1966

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Recommended Citation

Melcer, Sheldon Joel, "An investigation of the relationship between manufacturing policies and plant layout in a job shop" (1966). *Theses and Dissertations*. 3475.
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AN INVESTIGATION OF THE RELATIONSHIP BETWEEN MANUFACTURING POLICIES AND PLANT LAYOUT IN A JOB SHOP

by

Sheldon Joel Melcer

A Thesis
Presented to the Graduate Faculty
of Lehigh University
in Candidacy for the Degree of
Master of Science

Lehigh University
1966

Certificate of Approval

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

May 16, 1966
Date

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Head of the Department
of Industrial Engineering

ACKNOWLEDGMENT

The author wishes to express his appreciation to Professor W. J. Richardson of the Industrial Engineering Department, Lehigh University, who gave so generously of his time and support in the guidance and counseling of this thesis.

In addition, A. G. Beged-dov, Western Electric Company, Engineering Research Center, has contributed his time and knowledge as advisor to my work project.

Professor T. E. Vollmann of the Amos Tuck School of Business, Dartmouth College, who supplied the CRAFT program and provided knowledge in the area of facility allocation.

The Western Electric Company, whose generous sponsorship of the Lehigh Master's Program made this study possible.

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ABSTRACT

Whenever physical facilities are utilized in the performance of productive operations the question of what relative location each facility should occupy with respect to all other related facilities may properly be raised.

The facilities location problem has been most acute in a process controlled "job shop" layout. In this case no single layout is optimum for all products to be manufactured. The problem is further complicated when different manufacturing policies, production planning and inventory control, are considered.

Utilizing CRAFT an optimum plant layout with regard to all products manufactured can be realized. In addition, two manufacturing policies; related to production and inventory control, will be investigated with respect to the effect of said policies on plant layout.

I. STATEMENT OF THE PROBLEM

Facility planning has been practiced by a man since prehistoric times. The continuous search for a strategic location for shelter, concern for craftsman-like construction, the insistence on proper orientation, and attention to reasonable maintenance -- all of these basic facility planning problems have been part of man's struggle to control his environment.

With the growth of industrial enterprise the objectives of facility planning have changed to the striving achievement of optimum productive or economic efficiency. Although this thesis will concentrate on the facility planning within a manufacturing environment, the basic theme has equal application in such service activities as offices, cafeterias, hospitals, and libraries. The principles of facility planning should be independent of the particular system or process under consideration.

The term plant layout shall be used when referring to facility planning in an industrial environment. Plant layout involves the optimum arrangement of industrial facilities including personnel, operating equipment, storage space, material handling equipment, and all other supporting services, along with the design of the best structure to contain these facilities.

Industrial engineers are frequently faced with the problem of having to design a plant layout. Several authors (1, 15, 17, 30) have developed techniques and procedures to assist in the design of an optimum layout. Richard Muther (32) states that there are four basic phases in layout planning:

1. Location - determination of the location of the area to be laid out.
2. General Overall Layout - establishment of the general arrangement of the area to be laid out.
3. Detailed Layout Plan - location of each specific piece of machinery, equipment and/or department.
4. Installation - measuring the physical moves of the equipment.

This thesis will concentrate of phase two.

The facilities location problem within a production system has been most acute when the nature of the products and demands dictate what is commonly termed process controlled "job shop" layout. In process controlled layout, equipment of a common generic type is grouped together. Parts and products flowing through the system, Figure (1), proceed by routes dictated by the sequence of operations to be performed. These routes vary considerably for different parts and products so that no one choice of relative location of departments is best for all parts. One choice of relative locations may be excellent for some parts but poor for others. Thus, it is necessary to determine a choice of locations which minimizes incremental costs which vary with changes in location pattens.

The determination of an optimum relative location pattern is further complicated when different production planning and inventory control policies are considered. These policies, to be referred to as manufacturing policies, may be viewed as a system for establishing

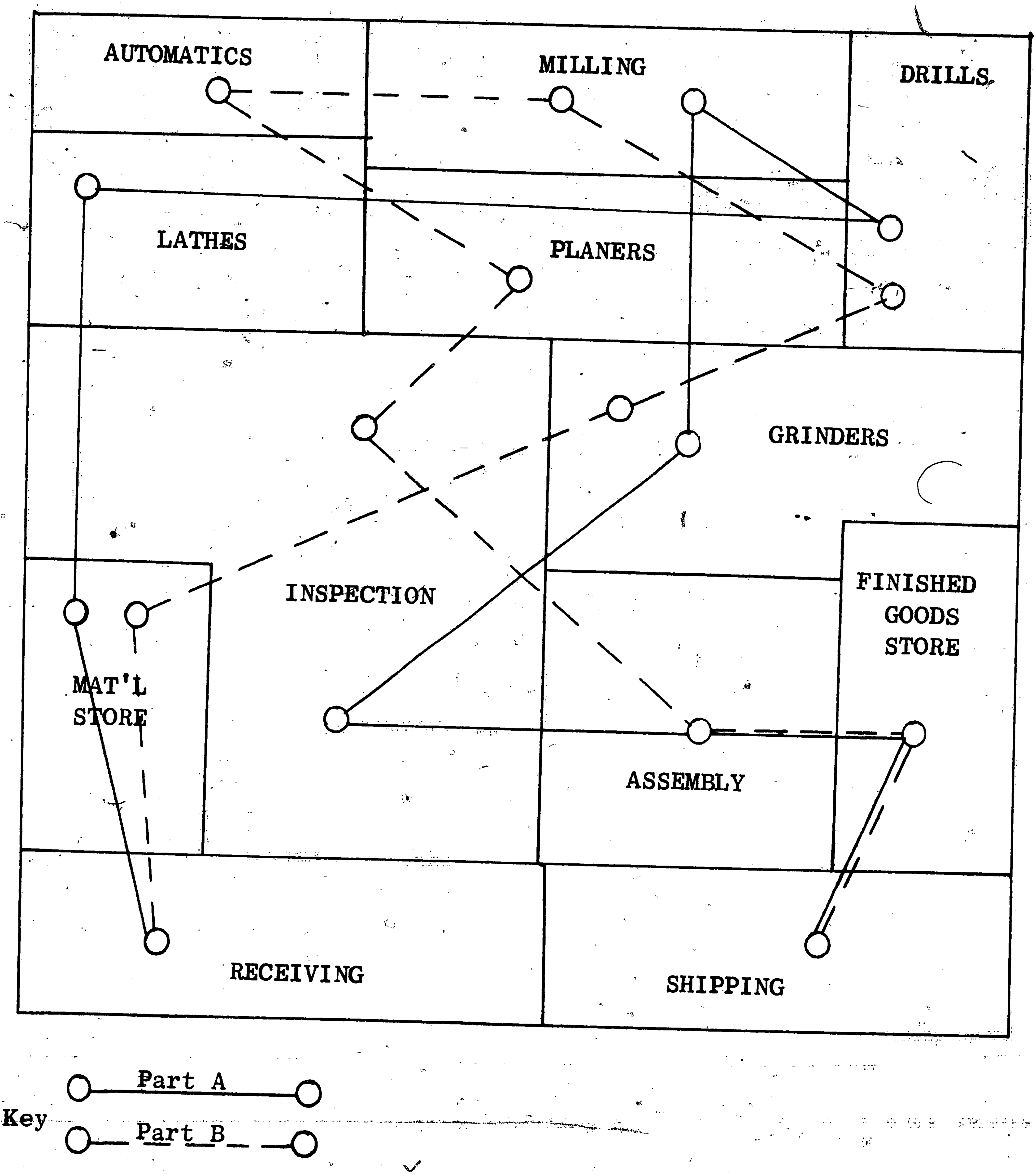

Figure (1)

Typical "Job Shop" Layout

operating and inventory levels in existing facilities, to meet demand, for adjusting operating levels and replenishing inventories, and to take account of actual demand as it materializes. Since manufacturing policies have received rigorous treatment in the literature (7, 11, 24, 42) it suffices then to just mention the relationship it bears on plant layout.

The optimum relative location pattern is a function of the interdepartmental flow matrix. The manufacturing policy determines the lot sizes of each part produced and thus the frequency of transports between departments, as dictated by the routing sequence. This then determines the relationship between departments in the form of an interdepartmental flow matrix. Two manufacturing policies, described in Chapter V, will be utilized in the investigation.

In the following chapters a criterion for plant layout and several quantitative techniques for evaluating plant layout will be presented.

II. INTRODUCTION TO PLANT LAYOUT

In the analysis of an overall layout several factors must be examined. Two basic factors on which every plant layout rests are the products to be manufactured and the quantity required of each product. A subsequent factor the routing (or process) must be studied. After these three factors are determined a specific type of layout, of which there are three, must be selected. The three classical types of layouts are:

(1) Fixed position - This is a layout where the material or major component remains in a fixed place. All tools, machinery, men, and other pieces of material are brought to it. The complete job is done or the product is made with the major component staying in one location.

(2) Product Layout - In this mode one product or one type of product is produced in one area. Unlike layout by fixed position, the material moves. This layout places one operation immediately adjacent to the next. This layout is solely determined by operational sequence.

(3) Process Layout - Here all operations of the same process are grouped in a generic fashion. The process layout is particularly useful where low volume or multiproduct items are required.

Muther (25) provides several lists as to which type of layout to use, and numerous factors which tend to influence plant layout. Moore (30) takes this approach one step further and indicates the actual cost incurred as a function of production volume and type of layout selected.

Figure (2) pictorially depicts the relationship of the three major types of layouts on the basis of cost and production volume. Breakeven points are identified on the basis of sales income versus cost to manufacture. Also, breakeven points are indicated where a change in type of layout is economically warranted with respect to production volume. In Figure (3) the relative advantages and when to use factors are listed for product and process layouts.

The next phase considers the flow of material which occurs as a result of the manufacturing cycle. Muther states that the flow-of-material analysis is the heart of layout planning. The intensity of flow is the magnitude of material movement. The magnitude of the movement over the various routings is the basic measure of relative importance of each route and therefore of relative closeness of operations or departments to each other. A typical interdepartmental flow matrix is depicted in Figure (7).

The values within the flow matrix represent the number of loads which must be transported between departments (row and column indices). The number of loads are expressed in common units, i.e., pounds, gallons, tote-boxes, etc., per unit of time.

