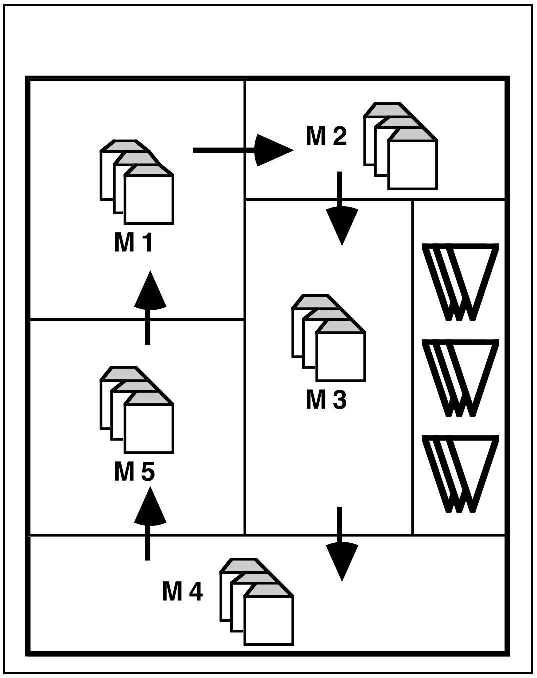
Facility Layout



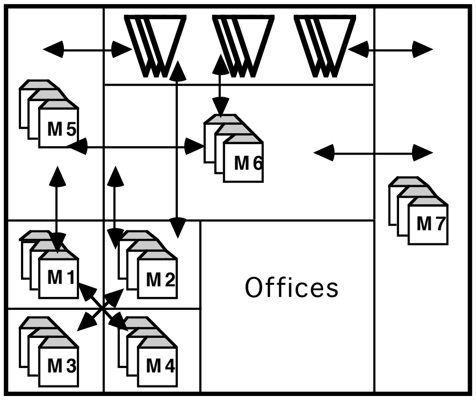
A typical manufacturing plant has a number of diverse activities interacting with each other. Thus, raw materials arrive at a shipping dock, they are unpacked and checked in a quality control area, they may then be processed through several processing areas, and finally the finished product again passes through the shipping dock. In addition to areas specifically related to production, there must be dressing rooms, lunch rooms, and restrooms for employees; offices for supervision, design, and production control; and space for inventory and aisles. In fact, a plant may be viewed as a large number of finite geometric areas arranged on the floor space of the building. The problem of arranging these areas in an effective manner is the facility layout problem.

Clearly, the layout problem has relevance in many areas of facility and equipment design, from the layout of the rooms in a home to the layout of chips on an electronic circuit board. Although the facility layout problem may arise in many contexts, in this section we assume we are dealing with a plant manufacturing products for sale.

Types of Layouts

There are several alternative layout types that are appropriate for different product mixes and production volumes. Determination of the layout type is a major design decision because it impacts on so many other aspects of the production system.

Job Shop Layout

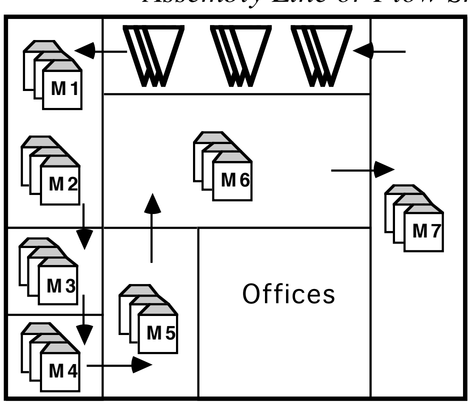


In the Job Shop Layout, machines are grouped according to function into machine centers. Orders for individual products are routed through the various machine centers to obtain the required processing. This layout may be appropriate when there are many different products, each with a low volume of production. Machines are general purpose, within their general function area, so that a wide variety of products can be handled. Because the expense of automation may be too great to be justified by the low volume, the machines in this arrangement will probably be at a relatively low level of automation. Workers will be highly skilled.

