COMPUTER AIDED SELECTION OF PLANT LAYOUT

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ABSTRACT

This paper deals with the fundamental concepts of plant layout, in which the need for plant layout, the systematic and logical approaches to the problems, layout solutions and the objectives of plant layout are discussed. Further the approaches and the scoring techniques of the two available computer routines are presented. Special focus is directed at improving the preparation of the input data to enhance computer assistance to plant layout. A brief computer algorithm is given in order to encourage interested readers to write their own computer aided facilities layout programmes.

INTRODUCTION

Plant layout problems have been the subject of analysis for centuries. As the factory system and modern businesses developed, more attention had to be given to the process of obtaining a good workable disposition of physical facilities. In a broader sense, facilities layout is meant to include the layout of non-manufacturing facilities. The benefits of a little time spent in planning the arrangement of facilities before it is installed can be tremendous, ranging from improved employee moral and job satisfaction to improved product quality and accrue profits. The recent growth in the sophistication and management levels of facilities has generated the need for computerization.

This trend can be traced back to the early 1960's with the development by industrial engineers and operational researchers of optimisation algorithms. Computer Aided Design (CAD) software specifically designed for facilities planning and design began to appear commercially in the late 1970's. The recent development in this area is the large scale integration of the computer data base management and graphics capabilities.