It is assumed that the system under study is in a deterministic mode. When necessary stochastic properties of the data can be incorporated. Sensitivity analysis techniques are available to observe the effect of stochastic properties on the particular system. However, by assuming a system is deterministic emphasis can be concentrated on the technique and basic application of a specific model.

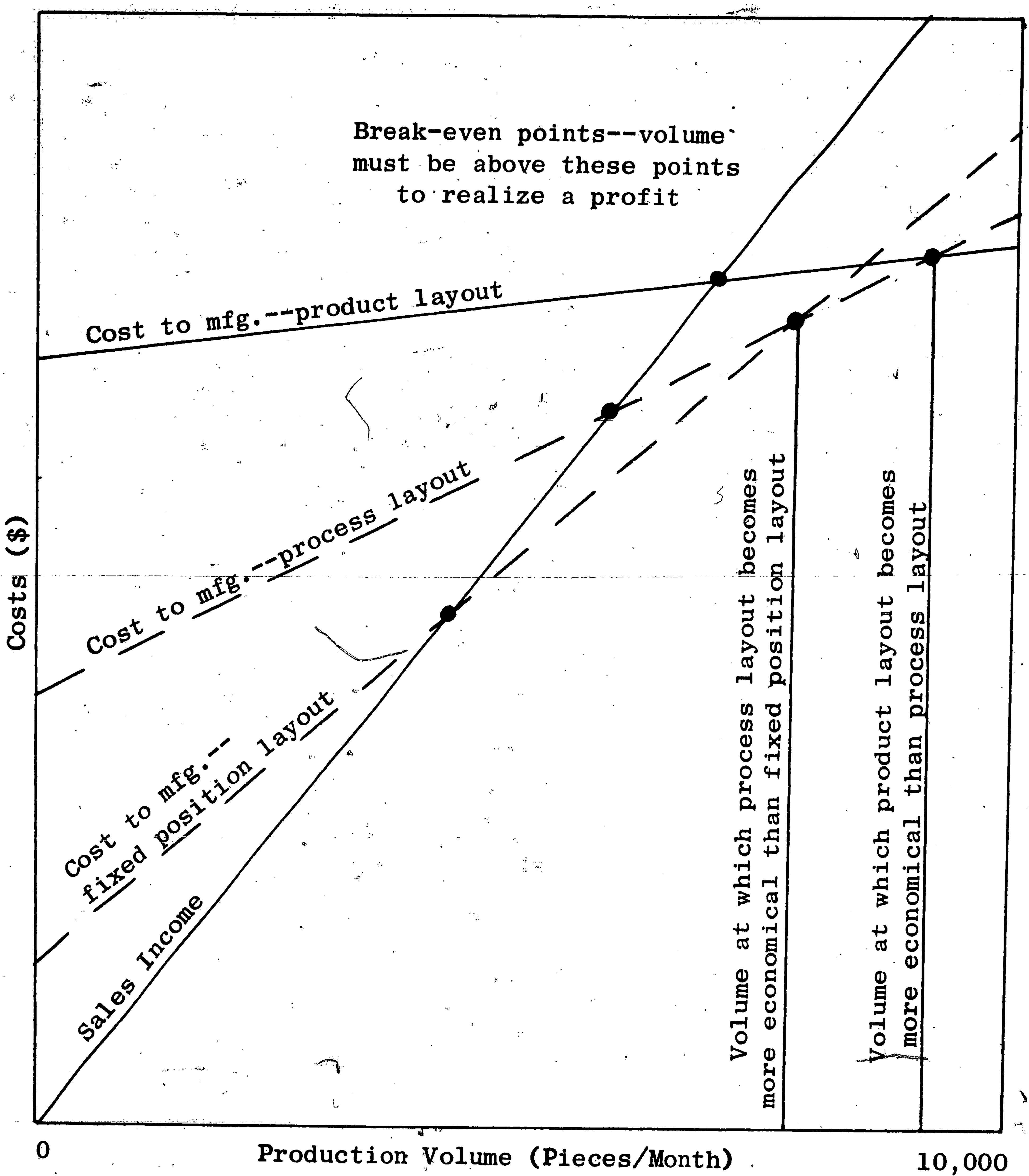

Figure (2)*

Breakeven-point Analysis for Various Types of Layouts for a Given Product

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* Moore, J.M., Plant Layout and Design, New York: Macmillan Company, 1962, p. 109.

Figure (3)* PRODUCT VS. PROCESS LAYOUT

Relative Advantages of Product and Process Layout

Product Layout	Process Layout
1. Lower total materials handling cost.	1. Less duplication of equipment, hence lower total investment in equipment.
2. Lower total production time.	2. Greater flexibility of production.
3. Less work-in-process.	3. Better and more efficient supervision possible through specialization.
4. Greater incentive for groups of workers to raise level of performance (and greater possibility for group incentive pay plans with broader coverage).	4. Greater incentive for individual workers to raise level of performance (and greater possibility for individual incentive pay plans).
5. Less floor area required per unit of production.	5. Better control of complicated or precision processes, especially where much inspection is required.
6. Greater simplicity of production control--fewer controls and records needed, lower accounting cost.	6. Easier to handle breakdowns of equipment by transferring work to another machine or station.

When to Use Product and Process Layouts

Product Layout	Process Layout
1. One or few standard products.	1. Many types or styles of products, or emphasis on special orders.
2. Large volume of production of each item over a considerable period of time.	2. Relatively low volume of production on individual items (though total production may be high).
3. Possibility of time and motion studies to determine rate of work.	3. Adequate time and motion studies difficult or impossible to make.
4. Possibility of good labor and equipment balance (each machine or work station producing equivalent number of units per hour).	4. Difficult to achieve good labor and equipment balance.
5. Minimum of inspection required during sequence of operations.	5. Many inspections required during a sequence of operations.
6. Minimum of very heavy equipment or equipment requiring special facilities (isolation from general production areas, etc.).	6. High proportion of very heavy equipment or equipment requiring special treatment.
7. Materials and products permit bulk or continuous handling by mechanical means.	7. Materials or products too large or too heavy to permit bulk or continuous handling by mechanical means (in extreme cases, process may have to be brought to work, instead of vice versa).
8. Little or no occasion to use same machine or work station for more than one operation (minimum number of setups required).	8. Frequent necessity to use same machine or work station for two or more different operations

* Moore, J.M., Plant Layout and Design, New York: Macmillan Company, 1962, p. 107.

Once a specific type of layout has been determined, and the interdepartmental flow relationship established, some measure of effectiveness or evaluation criterion must be employed so that an optimum layout can be designed.

Bartolacci (4) lists a series of 50 factors which may be employed by a company advantageously to evaluate plant layout. Typical factors are ratios of aisle area/total area, office area/production area, number of 90° turns made/distance moved by product, and number of operators/number of machines. Moore (6) claims that the arrangement of plant facilities is so closely allied with material handling that a criterion of minimum material handling cost should be used as a measure of effectiveness. Anderson and Reis (1) state that consideration of volume of product and distances are rarely adequate for satisfactory layout design. They point out that "relative importance factors" must be considered. Some importance factors are:

(1) Priority of one product over others.

(2) Hazardous moves which should be as short as possible.

(3) Undesirability of conjestion, cross-flow, or counterflow.

(4) Unusually valuable or fragile materials.

Several authors (3, 15, 17, 18, 22) have employed the criterion stated by Moore and some have incorporated the relative importance factors indicated by Anderson and Reis. The relative importance factors are accounted for by simply adjusting the interdepartmental flow matrix.

Although Moore states that material handling cost is a valid criterion for evaluating plant layout his objective function is in terms of total material distance moved. Moore, and others, have assumed that material handling costs are directly related to material distance moved. This is a valid assumption and in agreement with several of the predetermined time systems. Work Factor (34) states that the average walking rate is three miles per hour. Given the hourly wage rate of an operator the cost to walk a given distance is readily available. Thus the objective function which originally was developed in units of distance can be transformed to costs.

The criterion, to be employed in this thesis, for evaluating plant layout can be expressed mathematically by:

$$\text{Total Cost} = \sum_{i=1}^{N} \sum_{j=1}^{N} u_{ij}\, v_{ij}\, d_{ij} \qquad \text{II - 1}$$

where:

N = the number of facilities or departments to be assigned a physical location within a plant layout.

u_{ij} = the number of loads which are transported from department i to department j.

v_{ij} = the cost to transport a unit load a unit distance from department i to department j.

d_{ij} = the number of unit distances between departments i and j.

Values of u_{ij} are obtained from the interdepartmental flow matrix. The cost figures, v_{ij}, are obtained from a cost matrix, similar to the flow matrix. The distances between departments are expressed in terms of the rectangular center to center distances. That is, each department or area is considered as being represented by a single point. To the extent that the centroid assumption is a poor representation of reality, the utilization of any model with the centroid assumption yields results which are necessarily inferior.. However, it has been shown that rectangles and squares are the generally accepted departmental shape for layouts. Therefore the centroid assumption can be used in plant layout with acceptable results.

An optimum layout can now be defined in terms of the objective function, II - 1. The optimum layout is that layout which minimizes the objective function.

All possible arrangements must now be considered and the objective is to determine a choice of locations which minimizes incremental costs which vary with changes in location patterns. Although this procedure appears to be a meager task one need only to consider the enormous number of relative location pattern. The inherent difficulty of the relative location problem is the large number of possible combinations of center locations. For 12 departments there are 12!/4 (or 119,750,500) nonredundant location patterns. It is obvious that evaluation of all patterns is impractical.

Prior to investigating the relationship between manufacturing policy and plant layout in a job shop, some technique or model must be employed in evaluating plant layout subject to the objective function, II-1.

Several mathematical models, proposed for determining the optimum relative location of departments, will be described in Chapter III.

III. MATHEMATICAL MODELS FOR PLANT LAYOUT

As stated in the introduction, plant layout is dated back to the industrial revolution. In the past, evaluation techniques for plant layout have shifted from qualitative to increasingly quantitative methods. Since the geneology of plant layout lies outside the scope of this thesis, and in view of the amount of literature which is readily available, this portion of plant layout will not be covered. For the interested reader the references, page 57, are intended to provide a concise and thorough coverage of the general aspects of plant layout.

