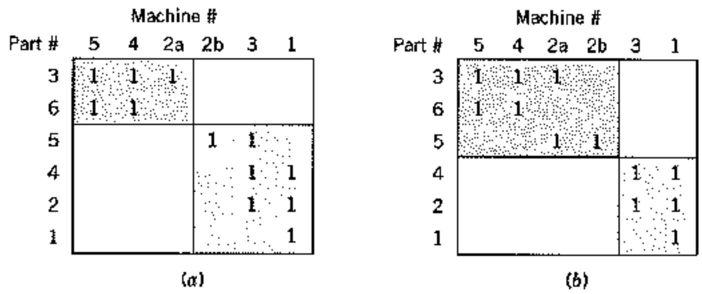


Figure 3.10 Formation of cells with duplicate of (*a*) machine 2 and (*b*) machine 3.

Example 3.3

Consider the machine-part matrix for a situation involving 13 parts and 26 machines given in Figure 3.11. Applying the DCA algorithm yields the results depicted in Figures 3.12 through 3.14. As with the previous example, step 3 was not required, since shifting rows would not improve the formation of cells. From Figure 3.14, it is evident that only 2 "pure" cells can be formed, due to machines 1 and 3. However, if multiple machines are needed, such that Figure 3.14c is feasible, then 3 "pure" cells can be formed for this example. As noted in the previous example, an alternative approach is to form the cells as shown in Figure 3.14b and locate machines 1 and 3 at the boundary between the cells A and B to minimize material handling between cells.

Using cellular manufacturing terminology, machines 1 and 3 are called "bottleneck" machines since they bind two cells together. When bottleneck conditions exist, as discussed previously, one can attempt to minimize the disruptive effects of having parts from other cells intrude on neighboring cells by locating bottleneck machines at the boundary between cells. Alternatively, the parts that require processing by the bottleneck machines could be reexamined to determine if alternative processing approaches can be used. Perhaps parts can be redesigned so that other machines can

	Machine #																										
Part #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	# of 1s
1	1		1		1			1	1		1						1	1				1					9
2	1		1		1			1	1		1						1	1				1					9
3	1		1		1			1	1		1						1	1				1					9
4	1		1		1			1	1		1						1	1				1					9
5	1		1			1		1	1		1						1	1				1					9
6	1		1			1		1	1		1						1	1				1					9
7	1		1			1		1	1		1						1	1				1					9
8		1		1			1			1		1							1	1			1				8
9		1		1			1			1		1							1	1			1				8
10	1		1										1	1	1	1					1			1	1	1	10
11	1		1										1	1	1	1					1			1	1	1	10
12	1		1										1	1	1	1					1			1	1	1	10
13	1		1										1	1	1	1					1			1	1	1	10
# of 1s	11	2	11	2	4	3	2	7	7	2	7	2	4	4	4	4	7	7	2	2	4	7	2	4	4	4	

Figure 3.11 Machine-part matrix.

	Machine #																										
Part #	23	20	19	12	10	7	4	2	6	26	25	24	21	16	15	14	13	5	22	18	21	17	11	9	3	1	# of 1s
13										1	1	1	1	1	1	1	1								1	1	10
12										1	1	1	1	1	1	1	1								1	1	10
11										1	1	1	1	1	1	1	1								1	1	10
10										1	1	1	1	1	1	1	1								1	1	10
7									1										1	1	1	1	1	1	1	1	9
6									1										1	1	1	1	1	1	1	1	9
5									1										1	1	1	1	1	1	1	1	9
4																		1	1	1	1	1	1	1	1	1	9
3																		1	1	1	1	1	1	1	1	1	9
2																		1	1	1	1	1	1	1	1	1	9
1																		1	1	1	1	1	1	1	1	1	9
9	1	1	1	1	1	1	1	1																			8
8	1	1	1	1	1	1	1	1																			8
# of 1s	2	2	2	2	2	2	2	2	3	4	4	4	4	4	4	4	4	4	7	7	7	7	7	7	11	11	

Figure 3.12 Ordered machine-part matrix.

	Machine #																										
Part #	3	1	26	25	24	21	16	15	14	13	22	18	17	11	9	8	6	5	23	20	19	12	10	7	4	2	# of 1s
13	1	1	1	1	1	1	1	1	1	1																	10
12	1	1	1	1	1	1	1	1	1	1																	10
11	1	1	1	1	1	1	1	1	1	1																	10
10	1	1	1	1	1	1	1	1	1	1																	10
7	1	1									1	1	1	1	1	1	1										9
6	1	1									1	1	1	1	1	1	1										9
5	1	1									1	1	1	1	1	1	1										9
4	1	1									1	1	1	1	1	1		1									9
3	1	1									1	1	1	1	1	1		1									9
2	1	1									1	1	1	1	1	1		1									9
1	1	1									1	1	1	1	1	1		1									9
9																			1	1	1	1	1	1	1	1	8
8																			1	1	1	1	1	1	1	1	8
# of 1s	11	11	4	4	4	4	4	4	4	4	7	7	7	7	7	7	3	4	2	2	2	2	2	2	2	2	

Figure 3.13 Column-sorted machine-part matrix.

be used; in the best of all possible worlds, the part would be redesigned for processing by machines already assigned to the cell! If no better alternative is available, then the possibility of outsourcing the processing of the part should be considered.

In the example, every part processed in the first cell is also processed in the second cell. Hence, it is unlikely that the conflicts can be resolved by redesigning or outsourcing certain manufacturing steps for the parts. As noted previously, the viability of adding multiple machines of types 1 and 3 should be explored.

The cellular manufacturing system can be designed once the cells have been formed. The system can be either decoupled or integrated. Typically, a decoupled cellular manufacturing system uses a storage area to store part families after a cell has finished operating on them. Whenever another cell or department is to operate on the parts, they are retrieved from the storage area. Thus, the storage area acts as a decoupler making the cells and departments independent of each other. Unfortunately, this leads to excessive material handling and poor responsiveness.

To eliminate such inefficiencies, many companies use an integrated approach to the design and layout of cellular manufacturing systems. Here, cells and departments are linked through the use of kanbans or cards.

Shown in Figure 3.15, production cards (POK) are used to authorize production of more components or subassemblies and withdrawal cards (WLK) are used to authorize delivery of more components, subassemblies, parts, and raw materials.

To understand what kanbans are, the motivation behind their development needs to be discussed. Traditionally, when a workstation completes its set of operations, it pushes its finished parts onto the next workstation irrespective of its need for those parts. This is referred to as "push" production control. For a situation where the supplying workstation operates at a rate faster than its consuming workstation, parts will begin to build up. Eventually, the consuming workstation will be overwhelmed with work.

To prevent this from happening, it would make sense if the supplying workstation did not produce any parts until its consuming workstation requested parts. This "pull" production control is typically called *kanban*. Kanban means signal and commonly uses cards to signal the supplying workstation that its consuming workstation requests more parts.

Machine #

Part #	3	1	26	25	24	21	16	15	14	13	22	18	17	11	9	8	6	5	23	20	19	12	10	7	4	2
13	1	1	1	1	1	1	1	1	1	1																
12	1	1	1	1	1	1	1	1	1	1																
11	1	1	1	1	1	1	1	1	1	1																
10	1	1	1	1	1	1	1	1	1	1																
7	1	1									1	1	1	1	1	1	1									
6	1	1									1	1	1	1	1	1	1									
5	1	1									1	1	1	1	1	1	1									
4	1	1									1	1	1	1	1	1		1								
3	1	1									1	1	1	1	1	1		1								
2	1	1									1	1	1	1	1	1		1								
1	1	1									1	1	1	1	1	1		1								
9																			1	1	1	1	1	1	1	1
8																			1	1	1	1	1	1	1	1

Cell A
Cell B

(*a*)

Machine #

Part #	3	1	26	25	24	21	16	15	14	13	22	18	17	11	9	8	6	5	23	20	19	12	10	7	4	2
13	1	1	1	1	1	1	1	1	1	1																
12	1	1	1	1	1	1	1	1	1	1																
11	1	1	1	1	1	1	1	1	1	1																
10	1	1	1	1	1	1	1	1	1	1																
7	1	1									1	1	1	1	1	1	1									
6	1	1									1	1	1	1	1	1	1									
5	1	1									1	1	1	1	1	1	1									
4	1	1									1	1	1	1	1	1		1								
3	1	1									1	1	1	1	1	1		1								
2	1	1									1	1	1	1	1	1		1								
1	1	1									1	1	1	1	1	1		1								
9																			1	1	1	1	1	1	1	1
8																			1	1	1	1	1	1	1	1

Cell A
Cell B
Cell C

(*b*)

Machine #

Part #	26	25	24	21	16	15	14	13	3a	1a	22	18	17	11	9	8	3b	1b	6	5	23	20	19	12	10	7	4	2
13	1	1	1	1	1	1	1	1	1	1																		
12	1	1	1	1	1	1	1	1	1	1																		
11	1	1	1	1	1	1	1	1	1	1																		
10	1	1	1	1	1	1	1	1	1	1																		
7											1	1	1	1	1	1	1	1	1									
6											1	1	1	1	1	1	1	1	1									
5											1	1	1	1	1	1	1	1	1									
4											1	1	1	1	1	1	1	1		1								
3											1	1	1	1	1	1	1	1		1								
2											1	1	1	1	1	1	1	1		1								
1											1	1	1	1	1	1	1	1		1								
9																					1	1	1	1	1	1	1	1
8																					1	1	1	1	1	1	1	1

Cell A
Cell B
Cell C

(*c*)

Figure 3.14 Final solution to Example 3.3.

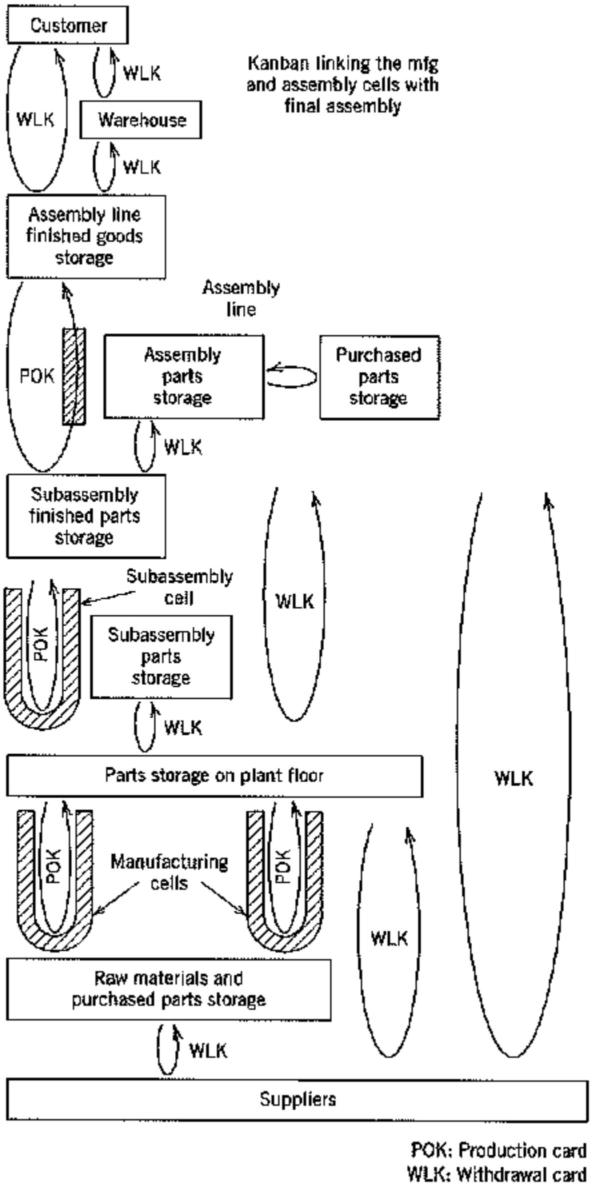


Figure 3.15 Integrated cellular manufacturing system.