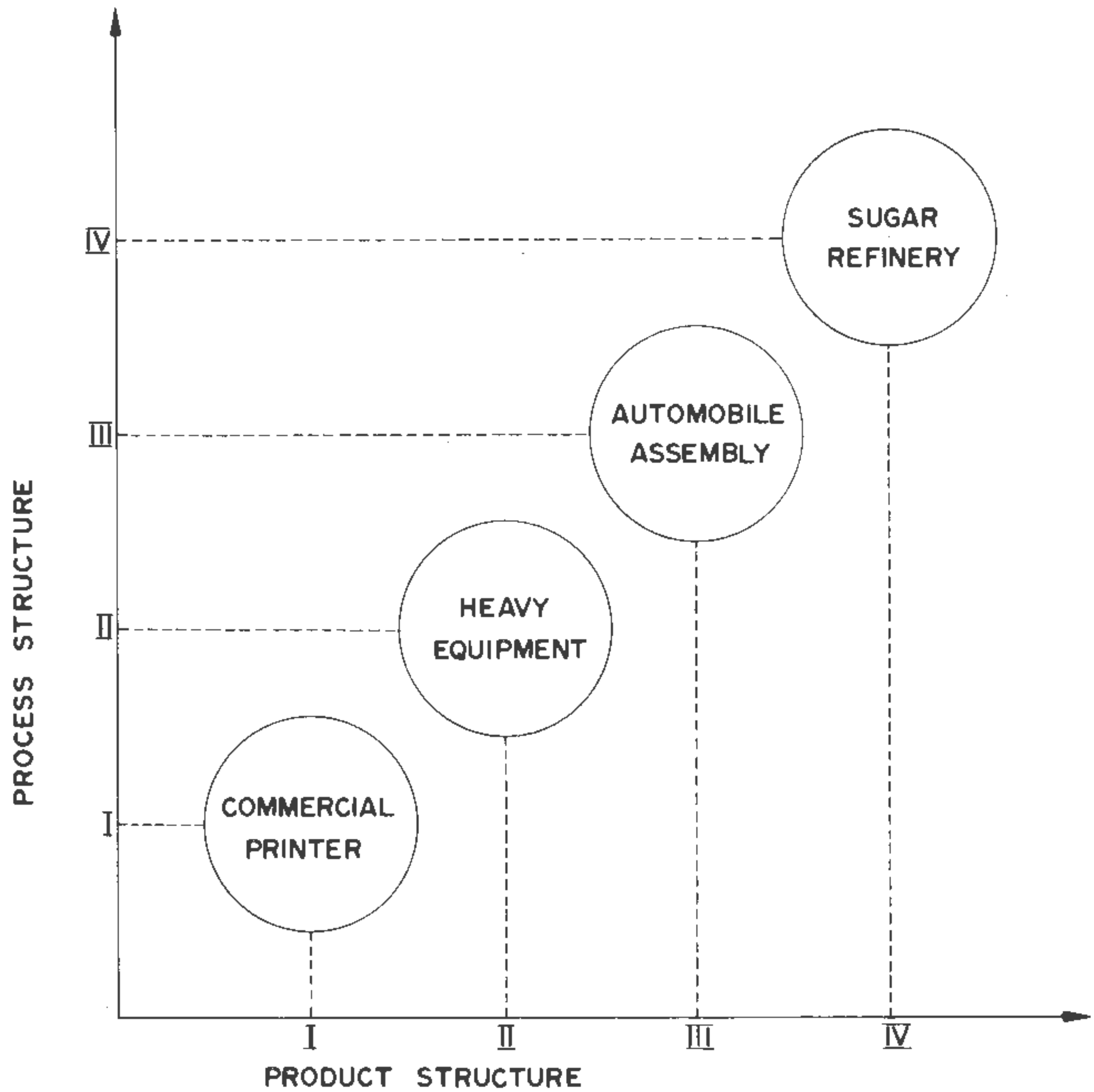
PLANT LAYOUT

Plant layout can be defined as the plan of, or the act of planning, a good workable disposition of industrial facilities, like operating equipment, storage space, materials handling equipment, and all other supporting services; along with the design of the best structure to contain these facilities [1,2,3].

The layout analyst may be called upon to detrmine the location for a new machine, or to rearrange the existing plant or to develop the layout for a new plant. The need for modified products may result in a need to reorganize the existing plant or to creat an additional plant. Variations in the level of demand or the location of markets may have similar results. Layout problems often created by the obsolescence of industrial equipment, processes and buildings may require minor or radical changes in the existing layout. The need for cost reduction may be achieved in a number of ways, such as the production of new materials to replace more expensive ones, a better utilization of floor area, tools and equipment. Problems of safety and poor working conditions mav be resolved by changes in plant layout. Similarly, problems in supply, service and transport opertions may give rise to layout or relayout [2,4,5]. The different types of layout solution may be summarized as locating or moving the position of the plant in a product-process matrix (Fig. 1).

The position of any plant occupying a particular region in the matrix is determined by the nature of the product and its choice of production process for the product [6,7,8]. Generally, it is believed that if product variety is increased, process variety must increase and conversely if process variety decreases so does product variety. The prime concern of most enterprises is to increase profits. To achieve this, there is as such no best choice; it is simply a matter of corporate preference for one mode of competitive behaviour or another. Shifting the position of a plant to the left or to the right of the matrix diagonal implies greater product diversity and more rapid product change, or fewer, more stable products. Positioning a plant below or above the matrix diagonal implies, flexible, less capital intensive processes or more mechanized, cost-efficient and rigid processes. Once the management selects a strategy for both products and process development on the basis of the assessments of how markets will develop and competitors will react, the layout analyst should start developing alternative layouts that would go along with the management's decision.

There are a number of goals that must be weighed in efforts to develop alternative layouts which provide maximum satisfaction to employees and management as well as the stockholders [2,9,10]. Thus, some of the objectives of plant layout are to:



PROCESS STRUCTURE

I = Jumbled Flow (Job Shop); II = Disconnected Line Flow (Batch);
III = Connected Line Flow (Assembly Line); IV = Continuous Flow;

PRODUCT STRUCTURE

I = Low Volume - Low Standardization, One of A Kind;
II = Multiple Products, Low Volume;
III = Few Major Products, Higher Volume;
IV = High Volume - High Standardization, Commodity Products;

FIG.1 The Product-Process matrix.

1. Provide overall simplification:-

   i) equipment involving high capital investment should be located so that it can be used on a multiple shift basis.

   ii) a good layout will minimize production delays and reduce congestion.

   iii) equipment must be located so that routine maintenance is easy to perform.

   iv) increasing output or shortening manufacturing time (eliminating idle time) can be realized in an improved layout.

2. Make a good choice of materials handling equipment considering:-

   i) flexibility:- the capability to respond or conform to new situations easily.

   ii) compatibility:- requires the number of varieties of models and makes of equipment to be reduced.

   iii) ease of maintenance:- the ability of the materials handling equipment and system to operate frequently, reliably and inexpensively has become increasingly important.

   iv) safety:- most industrial accidents involve materilas handling.