There have been several proposed techniques for evaluating plant layout which are basic to the theme of this thesis and their respective objective function generally conform to the one stated, II-1. These techniques will therefore be mentioned.

Moore (29) has proposed a mathematical model for the optimum location of r departments, given that the location of p departments are determined (N = p + r). Due to building configuration, floor load capacity, ventilation systems, etc. several departments must be located in a specific area regardless of the interdepartmental flow relationships with all other departments.

Moore's approach is similar to the assignment type problem. It is therefore necessary to develop an effective matrix. The Hungarian Method (20) can then be applied.

The problem can be stated and solved as follows:

Let:

N = total number of departments to be located

p = number of departments which are fixed

r = number of departments to be located ($r = N - p$)

m = the number of available assignments

A = the distance matrix, where distances can include cost and difficulty of handling

B = the traffic matrix, where traffic can be expressed in terms of volume, weight, etc. per unit of time

C = the effectiveness matrix ($C = AB$)

Assume first that $r = m$, then

$$AB = \begin{vmatrix} a_{11} & a_{12} \cdots a_{1p} \\ a_{21} & a_{22} \cdots a_{2p} \\ \cdot & \cdot \; \cdots\cdots \\ \cdot & \cdot \; \cdots\cdots \\ a_{r1} & a_{r2} \quad\; a_{rp} \end{vmatrix} \cdot \begin{vmatrix} b_{11} & b_{12} \cdots b_{1r} \\ b_{21} & b_{22} \cdots b_{2r} \\ \cdot & \cdot \; \cdots\cdots \\ \cdot & \cdot \; \cdots\cdots \\ b_{p1} & b_{p2} \quad\; b_{pr} \end{vmatrix} = \begin{vmatrix} c_{11} & c_{12} \cdots c_{1r} \\ c_{21} & c_{22} \cdots c_{2r} \\ \cdot & \cdot \; \cdots\cdots \\ \cdot & \cdot \; \cdots\cdots \\ c_{r1} & c_{r2} \quad\; c_{rr} \end{vmatrix} = C$$

where

a_{ij} = the distance from candidate area i to fixed department j

b_{ji} = the traffic volume between the fixed department j and the department i to be added

c_{ij} = the effectiveness of each candidate area and department to be added

From the resulting effectiveness r by r matrix r values have to be chosen, so that:

a. every column and every row will be used once (independence)

b. the sum of the r values (measure of effectiveness) is minimum

According to the Hungarian Method the steps to be followed are:

1. Substract the minimum of each row from all elements of the row of matrix C and then subtract the minimum element of each column from all elements of the column, obtaining the first reduced matrix.
2. Determine the optimum assignment using those resulting zeros which provide the required independence. If a feasible solution is not obtained go to step 3.
3. Cover all zeros with a minimum number of horizontal or vertical lines. Find the smallest element from all elements lying at the intersection of two lines. This reveals the second reduced matrix.
4. Repeat steps 2 and 3 until a complete feasible solution is obtained.

This minimizing technique is acceptable only if the effectiveness matrix is square and does not take care of limitations which could not allow the realization of the optimum solution. Such limitations, for example, would arise when a candidate location does not fulfill space, labor, supervisory, factory services or material handling requirements for one or more of the new departments to be added.

This limitation can be overcome in pratice by assigning an infinite value, ∞ , to any non-available combination of departments j and candidate area i shown in the effectiveness matrix.

As for the requirements that the effectiveness matrix be square, if $m > r$ add $m - r$ dummy columns, if $m < r$ add $r - m$ dummy rows.

Illustrative Problem

Three departments, A, B, and C, have to be added to an existing layout containing four fixed departments and offering four candidate areas, V, X, Y, and Z, with a constraint that department B is too large for area X.

Material will follow rectangular movement and no weighting factors are required. Figure (4) is a spatial representation of the floor plan. Departments and candidate areas are identified by their centroid coordinates.

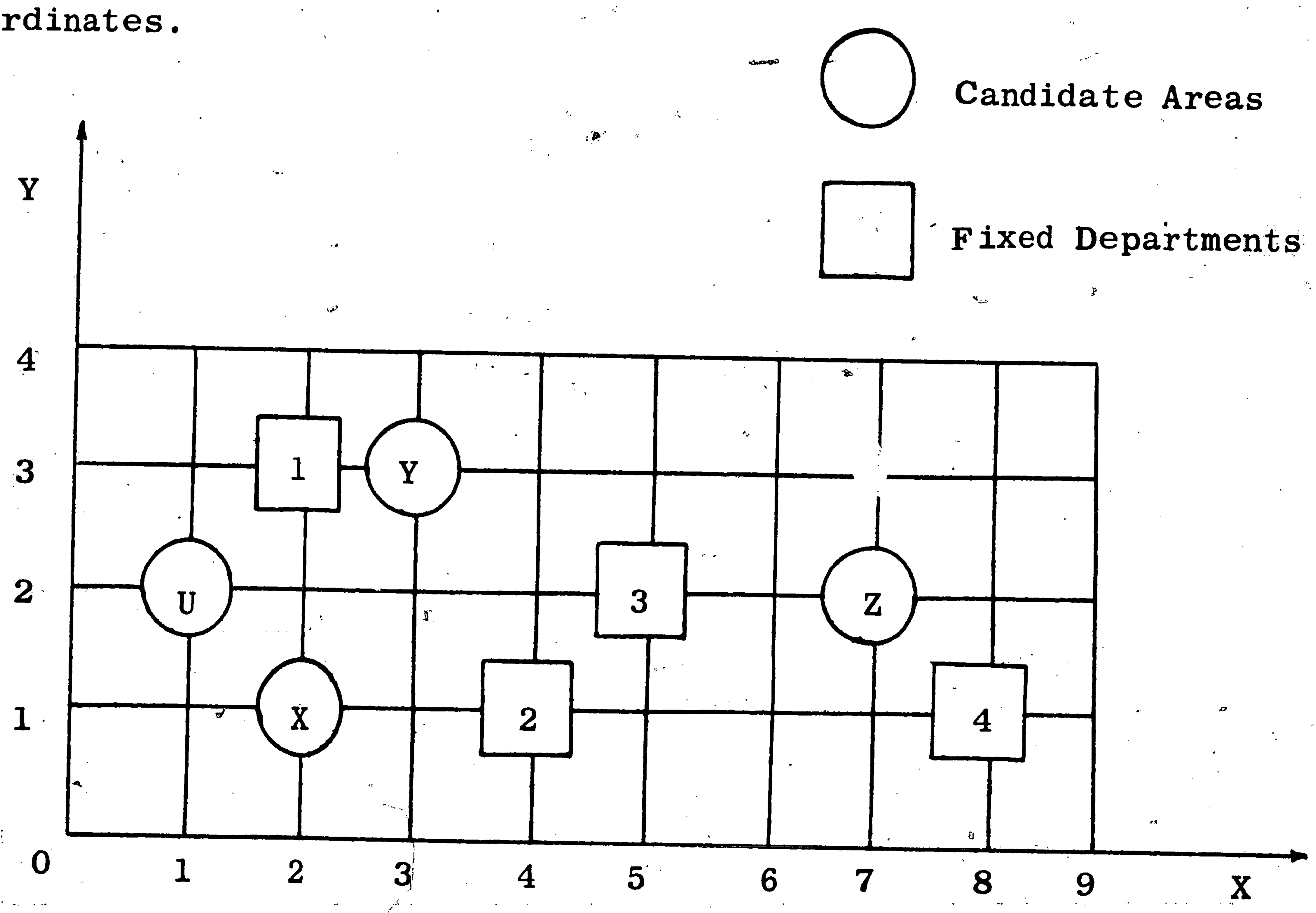

Figure (4) Spatial Layout

Figures (5) and (6) give data for distance matrix A and traffic matrix B, respectively.

		Fixed Departments			
		1	2	3	4
Candidate	U	2	4	4	8
	X	2	2	4	6
	Y	1	3	3	7
	Z	6	4	2	2

Figure (5)

Distance Matrix

		Fixed Departments			
		1	2	3	4
Departments to be Added	A	15	8	4	0
	B	0	7	10	12
	C	8	5	6	0

Figure (6)

Interdepartmental Flow Matrix

Calculation of the effectiveness matrix:

$$AB = \begin{vmatrix} 2 & 4 & 4 & 8 \\ 2 & 2 & 4 & 6 \\ 1 & 3 & 3 & 7 \\ 6 & 4 & 2 & 2 \end{vmatrix} \cdot \begin{vmatrix} 15 & 0 & 8 \\ 8 & 7 & 5 \\ 4 & 10 & 6 \\ 0 & 12 & 0 \end{vmatrix} = \begin{vmatrix} 58 & 164 & 60 \\ 62 & 126 & 50 \\ 51 & 135 & 41 \\ 130 & 72 & 80 \end{vmatrix} = C$$

The following steps I through V show the derivation of the minimization of matrix C, which gives the optimum solution of the problem.

	A	B	C
U	58	164	60
X	62	126	50
Y	51	135	41
Z	130	72	80

(I) Derived Effectiveness Matrix

	A	B	C	Dummy
U	58	164	60	0
X	62	126	50	0
Y	51	135	41	0
Z	130	72	80	0

(II) Squared Effectiveness Matrix

	A	B	C	Dummy
U	58	164	60	0
X	62	∞	50	0
Y	51	135	41	0
Z	130	72	80	0

(III) Exclusion of Combination of B and X

$$\begin{array}{c|cccc|} & A & B & C & \text{Dummy} \\ \hline U & 7 & 92 & 19 & 0 \\ X & 11 & \infty & 9 & 0 \\ Y & 0 & 63 & 9 & 0 \\ Z & 79 & 0 & 39 & 0 \\ \hline \end{array}$$

(IV) First Reduced Matrix

$$\begin{array}{c|cccc|} & A & B & C & \text{Dummy} \\ \hline U & 0 & 85 & 12 & 0 \\ X & 4 & \infty & 2 & 0 \\ Y & 0 & 63 & 0 & 7 \\ Z & 79 & 0 & 39 & 7 \\ \hline \end{array}$$

(V) Second Reduced Matrix

From the last matrix, departments A, B, and C are located in areas U, Z, and Y, respectively. The measure of effectiveness is:

$$F = C_{11} + C_{32} + C_{33} = 58 + 72 + 41 = 171$$

There are, however, several disadvantages with the application of Moore's model. It can assign a small department to a large area resulting in a large amount of wasted space. There must be p departments with a fixed location, thus imposing a restriction on the system. Another limitation is that there must be independence among the r departments to be added. Moore points out that it is possible to eliminate the latter limitation by setting the problem up in the format of a linear programming problem.