The next phase in the design of a cellular manufacturing system is the layout of each cell. Figure 3.16 illustrates an assembly cell layout at the Hewlett-Packard, Greely Division [4]. The U-shaped arrangement of workstations significantly enhances visibility since the workers are aware of everything that is occurring within the cell. Notice that the agenda easel ensures that all workers know what are the daily production requirements of the cell. Materials flow from workstation to workstation via kanbans. Also, red and yellow lights or *andons* are used to stop production whenever a workstation has a problem. Problems as they occur are tabulated on the "Problem" display. This helps the workers by indicating potential problems that might arise.

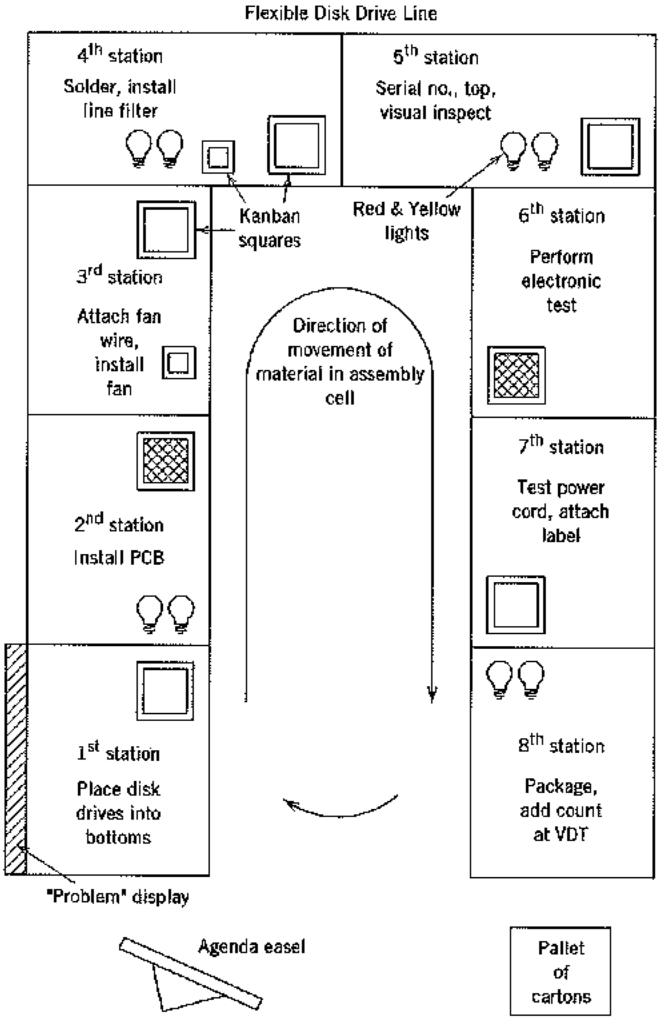


Figure 3.16 An assembly cell for disk drives, designed by workers at Hewlett-Packard, Greely Division.

3.3 ACTIVITY RELATIONSHIPS

Activity relationships provide the basis for many decisions in the facilities planning process. The primary relationships considered are

1. Organizational relationships, influenced by span of control and reporting relationships
2. Flow relationships, including the flow of materials, people, equipment, information, and money
3. Control relationships, including centralized versus decentralized materials control, real time versus batch inventory control, shop floor control, and levels of automation and integration

4. Environmental relationships, including safety considerations and temperature, noise, fumes, humidity, and dust
5. Process relationships other than those considered above, such as floor loadings, requirements for water treatment, chemical processing, and special services

Several relationships can be expressed quantitatively; others must be expressed qualitatively. Flow relationships, for example, are typically expressed in terms of the number of moves per hour, the quantity of goods to be moved per shift, the turnover rate for inventory, the number of documents processed per month, and the monthly expenditures for labor and materials.

Organizational relationships are usually represented formally by an organization chart. However, informal organizational relationships often exist and should be considered in determining the activity relationships for an organization. As an example, quality control may seem to have a limited organizational relationship with the receiving function in a warehouse; however, because of their requirement to interact closely, informal organizational relationships generally develop between the two functions. Organizational restructurings based on modern manufacturing approaches and motivated by increased international competition are decentralizing and relocating functions. The facilities design planner needs to be aware of such possibilities.

Flow relationships are quite important to the facilities planner, who views flow as the movement of goods, materials, energy, information, and/or people. The movement of refrigerators from the manufacturer through various levels of distribution to the ultimate customer is an important flow process. The transmission of sales orders from the sales department to the production control department is an example of an information flow process. The movement of patients, staff, and visitors through a hospital are examples of flow processes involving people.

The situations described are discrete flow processes where individual, discrete items move through the flow process. A continuous flow process differs from a discrete flow process in that movement is perpetual. Examples of continuous flow processes would include the flow of electricity, chemicals flowing through a processing facility, and oil flowing through a pipeline. Although many of the concepts described in this text are applicable to continuous flow processes, the primary emphasis is on discrete flow processes.

A flow process may be described in terms of the **subject** of flow, the **resources** that bring about flow, and the **communications** that coordinate the resources. The subject is the item to be processed. The resources that bring about flow are the processing and transporting facilities required to accomplish the required flow. The communications that coordinate the resources include the procedures that facilitate the management of the flow process. The perspective adopted for a flow process depends on the breadth of subjects, resources, and communications that exist in a particular situation.

If the flow process being considered is the **flow of materials into a manufacturing facility,** the flow process is typically referred to as a **materials management system.** The subjects of material management systems are the materials, parts, and supplies purchased by a firm and required for the production of its product. The resources of material management systems include:

1. The production control and purchasing functions
2. The vendors

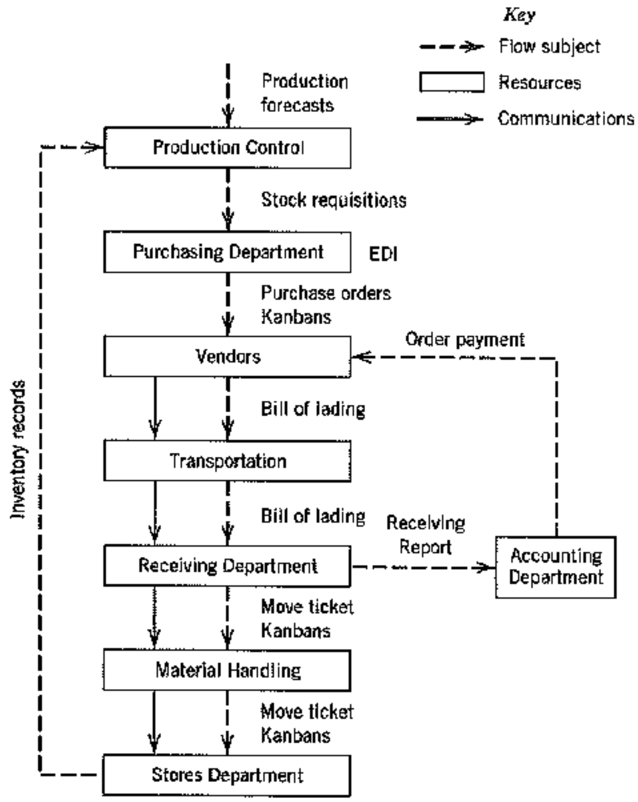


Figure 3.17 Material management system.

3. The transportation and material handling equipment required to move the materials, parts, and supplies
4. The receiving, storage, and accounting functions

The communications within material management systems include production forecasts, inventory records, stock requisitions, purchase orders, bills of lading, move tickets, receiving reports, kanbans, electronic data interchange (EDI), and order payment. A schematic of the material management system is given in Figure 3.17.

If the flow of materials, parts, and supplies ***within* a manufacturing facility** is to be the subject of the flow process, the process is called the **material flow system.** The type of material flow system is determined by the makeup of the activities or planning departments among which materials flow. As noted previously, there are four types of production planning departments.

1. Production line departments
2. Fixed materials location departments
3. Product family departments
4. Process departments

Typical material flow systems for each department type are shown in Figure 3.18. (Additional discussion regarding these layout alternatives is provided in Chapter 6,

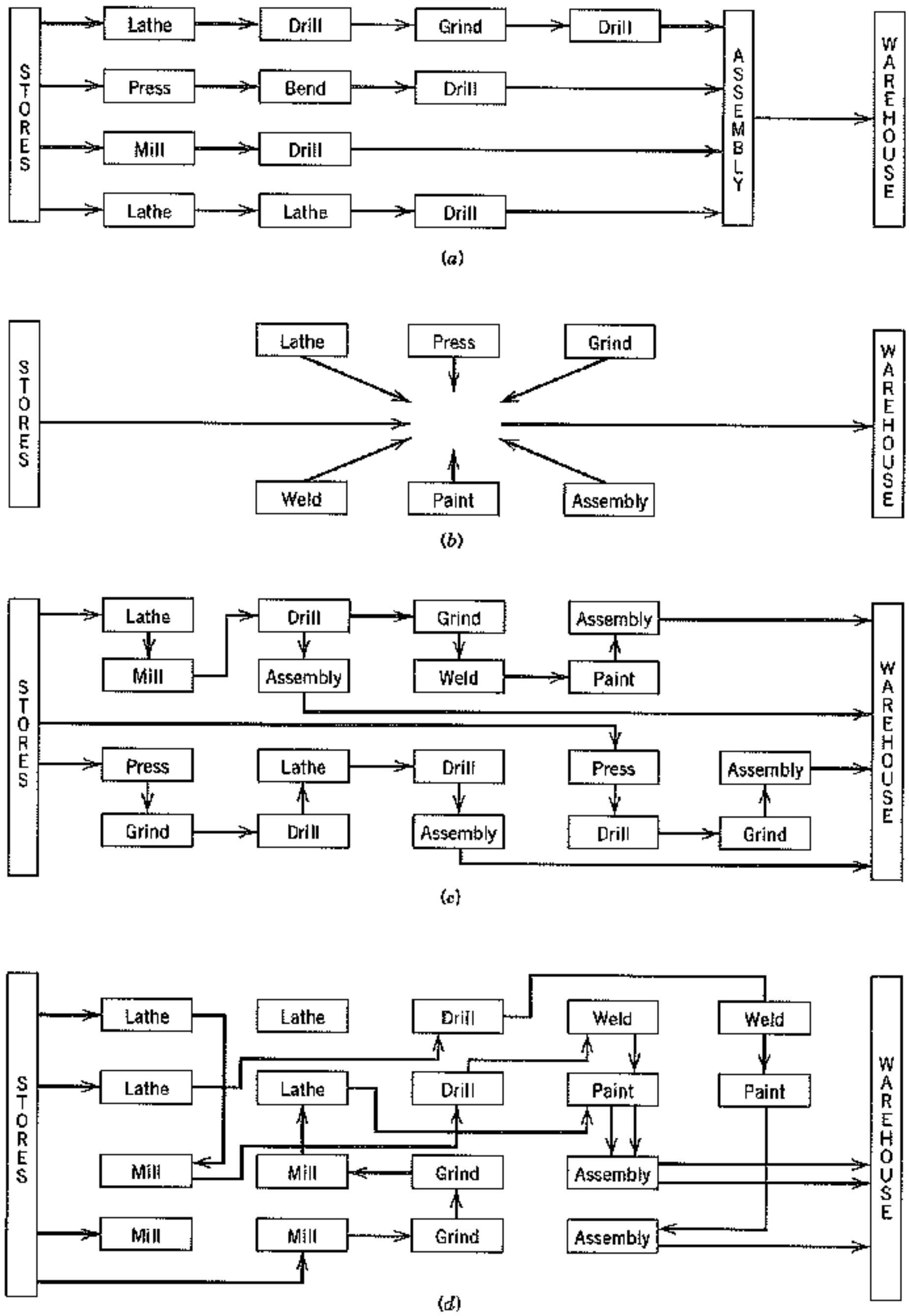


Figure 3.18 Material flow systems for various types of departments. (*a*) Product planning departments. (*b*) Fixed materials location planning departments. (*c*) Product family planning departments. (*d*) Process planning departments.