3. Provide high work-in-process turnover: a good layout can be helpful in reducing work-in-process. Every second that the material is held up at the plant adds to the cost of the product because of the tied up capital investment. Thus a good layout keeps buffer stocks to the minimum possible.

4. Maximize use of volume:- efficient use should be made not only of the floor area but also of the space above the floor area. Building costs (cost/m^2) vary with building heights. Maintenance, heating and air conditioning costs are bound to increase with volume. Hence, proper space utilization reduces investment as well as running costs.

5. Provide good working conditions:-poor lighting, excessive sunlight, heat, noise, vibrations, smell, moisture and dust should be minimized and wherever possible counteracted.

The solution of any size and type of plant layout problems could be facilitated by using a systematic and logical approach [11]. An early pioneer in this area was Richard Muther, developer of the Systematic Layout Planning (SLP) methodology (fig. 2). The SLP procedure leads the planner through:

ABSTRACTION (ANALYSIS):- Gathering appropriate information and analysing the flow of materials and the activity relationships to form a relationship diagram. Space considerations when combined with the relationship diagram develop the space relationship diagram.

SEARCH:- The overall layout is designed by combining space consideration with the relationship diagram. The search phase is the phase in which alternative layouts are developed by examining the space relationship diagram under modifying considerations such as materials handling, storage facilities, site conditions and surroundings, building features, personnel convenience etc. and practical limitations.

EVALUATION:- The most effective general method of evaluating layout alternatives is that termed factor analysis. It follows the engineering concept of breaking down the problem into its elements and analysing each one. The procedure involves:

i) identifying the plan to be evaluated

ii) establishing the factors or considerations

iii) arranging a rating sheet

iv) determining the relative importance of each factor

v) rating each factor for alternative plans

vi) calculating the weighted value and total

The disadvantage of any manual system, however systematic it may be, is its inflexibility. the reasons are that moving templates and recalculating alternatives take a considerable amount of time and labour, especially when the number of facilities to be handled is large.