In order to utilize this approach in a actual situation, further research is necessary.

Francis (16) extends Moore's model by allowing for interdepartmental flow between the r departments which are to be located. Francis cannot utilize the Hungarian Method to obtain an optimum solution. His objective function, similar to Equation II-1, is:

$$F = \sum_{h=1}^{r} \sum_{j=1}^{n} A_{hj} \left| X_h - a_j \right| + \sum_{h=1}^{r} \sum_{i=1}^{m} B_{hi} \left| y_h - b_i \right|$$

$$+ \sum_{f=1}^{r-1} \sum_{g=f+1}^{r} D_{fg} \left[\left| X_f - X_g \right| + \left| Y_f - Y_g \right| \right]$$

where:

a_j = coordinates of the fixed departments in ascending order along the X - axis.

b_i = coordinates of the fixed departments in ascending order along the Y - axis.

A_{hj} = represents the material exchange between departments h and j.

B_{hi} = represents the material exchange between departments h and i.

r = number of departments to be located

p = number of departments which have been located

n = number of coordinate points along the X - axis

m = number of coordinate points along the Y - axis

D_{fg} = represents the exchange between new departments f and g.

As indicated, every fixed department is assigned coordinates (X_i, Y_i). When two or more departments have the same X and/or Y values then only one of the values is applied and given an a_j or b_i value. Thus n, m, and p are only equal when all the X_i value and Y_i values are different.

The problem is to find values of X_h and Y_h for h = 1, 2, ..., r which minimizes the objective function F. In his earlier journal article (15) Francis proved that the objective function, F, does have a minimum value. However, when incorporating interdepartmental flow between the r departments the minimization of the objective function cannot be solved directly. The author is therefore forced into making the following restriction, for any h, all A_{h_j} take on the same value, which is denoted by A_h; all B_{h_i} take on the same value, which is denoted by B_h. The author then proceeds to an optimum solution subject to the restrictions.

Here again the imposed restriction tends to limit the application of this model to a specific type of layout problem. Although useful in some instances it is not appropriate for determining a optimum layout in a job shop.

Hillier (17) developed a heuristic model in order to determine the optimum relative location of N departments. Hillier's heuristic layout technique utilizes departments of equal size. This simplification allows attention to be focused on the heuristic rather than on other complicating factors.

Hillier uses as an example 12 square departments in a 3 by 4 rectangular pattern, Figure (10). An interdepartmental symmetrical flow matrix indicating the relationship between departments is shown in Figure (7). Improvements are generated by shifting any department one unit space to the left, right, up, or down.

The objective function can be mathematically expressed as:

$$S = \frac{1}{2} \sum_{X=1}^{4} \sum_{Y=1}^{3} \sum_{X=1}^{4} \sum_{Y=1}^{3} C\left[X_1, Y_1 : X_2, Y_2\right]$$

$$\left[|X_2 - X_1| + |Y_2 - Y_1|\right]$$

where (X_1, Y_1) and (X_2, Y_2) are the coordinates of the ith and jth departments, respectively. $C\ (X_1, Y_1 : X_2, Y_2)$ therefore represents the quantity in the ith row, jth column of the flow matrix. Here again, any linear cost differential is accounted for in the traditional way by adjusting the flow matrix.

A series of move desirability tables, Figure (8), are generated to indicate the potential savings resulting from moving departments in the four directions. The move yielding the greatest reduction (the most positive) is then investigated. In the first iteration department 8 if moved to the left yields a savings of +37. Once the depart-

Departments

Departments	1	2	3	4	5	6	7	8	9	10	11	12
1	0	5	2	4	1	0	0	6	2	1	1	1
2	5	0	3	0	2	2	2	0	4	5	0	0
3	2	3	0	0	0	0	0	5	5	2	2	2
4	4	0	0	0	5	2	2	10	0	0	5	5
5	1	2	0	5	0	10	0	0	0	5	1	1
6	0	2	0	2	10	0	5	1	1	5	4	0
7	0	2	0	2	0	5	0	10	5	2	3	3
8	6	0	5	10	0	1	10	0	0	0	5	0
9	2	4	5	0	0	1	5	0	0	0	10	10
10	1	5	2	0	5	5	2	0	0	0	5	0
11	1	0	2	5	1	4	3	5	10	5	0	2
12	1	0	2	5	1	0	3	0	10	0	2	0

Figure (7)*

Interdepartmental Symmetrical Flow Matrix

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* Hillier, F.S., "Quantitative Tools for Plant Layout Analysis", Journal of Industrial Engineering, Vol XIV, No. 1, Jan.-Feb., 1963.

Figure (8)*

MOVE DESIRABILITY TABLES

Values indicate the net saving in the objective function if the indicated department were unilaterally moved one step in the indicated direction.*

	ITERATION 1				ITERATION 2				ITERATION 3			
Dept.	Left	Right	Up	Down	Left	Right	Up	Down	Left	Right	Up	Down
1	-11	+ 5	+ 7	---	-11	+ 5	+ 7	---	-15	+ 5	+ 7	---
2	+ 5	- 9	+ 3	---	+ 5	- 5	+ 3	---	+ 5	- 5	+ 3	---
3	---	+21	+11	---	---	+21	+11	---	---	+11	+11	---
4	---	+29	---	+23	---	+29	---	+23	-29	+11	---	+23
5	+15	---	+19	---	+15	---	+19	---	+15	---	+19	---
6	---	+26	- 6	- 6	---	+26	- 6	- 6	---	+28	- 6	- 6
7	- 2	- 8	- 8	-28	+28	---	- 8	-28	+28	---	- 8	-28
8	+37	---	- 7	-15	+ 7	-17	- 7	-15	+ 7	-17	- 7	-15
9	-25	+ 1	---	+17	-25	+ 1	---	+17	---	+25	---	+17
10	+15	---	---	+15	+11	---	---	+15	+11	---	---	+15
11	+10	-16	---	- 2	+10	-20	---	- 2	+10	-20	---	- 2
12	-10	-12	+10	-16	-10	-12	+10	-16	0	-12	+10	-16

	ITERATION 4				ITERATION 5				ITERATION 6			
Dept.	Left	Right	Up	Down	Left	Right	Up	Down	Left	Right	Up	Down
1	-13	+ 5	+ 7	---	-13	- 7	+ 7	---	-13	- 7	+ 7	---
2	+ 5	- 5	+ 3	---	+ 1	- 5	+ 3	---	+ 1	- 5	+ 3	---
3	---	+ 7	+11	---	---	+ 7	+11	---	---	+ 7	+11	---
4	-23	+11	---	+23	-23	- 5	---	+23	-23	- 5	---	+23
5	+15	---	+19	---	+15	---	+19	---	- 5	---	+19	---
6	-28	+24	- 6	- 6	-22	+10	- 6	- 6	0	---	- 6	- 6
7	+28	---	- 8	-28	-28	---	- 8	-28	+ 8	-18	- 8	-28
8	+ 7	-17	- 7	-15	-27	- 5	- 7	-15	-27	- 5	- 7	-15
9	---	+ 7	---	+17	---	+ 7	---	+17	---	+ 7	---	+17
10	+11	---	---	+15	+11	---	---	+15	+ 5	---	---	+15
11	+10	-20	---	- 2	+10	-20	---	- 2	+10	-18	---	- 2
12	---	0	+10	-16	---	0	+10	-16	---	0	+10	-16

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* Hillier, supra

Figure (8) (continued)

	ITERATION 7				ITERATION 8				ITERATION 9			
Dept.	Left	Right	Up	Down	Left	Right	Up	Down	Left	Right	Up	Down
1	-13	+ 1	+ 7	---	-13	+ 1	+ 7	---	-13	+ 1	+ 7	---
2	+ 5	- 5	+ 3	---	+ 5	- 5	+ 3	---	+ 5	- 5	- 3	---
3	---	+ 7	+11	---	---	+ 7	+11	---	---	+ 7	+ 7	---
4	+ 9	-19	-19	-15	+ 9	-19	-15	-15	+ 9	-19	-15	-25
5	- 5	---	+19	---	- 5	---	+19	---	- 5	---	- 3	- 9
6	0	---	0	- 6	0	---	---	+10	0	---	---	+10
7	-16	- 4	---	+12	-16	- 4	---	+ 6	-16	- 4	---	+ 6
8	-27	- 5	- 7	-15	-27	- 5	- 5	-15	-27	- 5	- 5	-15
9	---	+ 7	---	+ 7	---	+ 7	---	+ 5	---	+ 7	---	+ 5
10	+ 5	---	---	+11	+ 5	---	- 1	+ 1	+ 5	---	+ 9	---
11	+ 8	-18	---	+ 2	+ 8	-18	---	+ 4	+ 8	-18	---	+ 4
12	---	0	+ 6	-10	---	0	+ 6	-16	---	0	+ 6	-18

ment is shifted, a second department must be moved into the vacant position. The department to be shifted into the vacant position is to have the smallest negative value. For the first iteration department 7 is shifted to the right indicating a loss of 8. The effect on the objective function is not a decrease of 37 nor 29 (37-8=29) but rather a reduction of only 9. In calculating the effect on S it is necessary to consider the material flow relationship of 10 loads between departments 8 and 7. Thus (+37-10) + (-8-10) = +9. After an exchange is made the procedure is repeated until there is no further reduction in the objective function. For the example considered the reduction in the objective function per iteration is listed in Figure (9). Figure (10) shows the initial and final relative departmental configuration.

