

QUANTITATIVE TECHNIQUES FOR
PLANT LAYOUT ANALYSIS

by

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INTRODUCTION

In recent years industrial engineers have been much concerned with the question "How good is the layout we have?" Plant layout has become one of the most interesting and important phases of industrial engineering.

Reference is made to plant layout, in very general terms, in the definition of industrial engineering adopted by the American Institute of Industrial Engineers. The definition reads, "Industrial engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design to specify, predict and evaluate the result to be obtained from such systems." Plant layout is closely concerned with the design and installation of systems of men, materials and equipment. Good plant layout is fundamental to the operation of an efficient industrial organization. In some cases it is a critical factor in the survival of an enterprise.

Plant layout is a plan of or the act of planning an optimum arrangement of industrial facilities, including personnel, operating equipment, storage space, materials handling equipment, and all other supporting services, along with the design of the best structure to contain these facilities.

Everyone within an industrial organization is connected with plant layout in some way, and every one within a plant is interested in its layout to some degree. The worker is interested in the arrangement of his work station. The foreman is interested in layout as it affects the output of his department. Middle management is interested in layout as it affects the output and costs of its areas of responsibility. Suggestions that result in plant layout

thinking may come from anyone in the organization, from the president to the production worker.

Although in individual cases the details may be different, most plant layouts are stimulated by one of the following developments.

1. New product
2. Changes in volume of demand
3. Product design change
4. Frequent accidents
5. Facilities becoming obsolete
6. Change in the location
7. Cost reduction
8. Poor worker environment

Plant layout problems seem to fall into the following four categories listed in order of magnitude:

1. Minor changes in present layouts
2. Existing layout rearrangement
3. Relocating into existing facilities
4. Building a new plant.

The objectives of the plant layout department should be to provide overall simplification of the product process, minimize the costs of materials handling, provide facilities for a high work-in-process turnover, for effective space utilization, and for worker convenience as well as safety, promote job satisfaction, avoid unnecessary capital investment, and stimulate effective labor utilization.

The factor that is most concerned during the plant layout analysis is materials handling. In this paper the quantitative approaches to the plant

layout problems will be discussed keeping in mind the objective to minimize materials handling effort.

MATERIALS HANDLING RELATION TO PLANT LAYOUT ANALYSIS

In order for raw materials to be converted to a finished product, it is necessary that movement of at least one of the three basic elements of production, i.e., material, men or machines; take place. Without this movement, mass production as we think of it today, would stop. In most industrial processes it is the material that moves rather than the men or machines. Occasionally it is easier to move the men or machines or both than it is to move the materials. In the aircraft industry, for example, it is easier to move a man with his portable electric drill than it is to move the aircraft to him. Since it seems that materials are more widely moved, the term "materials handling" has been coined to describe problems of this nature.

A great deal of literature is available on materials handling and its various phases. The term "materials handling" has been defined in different ways. The American Materials Handling Society has defined it as follows: "Materials handling is the art and science involving the movement, packaging and storing of substances in any form." This is a very broad definition which encompasses a great number of cases. It must be interpreted to mean substances in any form; gaseous, liquid or solid. The natural-gas industry is concerned with the movement of gaseous substances, which involves the use of such materials handling equipment as pumps and pipes. Railroads are concerned with the movement of materials outside the factory.

As the term "materials handling" will be used in this paper it will primarily infer that material in a solid state, and the term will be used to

consider only movement within the factory itself. The definition by Haynes* better fits the needs of this paper. "Materials handling embraces the basic operations in connection with the movement of bulk, packaged and individual products in a semi-solid or a solid state by means of gravity, manually or power-actuated equipment and within the limits of an individual producing, fabricating, processing or service establishment." Although this definition is somewhat lengthy it describes the term in the sense that the layout man is connected with it in his planning.

Materials handling has traditionally been broken down according to the various equipment classifications but recently an effort has been made to classify subject matter into functional activities. The Materials Handling Handbook classifies these functional areas as follows (1):

1. Bulk handling
2. Unit handling
3. Industrial packaging
4. Warehousing
5. Carrier handling
6. Handling operation analysis

Layout men in industries dealing with a product in the solid form are interested primarily in the unit handling and warehousing problems, along with handling operation analysis.