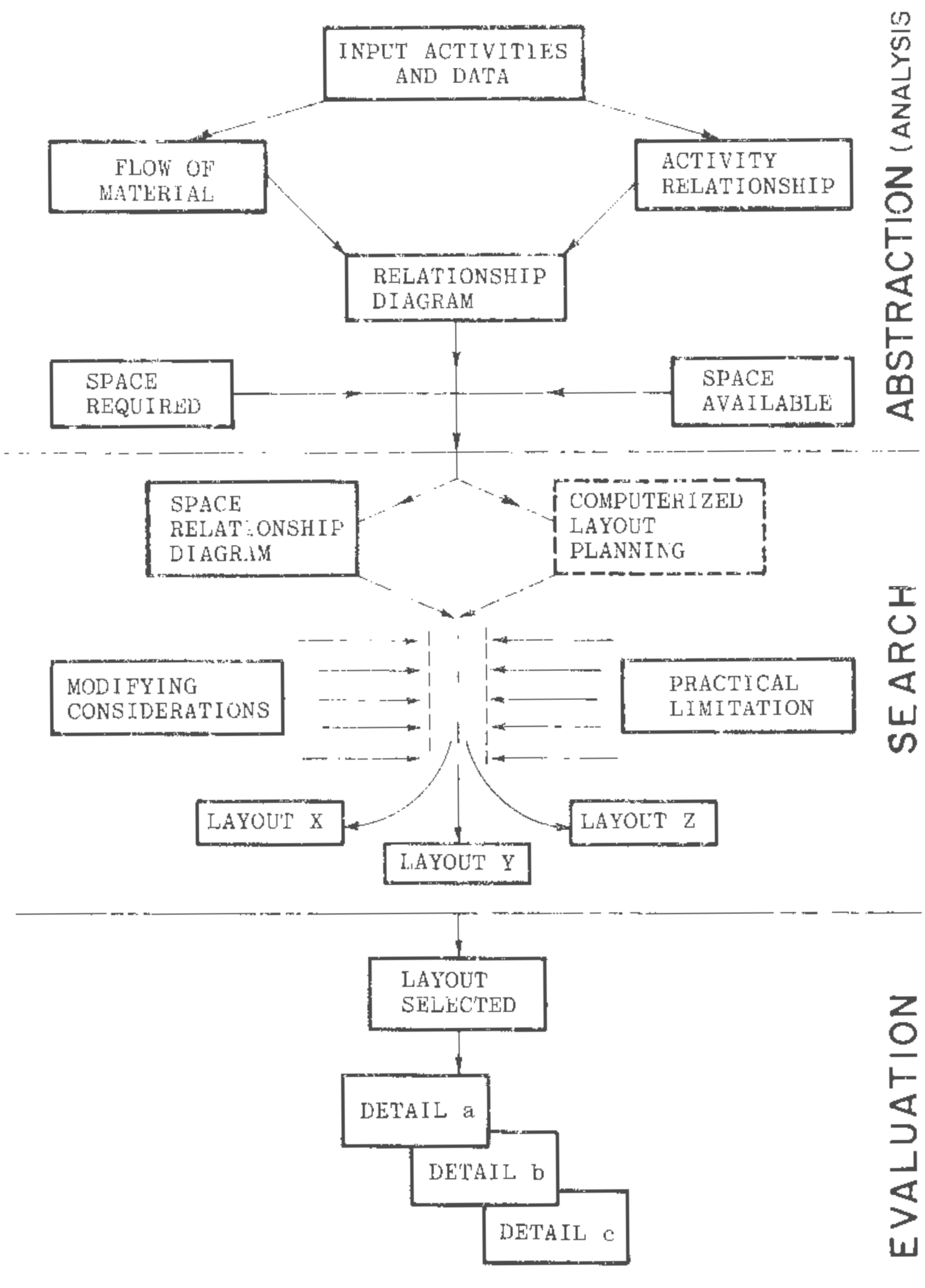


FIG. 2 The Systematic Layout Planning Procedure

COMPUTER AIDED LAYOUT

It is felt that computerized layout planning can improve the search phase of layout design process [3]. Since the publication of CRAFT (Computerized Relative Allocation of Facilities Technique) in 1964, there are more than 50 published algorithms available for use on a variety of computer systems. By using computer programme, the layout analyst can quickly generate a number of alternative layouts. In some plants, the cost of repeated handling constitute a very high proportion of the total cost of the end product and in some others the distance materials have to move is not the sole criterion and often is not even the primary concern for locating an area or an operation. Hence, more realistic value assessment of the factors that truly affect total cost in different kinds of layout planning situations is needed. The available computer aided layout algorithms fall into either imporvement or construction routine categories.

IMPROVMENT ROUTINE:- The basic approach is to find a suboptimum design by making improvements in sequential fashion [12,13,14,15]. First, a given layout has to be evaluated to determine what the effect will be if department locations are interchanged. If improvements can be made by making pairwise exchanges, the exchange producing the greatest improvement can be adopted. The process continues until no improvement is possible by pairwise exchanges. The objective function to be evaluated is:

$$TC = \sum_{i-1}^{n} \sum_{j-i}^{n} W_{ij} \; C_{ij} \; D_{ij}$$

where

TC= Total internal transport cost

C_{ij}= Cost of internal transport per unit distance per unit weight for material movement between dept. i and j

W_{ij}= Weight of material transported per unit time from department i to j

D_{ij}= Distance from department i to j

The routine accepts input data of W_{ij} and C_{ij} in the form of a FROM - TO chart (Fig.3) It may also accept D_{ij} in the form of a FROM-TO chart or it may accept the co-ordinates of the work centers. A FROM - TO chart is a square matrtix whose elements represent flow or distance between departments. The chart is constructed by listing the departments down the left hand column and then across the top in the same order. The departments on the left are the originating (FROM) departments and the ones at the top are the receiving (TO) ones.