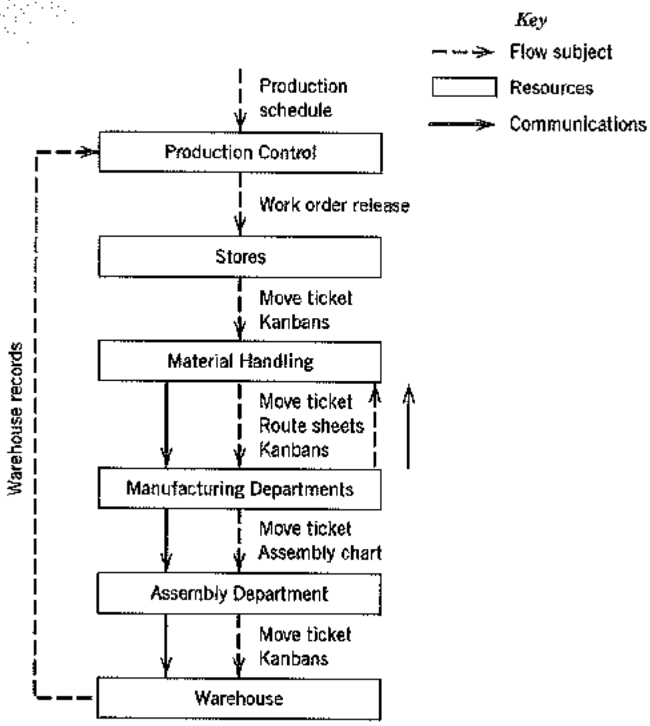


Figure 3.19 Material flow system.

Sections 6.2 and 6.3.) The subjects of material flow systems are the materials, parts, and supplies used by a firm in manufacturing its product. The resources of material flow systems include:

1. The production control and quality control departments
2. The manufacturing, assembly, and storage departments
3. The material handling equipment required to move materials, parts, and supplies
4. The warehouse

Communication within the material flow system includes: production schedules, work order releases, move tickets, kanbans, bar codes, route sheets, assembly charts, and warehouse records. A schematic of the material flow system is given in Figure 3.19.

If the **flow of products from a manufacturing facility** is to be the subject of the flow, the flow process is referred to as the **physical distribution system.** The subject of physical distribution systems are the finished goods produced by a firm. The resources of physical distribution systems include:

1. The customer
2. The sales and accounting departments and warehouses
3. The material handling and transportation equipment required to move the finished product
4. The distributors of the finished product

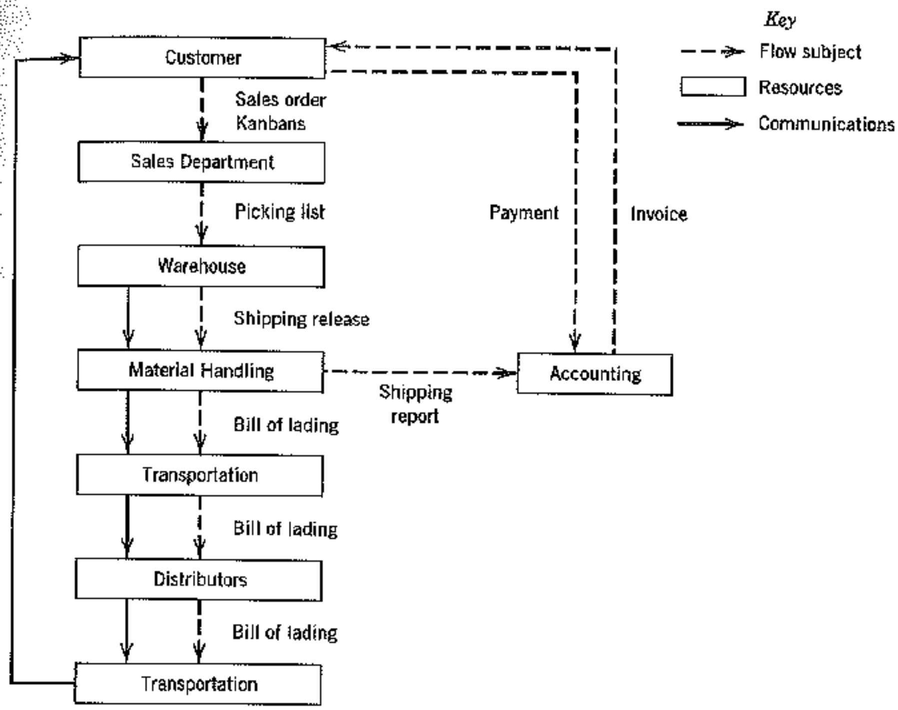


Figure 3.20 Physical distribution system.

The communications within the physical distribution system include: sales orders, packing lists, shipping reports, shipping releases, kanbans, EDI invoices, and bills of lading. A schematic of the physical distribution system is given in Figure 3.20.

The material management, material flow, and physical distribution system may be combined into one overall flow system. Such an overall flow process is referred to as the logistics system. A schematic of the **logistics system** is given in Figure 3.21.

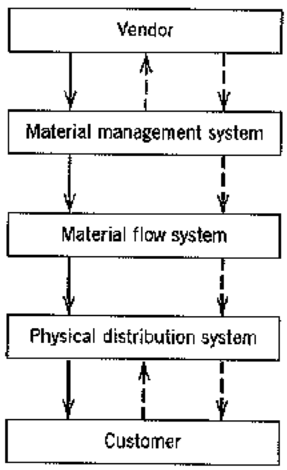


Figure 3.21 Logistics system.

Modern manufacturing approaches are impacting the logistics system in different ways. For example, some suppliers are locating facilities closer to the customer to deliver smaller lot sizes; customers are employing electronic data interchange systems and kanbans to request materials just-in-time; customers and suppliers are using continuous communication technologies with transportation system operators to prevent contingencies; products are being delivered to multiple receiving docks; products are being received in decentralized storage areas (supermarkets) at the points of use; in many cases, no receiving inspection is being performed (suppliers have been certified) and no paperwork is needed; production operators are retrieving materials from the supermarkets when needed; products are being moved short distances in manufacturing cells and/or product planning arrangements; and simpler material handling and storage equipment alternatives are being employed to receive, store, and move materials (production operators perform retrieval and handling operations from supermarkets and among processes). These changes are creating efficient logistics systems with shorter lead times, lower cost, and better quality.

3.4 FLOW PATTERNS

The macroflow considerations of material management, material flow, physical distribution, and logistics are of value to the facilities planner in that they define the overall flow environment within which movement takes place. Within the overall flow environment, a critical consideration is the pattern of flow. Patterns of flow may be viewed from the perspective of flow within workstations, within departments, and between departments.

Flow Within Workstations

Motion studies and ergonomics considerations are important in establishing the flow within workstations. For example, flow within a workstation should be simultaneous, symmetrical, natural, rhythmical, and habitual. Simultaneous flow implies the coordinated use of hands, arms, and feet. Hands, arms, and feet should begin and end their motions together and should not be idle at the same instant except during rest periods. Symmetrical flow results from the coordination of movements about the center of the body. The left and right hands and arms should be working in coordination. Natural flow patterns are the basis for rhythmical and habitual flow patterns. Natural movements are continuous, curved, and make use of momentum. Rhythmical and habitual flow implies a methodical, automatic sequence of activity. Rhythmical and habitual flow patterns also allow for reduced mental, eye and muscle fatigue, and strain.

Flow Within Departments

The flow pattern within departments is dependent on the type of department. In a product and/or product family department, the flow of work follows the product flow. Product flows typically follow one of the patterns shown in Figure 3.22 End-to-end, back-to-back, and odd-angle flow patterns are indicative of product departments

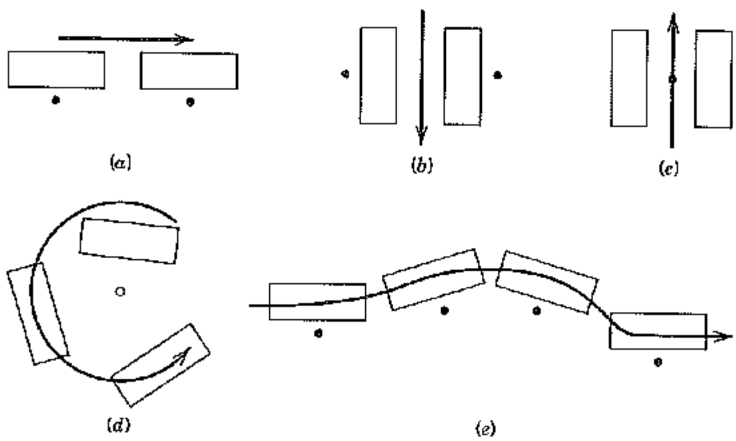


Figure 3.22 Flow within product departments. (*a*) End-to-end. (*b*) Back-to-back. (*c*) Front-to-front. (*d*) Circular. (*e*) Odd-angle.

where one operator works at each workstation. Front-to-front flow patterns are used when one operator works on two workstations and circular flow patterns are used when one operator works on more than two workstations.

In a process department, little flow should occur between workstations within departments. Flow typically occurs between workstations and aisles. Flow patterns are dictated by the orientation of the workstations to the aisles. Figure 3.23 illustrates three workstation-aisle arrangements and the resulting flow patterns. The determination of the preferred workstation-aisle arrangement pattern is dependent on the interactions among workstation areas, available space, and size of the materials to be handled.

Diagonal flow patterns are typically used in conjunction with one-way aisles. Aisles that support diagonal flow patterns often require less space than aisles with either parallel or perpendicular workstation-aisle arrangements. However, one-way aisles also result in less flexibility. Therefore, diagonal flow patterns are not utilized often.

Flow within workstations and within departments should be enriched and enlarged to allow the operators not only to use their muscles but also their minds. Multifunctional operators can work on more than one machine if needed and can get involved in support and continuous improvement functions like quality, basic maintenance, material handling, record keeping, performance measurement tracking, and teamwork. This means that flow and location of materials, tools, paperwork, and quality verification devices should be considered in an integrated way.