Plant layout is so closely interwoven with materials handling that it is difficult to discuss one without the other. To install an effective handling system without considering the plant layout. On the otherhand, a plant

* D-Cliphant Haynes, Materials Handling Equipment, p. viii.

layout solution will not be good unless the materials handling problems have been analyzed.

Materials handling costs are somewhat elusive when the costs of manufacturing are examined. As materials handling increases, the manufacturing cost of the product rises; when cost is added to a product, value should be added at the same time. This is not the case with materials handling; when a product is moved from here to there, no value is added to it. The product will not be worth any more to the consumer simply because it is moved, but it will cost the customer more. The customer will not pay more for a watch which has been moved ten miles within the plants than he would for the same watch which had been moved only 1,000 feet.

A manufacturing process which consisted only of steps that added value to the product would be a theoretically optimum process. From a practical point of view, very few processes will ever approach this stage. A good layout will attempt to minimize the number of steps in the manufacturing process which add cost to the product without adding any value. Materials handling is a prime step in most manufacturing processes that does just this. It then behooves the layout man to give considerable thought to the costs of materials handling.

However, steps that add cost to a product must be considered from the over-all point of view. There would be no sense in specifying movement of materials between A and B, if movement between A and C, which performs the same operation as B, would minimize the amount of materials handling if the result was an idle man and machine at position C for a prolonged period of time. Materials handling is a means of supporting and simplifying a manufacturing process. It is not an end in itself. It should

be used to minimize over-all costs, not just the local costs of handling.

When industrial management first realized that handling could be a problem, there was a tendency to mechanize materials handling with little thought to over-all costs. If, for example, the layout man was conveyor-oriented, he might simply specify conveyors to solve all handling problems. No universal answer can be given to all handling problems. Each problem must be considered on its own merits, and each type of materials handling equipment should be used in its proper place.

Recently people concerned with materials handling have stressed minimizing of all handling. Their recommendation that materials handling be reduced to the minimum can be somewhat misleading. Perhaps this outlook is acceptable in the majority of cases, but sometimes extra materials handling results in better utilization of men and machines. The ability to move materials can result in increased productivity by a division of labor, reducing the skills required. The layout man may well want to reduce unnecessary and uneconomical materials handling, but to minimize all materials handling according to a hard and fast rule may occasionally be suboptimum in terms of the over-all picture.

A more enlightened viewpoint is to move materials as little as possible without incurring excessive costs in other production factors. Supplementing this with layout to provide short moves which are always toward the completion of the product establishes a sound production situation.

Product Flow

Providing an efficient flow of the product through a plant is fundamental it must be considered at a number of different stages during the layout

procedure. If the layout is properly planned, it automatically reduces the cost of materials handling, since flow is determined primarily by the layout.

The flow of the product is of primary importance during the planning of: (a) the block plan and (b) the detailed floor layout itself. The sequence of developing the block plan and the floor layout may vary, depending upon the type of planning problem. The sequence is somewhat different in a relayout problem than it is when a new plant is being designed from the start. The flow of the product involves the flow of raw materials from the time they enter the plant until they become work-in-process. The flow of work-in-process must show the path of all components of the final product as individual items as well as when they are parts of an assembled component. Subassemblies and assemblies become part of the flow until they are finally packaged into finished goods. The flow of finished goods within the plant is also of importance in planning a layout and should be shown until the time the finished goods leave the plant.

When the block plan is under consideration, one of the decisions that must be made is the arrangement of departmental areas. Once the area requirement for each department is determined, the arrangement of the departments is quite dependent upon the product flow, i.e., the materials handlings between departments. For the single product plant, if the product is not too complex, it is fairly easy to ferret out unnecessary handling. The block plan for such a plant can rather easily be adjusted by moving the various areas or departments until the handling is minimized. In the case of an industry that is involved with a number of products or a product that has many components in its final assembly, the flow on the block plan can easily become so complex that a great deal of difficulty is encountered in the analysis of the situation.

By themselves, the flow lines drawn on the block plan offer no systematic means of evaluating a layout alternative for handling efficiency.