The above investigation only considers exchanges of a pair of work centers which are adjacent to each other. Calculations of department exchanges on a two step, three step, etc. should be made if warranted. The analysis now becomes a formidable task. The procedure terminates when no further improvement can be realized. However, as Hillier states:

> "Unfortunately, this does not guarantee an optimal solution simply because the procedure is not able to identify all possible improvements; it only identifies all those improvements by exchanging any pair of work centers. Thus, those improvements possible by the simultaneous exchanging of more than one pair of work centers even though any individual exchange would increase S are not indicated." (17)

As expected this technique being heuristic is therefore definitionally nonoptimizing. This technique, nevertheless, provides the

Exchange	Area Initiating Exchange	Replaced Area	Objective Function Improvement
1	8	7	9
2	4	9	4
3	6	12	28
4	6	8	29
5	7	6	28
6	4	7	10
7	10	6	1
8	5	10	10

Figure (9) Summary of Improvements*

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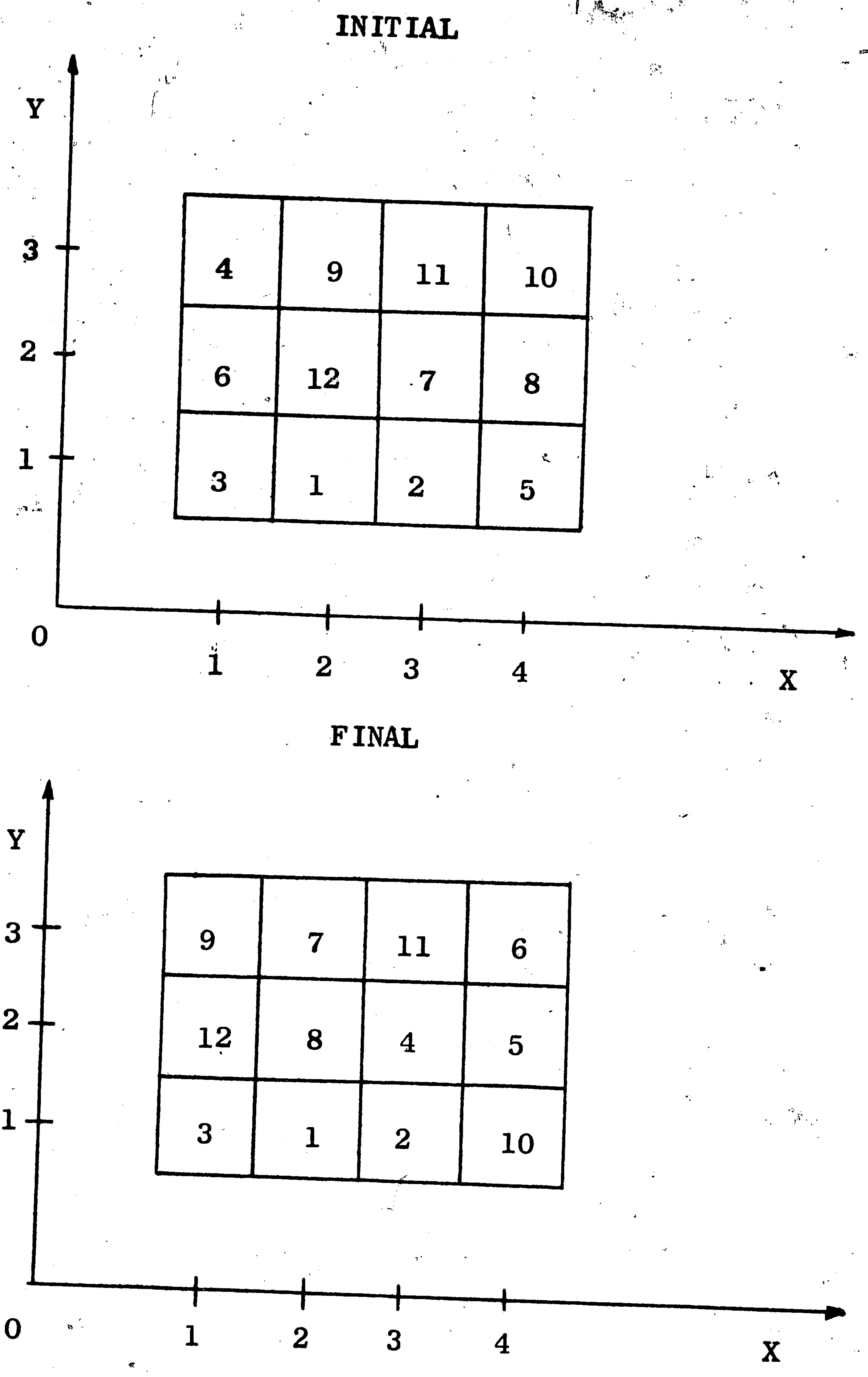
* Hillier, supra



INITIAL

4	9	11	10
6	12	7	8
3	1	2	5

FINAL

9	7	11	6
12	8	4	5
3	1	2	10

Figure (10)*

Initial and Final Spatial Configuration

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* Hillier, supra

layout engineer with a subservient method for determining an optimum or near optimum layout.

Attempts have been made, then, in the direction of solving the aforementioned problem. Some of the previous work has pointed towards the solution or perhaps towards a guideline for the solution but not quite reaching an optimum point.

It is evident that a new and superior methodology for determinimg relative location patterns of N departments is required. Such a methodology, the author believes, was developed by Armour (2). Armour's model, which is commercially known as CRAFT (Computerized Relative Allocation of Facilities Technique) provides greater flexibility and allows wider latitude in the area configuration and material flow within an operating organization. The balance of this thesis will concentrate on the model CRAFT and the results of CRAFT when applied to an actual job shop layout, subject to two manufacturing policies.

IV. COMPUTERIZED RELATIVE ALLOCATION OF FACILITIES TECHNIQUE-CRAFT

Armour recognized the need for a new and superior methodology for determining an optimum location pattern for physical facilities. The combinatorial nature and allowable changes in area configuration restrict the solution approach to that of a heuristic algorithm. Although CRAFT is heuristic and defies proof of optimality, it offers a feasible approach for evaluating plant layout.

The methodology was presented as a journal article (3) by the common process of reprinting verbatim from the author's dissertation. The journal article will be referred to below for it is more widely available and contains all the necessary information.

Let:

N = the number of departments

v_{ij} = the number of unit loads moving between departments i and j

u_{ij} = the cost to move a unit load a unit distance between departments i and j

d_{ij} = the center to center distance between departments i and j

All v_{ij} and u_{ij} elements of V and U matrices, respectively, are nonvarying with changes in locations. The matrices can therefore be combined to form a new matrix $Y = U \times V$, where $y_{ij} = u_{ij} v_{ij}$, the cost to move the total product flow between departments i and j a unit distance between i and j. The remaining variable of the objective function is the distance between departments. The distance is computed on a center to center basis. The distance changes as the relative location changes, and in addition may change as the departmental area configuration changes. The distance between departmental centers may also be expressed in matrix form with row and column headings corresponding to the Y matrix.

Thus,

$$Y = \begin{vmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & & \vdots \\ y_{n1} & y_{n2} & \cdots & y_{nn} \end{vmatrix}$$

and therefore

$$D = \begin{vmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nn} \end{vmatrix}$$

The variables y_{ij} and d_{ij} represent the relationship between departments i and j, thus $d_{ij} = 0$, $y_{ij} = 0$ where $i = j$. Also, $y_{ij} = y_{ji}$ and $d_{ij} = d_{ji}$. That is, Y and D are symmetric matrices.

The cost of any particular relative location pattern or layout is:

$$\text{Total Cost} = \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} y_{ij}\, d_{ij}$$

The three basic inputs, V, U, and D are necessary for the heuristic algorithm, which has been programmed for the IBM 7094 computer. The inputs V and U are read into the computer in matrix format. A subroutine then calculates the Y matrix. A spatial representation of the layout, in block form, is read into the computer. Here again, a subroutine utilizing the block diagram computes the D matrix.

The following is a description of the program. Figure (11) is a flow diagram of the computer program. The terminology is defined in Figure (12). Figure (13) reflects the change in material handling cost as a function of the number of iterations.

The Heuristic Algorithm

1. Compute a matrix, D, of distances between computed department centers for the first feasible initial location pattern.

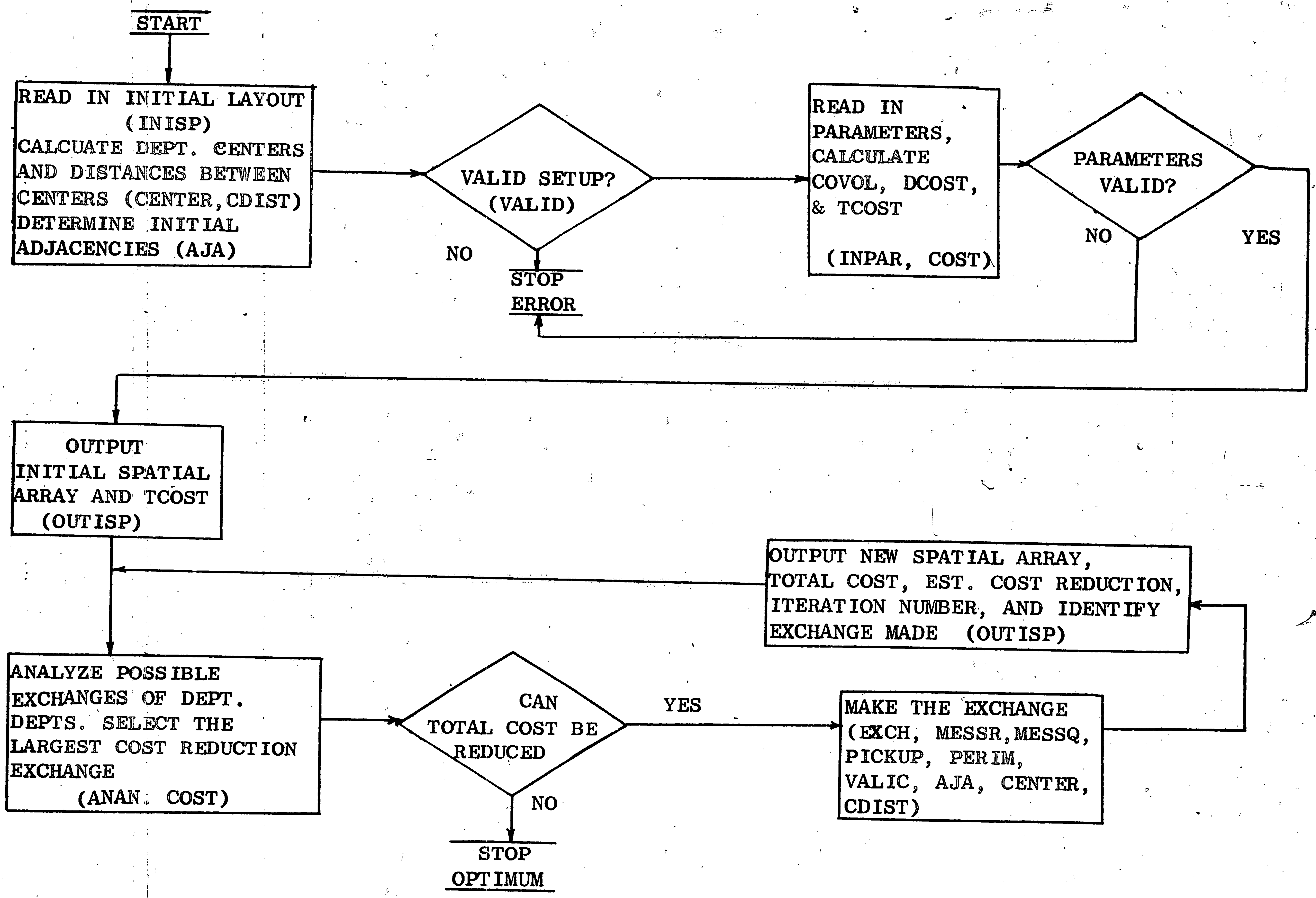
2. Compute the Y matrix.