CONSTRUTION ROUTINE:- This routine constructs layouts without the need for an existing (preliminary) layout. Basically it is to find the starting point or initial activity placement and then add remaining activity areas in accordance with logical rule [14,16,17]. Thus the routine accepts qualitative information from the relationship chart with closeness value numerically rated [11]. A relationship chart is a triangular martix whose elements represent the relationships among plant layout departments. Letter codes are also used to represent desirable or undesirable levels of closeness between departments. Six standard letter codes are used to show closeness relationships. "A" indicates an absolutely necessary closeness relationship; "E" indicates especially important; "I" important; "O" ordinary; "U" unimportant; "X" indicates a not desirable closeness relationship. Although the letter codes are standard, the ratings reflect the user's own reasons for assigning the letter codes (Fig. 4).

The relationship chart and the numerical weighted ratings assigned to the closeness values are the basis for the order and placement in which departments enter the layout. The ratings assigned for A,E,I,O,U and X are used to calculate the Total Closeness Rating (TCR) for each department.

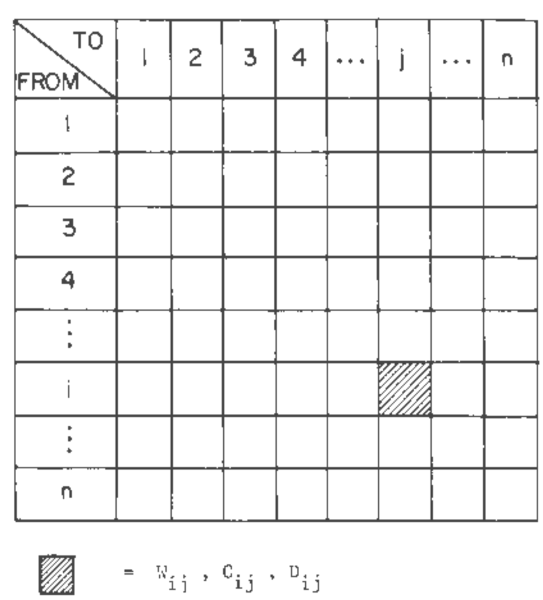


FIG. 3 The FROM - TO chart

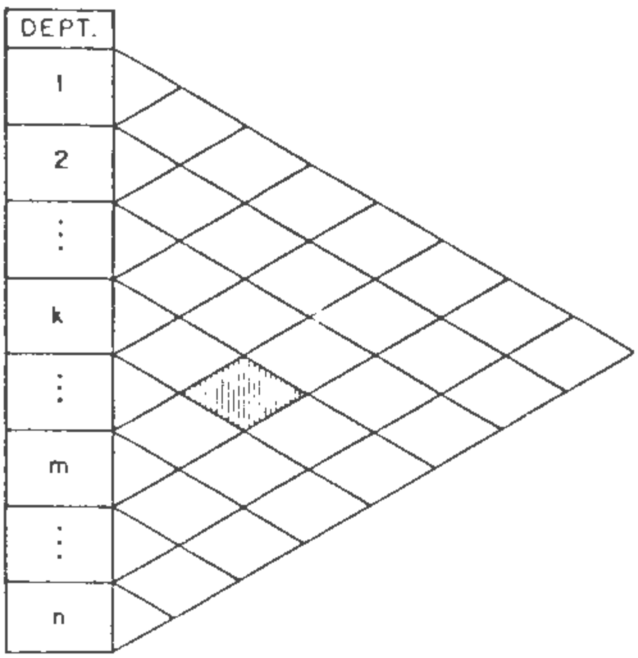
$$TCR_i = \sum_{j=1}^{n} V(r_{ij}); \quad i = 1 \ldots m$$

where

TCR_i = Total Closeness Rating for deprtment

$V(r_{ij})$ = Numerical value assigned to the closeness value for department i and j

n = Total number of departments



The relation between the K^{th} and the M^{th} dept. can have nay closeness value (*A, E, I, O, U OR X*)

FIG. 4: The relationship chart

The first department to be placed in the layout is assigned by taking the department with the greatest *TCR*. Next, the relationship chart is scanned to see if there is any department that has an *A* value with the department already placed. If no *A* value exists a check is made for *E* value and if no *E* value appears a check is made for I value, followed by *O* value.
If ties develop, the department having the greatest *TCR* is chosen. This process is continually used until finally all departments are placed in the layout.