Travel Chart

One technique that can be very helpful in the analysis of such a problem is the travel chart. This can be of use not only when considering the arrangement of departments or areas within the block plan, but also when considering the arrangement of equipment in the floor layout if the situation is analogous. In the classical product type of layout, there is no need for using a travel chart, but the process type of layout, can be a hodge-podge of confusion with respect to flow, and the travel chart can provide a systematic arrangement.

An effective process-type layout can be determined by establishing the magnitude of relationships between all combinations of departments (the term "relationships" here is used to mean materials handling relationships). The theoretical optimal layout would then be one in which each department would be adjacent to every other department with which it has relationships. In most practical problems of this nature, this theoretical optimum is very difficult to achieve, but one should attempt to approach it.

The travel chart is a device which may be used to assemble in compact form a large quantity of data in the form of a matrix. In the matrix form a large quantity of data can be understood by the layout analyst. The travel chart is analogous to the mileage chart, commonly found on road maps, which indicates the distance in miles from one destination to another.

The travel chart appears to be similar to the mileage chart in many respects. The units appearing in the mileage chart are units of distance.

In the travel chart the numbers entered represent an amount of materials handling. In practice a wide variety of units may be entered in the matrix, depending upon factors that might be pertinent to the problem. The unit used might represent only the frequency of handlings or it might indicate both frequency and distance of handlings. Factors could be included to provide an indication of the weight of the product or its bulkiness, or to balance up different modes of materials handling, i.e., different types of handling equipment. The units utilized in the travel chart should be chosen carefully to reflect the true characteristics of the problem.

Procedure for Travel Charting

The steps in travel charting can be generalized as follows (2):

1. State the restrictions within which the study must operate.
2. State the assumptions upon which the study will be used.
3. Collect the necessary data.
4. Prepare a sequence summary.
5. Treat the data as indicated in the assumptions, and prepare the travel chart.
6. Develop the schematic layout.
7. Check the efficiency of the layout.
8. Repeat steps 5 through 7 as required.

Methods for Improving the Layout

A number of possible factors may be changed to approach the optimum layout. It is possible to change these, one at a time or more than one at a time, to improve the layout.

- (a) Changing the arrangement of the destinations.
- (b) Changing the sequence of operations on the parts involved.
- (c) Changing the product mix.

Since we are involved primarily with layout, optimum solution will be arrived at by changing arrangements. Changing the sequence of operations of the parts involved complicates the analysis of the problem considerably, but could aid the approach to the optimum solution. Changing the product mix also complicates the analysis, but can be used to alter the optimum solution.

Example: Plot Plan by Travel Charting.

In establishing the plot plan during the planning of the factory, it is often useful to arrange the plots, i.e., the areas to be allocated, which may or may not be departments; so that the over-all amount of materials handling is minimized. The travel chart procedure does not guarantee a solution with minimum handling, but it does provide a way of systematically gathering large quantities of data which can be used towards this goal.

The hypothetical example will be illustrated with the aid of travel charting procedure. Keating Products Inc., of Cleveland finds that its facilities have become inadequate, and has gathered enough capital together to build a new plant in a less industrialized section of the city. The problem is to determine the optimum arrangement for the departments in the proposed new plant.

1. Restrictions.

- (a) Each department requires equal area.
- (b) Production planning specifies the sequence of operations and indicates that they are not to be changed.

- (c) Diagonal aisles are prohibited.
 - (d) Sales department requires that the product mix remain stable.
2. Definitions of assumptions.
- (a) The measure of effectiveness of the layout is the sum of the products of moves per year multiplied by the distance moved, that is

$$M = \sum_{j=1}^9 \sum_{i=1}^9 a_{ij} \cdot b_{ij}$$

where a_{ij} is the moves per year from i^{th} to the j^{th} department.
and b_{ij} is the distance from the i^{th} to the j^{th} department.

3. Collection of necessary data.
- (1) The departments are as follows:
 - (a) Receiving
 - (b) Snagging and inspection
 - (c) Milling
 - (d) Automatic screw machines
 - (e) Welding
 - (f) Grinding
 - (g) Plating
 - (h) Painting
 - (i) Packing and warehouse.