3. Evaluate the changes in T, ΔT, which would occur if each department was exchanged with all other departments in location. Find the largest favorable ΔT. This requires $(n^2 - n)/2$ evaluations. However, in evaluating the exchange in any two departments with each other it is only necessary to consider vectors headed by the two departments being evaluated for possible exchange. To illustrate this, consider an exchange evaluation involving departments, say, E and F.

Pre-exchange partial transportation costs contributed by E and F are:

$$C_e + C_f = \sum_{j=1}^{N} d_{ej}\, y_{ej} + \sum_{j=1}^{N} d_{fj}\, y_{fj} - d_{ef}\, y_{ef}$$

Post-exchange partial transportation costs contributed by E and



Figure(11) Flow Diagram of CRAFT Program

INISP - This subroutine reads in the initial areas and spatial configurations of each sub unit and the parent unit. It also reads in the number of departments and performs several checks on correctness of this initial data.

VALID - This subroutine tests the validity of the configuration of each department for the initial and all modified spatial locations.

AJA - This subroutine determines which departments may or may not be moved in exchange.

INPAR - This subroutine reads in volume of product flow between all departments, unit cost per unit distance for that flow, and multiplies the matrices together to produce COVOL.

CENTER - The subroutine determines the center of each sub unit or department.

CDIST - This subroutine computes a matrix of distances between all centers found by CENTER.

ANAN - This subroutine evaluates the cost advantage to be gained in exchanging each department in location with all other exchange eligible departments. It then commands that exchange to be made which produces the greatest cost advantage. The rest of the computer program is essentially a slave to the ANAN subroutine.

FUNCTION COST - This subroutine is used by the ANAN subroutine to calculate departmental and total costs of alternative locations.

EXCH - This subroutine exchanges equal size departments in location. It sets up unequal size departments for location exchange in a temporary matrix. It calls MESSR and/or MESSQ to exchange unequal size departments. It compares the exchanges made by MESSR and MESSQ and selects the best one. PICKUP is called to put departments back into the permanent matrix.

MESSR - This subroutine exchanges departments of unequal size in location. It calls PERIM and PICKUP.

MESSQ - This subroutine has the same purpose as MESSR; but it accomplishes exchanges differently.

PICKUP - This subroutine picks up the exchanged departments from the temporary matrix and places them in the permanent matrix. It calls VALID.

PERIM - This subroutine is a mechanism for the measuring and limiting spatial dispersion of departments.

IALPHA - This is the only FAP, Fortran Assemby Program, in the entire program. It converts numeric to alphabetic information for printing out the spatial arrays.

OUTISP - This subroutine is the mechanism for printing out the results of the work done by the rest of the program.

Figure (12)

CRAFT Program Subroutine Description

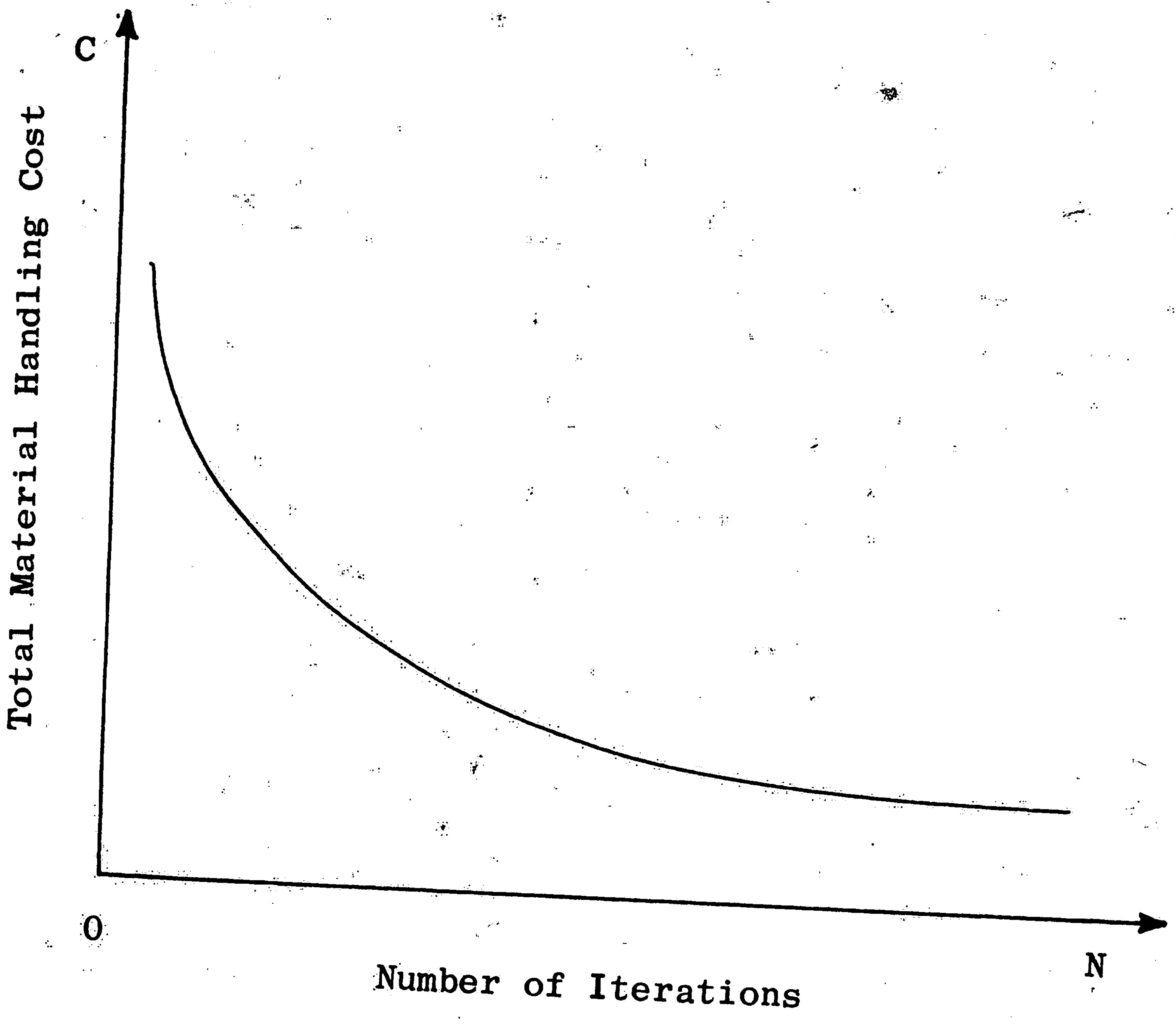


Figure (13)

General Effect Of The CRAFT Algorithm

F are:

$$C_f' + C_e' = \sum_{j=1}^{N} d_{ej}\, y_{fj} + \sum_{j=1}^{N} d_{fj}\, y_{ej} + d_{ef}\, y_{ef}$$

Let ΔT_{ef} = the change in T resulting from an exchange of departments E and F.

$$\Delta T_{ef} = \sum_{j=1}^{N} d_{ej}\, y_{ej} + \sum_{j=1}^{N} d_{fj}\, y_{fj} - \sum_{j=1}^{N} d_{ej}\, y_{fj}$$

$$\sum_{j=1}^{N} d_{fj}\, y_{ej} - 2\, d_{ef}\, y_{ef}$$

Compare ΔT_{ef} to the sign and magnitude of the last ΔT_{ij} found. Retain the larger positive value. Continue until all exchanges have been evaluated.

4. If no positive ΔT_{ij} exists go to step 6. If a positive ΔT_{ij} exists make the exchange corresponding to the largest $+\Delta T_{ij}$ found during step 3. Recompute D. Print the new relative location pattern and associated cost and move identifying information.

5. Go to step 3.

6. Stop, the optimum has been reached.

As stated previously, CRAFT is an heuristic algorithm. Although an optimum layout in not guaranteed, there are a number of distinct advantages of CRAFT.

1. The computer program is able to evaluate a far greater number of relative location patterns than is humanly possible.
2. The three basic inputs would have to be gathered and tabulated regardless of the model to be used.
3. One or more departments can be assigned a permanent location. The cost of constraint can easily be determined.
4. Areas of unequal sizes can easily be analyzed.
5. Generating an optimum layout requires approximately 2-3 minutes of computer time, subject of course to variations and complexities of the problem.*

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* Average computer time for layouts analyzed in this thesis was 1.75 minutes.

V. EXPERIMENTAL PROCEDURE

Deciding how many of an item to make for inventory stock at one time is one of the most common and still frequently unresolved questions of inventory management. Even though formulas for selecting the optimum lot size are presented in many industrial engineering texts, few companies make any attempt to arrive at an explicit quantitative balance of inventory and setup costs. Furthermore, there has been no emphasis on incorporating the cost of material handling into the total cost equation. In a total systems concept the following cost equation would be applicable.