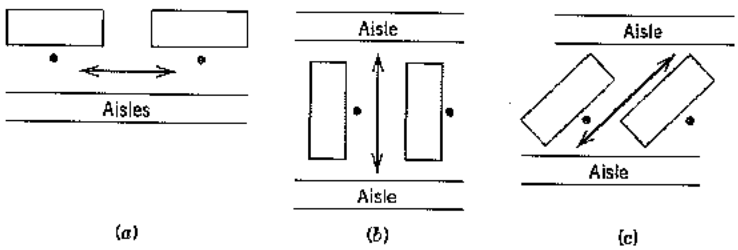


Figure 3.23 Flow within process departments. (*a*) Parallel. (*b*) Perpendicular. (*c*) Diagonal.

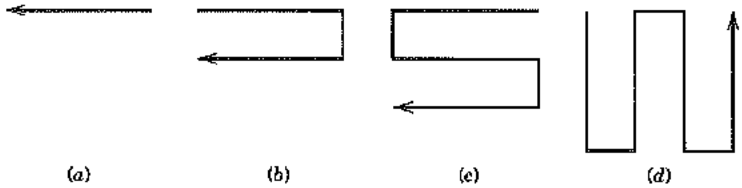


Figure 3.24 General flow patterns. (*a*) Straight-line. (*b*) U-shaped. (*c*) S-shaped. (*d*) W-shaped.

Flow Between Departments

Flow between departments is a criterion often used to evaluate overall flow within a facility. Flow typically consists of a combination of the four general flow patterns shown in Figure 3.24 An important consideration in combining the flow patterns shown in Figure 3.24 is the location of the entrance and exit. As a result of the plot plan or building construction, the location of the entrance (receiving department) and exit (shipping department) is often fixed at a given location and flow within the facility conforms to these restrictions. A few examples of how flow within a facility may be planned to conform to entrance and exit restrictions are given in Figure 3.25.

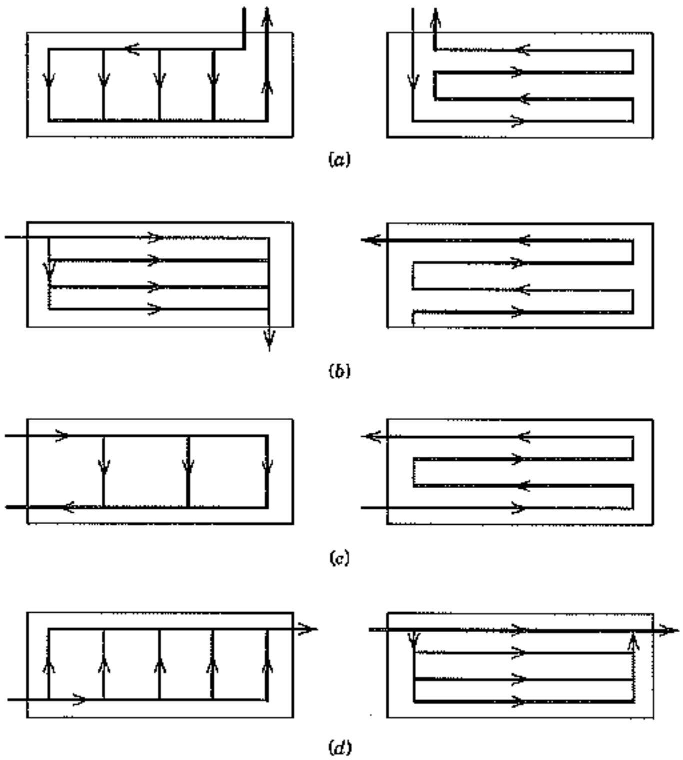


Figure 3.25 Flow within a facility considering the locations of the entrance and exit. (*a*) At the same location. (*b*) On adjacent sides. (*c*) On the same side but at opposite ends. (*d*) On opposite sides.

An important design issue in Just-In-Time facilities is the determination of the appropriate number of receiving/shipping docks and decentralized storage areas (supermarkets) and their location. Each combination of number and location of receiving/shipping docks and supermarkets should be analyzed in detail considering integrated layout-handling alternatives to identify flow-time-cost-quality impact.

3.5 FLOW PLANNING

Planning effective flow involves combining the flow patterns given in Section 3.4 with adequate aisles to obtain a progressive movement from origination to destination. Effective flow within a facility includes the progressive movement of materials, information, or people *between departments*. Effective flow within a department involves the progressive movement of materials, information, or people *between work-stations*. Effective flow within a workstation addresses the progressive movement of materials, information, or people *through the workstation*.

As noted, effective flow planning is a hierarchical planning process. The effective flow within a facility is contingent upon effective flow between departments. Such flow depends on effective flow within departments, which depends on effective flow within workstations. This hierarchy is shown in Figure 3.26 Planning for effective flow within the hierarchy requires the consideration of flow patterns and flow principles.

Morris [33] defines a principle as "simply a loose statement of something which has been noticed to be sometimes, but not always, true." The following principles have been observed to frequently result in effective flow: maximize directed flow paths, minimize flow, and minimize the costs of flow.

A directed flow path is an uninterrupted flow path progressing directly from origination to destination. An uninterrupted flow path is a flow path that *does not intersect with other paths.* Figure 3.27 illustrates the congestion and undesirable intersections that may occur when flow paths are interrupted. A directed flow path progressing from origination to destination is a flow path with no backtracking. As can be seen in Figure 3.28 backtracking increases the length of the flow path. The

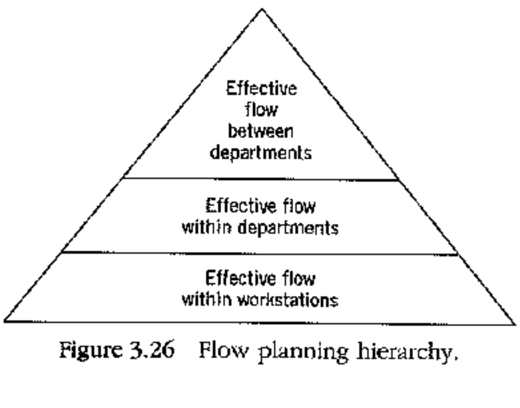


Figure 3.26 Flow planning hierarchy.

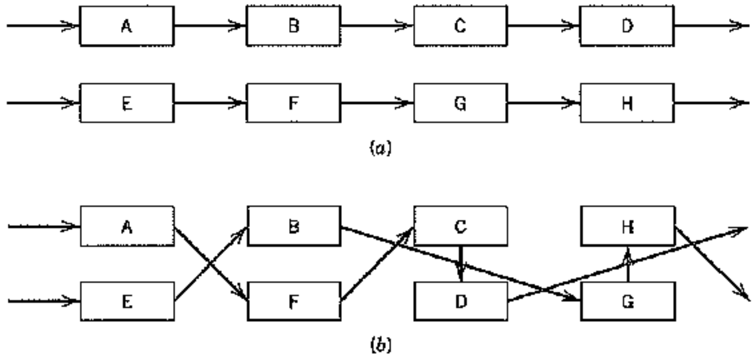


Figure 3.27 The impact of interruptions on flow paths. (*a*) Uninterrupted flow paths. (*b*) Interrupted flow paths.

principle of minimizing flow represents the work simplification approach to material flow. The work simplification approach to material flow includes:

1. Eliminating flow by planning for the delivery of materials, information, or people directly to the point of ultimate use and eliminate intermediate steps
2. Minimizing multiple flows by planning for the flow between two consecutive points of use to take place in as few movements as possible, preferably one
3. Combining flows and operations wherever possible by planning for the movement of materials, information, or people to be combined with a processing step

The principle of minimizing the cost of flow may be viewed from either of the following two perspectives.

1. Minimize manual handling by minimizing walking, manual travel distances, and motions.
2. Eliminate manual handling by mechanizing or automating flow to allow workers to spend full time on their assigned tasks.

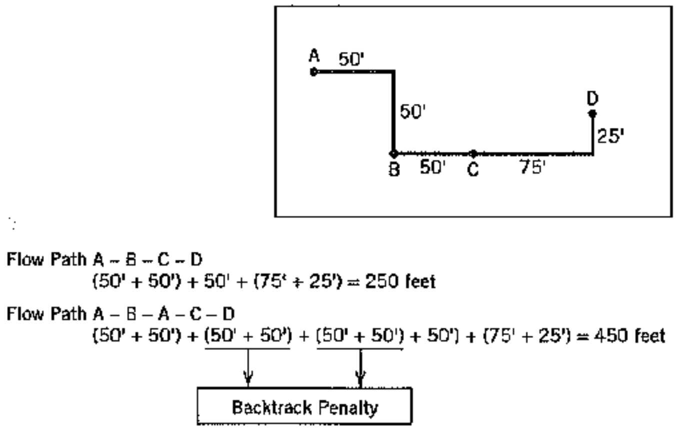


Figure 3.28 Illustration of how backtracking impacts the length of flow paths.

3.6 MEASURING FLOW

Flow among departments is one of the most important factors in the arrangement of departments within a facility. To evaluate alternative arrangements, a measure of flow must be established. Flows may be specified in a quantitative manner or a qualitative manner. Quantitative measures may include pieces per hour, moves per day, or pounds per week. Qualitative measures may range from an absolute necessity that two departments be close to each other to a preference that two departments not be close to each other. In facilities having large volumes of materials, information, and people moving between departments, a quantitative measure of flow will typically be the basis for the arrangement of departments. On the contrary, in facilities having very little actual movement of materials, information, and people flowing between departments, but having significant communication and organizational interrelations, a qualitative measure of flow will typically serve as the basis for the arrangement of departments. Most often, a facility will have a need for both quantitative and qualitative measures of flow and both measures should be used.

A chart that can be useful in flow measurement is the mileage chart shown in Figure 3.29. Notice the diagonal of the mileage chart is blank, since the question "How far is it from New York to New York?" makes little sense. Furthermore, the mileage chart is a symmetric matrix. (Distance charts do not have to be symmetric; if one-way aisles or roads are used, distance between two points will seldom be symmetric.) In Figure 3.29, it is 963 miles from Boston to Chicago and also 963 miles from Chicago to Boston. When this occurs, the format of the mileage chart is often changed to a triangular matrix as shown in Figure 3.30.

Quantitative Flow Measurement

Flows may be measured quantitatively in terms of the amount moved between departments. The chart most often used to record these flows is a from-to chart. As

From \ To	Atlanta, GA	Boston, MA	Chicago, IL	Dallas, TX	New York, NY	Pittsburgh, PA	Raleigh, NC	San Francisco, CA
Atlanta, GA		1037	674	795	841	687	372	2496
Boston, MA	1037		963	1748	206	561	685	3095
Chicago, IL	674	963		917	802	452	784	2142
Dallas, TX	795	1748	917		1552	1204	1166	1753
New York, NY	841	206	802	1552		368	489	2934
Pittsburgh, PA	687	561	452	1204	368		445	2578
Raleigh, NC	372	685	784	1166	489	445		2843
San Francisco, CA	2496	3095	2142	1753	2934	2578	2843	

Figure 3.29 Mileage chart.