4. The data on the parts, volume, sequence, and parts per load are shown in Table 1.

Table 1
Sequence Summary

Part No.	Volume : pcs/year	Bulk factor : pcs/load	Sequence
1	5,000	20	(a) (b) (c) (h) (i)
2	12,000	200	(a) (c) (e) (g) (i)
3	600	30	(a) (b) (c) (f) (g) (i)
4	2,000	500	(a) (d) (e) (c) (i)
5	5,000	100	(a) (b) (h) (c) (f) (i)
6	9,000	50	(a) (d) (i)
7	20,000	1,000	(a) (d) (g) (i)
8	2,000	100	(a) (h) (f) (i)
9	1,000	250	(a) (b) (d) (g) (i)

5. Treat the data and prepare the travel chart.

- a. According to the assumption made in step 2, the data are treated to determine the trips per year, or moves per year. The number of loads per year is determined from the volume and bulk factor as follows:

$$\text{Load/year} = \frac{5,000 \text{ pcs/year}}{20 \text{ pcs/load}} = 250 \text{ loads/year}$$

The moves per part are determined from the sequence of operations shown in the Sequence Summary. This figure will be one less than the number of operations performed on that particular part. The moves per year then determined by multiplying the loads per year times the moves per part, as follows:

$$\text{Moves/year} = 250 \frac{\text{loads}}{\text{year}} \times 4 \frac{\text{moves}}{\text{part}} = 1,000 \text{ moves/year}$$

The treated data are summarized in Table 2.

Table 2.

Summary of Treated Data

Part No.	:	Loads/year	:	Moves/part	:	Moves/year
1		250		4		1,000
2		60		4		240
3		20		5		100
4		4		4		16
5		50		5		250
6		180		2		360
7		20		3		60
8		20		3		60
9		4		4		16
Total						2,102

b. In preparing the travel chart, units of loads per year were chosen since they seemed to best describe the amount of materials handling.

The travel chart is shown in Fig. 1.

6. Developing a schematic layout.

Working from the travel chart, a schematic layout is developed which uses small circles to represent departments. The lines joining the departments are used to indicate a materials handling relationship between the two indicated departments. While the numbers indicate

		To									Total
		Rec (a)	Snag (b)	Mill (c)	Auto (d)	Weld (e)	Grind (f)	Plate (g)	Paint (h)	Pack (i)	
From	Rec (a)		324	60	204				20		608
	Snag (b)			270	4				50		324
	Mill (c)					60	70		250	4	384
	Auto (d)					4		24		180	208
	Weld (e)			4				60			64
	Grind (f)							20		70	90
	Plate (g)									104	104
	Paint (h)			50			20			250	320
	Pack (i)										0
	Total	0	324	384	208	64	90	104	320	608	2,102

Fig. 1. Travel Chart for Keating Products, Inc.

loads per year taken from the travel chart. The schematic layout is not to be considered to scale, so that floor area restrictions must be taken into consideration in a later step. The first schematic layout of the new Keating Products plant is shown in Fig. 2.

7. Checking the efficiency of the layout.

- a. In order to make an efficiency comparison it is necessary to determine the reference plane of comparison. The theoretical optimum layout would be one which every department was adjacent to every other department with which it has materials handling relationship, either receipt from or delivery to. In the restrictions defined earlier it was stated that each department has equal area.

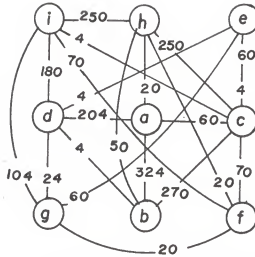


Fig. 2. Schematic Layout (1st Alternative)

With this restriction in the theoretical optimum layout, each is considered one unit of distance, which means that the number of moves is a direct function of distance moved. The total moves per year shown in Table 2 is then considered the minimum number of moves required in the theoretical optimum layout. This total is utilized as the basis of efficiency comparison. The efficiency computation for the first schematic layout is in Table 3. Note that the path numbers are not assigned to any particular paths, but are included to provide a check to insure that all data are included in the efficiency computation.