The coexistence of a large number of criteria makes the definition of an optimum schedule virtually impossible. Furthermore, the writing of a computer programme for plant layout might entail considerable difficulties unless some very drastic simplifications are made. This shows why the routines explained must consider single factors to develop layout alternatives. Nevertheless, a little more effort in the preparation of input data, taking into consideration multiple criteria rather than a single criterion can further improve the assistance of computer programmes.

This can be done by introducing a multi-criteria rating chart to fill the FROM-TO and/or the relationship chart (TAB.1).

In calculating the Multi-criteria Closeness Rating sum (*MCR*) for all pairs of departments, it should be noted that the rating of the closeness value may be different for the various factors depending upon their relative importance with respect to the specific plant layout we are working on. The objective functions corresponding to the modified inputs are:

$$TC(MCR) = \sum_{i=1}^{n} \sum_{j=i}^{n} MCR_{ij} D_{ij} \quad \ldots \text{ improvement routines}$$

and

$$TCR^{i}\,(MCR) = \sum_{j=1}^{m} MCR_{ij} \quad i = 1 \ \ldots m \text{ construction routines}$$

Further if the problem is of a single facility location, the objective function *TC* is written in terms of (b_x, b_y) the required coordinates of the optimum location of the new facility.

$$\underset{b_x,\, b_y}{\text{Minimize}} \sum_{j=1}^{n} MCR_{bi} D_{bi}$$

where

MCR_{bi} = Multi-criteria closeness rating between b and i

D_{bi} = The distance between b and i

The next question could be: "What if the calculated optimum coordinate (b_x, b_y) is not feasible for a location site?" That is it may be inaccessible or it may coincide with another structure, a plant, a river etc. The response to the question is to construct contour lines of the cost function. The curves indicate (Fig. 5) at a glance the cost penality associated with a choice of a non optimum location.

TAB. 1: Multi-Criteria Rating chart for any two departments.

No.	REASONS	Closeness value	Closeness rating
1	Flow of material	*A*	12
2	Common personnel and/or common equipment	*E*	5
3	Ease of supervision	*A*	6
.		.	.
.		.	.
.		.	.
N	Noise-dirt, dust, fumes & hazards	*0*	2

$MCR = \Sigma$ Closeness rating

Often it may be required to reduce the number of departments and the variation of departmental areas to the minimum possible. It can be performed by combining all or certain items which are alike in design (similarities in dimension, shape, chemical or other characterstics) or items which are alike in process (items which begin or end at some operation or which pass through certain key operation). By so doing it is possible to reduce the time needed for the preparation of input data and to make use of micro computers (lower memory capacity) to run facilities layout programmes.

A COMPUTER ALGORITHM

The algorithm is presented in brief here, in order that the reader may develop his own software to solve layout problems. It uses the improvement routine and the modified scoring technique explained. The assumptions made in the algorithm is that the departments under consideration have equal areas.