	Atlanta, GA	Boston, MA	Chicago, IL	Dallas, TX	New York, NY	Pittsburg, PA	Raleigh, NC
Atlanta, GA							
Boston, MA	1037						
Chicago, IL	674	963					
Dallas, TX	795	1748	917				
New York, NY	841	206	802	1552			
Pittsburg, PA	687	561	452	1204	368		
Raleigh, NC	372	685	784	1166	489	445	
San Francisco, CA	2496	3095	2142	1753	2934	2578	2843

Figure 3.30 Triangular mileage chart.

can be seen in Figure 3.31, a from-to chart resembles the mileage chart given in Figure 3.29. The from-to chart is a square matrix, but is seldom symmetric. The lack of symmetry is because there is no definite reason for the flows from stores to milling to be the same as the flows from milling to stores.

A from-to chart is constructed as follows:

1. List all departments down the row and across the column following the overall flow pattern. For example, Figure 3.32 shows various flow patterns that result in the departments being listed as in Figure 3.31.
2. Establish a measure of flow for the facility that accurately indicates equivalent flow volumes. If the items moved are equivalent with respect to ease of movement, the number of trips may be recorded in the from-to chart. If the items

From \ To	Store	Milling	Turning	Press	Plate	Assembly	Warehouse
Stores		12	6	9	1	4	
Milling					7	2	
Turning		3			4		
Press					3	1	1
Plate		3	1			4	3
Assembly	1						7
Warehouse							

Figure 3.31 From-to chart.

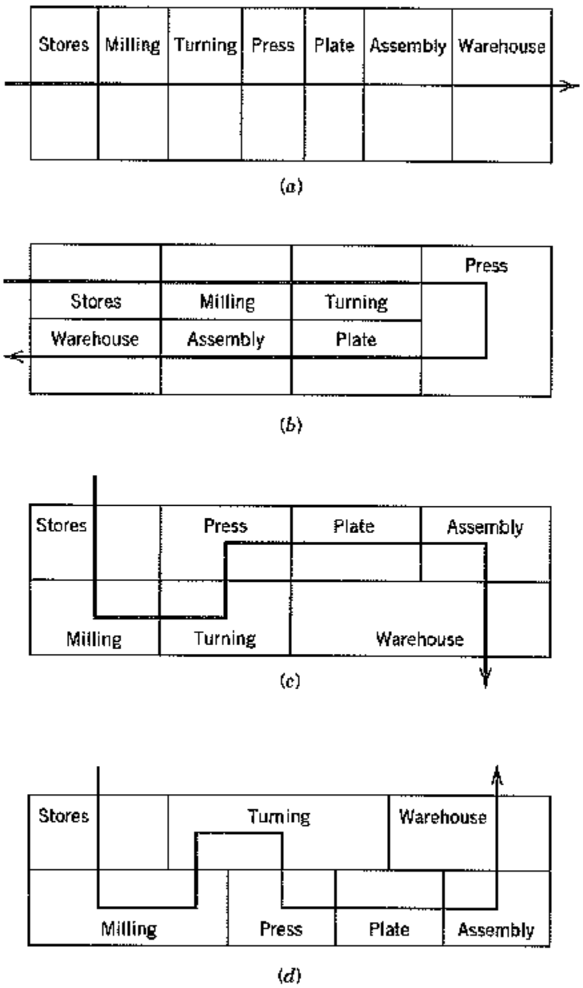


Figure 3.32 Flow patterns indicating the order of flow given in (*a*) Straight-line flow. (*b*) U-shaped flow. (*c*) S-shaped flow. (*d*) W-shaped flow.

moved vary in size, weight, value, risk of damage, shape, and so on, then some common unit of measure may be established so that the quantities recorded in the from-to chart represent the proper relationships among the volumes of movement.

3. Based on the flow paths for the items to be moved and the established measure of flow, record the flow volumes in the from-to chart.

Example 3.4

A firm produces three components. Components 1 and 2 have the same size and weight and are equivalent with respect to movement. Component 3 is almost twice as large and moving two units of either component 1 or 2 is equivalent to moving 1 unit of component 3.

From \ To	A	C	B	D	E
A		① 30 ③2(7) = 14	②12		
		44	12	0	0
C			①30	③2(7) = 14	
	0		30	14	0
B				①30 ②12	③2(7) = 14
	0	0		42	14
D			③2(7) = 14		①30 ②12
	0	0	14		42
E	0	0	0	0	

Figure 3.33 From-to chart for Example 3.4. The circled numbers represent component numbers and the number following the circled numbers indicates the volume of equivalent flows for the component.

The departments included in the facility are A, B, C, D, and E. The overall flow path is A-B-C-D-E. The quantities to be produced and the component routings are as follows:

Component	Production Quantities (per day)	Routing
1	30	A-C-B-D-E
2	12	A-B-D-E
3	7	A-C-D-B-E

The first step in producing the from-to chart is to list the departments in order of the overall flow down the rows and across the columns. Then by considering each unit of component 3 moved to be equivalent to two moves of components 1 and 2, the flow volumes may be recorded as shown in Figure 3.33.

Notice that flow volumes below the diagonal represent backtracking and the closer the flow volumes are to the main diagonal, the shorter will be the move in the facility. The moves below the diagonal in the from-to chart given in Figure 3.31 are turning to milling, plate to milling, plate to turning, and assembly to stores. If these moves are traced on the flow paths shown in Figure 3.32 it may be seen that they are all counter to the overall flow pattern. The diagonal 1 units above the main diagonal in Figure 3.31 include the moves: stores to milling, press to plate, plate to assembly, and assembly to warehouse. These moves may be seen in Figure 3.32a to be between adjacent departments, or departments one department away. The diagonal 2 units above the main diagonal in Figure 3.31 include the moves: stores to turning, turning to plate, and press to assembly. These moves may be seen in Figure 3.32a to be of length two departments away along the overall flow path. In a similar manner, the fifth diagonal units above the diagonal includes the move stores to assembly, and the fifth diagonal unit below the diagonal includes the move assembly to stores; these moves are five departments apart along the overall flow path, with the move from assembly to stores being counter to the direction of flow.

Table 3.2 *Closeness Relationship Values*

Value	Closeness
A	Absolutely necessary
E	Especially important
I	Important
O	Ordinary closeness okay
U	Unimportant
X	Undesirable

Qualitative Flow Measurement

Flows may be measured qualitatively using the closeness relationships values developed by Muther [34] and given in Table 3.2. The values may be recorded in conjunction with the reasons for the closeness value using the relationship chart given in Figure 3.34.

A relationship chart may be constructed as follows:

1. List all departments on the relationship chart.
2. Conduct interviews or surveys with persons from each department listed on the relationship chart and with the management responsible for all departments.

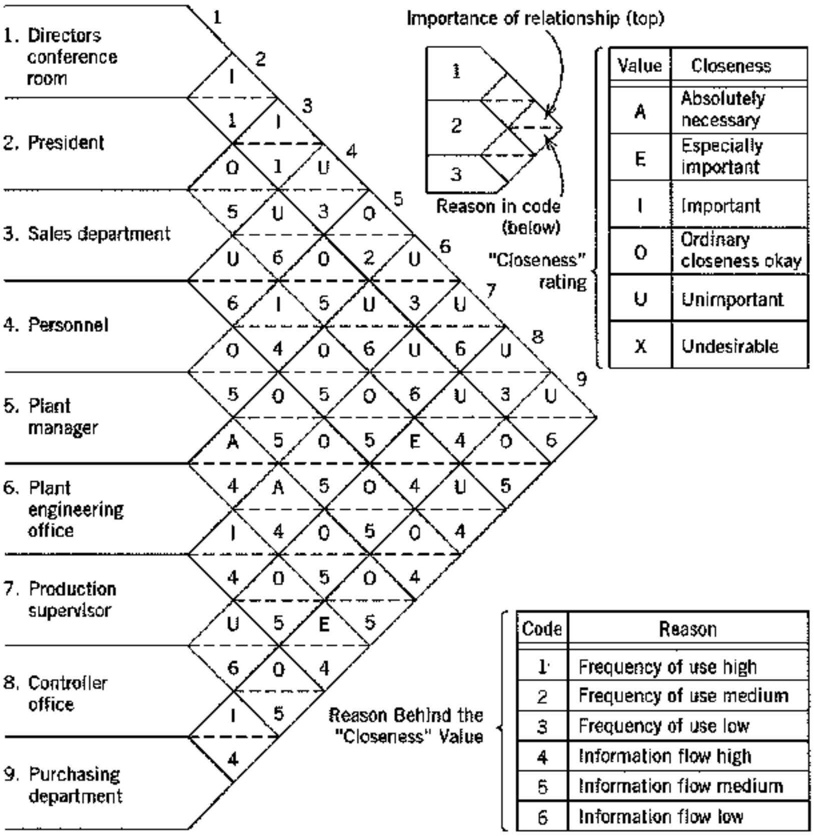


Figure 3.34 Relationship chart.

The determination of production space requirements is presented in the following sections. A section is also included to address the issue of visual management and space requirements. Personnel and storage space requirements are presented in Chapters 4 and 9, respectively.

Workstation Specification

Recall that a facility was defined in Chapter 1 as including the fixed assets required to accomplish a specific objective. Because a workstation consists of the fixed assets needed to perform specific operations, a workstation can be considered to be a facility. Although it has a rather narrow objective, the workstation is quite important. Productivity of a firm is definitely related to the productivity of each workstation.

A workstation, like all facilities, includes space for equipment, materials, and personnel. The equipment space for a workstation consists of space for:

1. The equipment
2. Machine travel
3. Machine maintenance
4. Plant services

Equipment space requirements should be readily available from machinery data sheets. For machines already in operation, machinery data sheets should be available from either the maintenance department's equipment history records or the accounting department's equipment inventory records. For new machines, machinery data sheets should be available from the equipment supplier. If machinery data sheets are not available, a physical inventory should be performed to determine at least the following:

1. Machine manufacturer and type
2. Machine model and serial number
3. Location of machine safety stops
4. Floor loading requirement
5. Static height at maximum point
6. Maximum vertical travel
7. Static width at maximum point
8. Maximum travel to the left
9. Maximum travel to the right
10. Static depth at maximum point
11. Maximum travel toward the operator
12. Maximum travel away from the operator
13. Maintenance requirements and areas
14. Plant service requirements and areas

Floor area requirements for each machine, including machine travel, can be determined by multiplying total width (static width plus maximum travel to the left and right) by total depth (static depth plus maximum travel toward and away from the operator). To the floor area requirement of the machine add the maintenance and plant service area requirements. The resulting sum represents the total machinery area for a machine. The sum of the machinery areas for all machines within a workstation gives the machinery area requirement for the workstation.

The materials areas for a workstation consist of space for:

1. Receiving and storing inbound materials
2. In-process materials
3. Storing outbound materials and shipping
4. Storing and shipping waste and scrap
5. Tools, fixtures, jigs, dies, and maintenance materials

To determine the area requirements for receiving and storing materials, in-process materials, and storing and shipping materials, the dimensions of the unit loads to be handled and the flow of material through the machine must be known. Sufficient space should be allowed for the number of inbound and outbound unit loads typically stored at the machine. If an inventory holding zone is included within a department for incoming and outgoing materials, one might provide space for only two unit loads ahead of the machine and two unit loads after the machine. Depending on the material handling system, the minimum requirement for space might include that required for one unit load to be worked next, one unit load being worked from, one unit load being worked to, and one unit load that has been completed. Additional space may be needed to allow for in-process materials to be placed into the machine, for material such as bar stock to extend beyond the machine, and for the removal of material from the machine. Space for the removal of waste (chips, trimmings, etc.) and scrap (defective parts) from the machine and storage prior to removal from the workstation must be provided.