- b. The total numbers of paths can be quickly checked by counting the number of filled squares on the matrix of the travel chart.

$$\text{Efficiency} = \frac{\text{moves/year (optimum)}}{\text{moves/year (1st alternative)}} \times 100$$

$$= \frac{2,102}{3,296} \times 100 = 63.8\%$$

Table 3
Calculation for Efficiency (1st Alternative)

Path No.	: Path : destination	: Moves/year	: Units of : distance	: Moves-distance : year
1	(h) (i)	250		
2	(d) (i)	180		
3	(d) (g)	24		
4	(a) (d)	204		
5	(a) (b)	324		
6	(a) (h)	20		
7	(a) (c)	60		
8	(c) (f)	70		
9	(c) (e)	60		
10	(e) (c)	4	1,196	1,196
11	(b) (d)	4		
12	(b) (c)	270		
13	(c) (h)	250		
14	(h) (c)	50		
15	(f) (g)	20		
16	(g) (i)	104		
17	(b) (h)	50	748	1,496
18	(d) (e)	4		
19	(c) (i)	4		
20	(h) (f)	20	28	84
21	(e) (g)	60		
22	(f) (i)	70	130	520
Total				3,296

The efficiency for the 1st alternative layout is indicated in the computation. The efficiency of alternative solutions to follow is compared to this figure.

- c. Since, in the restrictions no diagonal aisles are to be permitted, the diagonal paths shown on the schematic layout are assigned two unit distances. In a like manner, the path between destinations (f) and (h) is assigned three unit distances.
8. Repeat steps 6 and 7 as necessary.
- a. Examining Table 3 and considering the schematic layout by trial and error the following improvements are recommended:

Move (a) to the outside of the building, since it is the receiving room and requires trucking docks. The center department should be one with the maximum number of departments as materials handling contacts. Department (a) has contact with only four other departments, while (h) and (i) both have contact with five departments.

By trial and error method further refinements may lead to the schematic layout shown in Fig. 3.

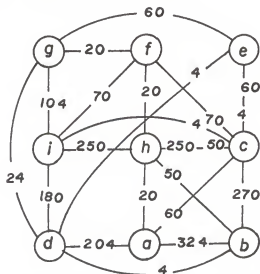


Fig. 3. Schematic Layout of Improved Alternative at Keating Products, Inc.

- b. The efficiency computation indicates that there is considerable improvement. The computational data for this efficiency are shown in Table 4. For the improved solution the efficiency is as follows:

$$\text{Efficiency} = \frac{2,102}{2,456} \times 100 = 85.8\%$$

Considerable improvement is shown in the amount of materials handling in the improved solution.

- c. Very probably, by further trial and error solution some refinements may be made upon this solution. Nevertheless, from this schematic layout it is possible to work out a block diagram which is shown in Fig. 4. The block diagram is relatively simple, since one of the restrictions indicated that all departments should have equal areas. Notice that both Receiving and Packing are on the outside of the layout for accessibility for outside truckers and haulers.

Plating g	Grinding f	Welding e
Packing i	Painting h	Milling c
Automatics d	Receiving a	Snagging b

Fig. 4. Block Diagram Resulting from Improved Solution.

Table 4
Efficiency Computation for Improved Solution

Path No.	: Path : destination	: Moves/year	: Units of : distance	: Moves-distance : year
1	(a) (b)	324		
2	(a) (h)	20		
3	(b) (c)	270		
4	(c) (h)	250		
5	(h) (c)	50		
6	(a) (d)	204		
7	(d) (i)	180		
8	(h) (i)	250		
9	(g) (i)	104		
10	(f) (g)	20		
11	(f) (h)	20		
12	(c) (e)	60		
13	(e) (c)	4	1,756	1,756
14	(f) (i)	70		
15	(c) (f)	70		
16	(a) (c)	60		
17	(b) (h)	50		
18	(b) (d)	4		
19	(d) (g)	24		
20	(e) (g)	60		
21	(c) (i)	4	342	684
22	(d) (e)	4	4	16
Total				2,456

TECHNIQUES FOR DEVELOPING IDEALIZED LAYOUTS

Present Available Techniques

The travel charting technique presents a useful method of attacking the problem involving complex interrelations. The same basic technique is applicable to other industrial problems, such as the location of controls for complex operations and the layout of systems of men and machines. One frequently meets more complex problems than the one illustrated in the previous section, so that greater trial and error effort may be required. It must be made clear that the travel chart technique is highly dependent upon the ingenuity of the layout man, since it utilizes a trial and error technique at the very last, and most important, step. It does not guarantee an optimum solution, although one may be achieved. Sure knowledge of having arrived at an optimum solution would involve the efficiency computation of all possible combinations which would be difficult at best in a practical problem.