Production scheduling is difficult with this type of arrangement because the level and type of work is highly variable. This results in large amounts of work-in-process, long product lead times, and high levels of management interaction. Typically there is a high degree of product movement required by the long and variable routes of individual products through the system. The costs for setting up machines to produce the various products will be high because of the variety of different products and small lot sizes.

The arrangement can adapt readily to changes in product volume and design because of its inherent flexibility.

Assembly Line or Flow Shop Layout

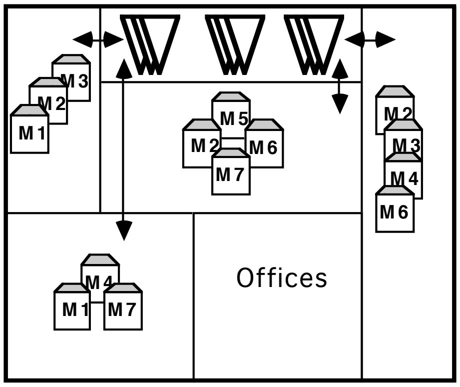


Here the product (or products) follows a fixed path through the production resources. The resources are arranged to minimize the material movement required. This type of layout is typical for an assembly line where a single product, or a few very similar products, passes through the line in a continuous fashion. Because of the high volume of production, the machines on the line can be designed with a high level of fixed automation, with very little manual labor. Direct labor will be much less than for the job shop, but there will be high costs for maintenance. Setup costs and work-in-progress will be low for this arrangement.

The line, in general, is not flexible to product or volume changes. It is very sensitive to failures that cause the entire line to shut down.

The arrangement is also appropriate for a flow shop that may have a number of products that all pass through the machine centers in the same order. In this case, the machines implementing the system may or may not be automated depending on the product mix and volume, but one would expect a higher level of automation than for the job shop.

Group Technology Layout



The product mix appropriate for this arrangement is similar to that of the job shop. Products are grouped into classes that have some similarity with respect to processing. A manufacturing cell is designed for each group consisting of machines particularly adapted to the processing required. The figure shows the cells as collections of dissimilar machines. Because the range of products manufactured by each cell is less than that for the job shop, the machines and workers can be more specialized.

Typically, the workers in a cell are given more of the responsibility for production scheduling of a product class. This, together with the start-to-finish nature of the processing, results in more interesting jobs for the workers.

The group technology arrangement requires less setup time and cost than the job shop because of the greater specialization of function. It is compatible with the *just-in-time* concept of manufacture, so prevalent today, because of the smaller lot sizes made possible by the low setup costs.

Often the level of automation with group technology is low, indicating the dependence of the concept on the skill of the labor force. Many companies have, however, introduced highly automated *flexible manufacturing cells* into the system. Because the cell has a smaller range of products than the entire plant, it is easier to design the automation to handle the set of products in a group.

The group technology approach is more sensitive to changes in product mix and volume than the job shop, again because of the specialization introduced because of the manufacturing cell approach. When a product requires processing in more than one cell, problems similar to those of the job shop are introduced.

Fixed Location Layout

For tasks on large objects such as the manufacture of an electrical generator, the construction of a building, or the repair of a large airplane, the machines implementing the operation must come to the product, rather than the product moving to the machines. Here the question is more often the scheduling of operations rather than the layout of machines.

Flexible Manufacturing Systems

The FMS is a system with automated material handling moving individual units of product between automated processors. Robotic manipulators often handle material. Using computer controlled movement and processing, a wide variety of products can be manufactured. All of this is to be accomplished with very low setup time, great flexibility of function, and very little manual labor.

The diversity of possible FMS, and the rapidly changing technologies, makes detailed consideration of the design of FMS beyond the scope of this text. Certainly many of the classical questions (and answers) associated with facility design are no longer relevant for the FMS. In this text we consider the FMS as just another kind of machine, with perhaps a very broad range of capabilities.