1. Read in corretly the FROM - TO chart and the coordinates of department centres for the location pattern.

2. Compute a matrix of distance between departments.

   i) $D_{ij} = [(x_i - x_j)^2 + (y_i - y_j)^2]^{1/2}$

   ... Euclidean distance

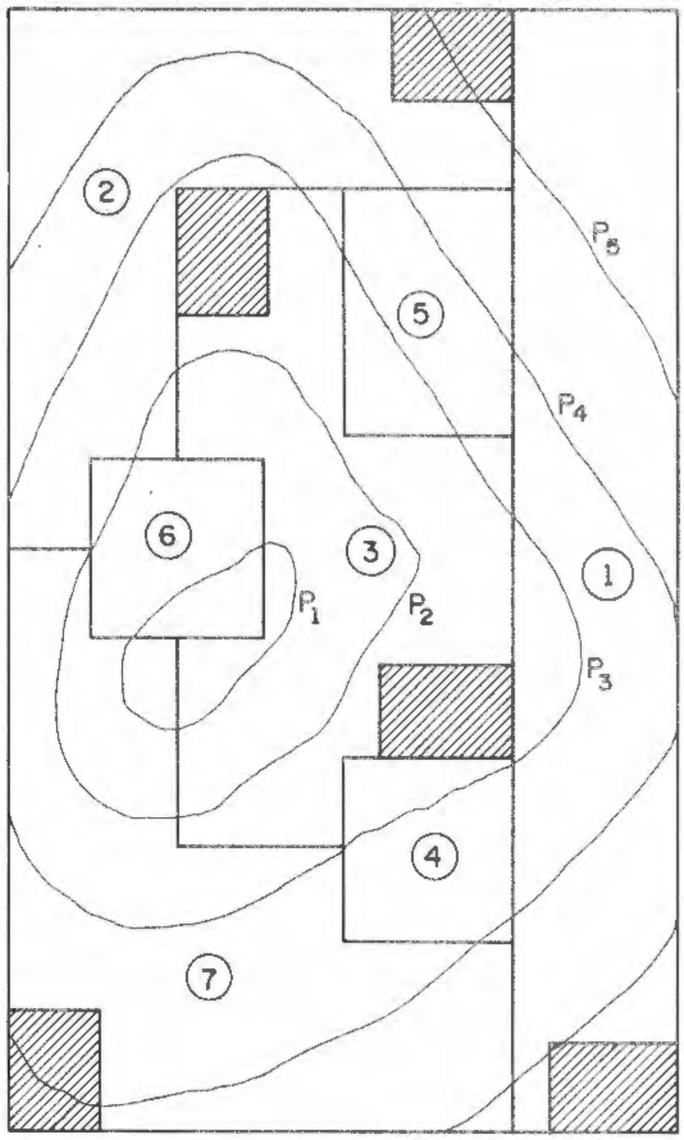
   ii) $D_{ji} = | x_i - x_j | + | y_i - y_j |$

   ... Rectangular distance

3. If the problem is of a single facility location go to step 10.

4. Compute the objective function, which measures the value of any location pattern.

$$TC(MCR) = \sum_{i=1}^{n} \sum_{j=i}^{n} MCR_{ij} D_{ij}$$



Available Site

P_1, P_2, P_3, P_4, & P_5, are different penality values

FIG. 5: Level curves for the location of a new machine in a-seven department plant.

5. Make exchanges of departmental locations to achieve a new location pattern (two departments at a time).

6. Go to step 4 unitl all the possible exchanges are made.

7. Arrange the calculated Objective Function Values (OFV) in increasing order along with their location patterns.

8. Print out the best 5 or 10 (depending upon the alternatives required) alternative location patterns and the corresponding OFV.

9. Go to step 13.

10. Calculate the optimum location of a single facility

i) $f(b_x b_y) = \sum_{j=1}^{n} MCR_{bi} (|x_i b_x| + |y_i b y|)$

.... rectangualr distance

The properties of finding an optimum solution to the problem are:

a) The x and y coordinates (b_x, b_y) new facility will be the same as the x and y coordinates of the existing facilities. (The coordinates need not be of the same existing facility).

b) The optimum x-coordinate (y-coordinate) of the new facility is a MEDIAN LOCATION such that no more than one half of the cumulative weight is to the left (below) the new facility location and no more than one half of the cumulative weight is to the right of (above) the new facility.