Several articles have been written relative to the travel charting or cross charting techniques. Most of these articles have dealt with theoretical or purely analytical techniques and do not necessarily present a practical approach that is either economical or simple to apply.

Smith (6) made the first attempt to illustrate usefulness of the travel charting technique. He pointed out that this technique is useful where the process layout exists and showed the computation of materials handling efficiency. Although his efficiency criterion was not realistic, his procedure indicated that improvements could be made from one layout to the next.

Buffa (2) in his sequential analysis for the functional layouts gave an additional tool of schematic diagram to visualize the interrelationships

between all combinations of the departments. This tool is little helpful in reducing the trial and error effort to develop improved layout from the present one.

The use of travel charts in the situation where the floor area requirements vary from department to department is given by Llewellyn (4). In practical problems area requirements do vary from department to department so that the inclusion of this factor makes travel charting that much more realistic, although the computation is somewhat more complex than the example illustrated in the previous section. Llewellyn (4) points out that some of the advantages to travel charting are; one, that the method can be extended to any number of products, any number of departments or any shape of building, and two that the method is not limited to a given list of products, i.e., the product mix can be changing and sampling procedure used in the shop to estimate the number of moves between departments.

As we have noted, the judgement plays an important part in identifying the improvements in the layout under consideration. Wimmart (7) in his mathematical method of equipment location, points this judgement factor can be reduced to a minimum. His approach is complex even for a simple problem he has illustrated. In his conclusion he says "Even in its present form this methodology provides a completely objective equipment location technique."

Reis and Anderson (5) gave a more realistic picture of load movement or of distance travelled in their article "Relative Importance Factor," by assigning the relative importance factors to different kinds of products according to their importance. Thus, reflecting this consideration in travel chart, gives more realistic approach than the previous approaches.

Hillar's New Approach

Recently Hillar (3) has attempted a systematic approach to the problem of developing the relative positions of work centers or departments with the objective of minimizing the total materials handling effort between these centers. His work is mainly concerned with reducing a trial and error effort that was required in this type of problem attempted with the available procedures. He illustrates his procedure with the simple example of laying out twelve departments in a large rectangular area. He simplified the problem by assuming that the rectangular area is to be divided into twelve equal areas. This assumption enabled him to choose, a side of each area or a center to center distance between areas, as a unit of distance thus, the distance a load travels is one, if traveling to an adjacent work center, two, if traveling to another work center adjacent to an adjacent work center, etc. The underlying assumption is that material movement is expected to be along a system of orthogonal aisles parallel to the sides of work center areas.

His objective in this phase of analysis is to minimize the total cost of materials handling movement between work centers. He attempts the problem with this objective by minimizing the sum of the distance each load must travel. He begins his procedure by examining any randomly selected solution and suggests how the calculation should be made to pinpoint the improvements. After each improvement is made, the few new calculations were made to ascertain further improvements. He continued this process until no further improvements were indicated. Although this procedure identifies the improvements possible only by exchanging any pair of work centers, it certainly improves the assignments as much as possible.

The important point in this procedure is the calculation of desirability numbers of moving a given work center left, right, up or down. Thus, the desirability numbers of all the centers in all four directions help in finding which work center could be moved desirably in which direction. This procedure was repeated in the second trial solution which was the result of an exchange of a pair in the first solution.

This approach has considerable merit, since it involves purely arithmetical calculations so that the procedure could be used by people with no background in higher mathematics. Furthermore, it eliminates the trial and error procedure which severely taxes the layout man in solving more complex problems. Unfortunately, this approach does not guarantee an optimal solution because the procedure is not able to identify all possible improvements.

EVALUATION OF LAYOUTS

The most difficult part of the plant layout is the evaluation of various alternative proposals. To date, no procedure for evaluating layout alternatives has achieved general acceptance. It may well be that each layout problem is so unique that a general evaluation procedure cannot be found.

Recently the mathematicians have become interested in the problem of plant layout and location. This interest has led to the development of techniques which can be most helpful to the layout analysis in evaluating alternatives.