Total Cost = Production Cost + Inventory Cost + Material Handling Cost

Mathematically this can be expressed as:

$$T.C. = \sum_{i=1}^{n} \frac{R_i A_i}{Q_i} + \sum_{i=1}^{n} \frac{Q_i}{2} C_i I + \sum_{i=1}^{N} \sum_{j=1}^{N} u_{ij} v_{ij} d_{ij} \qquad \text{V-1}$$

where:

R_i = yearly demand of item i

Q_i = production lot size of item i

A_i = setup and/or ordering cost of item i

C_i = unit cost of item i

I = inventory carrying cost per year based on a percentage of unit cost

n = number of different items

The remaining variables u_{ij}, v_{ij}, d_{ij}, and N were defined in Chapter IV.

At the present time there is no mathematical expression which would minimize the above equation. Although the v_{ij}'s are constant, the u_{ij}'s are a function of $\sum_{i=1}^{n} \frac{\bar{R}_i}{Q_i}$. There is no way of expressing this relationship in mathematical form. In addition, the d_{ij}'s are dependent upon the specific relative location pattern being evaluated. Thus, it is necessary to determine whether an adjustment in the number of setups for one or more products and/or just a change in relative location pattern will result in a lower overall cost. This approach introduces a formidable combinatorial problem for which there is no algorithm available in the literature today.

As a result, an optimum policy with regard to inventory, production setup, and material handling costs cannot be determined at this time.

However, two production and inventory policies were selected and the effect on an existing job shop layout was investigated. Specifically, two manufacturing policies were utilized in determining the number of production lots per part, and thus the interdepartmental flow matrix. For each policy an optimum layout and associated material handling cost were generated using the CRAFT model.

The job shop selected for study was a Metal Piece Part Shop. The shop manufactures parts for electro-mechanical and electronic devices. At the time this investigation was conducted there were 660 different piece parts being manufactured. The number of operations per part ranged from 2 to 24, with an average of 5. The production quantity, by part, for a twelve month interval was obtained from the Accounting Department. Manufacturing layouts, indicating the routing sequence and unit cost were obtained from the Data Processing Organization.

The job shop is composed of 26 departments. Figure (14) is a list of the departments along with their identifying letter code and area requirements. Since CRAFT requires the overall shop area to be rectangular two vacuous areas, C and Z were added. Figure (15) is the existing floor plan layout. Each departmental area is shown by its identifying letter code. The periphery need only be indicated. Each lettered character represents a unit square of $6\frac{1}{4}$" x $6\frac{1}{4}$", and is referred to as a unit square. A unit distance is then $6\frac{1}{4}$". Figure (15) is the spatial configuration for the CRAFT model.

In order to determine the V matrix, the cost to move a unit load a unit distance, it was necessary to determine a suitable walking rate. Work Factor (34) assumes a walking rate of 3 miles per hour. However, for this particular case it was felt that a different rate be applied which would more closely approximate the prevailing conditions. Material is transported by hand, carrying trays, or loading the trays on a wagon. The average transporting distance is approximately 75 feet and requiring two 90^{0} turns. Based on elemental time standards a walking rate of 2.4 miles per hour was developed. The cost to move a unit load a unit distance ($6\frac{1}{4}$") was based on the developed walking rate and the hourly wage of the material handler or layout operator, depending on who transported the material. Figure (16) is the cost matrix in terms of 100 unit distances. Each value was multiplied by 100 so as to retain significant digits.

Letter Code	Department	Area (Square Feet)
A	Multi-Slides	274
B	Four Slide (Artos)	1600
C	Vacuous Area (Fixed Location)	1094
D	Punch Presses	2500
E	Milling Machines	234
F	Broaches	156
G	Cone	1328
H	Brown and Sharp Lathes	1367
I	Esco	78
J	Swiss	700
K	Tool Crib	1133
L	Screw Machines, Turret Lathes	2265
M	Assembly and Bench Area	1015
N	Staircase (Fixed Location)	312
O	Locker Room	781
P	Electronic Discharge Machine	156
Q	Drill Presses	586
R	Degreaser	625
S	Kummer Machine	78
T	Tumbling Area	1250
U	Cylinderical Grinder	469
V	Electrical Substation	742
W	Definite Order Shop	1953
X	Automatic Cutoff Machine	234
Y	Inspection (Fixed Location)	39
Z	Vacuous Area (Fixed Location)	1290
		Total 22,259

Figure (14) List of Departments

```
A A A B B B B B B B B B C C C C C C C
B A A B                 B C         C
B A A B                 B C         C
B B B B B B B B B B B B C C C C C C C
D D D D D D D D E E E E E E G G G G H
D             D F F F F K K G     G H
D             D K K K K   K G     G H
D             D K         K G     G H
D             D K         K G     G H
D             D K K K K K K I G   G H
D D D D       D K L L L L L I G   G H
N N N N D     D K L       L G     G H
N N N N D D D D K L       L G G G G H
O O O O M M M M M L       L J J H H H
O     O M M     M L       L J J H   H
O     O P P M   M L       L J J H   H
O     O P P M   M L       L J J H   H
O O O O M M     M L       L J J H   H
R R R R M M M M M L       L J J H   H
R     R Q Q Q Q Q L   L   L J J H   H
R     R Q       Q L L S L L J J H   H
R R R R Q Q Q Q Q L L S L L J J H H Y
T T T T U U U U V V V V V W W W W W W
T     T U     U V       V W         W
T     T U U U U V       V W         W
T     T Z Z Z Z Z V V V V W         W
T     T Z       Z X X X X X W       W
T     T Z       Z X W W W W         W
T     T Z         Z Z Z Z W         W
T T T T Z Z Z Z Z Z Z Z Z W W W W W W
```

Figure (15)

Initial "Job Shop" Spatial Layout

	A	B	C	D	E	F	G	H	I	J	K	L	M
A	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0.130	0.124	0	0	0	0	0	0	0.124
C	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	0	0.120	0.148
E	0	0.130	0	0	0	0.124	0	0	0	0	0	0.129	0.108
F	0	0.124	0	0	0.124	0	0	0	0	0	0	0.130	0.124
G	0	0	0	0	0	0	0	0	0	0	0	0.151	0
H	0	0	0	0	0	0	0	0	0	0	0	0.151	0.151
I	0	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	0.151	0.151
K	0	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0.120	0.129	0.130	0.151	0.151	0	0.151	0	0	0.124
M	0	0.124	0	0.148	0.108	0.124	0	0.151	0	0.151	0	0.124	0
N	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	0.117	0	0	0	0.151	0	0	0	0.117	0.092
Q	0	0	0	0.109	0.112	0.124	0	0.151	0	0	0	0.109	0.096
R	0	0.092	0	0.092	0.092	0	0.092	0.092	0.092	0.092	0	0.092	0.092
S	0	0	0	0	0	0	0.151	0	0	0	0	0.141	0
T	0	0.092	0	0.184	0.092	0.092	0.092	0.092	0	0.092	0	0.092	0.092
U	0	0	0	0	0	0	0	0	0	0	0	0.133	0
V	0	0	0	0	0	0	0	0	0	0	0	0	0
W	0	0	0	0	0	0.133	0	0	0	0	0	0.133	0.114
X	0	0	0	0.100	0.100	0	0	0	0	0	0	0	0
Y	0	0	0	0	0.092	0	0	0.092	0	0	0	0.092	0.092
Z	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure (16) Interdepartmental Material - Handling Costs Per 100 Unit Distances

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0.092	0	0.092	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0.117	0.109	0.092	0	0.184	0	0	0	0.100	0	0
E	0	0	0	0.112	0.092	0	0.092	0	0	0	0.100	0.092	0
F	0	0	0	0.124	0	0	0.092	0	0	0.133	0	0	0
G	0	0	0	0	0.092	0.151	0.092	0	0	0	0	0	0
H	0	0	0.151	0.151	0.092	0	0.092	0	0	0	0	0.092	0
I	0	0	0	0	0.092	0	0	0	0	0	0	0	0
J	0	0	0	0	0.092	0	0.092	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0.117	0.109	0.092	0.141	0.092	0.133	0	0.133	0	0.092	0
M	0	0	0.092	0.096	0.092	0	0.092	0	0	0.114	0	0.092	0
N	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	0	0	0	0	0	0	0	0	0	0
Q	0	0	0	0	0.092	0	0.092	0	0	0.133	0	0	0
R	0	0	0	0.092	0	0	0.092	0.092	0	0	0.092	0.184	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0
T	0	0	0	0.092	0.092	0	0	0	0	0	0.092	0	0
U	0	0	0	0	0.092	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0	0
W	0	0	0	0.133	0	0	0	0	0	0	0	0	0
X	0	0	0	0	0.092	0	0.092	0	0	0	0	0	0
Y	0	0	0	0	0.184	0	0	0	0	0	0	0	0
Z	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure (16) (Continued)

The spatial configuration and cost matrix which have been developed are independent of the manufacturing policy. The interdepartmental flow matrix, U, however is dependent on the manufacturing policy. The two manufacturing policies will therefore be described. Policy 1 is the manufacturing policy presently being employed. All operating departments manufacture on a monthly basis. That is, the operating shop is required to produce a specified quantity for each part which must be available at the beginning of the subsequent month. Although this may not be the optimum policy for the operating shop, the overall system is optimized. The manner in which the parts are produced is determined by the operating department personnel. For Policy 1 the number of lots for each part were obtained from the Payroll Organization. A record was initiated as each lot was routed through the shop and then placed in finished inventory. Processing these activity records along with the manufacturing layouts, on an IBM 1410 computer, the interdepartmental flow matrix was obtained, Figure (17).

Policy 2 was based upon the minimization of production setup and inventory holding cost, Appendix I. For each part the optimum number of setups, and thus lots, were determined. Combined with the manufacturing layouts a second interdepartmental flow matrix, Figure (18), was developed.

The required inputs, D, V, and U for both manufacturing policies were determined. Due to physical restrictions the following departments C, N, O, R, V, Y, and Z were fixed in their initial locations. In addition, rejected lots were not accounted for, and the material handling cost of obtaining raw material from stock was omitted.