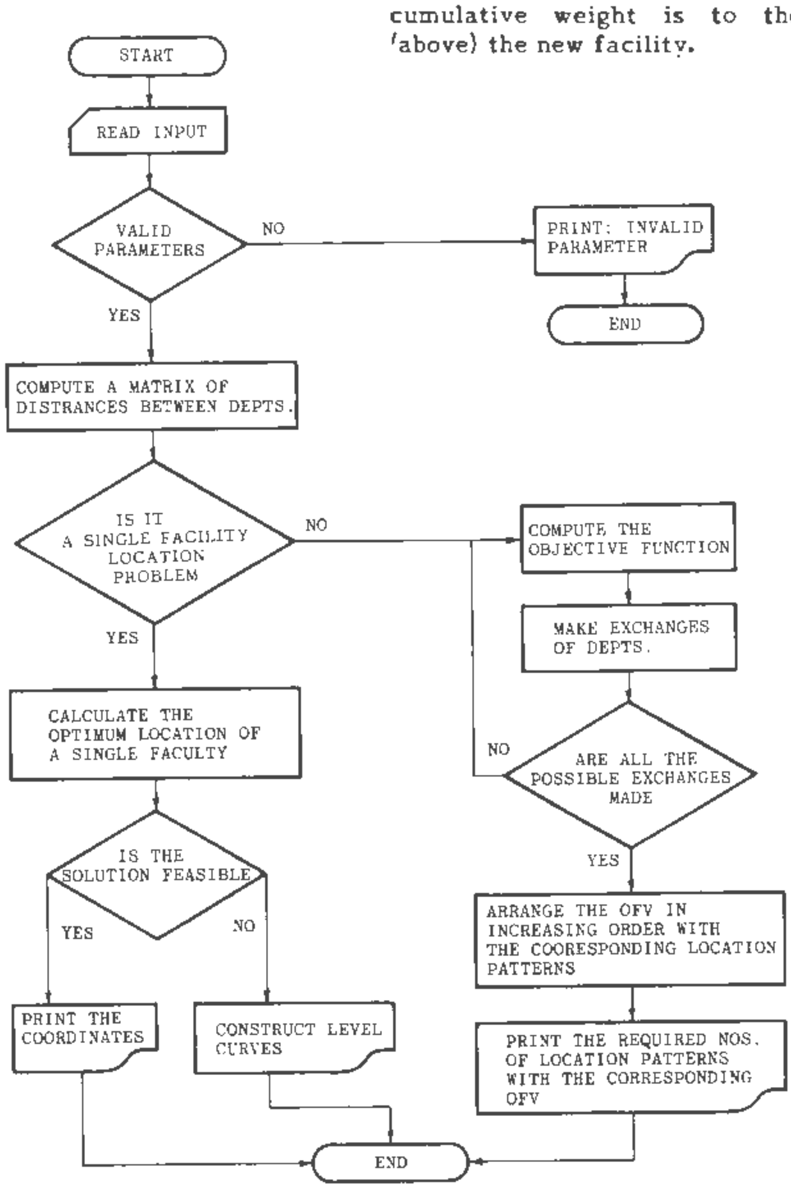


FIG. 6 Flow Chart

ii) $f(b_x,b_y) = \sum_{i=1}^{n} MCR_{bi} (x_i-b_x)^2+(y_i b_y)^{2\frac{1}{2}}$

... euclidean distance

The approach to solving the problem is to compute the partial derivatives and set them to zero. This gives the following eterative procedure.

$$g_i(b_x, b_y) = \frac{MCR_{bi}}{[(x_i - b_x)^2 + (y_i - b_y)^2]^{\frac{1}{2}}}$$

$$b_x^{(k)} = \frac{\sum_{j=1}^{n} x_i g_i (b_x^{(k-1)}, b_y^{(k-1)})}{\sum_{j=1}^{n} g_i (b_x^{(k-1)}, b_y^{(k-1)})}$$

$$b_y^{(k)} = \frac{\sum_{j=1}^{n} y_i g_i (b_x^{(k-1)}, b_y^{(k-1)})}{\sum_{j=1}^{n} g_i (b_x^{(k-1)}, b_y^{(k-1)})}$$

11. If the optimum solution is feasible print out the coordinates and go to step 13.

12. Construct contour lines
    Assign a penality value p to the cost function $f(b_x, b_y)$.

$$P_i = \sum_{j=1}^{n} MCR_{bi} D_{bi}$$

Pick a value x and search for y values that will satisfy the assigned penality P.

13. STOP

CONCLUSION

The process of obtaining a good workable disposition of physical facilities consists of problem formulation, analysis of the problem, search of the layout design, selection of the preferred design and specification of the layout design to be installed.

In most layout problems, the approach and the scoring techniques of the routines can be modified to fit the situation and then implemented to develop more efficient facilities layout planning. The usefulness of computer aided layout routines is further enhanced as layout problems become increasingly complex.

In recent times, efforts have been made to develop a computer graphics system which is capable of illustrating layout plans and evaluating materials handling alternatives. The availability of a wide range of graphics systems and facilities layout softwares is a lead for those who vitally depend on excellence in plant layout and design.

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