The most important and essential factor in the evaluation of layouts is that of choosing the suitable measures of effectiveness. For example, in a case where materials handling is the primary problem in establishing a new

layout, the distance moved by a product could be considered a proper measure of effectiveness, but in another situation the number of idle machine-hours could be considered proper.

There are two generally accepted components of a measure of effectiveness, viz., the importance of the objectives and the efficiency of the alternate layouts. The first component has been discussed earlier in this paper.

The definition of plant layout refers to the "optimum arrangements of facilities." In the present stage of development of plant layout techniques, it is difficult to know when one arrives at an optimum solution. But to know how close the developed layout is to the optimum, needs the efficiency computation. A reference plane is needed to compare the series of developed layouts. Attempts have been made to compare the developed layout to the ideal layout rather than comparing it with the optimum. Thus, the efficiency criteria developed by different authors appears to be unrealistic. Hillar's (3) approach in the evaluation of layout involves the finding of the lower bound of materials handling effort which indicates that value of optimum materials handling effort cannot be less than the lower bound. Further, he calculates the materials handling effort for the average randomly selected layout. In his efficiency computation he compares the difference between materials handling efforts of average randomly selected layout and the layout developed by his technique with the difference between the efforts of average randomly selected layout and the lower bound of the materials handling effort. This efficiency computation again does not give the realistic picture; because in the first place, the lower bound of materials handling effort is the effort which is not equal but less than the optimum effort and in the second place, the value of the effort of average randomly selected layout is not necessarily equal to that of our first trial solution. Thus, the Hillar's efficiency

criterion does not provide the answer.

It is apparent that more research is needed to find simpler techniques for developing idealized layouts and more realistic criteria to evaluate them.

CONCLUSION

With the best knowledge of available techniques the solutions to these types of problems would become more acceptable if the good points of different approaches were brought together. As it was noted, there are several points which make the problems more real. The data that are to be posted in the travel chart should be carefully collected and summarized. The important factors should be assigned accurately to the load and/or the type of movement so that adjustment of the numbers in the travel chart could be effected accordingly. The data collection and posting it to the travel chart is the most important step before starting the analysis, because the techniques of evaluation of layouts depend on the accuracy of the travel chart. With keeping the restrictions and assumptions in mind, the first trial layout could be developed with little judgement. By little effort and careful judgement in setting the first trial layout would definitely reduce the computations that would be needed to further improve the trial layout. At this point, Hillar's (3) approach could be applied to identify the further improvements until no further improvements are indicated. The evaluation of the final layout could be made with the aid of Hillar's (3) approach of efficiency criterion with slight modifications to know the improvement made from first trial solution to the final solution.

Each problem must be handled on its own merit and of course each solution will be no better than the assumptions that are made at the beginning of the

analysis. If either the restrictions or the assumptions are false, then it is quite likely that the improved final solution may actually be far from optimum.

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QUANTITATIVE TECHNIQUES FOR
PLANT LAYOUT ANALYSIS

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The materials handling system plays a very important role in the economics of manufacturing and must be considered as a major factor in the process of plant layout analysis. Numerous cost studies have been made of the cost of materials handling in many types of industrial plants, and the results have shown that the cost of materials handling is as much as 20 to 25 per cent of the total cost of converting the raw materials into the finished product. This fact alone is sufficient to prove that the materials handling system should be given exhaustive study whenever a new factory is being planned or an existing one is being remodeled.

The cost of materials handling usually arises from two sources: (1) The cost of owning and maintaining the mechanical equipment and (2) the cost of operating the system. The objective of materials handling study in connection with plant layout is to arrive at a system that will provide the most satisfactory movement of the materials through the necessary processes and into storage at the lowest cost. This can be translated to mean that all possible steps should be taken to reduce or eliminate the use of manual labor and to simplify the materials handling problem to such an extent that the greater portion of the movements can be accomplished by mechanical means.

It is obvious that the layout of the production equipment, the arrangement of the departments and the selection of the materials handling that is best suited to the materials to be handled are the major items for consideration. The most difficult item for a layout man to handle is that of arranging the departments.

Quantitative methods for the development of the relative positions of a number of departments with the objective of minimizing the total materials handling effort between these departments are presented. A brief survey of

quantitative procedures for solving such problems is presented and in conclusion it is suggested how to bring all good points of different approaches together for solving such problems.