Organizations that use kanbans have reported the need for less space for materials. Typically, only one or two containers or pallet loads of materials are kept close to the workstation and the rest of the materials (regulated by the number of kanbans) are located in a decentralized storage area (supermarket) located close by.

The only remaining material requirement to be added to that previously mentioned in determining the total material area requirement is the space required for tools, fixtures, jigs, dies, and maintenance materials. A decision with respect to the storage of tools, fixtures, jigs, dies, and maintenance materials at the workstation or in a central storage location will have a direct bearing on the area requirement. At the very least, space must be provided for the accumulation of tools, fixtures, jigs, dies, and maintenance materials required while altering the machine setup.

As the number of setups for a machine increases, so do the work station area requirements for tools, fixtures, jigs, dies, and maintenance materials. Also, from a security, damage, and space viewpoint, the desirability of a central storage location increases.

Consequently, organizations should allocate space to the workstations according to the concepts to be employed.

The personnel area for a workstation consists of space for:

1. The operator
2. Material handling
3. Operator ingress and egress

Space requirements for the operator and for material handling depend on the method used to perform the operation. The method should be determined using a motion study of the task and an ergonomics study of the operator. The following general guidelines are given to illustrate the factors to be considered.

1. Workstations should be designed so the operator can pick up and discharge materials without walking or making long or awkward reaches.
2. Workstations should be designed for efficient and effective utilization of the operator.
3. Workstations should be designed to minimize the time spent manually handling materials.
4. Workstations should be designed to maximize operator safety comfort and productivity.
5. Workstations should be designed to minimize hazards, fatigue, and eye strain.

In addition to the space required for the operator and for material handling, space must be allowed for operator ingress and egress. A minimum of a 30-in. aisle is needed for operator travel past stationary objects. If the operator walks between a stationary object and an operating machine, a minimum of a 36-in. aisle is required. If the operator walks between two operating machines, a minimum of a 42-in. aisle is needed.

Figure 3.35 illustrates the space requirements for a workstation. A sketch like Figure 3.35 should be provided for each workstation in order to visualize the operator's activities. The facilities planner should simulate the operator reporting to the job, performing the task, changing the setup, maintaining the machine, reacting to emergency situations, going to lunch and breaks, cleaning the workstation, evaluating quality, working in teams, responding to feedback boards, and leaving at the end of the shift. Such a simulation will assure the adequacy of the space allocation and may aid in significantly improving the overall operation.

Department Specification

Once the space requirements for individual workstations have been determined, the space requirements for each department can be established. To do this, we need to establish the departmental service requirements. Departmental area requirements are not simply the sum of the areas of the individual workstations included within the department. It is quite possible tools, dies, equipment maintenance, plant services, housekeeping items, storage areas, operators, spare parts, kanban boards, information-communication-recognition boards, problem boards, and andons may be shared to save space and resources (see Figure 3.16). However, care must be taken to ensure that operational interferences are not created by attempting to combine areas needed by individual workstations. Additional space is required within each department for material handling within the department. Aisle space requirements still cannot be determined exactly, as the department configurations, workstation alignments, and material handling system have not been completely defined. However, at this point we can approximate the space requirement for aisles, since the relative sizes of the loads to be handled are known. Table 3.3 provides a guide for use in estimating aisle space requirements.

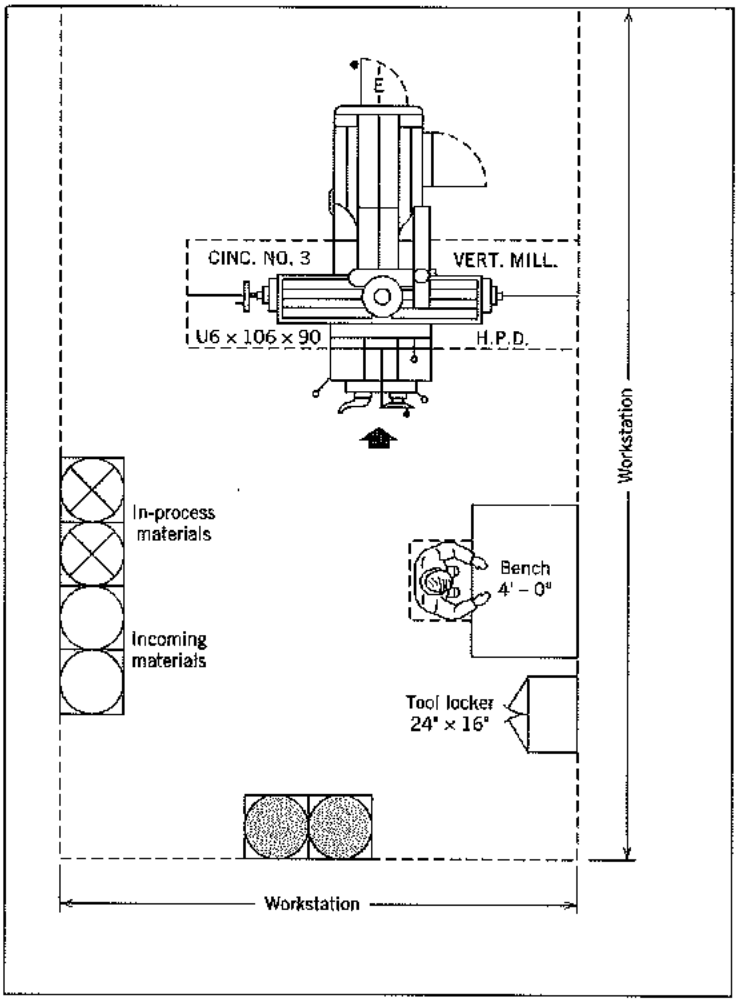


Figure 3.35 Workstation sketch required to determine total area requirements.

Departmental service requirements equal the sum of the service requirements for the individual workstations to be included in a department. These requirements, as well as departmental area requirements, should be recorded on a departmental service and area requirements sheet. Such a sheet is shown in Figure 3.36.

Table 3.3 ***Aisle Allowance Estimates***

If the Largest Load Is	Aisle Allowance Percentage Is[a]
Less than 6 ft^2	5-10
Between 6 and 12 ft^2	10-20
Between 12 and 18 ft^2	20-30
Greater than 18 ft^2	30-40

[a]Expressed as a percentage of the net area required for equipment, material, and personnel.

DEPARTMENTAL SERVICE AND AREA REQUIREMENT SHEET

Company A.B.C., Inc. Prepared by J.A.
Department Turning Date Sheet 1 of 1

Work Station	Quantity	Service Requirements: Power	Service Requirements: Compressed Air	Service Requirements: Other	Floor Loading	Ceiling Height	Area (square feet): Equipment	Area (square feet): Material	Area (square feet): Personnel	Area (square feet): Total
Turret lathe	5	440 V AC	10 CFM @ 100 psi		150 PSF	4′	240	100	100	440
Screw machine	6	440 V AC	10 CFM @ 100 psi		190 PSF	4′	280	240	120	640
Chucker	2	440 V AC	10 CFM @ 100 psi		150 PSF	5′	60	100	40	200

Net area required	1280
13% aisle allowance	167
Total area required	1447

Figure 3.36 Department service and area requirements sheet.

Example 3.3

A planning department for the ABC Company consists of 13 machines that perform turning operations. Five turret lathes, six automatic screw machines, and two chuckers are included in the planning department. Bar stock, in 8-ft bundles, is delivered to the machines. The "footprints" for the machines are 4 × 12 ft for turret lathes, 4 × 14 ft for screw machines, and 5 × 6 ft for chuckers. Personnel space footprints of 4 × 5 ft are used. Material storage requirements are estimated to be 20 ft^2 per turret lathe, 40 ft^2 per screw machine, and 50 ft^2 per chucker. An aisle space allowance of 13% is used. The space calculations are summarized in Figure 3.36. A total of 1447 ft^2 of floor space is required for the planning department. If space is to be provided in the planning department for a supervisor's desk, it must be added to the total for equipment, materials, personnel, and aisles.

Notice that in this example, Company ABC has organized the machines in a process planning department and that provisions for tooling, feedback boards, autonomous maintenance, quick changeovers, quality assurance, and team meetings have not been included in the design. It is also assumed that flexible material handling equipment alternatives are used to move materials, in-process inventory, and finished goods.

Aisle Arrangement

Aisles should be located in a facility to promote effective flow. Aisles may be classified as departmental aisles and main aisles. Consideration of departmental aisles will be deferred until departmental layouts are established. Recall that space was allotted for departmental aisles on the department service and area requirement sheet.

Planning aisles that are too narrow may result in congested facilities having high levels of damage and safety problems. Conversely, planning aisles that are too wide may result in wasted space and poor housekeeping practices. Aisle widths should be determined by considering the type and volume of flow to be handled by the aisle. The type of flow may be specified by considering the people and equipment types using the aisle.

Table 3.4 specifies aisle widths for various types of flow. If the anticipated flow over an aisle indicates that only on rare occasions will flow be taking place at the same time in opposite directions, the aisle widths for main aisles may be

Table 3.4 ***Recommended Aisle Widths for Various Types of Flow***

Type of Flow	Aisle Width (feet)
Tractors	12
3-ton Forklift	11
2-ton Forklift	10
1-ton Forklift	9
Narrow aisle truck	6
Manual platform truck	5
Personnel	3
Personnel with doors opening into the aisle from one side	6
Personnel with doors opening into the aisle from two sides	8

obtained from Table 3.4. If, however, the anticipated flow in an aisle indicates that two-way flow will occur frequently, the aisle width should equal the sum of the aisle widths required for the types of flow in each direction.

Curves, jogs, or non-right angle intersections should be avoided in planning for aisles. Aisles should be straight and lead to doors. Aisles along the outside wall of a facility should be avoided unless the aisle is used for entering or leaving the facility. Column spacing should be considered when planning aisle spacing. When column spacing is not considered, the columns will often be located in the aisle. Columns are often used to border aisles, but rarely should be located in an aisle.

Visual Management and Space Requirements

Manufacturing management approaches can impact the way facilities are designed. For example, consider the impact a visual management system (see Figure 3.37) might have. Notice that the example shown has the following features:

A. Identification, housekeeping, and organization (one place for everything and everything in place). Teams need to relate to a place they can identify as their own. A clean environment where they work, meet, review indicators of the status of the work, post information, display team identity symbols and examples of their products, display standard production methods, and identify properly locations for materials, tools, dies, fixtures, and so on. Figure 3.37 illustrates:

1. identification of the department;
2. identification of activities, resources, and products;
3. identification of the team;
4. markings on the floor (kanban squares, dedicated location for material handling equipment);
5. markings of tools, racks, fixtures;
6. technical area;
7. communication and rest area;
8. information and instructions; and
9. housekeeping tools.

B. Visual documentation (tolerances, work instructions, operating instructions for machinery, self-inspection instructions, auditing procedures, plant layout, and floor charts). Figure 3.37 illustrates

10. manufacturing instructions and technical procedures area.