Layout Problem

The layout problem is to arrange the physical spaces required for several departments in a given space provided for the departments. In practice the facility layout problem is often solved by intuition, using the artistic and spatial skills of the human designer; however, when there are quantitative considerations associated with the layout problem, the human is at a disadvantage as compared to the computer. In this chapter we concentrate on computerized procedures for solving the layout problem. There are a variety of problems regarding layout one might encounter. In this section we explain the problem by specifying the data and describing the decisions.

Input Data

Here we are considering the problem of arranging several departments on a plant with a single floor and fixed dimensions.
Certain data is necessary to describe the layout problem.

- Number of departments, n,
- Physical area of each department, A_i for $i = 1 \ldots n$
- Physical dimensions of the plant in which the departments are to be placed: Length, L, and Width, W.
- Product flow between every pair of departments: f_{ij} for $i = 1 \ldots n$ and $j = 1 \ldots n$.
- Material handling cost between every pair of departments measured in dollars per unit-foot: c_{ij} for $i = 1 \ldots n$ and $j = 1 \ldots n$.

Distance

Our models involve the distance from one department to another. The distance depends on the layout. To illustrate consider a problem with ten departments with each department having an area of 100 square feet. The ten departments are to be placed in an area that is 50 feet long by 20 feet wide. One layout is shown in Figure 1.

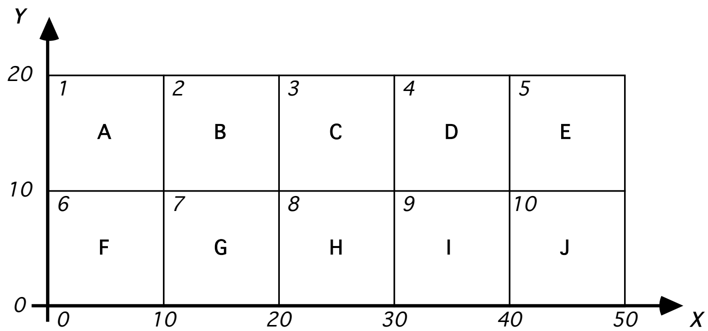


Figure 1. A layout of departments

This is only one of many possible layouts. If we assume that the departments must maintain a square shape, every permutation of the letters A through J is a different layout. There are $n!$ permutations.

The matrix as in Fig. 2 describes the flow between the departments. This is called the *From-To* matrix because an element (i, j) contains f_{ij}, the flow from department i to department j.

From \ To	A	B	C	D	E	F	G	H	I	J
A					5				1	9
B				3	4		1			
C				1			9			2
D							6		1	
E						8	3			
F							2	5		
G								6		
H									8	
I										
J										

Figure 2. From-to Matrix for the Office Example

The criterion for the layout problem involves the distance between departments. First we must prescribe the end points for the distance measurement. Here we assume that distances are measured between the centroids or centers of gravity of departments. Second, we must specify the route of travel. One possibility is that flow will follow a straight-line path. This is the Euclidean measure. More common in layout analysis, is to assume that flow travels via paths that are parallel to the axes of the layout. This is the rectilinear measure.

The centroids are specified in terms of the coordinate system as

$x(i)$ = x-coordinate of the centroid of department i, and

$y(i)$ = y-coordinate of the centroid of department i.

The centroid is the same as the center of the area when the department is rectangular. For a more general shape, the centroid is the center of gravity of area.

In the example case of Fig. 1 we have the centroids as follows.

Department A: $x(A) = 5$, $y(A) = 15$.

Department B: $x(B) = 15$, $y(B) = 15$.

Department C: $x(C) = 25$, $y(C) = 15$.

etc.

The distance between two departments by a rectilinear measure is

$$d_{ij} = |x(i) - x(j)| + |y(i) - y(j)|.$$

Here the vertical lines indicate absolute value. Fig. 3 shows both the flow and distance between all pairs of departments on the from-to chart . The flow appears above the diagonals and the distance appears below.