C. Visual production, maintenance, inventory, and quality control (wall-size schedule charts, kanban boards, autonomous maintenance boards, alarm lamps for machine malfunctions-andons, visual pass/fail templates for quick reading of gauges, charts generated by statistical process control methods, and boards on which problems are recorded). Figure 3.37 illustrates

11. computer terminal,
12. production schedule,
13. maintenance schedule,
14. identification of inventories and work-in-process,

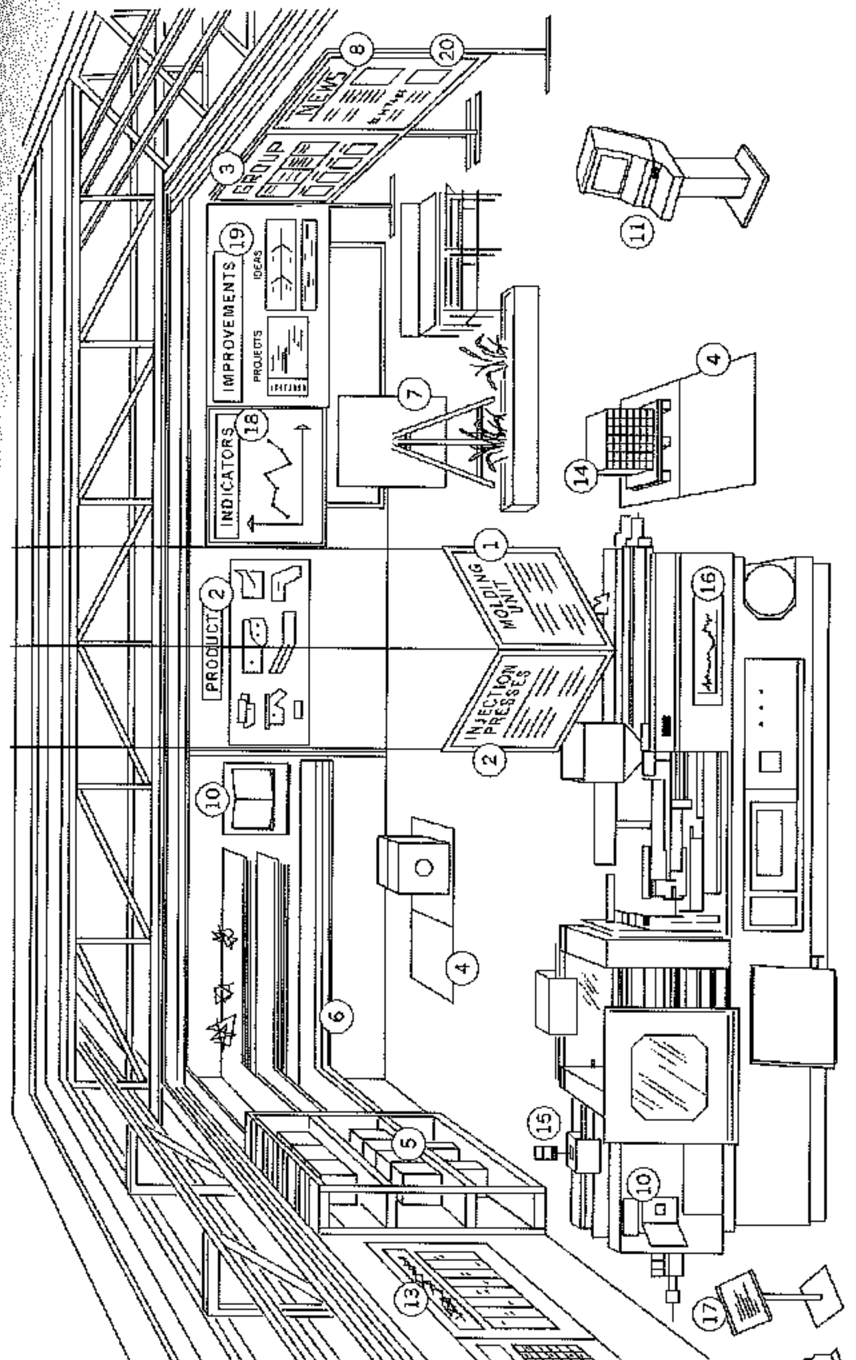


Figure 3.37 Visual factory scenario.

15. monitoring signals for machines,
16. statistical process control, and
17. record of problems.

D. Performance measurement (objectives, goals, indicators) to show the actual game score. Supervisors, facilitators and workers together look at the situation and examine ways to improve it. Figure 3.37 illustrates

18. objectives, results, and differences.

E. Progress status (visual mechanisms for tracking and celebrating progress and improvement). Figure 3.37 illustrates

19. improvement activities and
20. company project and mission statement.

It is obvious that a visual management system will make a department look better and will help production and support personnel achieve production and maintenance schedules; control inventories, spare parts, and quality; conform to standards; focus on objectives and goals; and provide follow up to the continuous improvement process. It is also obvious that to use space efficiently, facilities planners need to use walls and aisles to display as much information as possible and need to allow for dedicated areas for materials, dies, housekeeping and maintenance tools, team meetings, and computer terminals.

It is also obvious that a visual management system like that depicted in Figure 3.37 might be difficult to justify economically. If space and budgetary constraints preclude implementing the ideal solution, then you should endeavor to incorporate in the final design as many of the desirable features of the visual management system as can be justified. Sight lines are important, as are good housekeeping and displaying essential information. Having a well-organized working environment will pay dividends in the productivity of the workforce.

3.8 SUMMARY

Activity relationships and space requirements are essential elements of a facilities plan. In this chapter we have emphasized the importance of their determination, as well as indicated that such a determination will not be a simple process. In a sense, the activity relationships and space requirements used in facilities planning provide the foundation for the facility plan. How well the facility achieves its objectives is dependent on the accuracy and completeness of activity relationships and space requirements.

Among the activity relationships considered, flow relationships are of considerable importance to the facilities planner. Included in the consideration of flow relationships are the movement of goods, materials, information, and people. Flow relationships were viewed on a microlevel as the flow within a workstation and on a macrolevel as a logistics system. Flow relationships may be specified by defining the subject, resources, and communications comprising a flow process. Flow relationships may be conceptualized by considering overall flow patterns and may be analyzed by considering general flow principles. Both quantitative and qualitative measures of flow are to be considered. The evaluation of flow relationships is a primary criterion for good facilities plans and serves as the basis for developing most facilities layouts.

We have also emphasized in this chapter the impact that cellular manufacturing, visual management, and many other modern manufacturing approaches have on flow, space, and activity relationships determination. The use of these concepts could change dramatically building size and shape; external and internal flow; and location of production, support, and administrative areas.

BIBLIOGRAPHY

1. Al-Qattan, I., "Designing Flexible Manufacturing Cells Using a Branch and Bound Method," *International Journal of Production Research,* vol. 28, no. 2, 1990, pp. 325–336.
2. Ballakur, A., and Steudel, H. J., "A Within-Cell Utilization Based Heuristic for Designing Cellular Manufacturing Systems," *International Journal of Production Research,* vol. 25, no. 5, 1987, pp. 639–665.
3. Black, J T., "Cellular Manufacturing Systems Reduce Setup Time, Make Small Lot Production Economical," *Industrial Engineering,* November 1983, pp. 36–48.
4. Black, J T., *The Design of the Factory with a Future,* McGraw-Hill, New York, 1991.
5. Burbidge, J. L., "Production Flow Analysis," *The Production Engineer,* April–May, 1971, pp. 139–152.
6. Burbidge, J. L., *The Introduction of Group Technology,* John Wiley, New York, 1975.
7. Chan, H. M., and Milner, D. A., "Direct Clustering Algorithm for Group Formation in Cellular Manufacturing," *Journal of Manufacturing Systems,* vol. 1, no. 1, 1982, pp. 65–74.
8. Deming, W. E., *Out of the Crisis,* MIT Center for Advanced Engineering Study, Cambridge, MA, 1986.
9. Dertouzos, M. L., Lester, R. K., and Solow, R. M., *Made in America: Regaining the Productive Edge,* MIT Press, Cambridge, MA, 1989.
10. Dumolien, W. J., and Santen, W. P., "Cellular Manufacturing Becomes Philosophy of Management at Components Facility," *Industrial Engineering,* November 1983, pp. 72–76.
11. Gabor, A., *The Man Who Discovered Quality,* Penguin Books, New York, 1990.
12. Greif, Michael, *The Visual Factory,* Productivity Press, Cambridge, MA, 1991.
13. Gryna, F. M., *Quality Planning and Analysis: From Product Development Through Use,* 4th ed., McGraw-Hill, New York, 2000.
14. Gupta, T., and Seifoddini, H., "Production Data Based Similarity Coefficient for Machine-Component Cellular Manufacturing System, Grouping Decisions the Design of a Cellular Manufacturing System," *International Journal of Production Research,* vol. 28, no. 7, 1990, pp. 1247–1269.
15. Ham, I., *Introduction to Group Technology,* Pennsylvania State University, University Park, PA, 1975.
16. Han, C., and Ham, I., "Multiobjective Cluster Analysis for Part Family Formations," *Journal of Manufacturing Systems,* vol. 5, no. 4, 1986, pp. 223–229.
17. Harhalakis, G., Nagi, R., and Proth, J. M., "An Efficient Heuristic in Manufacturing Cell Formation for Group Technology Applications," *International Journal of Production Research,* vol. 28, no. 1, 1990, pp. 185–198.
18. Hirano, H., *JIT Factory Revolution: A Pictorial Guide to Factory Design of the Future,* Productivity Press, Cambridge, MA, 1989.
19. Imai, M., *Kaizen: The Key to Japan's Competitive Success,* McGraw-Hill, New York, 1986.