From \ To	A	B	C	D	E	F	G	H	I	J	Sum
A					5 / 40				1 / 40	9 / 50	690
B				3 / 20	4 / 30		1 / 10				190
C				1 / 10			9 / 20			2 / 30	250
D							6 / 30		1 / 10		190
E						8 / 50	3 / 40				520
F							2 / 10	5 / 20			120
G								6 / 10			60
H									8 / 10		80
I											0
J											0

Figure 3. Computation of the Total Distance Traveled

Criterion for Comparison

The flow multiplied by the distance and summed over all cells of the chart. We compute the cost for the flow from i to j as the product of the material handling cost, the flow and the distance between the departments. The cost of the layout is the sum of the flow cost.

$$z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} f_{ij} d_{ij}$$

The cost associated with each row of the chart is shown at the right of Figure 3. The cost of the layout is the sum of the row costs.

The factors c_{ij} and f_{ij} are given as data, but the factor d_{ij} depends on the layout.

Finding a Layout with the CRAFT Method

The plant layout problem is to find an arrangement of departments that minimizes the total distance traveled. This measure is called the "cost" in the following. The problem is difficult for the human because of the large number of calculations required to evaluate the cost of an alternative. The computer can greatly aid in the layout determination, but, as we will see, the computer also has its weaknesses.

The problem of finding the optimum arrangement is a very difficult one for mathematical optimization. Rather than attempt to obtain the optimum, we use a heuristic approach that tries to better a given solution by switching pairs of departments. At each iteration, every pair of departments is considered for switching locations. The pair that gives the greatest savings in cost will be interchanged and the process will continue by looking for another pair to switch. If no pair results in a positive savings the process stops. This is commonly called the CRAFT* method.

Note that when two departments are switched in Fig. 1, only the centroids of the two departments are affected. For example, if department A is switched with department H, the centroid of A becomes (25,5), while the centroid of H becomes (5, 15). All other departments remain fixed. The only effect on the cost of the layout is related to the flows entering or leaving the two departments. The cost of the flow between the other departments is unaffected because the distances between these departments have not changed. This is the logic used by the solution method. The cost savings associated with switching two departments is determined by calculating the effect of interchanging the centroids of the two departments.

There are several reasons why the CRAFT method may not yield the optimum solution. First, it may be necessary to switch more than two departments to find a better solution. More complex implementations of the method do allow switching three or more departments, but this increases considerably the computation time.

Problems for which the department areas are not equal cause several new difficulties. If two departments are not of equal area, switching their locations may not be equivalent to switching the centroids. In fact, if two unequally sized departments are not physically adjacent it will not be possible to interchange them. The method allows departments of different areas to be switched only if they are physically adjacent.

Allowing departments with different areas to switch causes another problem. When a small department is interchanged with a larger department there are a number of possible arrangements of the two areas with a corresponding variety of centroids. It is impossible to enforce a requirement that areas remain rectangular, so often the interchange of such departments causes irregularities in shape that grow worse as the algorithm progresses.

Because the change in cost is not exactly represented by the interchange of centroids, the estimate of the cost reduction may not be accurate. It is possible that the program will switch two areas and have the total cost increase. To guard against cycling, the method stops if a certain number of successive iterations do not result in an improvement.

Since the CRAFT method does not guarantee and optimum solution, it should be run several times with different initial layouts.

Centroids Fixed

Although layout analysis is not limited to departments of equal size and shape as the example in Fig. 1, problems of this type are somewhat simpler than the more general case. What makes this problem special is that we can identify *n* fixed points as centroids and assign the departments to the points. The distance between centroids does not vary, but the distance between departments depends on the assignment of departments to centroids. The problem can be modeled as a *Quadratic Assignment Problem* (QAP). Although this problem is simpler in concept than the problem with different sized departments, it remains a very difficult optimization problem to solve. Since the QAP is an appropriate model for a variety of problems, it has received a great deal of attention from researchers in combinatorial optimization.

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* E. S. Buffa, G.C. Armour, and T.E. Vollman, "Allocating Facilities with CRAFT," **Harvard Business Review, Vol. 42**, No. 2, March-April, 1964, pp 136-58.