20. Irani, S. A., editor, *Handbook of Cellular Manufacturing Systems,* John Wiley, New York, 1999.
21. Ishikawa, K., *What Is Total Quality Control?,* translated by D. J. Lu, Prentice-Hall, Englewood Cliffs, NJ, 1985.
22. Juran, J. M., *Juran on Leadership for Quality: An Executive Handbook,* The Free Press, New York, 1989.
23. Juran, J. M., *Juran on Quality by Design: The New Steps for Planning Quality into Goods and Services,* Free Press, New York, 1992.
24. Juran, J. M., and Godfrey, A. B., editors, *Quality Handbook,* 5th ed., McGraw-Hill, New York, 1999.
25. Khator, S. K., and Irani, S. A., "Cell Formation in Group Technology: A New Approach," *Computers in Industrial Engineering,* vol. 12, no. 2, 1987, pp. 131–142.
26. King, J. R., "Machine-Component Grouping in Production Flow Analysis: An Approach Using a Rank Order Clustering Algorithm," *International Journal of Production Research,* vol. 18, no. 2, 1980, pp. 213–232.
27. Konz, S., *Facility Design,* 1985, John Wiley, New York, 1985.
28. Kusiak, A., "The Generalized Group Technology Concept," *International Journal of Production Research,* vol. 25, no. 4, 1987, pp. 561–569.
29. Kusiak, A., editor, *Concurrent Engineering: Automation, Tools, and Techniques,* John Wiley, New York, 1993.
30. Logendran, R., and West, T. M., "A Machine-Part Based Grouping Algorithm in Cellular Manufacturing," *Computers in Industrial Engineering,* vol. 19, no. 1–4, 1990, pp. 57–61.
31. McAuley, J., "Machine Grouping for Efficient Production," *The Production Engineer,* February 1972, pp. 53–57.
32. Mizuno, S., *Company-Wide Total Quality Control,* Asian Productivity Organization, Tokyo, Japan, 1988.
33. Morris, W. T., *Analysis for Material Handling Management,* Richard D. Irwin, Homewood, IL, 1962.
34. Muther, R., *Systematic Layout Planning,* Cahners Books, Boston, 1973.
35. Ranson, G. M., *Group Technology,* Pergamon, New York, 1970.
36. Riley, F. J., *Assembly Automation: A Management Handbook,* Industrial Press, New York, 1983.
37. Rother, M. and Harris, R., *Creating Continuous Flow,* Lean Enterprise Institute, Brookline, MA, 2001.
38. Scherkenbach, W. W., *The Deming Route to Quality and Productivity: Road Maps and Roadblocks,* Mercury Press, Rockville, MD, 1991.
39. Schonberger, R. J., "Plant Layout Becomes Product-Oriented with Cellular, Just-In-Time Production Concepts," *Industrial Engineering,* November 1983, pp. 66–71.
40. Schonberger, R. J., *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity,* Free Press, New York, 1982.
41. Schonberger, R. J., *World Class Manufacturing,* Free Press, New York, 1986.
42. Schonberger, R. J., *World Class Manufacturing: The Next Decade,* Free Press, New York, 1996.
43. Schonberger, R. J., *Let's Fix It!: Overcoming the Crisis in Manufacturing,* Free Press, New York, 2001.
44. Seifoddini, H., "A Probabilistic Model for Machine Cell Formation," *Journal of Manufacturing Systems,* vol. 9, no. 1, 1990, pp. 69–75.
45. Shingo, S., *A Study of the Toyota Production System from an Industrial Engineering Viewpoint,* Translated by A. P. Dillon, Productivity Press, Cambridge, MA, 1989.
46. Singh, N. and Rajamani, D., *Cellular Manufacturing Systems: Design, Planning and Control,* Chapman & Hall, New York, 1996.

47. Srinivasan, G., Narendran, T. T., and Mahadevan, B., "An Assignment Model for the Part Families Problem in Group Technology," *International Journal of Production Research,* vol. 28, no. 1, 1990, pp. 215–222.
48. Stoner, D. L., Tice, K. J., and Asthon, J. E., "Simple and Effective Cellular Approach to a Job Shop Machine Shop," *Manufacturing Review,* vol. 2, June 1989, pp. 119–125.
49. Sule, D. R., *Manufacturing Facilities: Location, Planning, and Design,* 2nd ed., PWS Publishing, Boston, MA, 1994.
50. Sule, D. R., *Logistics of Facility Location and Allocation,* Marcel Dekker, New York, 2001.
51. Suzaki, K., *The New Manufacturing Challenge: Techniques for Continuous Improvement,* Free Press, New York, 1987.
52. Tsuchiya, S., *Quality Maintenance: Zero Defects Through Equipment Management,* Productivity Press, Cambridge, MA, 1992.
53. Walton, M., *The Deming Management Method,* Perigee Books, New York, 1986.
54. Walton, M., *Deming Management at Work,* Perigee Books, New York, 1990.
55. Womack, J. P., Jones, D. T., and Roos, D., *The Machine that Changed the World,* Macmillan, New York, 1990.
56. Wantuck, K. A., *Just-In-Time for America,* The Forum, Ltd., Milwaukee, WI, 1989.
57. Wemmerlov, U., and Hyer, N. L., "Cellular Manufacturing in the U.S. Industry: A Survey of Users," *International Journal of Production Research,* vol. 27, no. 9, 1989, pp. 1511–1530.
58. Wu, H. L., "Design of a Cellular Manufacturing System: A Syntactic Pattern Recognition Approach," *Journal of Manufacturing System,* vol. 5, no. 2, 1986, pp. 81–87.
59. *The Idea Book,* edited by Japan Human Relations Association, Productivity Press, Cambridge, MA, 1988.

PROBLEMS

3.1 Explain the meaning of a material management system, a material flow system, and a physical distribution system for a bank.

3.2 When would you recommend a group technology layout?

3.3 The paper flow to be expected through one section of city hall consists of the following:

10 medical records per day from records to marriage licenses

7 certificates per day from printing to marriage licenses

6 blood samples per day from marriage licenses to lab

6 blood sample reports per day from lab to marriage licenses

1 box of medical records per week from marriage licenses to records

The following load-equivalence conversions can be used:

One medical record is equivalent to one certificate.

One medical record is equivalent to one-half of a blood sample.

One medical record is equivalent to one blood sample report.

One medical record is equivalent to one-tenth of a box of medical records.

Develop a from-to chart for this section of city hall and then develop a relationship chart.

3.4 In designing the layout for an orthopedic hospital, describe how the design might be affected by the most important flow component being designated to be either patients, doctors, nurses, or access to expensive diagnostic equipment such as x-ray, cat-scan, and magnetic resonance imaging equipment.

3.5 When would you recommend a fixed position layout?

3.6 Which layout type is very popular in Just-In-Time facilities? Explain why.

3.7 Mention three limitations of the process layout type.

3.8 Use the direct clustering algorithm to form cells for the machine-part matrix shown below. If conflicts exist, propose alternative approaches for resolving the conflicts.

	Machine #			
Part #	1	2	3	4
1		1	1	
2	1			
3			1	
4	1			1

3.9 For the machine-part matrix shown below, form cells using the direct clustering algorithm and, if conflicts exist, propose alternative approaches for resolving the conflicts.

	Machine #				
Part #	1	2	3	4	5
1	1		1		
2					
3		1		1	1
4	1		1		
5		1			
6				1	1

3.10 Singh and Rajamani [46] provide data for a local wood manufacturer that wants to decrease material handling by changing from a process layout to a GT layout. It is considering installing a conveyor for intracellular movement of parts. It wishes to restrict interacellular movement. The machine-part matrix for the wood manufacturer is shown below. Use DCA to form the cells and, if conflicts exist, propose alternative approaches for resolving the conflicts.

	Machine #					
Part #	1	2	3	4	5	6
1					1	1
2	1			1		
3			1			1
4	1	1				
5	1					
6					1	1
7		1		1		
8			1			1

3.11 For Problem 3.10, suppose the machine-part matrix for the wood manufacturer is as shown below. Use DCA to form the cells and, if conflicts exist, propose alternative approaches for resolving the conflicts.

	Machine #					
Part #	1	2	3	4	5	6
1			1		1	1
2	1			1		
3			1			1
4	1	1				
5	1		1			
6					1	1
7		1		1		
8			1			1

3.12 Visit a local fast-food restaurant. Describe in detail the arrangement of aisles for the customers (the service line, the booth area, etc.) and the arrangement of aisles for the workers (the area behind the counter) by sketching a layout. Draw the flow of the customers and employees on the layout. Explain how the flow of the workers and customers would change if the layout was different. Is there adequate space for the customers and the employees to operate efficiently? Can any improvement in the layout create a more efficient flow? Describe any visual management approaches being used.

3.13 Choose ten main components of a kitchen, (e.g., oven, sink). Develop a relationship chart of the ten components. Sketch a kitchen containing the ten components and arrange them based upon the relationship chart findings.

3.14 What is the impact of "backtracking" in a manufacturing process? Discuss several methods to prevent "backtracking" from occurring.

3.15 What are the pros and cons of having multiple input/output points (receiving and shipping areas) in a given manufacturing facility (list at least three of each)? What types of considerations should a facilities designer take into account when determining whether or not to use multiple input/output points?

3.16 Which information does the facilities designer need from top management, product designer, process designer, and schedule designer? Describe at least ten modern manufacturing approaches that impact drastically the facilities design process.

3.17 Provide at least 10 benefits of using manufacturing cells. Which modern manufacturing approaches are usually employed in conjunction with manufacturing cells (include at least 10)?

3.18 Develop a part-machine matrix like the one in Figure 3.2 for a situation with ten parts and 15 machines. Use the DCA methodology to identify clusters (cells) of parts and machines. Do you have a bottleneck machine? Recommend at least three different ways to resolve this situation.

3.19 Define a kanban. Which are the different types of kanbans? List at least five benefits of using kanbans. Why are kanbans important in cellular manufacturing?

3.20 Mention at least seven benefits of using U-shape arrangements in manufacturing cells.

3.21 Describe the impact of modern manufacturing approaches on the logistics system.

3.22 Which new functions are being managed by multifunctional operators? Describe the impact of this new roles on activity relationships and flow and space requirements.

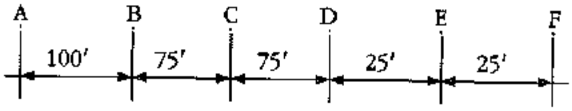
3.23 Why is it important for a facilities planner to consider the logistics system?

3.24 Go to a local quick food hamburger restaurant and assess the impact of the order taker's workstation on the overall facility flow. Describe the process and make recommendations for improvement.

3.25 What are the trade-offs involved in parallel, perpendicular, and diagonal flow within parking lots?

3.26 How are the flow principles taken into consideration by you from the time you wake up in the morning to go to school until you go to bed that evening? (Assume you did not cut your classes and you did not stay up all night studying.)

3.27 Given the spatial schematic below, evaluate the flow path lengths for the following components:



a. Component 1 routing A-B-C-D-E-F.

b. Component 2 routing A-C-B-D-E-F.

c. Component 3 routing A-F-E-D-C-B-A-F.

d. Component 4 routing A-C-E-B-D-F.

3.28 What is the impact on a city having streets that do not meet at right angles? Relate this to aisles.

3.29 A waiter at the famous French restaurant Joe's is interested in obtaining your help in improving the layout of the serving area. After establishing the space needs for the salad serving, beverage serving, dessert serving, soup serving, entree serving, and bill writing areas, you decide your next step is to develop a from-to chart. To do this you need to establish equivalency of loads. Establish these equivalencies and explain your reasoning.

3.30 Given the following from-to chart, recommend an overall flow pattern that will reduce flow.

From \ To	A	B	C	D
A			4	
B				4
C		4		
D	4			

3.31 Develop a relationship chart for the relationships between you, your professor, department chair, college dean, and university president. Develop another relationship chart from your professor's view point for the same people.

3.32 Design a survey that is to be used to determine the relationships among departments in a local bank.

3.33 Develop an activity relationship chart reflecting a student's perspective for the following campus areas: classroom A, classroom B, classroom C, classroom D, professor's office, registrar's office, financial aid office, resident hall room, dining area, parking place for student's automobile, library, computer lab, post office, barber shop or hair salon, and coffee house for students, faculty, and staff. Assume the student takes 2 classes in the morning in alphabetical order in classrooms A and B, plus 2 classes in the afternoon in alphabetical order in classrooms C and D.

3.34 Develop an activity relationship chart that you believe reflects a professor's perspectives for the following campus areas: professor's office, departmental office, academic dean's office, chief academic officer's (provost's) office, university president's office, library, classroom for teaching, laboratory for research, staff assistant's office, graduate assistant's office, professor's parking space, faculty lounge, faculty dining area, restroom, post office, barber shop or hair salon, departmental conference room, and coffee house.