	A	B	C	D	E	F	G	H	I	J	K	L	M
A	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	92	48	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	0	816	404
E	0	92	0	0	0	484	0	0	0	0	0	540	1260
F	0	48	0	4840	0	0	0	0	0	0	0	312	164
G	0	0	0	0	0	0	0	0	0	0	0	64	0
H	0	0	0	0	0	0	0	0	0	0	0	72	40
I	0	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	12	4
K	0	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	816	540	312	64	72	0	12	0	0	0
M	0	0	0	404	1260	164	0	40	0	4	0	0	0
N	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	188	0	0	0	240	0	0	0	240	188
Q	0	0	0	180	792	80	0	28	0	0	0	596	608
R	0	2148	0	2276	268	0	388	560	44	204	0	1024	1428
S	0	0	0	0	0	0	356	0	0	0	0	356	0
T	0	832	0	1248	140	8	224	20	0	40	0	48	132
U	0	0	0	0	0	0	0	0	0	0	0	56	0
V	0	0	0	0	0	0	0	0	0	0	0	0	0
W	0	0	0	0	0	20	0	0	0	0	0	24	220
X	0	0	0	4	12	0	0	0	0	0	0	0	0
Y	0	0	0	0	20	0	0	16	0	0	0	8	16
Z	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure (17) Interdepartmental Flow Matrix - Policy 1

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	2148	0	832	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	188	180	2276	0	1248	0	0	0	4	0	0
E	0	0	0	792	268	0	140	0	0	0	12	20	0
F	0	0	0	80	0	0	8	0	0	20	0	0	0
G	0	0	0	0	388	356	224	0	0	0	0	0	0
H	0	0	240	28	560	0	20	0	0	0	0	16	0
I	0	0	0	0	44	0	0	0	0	0	0	0	0
J	0	0	0	0	204	0	40	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	240	596	1024	356	48	56	0	24	0	8	0
M	0	0	188	608	1428	0	132	0	0	220	0	16	0
N	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	0	0	0	0	0	0	0	0	0	0
Q	0	0	0	0	540	0	156	0	0	4	0	0	0
R	0	0	0	540	0	0	1836	76	0	0	4	9998	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0
T	0	0	0	156	1836	0	0	0	0	0	56	0	0
U	0	0	0	0	76	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0	0
W	0	0	0	4	0	0	0	0	0	0	0	0	0
X	0	0	0	0	4	0	56	0	0	0	0	0	0
Y	0	0	0	0	9998	0	0	0	0	0	0	0	0
Z	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure (17) (Continued)

	A	B	C	D	E	F	G	H	I	J	K	L	M
A	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	8	8	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0	0	208	68
E	0	8	0	0	0	76	0	0	0	0	0	132	360
F	0	8	0	0	76	0	0	0	0	0	0	32	32
G	0	0	0	0	0	0	0	0	0	0	0	24	0
H	0	0	0	0	0	0	0	0	0	0	0	20	16
I	0	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	4	8
K	0	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	208	132	32	24	20	0	8	0	0	116
M	0	0	0	68	360	32	0	16	0	4	0	116	0
N	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	32	0	0	0	32	0	0	0	0	32
Q	0	0	0	36	152	16	0	12	0	0	0	136	176
R	0	804	0	1060	56	0	160	28	144	28	0	236	704
S	0	0	0	0	0	0	56	0	0	0	0	56	0
T	0	284	0	340	68	0	52	4	0	36	0	28	40
U	0	0	0	0	0	0	0	0	0	0	0	24	0
V	0	0	0	0	0	0	0	0	0	0	0	0	0
W	0	0	0	0	0	4	0	0	0	0	0	8	84
X	0	0	0	4	4	0	0	0	0	0	0	0	0
Y	0	0	0	4	0	0	0	0	0	0	0	4	8
Z	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure (18) Interdepartmental Flow Matrix - Policy 2

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	0	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	804	0	284	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0	0	0
D	0	0	32	36	1060	0	340	0	0	0	4	4	0
E	0	0	0	152	56	0	68	0	0	0	4	0	0
F	0	0	0	16	0	0	0	0	0	4	0	0	0
G	0	0	0	0	160	56	52	0	0	0	0	0	0
H	0	0	32	12	28	0	4	0	0	0	0	4	0
I	0	0	0	0	144	0	0	0	0	0	0	0	0
J	0	0	0	0	28	0	36	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	136	236	48	28	24	0	8	0	4	0
M	0	0	32	176	704	0	40	0	0	84	0	8	0
N	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	0	0	0	0	0	0	0	0	0	0
Q	0	0	0	0	184	0	68	0	0	4	0	0	0
R	0	0	0	184	0	0	852	36	0	0	4	4084	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0
T	0	0	0	68	852	0	0	0	0	0	4	0	0
U	0	0	0	0	36	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0	0
W	0	0	0	4	0	0	0	0	0	0	0	0	0
X	0	0	0	0	4	0	4	0	0	0	0	0	0
Y	0	0	0	0	4084	0	0	0	0	0	0	0	0
Z	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure (18) (Continued)

For each manufacturing policy an optimum layout and material handling cost was generated. Also the optimum layout resulting from one policy was evaluated using the interdepartmental flow matrix of the other policy.

VI. RESULTS

The results of the first phase of the investigation are shown in Table 1.

Table 1

Summary of CRAFT - Phase 1

	Policy 1	Policy 2
Initial Cost	$ 1,365	$ 488
Aggregate Number of Lots	5,400	2,300
Number of Computer Iteration	10	12
Final Cost	$ 1,225	$ 449
Savings	$ 140	$ 39
Savings as a % of Initial Cost	10.23%	7.98%

Figures (19) and (20) represent the optimum layout for Policies 1 and 2, respectively.

As indicated in Table 1, Policy 2 resulted in an initial reduction of 64% in material handling costs. This is attributed to the fact that the aggregate number of lots was decreased from 5,400 to 2,300, a 57% reduction. This savings does not necessarily indicate that Policy 2 is preferable. As it was infeasible to determine the production and inventory costs for Policy 1, a comparison of both policies on an overall cost basis could not be made.

In analyzing the affect of both manufacturing policies on the existing plant layout, improvements of only 10.23% and 7.98% for

```
A A A B B B B B Q Q Q Q C C C C C C C
B A A B       B Q     Q C           C
B A A B       B Q     Q C           C
B B B   B B B B B Q Q Q C C C C C C C
B     B M M M M E E F F F F W W W W W
B     B M     M E E E E W W         W
B     B M     M W W W W             W
B B B M       M W             W W W W
M M M M M M M M W           W K K K K
M D D D D D D D W W W W W W I K     K
D D D D       D W L L L L L I K     K
N N N N D     D W L       L K       K
N N N N D     D W L       L K K     K
O O O O D       D L       L H H K   K
O     O D D     D L       L H H K K K
O     O P P D   D L       L H H K H H
O     O P P D   D L       L H   H   H
O O O O D D     D L       L H       H
R R R R D       D L       L H       H
R     R D       D L   L   L H       H
R     R D       D L L S L L H   H H H
R R R R D D D D D L L S L L H H J J Y
T T T T T T T T V V V V V G G G J   J
T             T V       V G   G J   J
T       T T T T V       V G   G J   J
T T T T Z Z Z Z Z V V V V G   G J   J
U U U T Z       Z G G G G     G J J J
U   U T Z       Z G G G G     G J X X
U   U T Z         Z Z Z Z G     G X X
U U U T Z Z Z Z Z Z Z Z Z G G G G X X
```

Figure (19)

Optimum "Job Shop" Spatial Layout - Policy 1

```
A A A K K K P P Q Q Q Q C C C C C C C
K A A K   K P P Q     Q C           C
K A A K     K K Q     Q C           C
K K K         K K Q Q Q C C C C C C C
K K K K K K K T E E E E E E W W W W W
T T T T T T T T F F F F M M W       W
T               T M M M   M W       W
T         T T T T M       M W       W
T T T T T D D D D M       M W       W
D D D D D     D M M M M M M S W     W
D D D D       D M L L L L L S W     W
N N N N D     D M L       L W       W
N N N N D     D M L       L W W     W
O O O O D       D L       L G G W   W
O     O D       D L       L G G W W W
O     O D       D L       L G G W G G
O     O D       D L       L G   G   G
O O O O D       D L       L G       G
R R R R D       D L       L G       G
R     R D D D D D L   L   L G       G
R     R B B B B D L L I L L G G G G G
R R R R B       B L L I L L G H H H Y
B B B B       B V V V V V H H       H
B             B V       V H         H
B       B B B B V       V J H       H
B B B B Z Z Z Z Z V V V V J H       H
U U U B Z       Z J J J J   J H   H H
U   U B Z       Z J J J J   J H H X X
U   U B Z         Z Z Z Z J J H H X X
U U U B Z Z Z Z Z Z Z Z Z J J H H X X
```

Figure (20)

Optimum "Job Shop" Spatial Layout - Policy 2

Policies 1 and 2, respectively, could be realized.

In the second phase, the optimum layout for one manufacturing policy along with the interdepartmental flow matrix of the second were analyzed by CRAFT. Results are summarized in Table 2.

Table 2

Summary of CRAFT - Phase II

	Existing Layout	Optimum Layout of Policy 1	Optimum Layout of Policy 2	Absolute Difference Col 2-Col 3	% Deviation
Policy 1	$1,365	$1,225	$1,233	$8	0.65%
Policy 2	$488	$457	$449	$8	1.75%

VII. CONCLUSIONS

The purpose of this study was to investigate the relationship between manufacturing policies and plant layout in a job shop. The results, Table 1, indicate that an optimum layout based on one manufacturing policy is not necessarily the optimum layout for a second manufacturing policy. However, from Table 2, the magnitude of percent deviation when interchanging optimum layouts and manufacturing policies tends to indicate a relationship of independence between the two. This seems plausible since the basic relationship of departments is based on the routing sequence of the parts to be manufactured, which is predetermined. The manufacturing policy, in determining the lot size, establishes a numerical value for department relationships.

The author, however, is hesitant in making any categorical statement regarding the relationship of manufacturing policy and optimum plant layout. Perhaps "job shop" characteristics or type of product manufactured have a significant influence on plant layout. Before concluding, then, that one plant layout can be optimum, or near optimum (within acceptable limits) for all manufacturing policies, additional research and investigation in this area is necessary.

VIII. RECOMMENDATIONS FOR FUTURE STUDY

1. In investigating the relationship between manufacturing policies and plant layout in a job shop, only two different policies were employed. Perhaps an increase in the number of manufacturing policies investigated would yield additional information regarding the relationship.

2. The interdepartmental flow matrices were based on deterministic demand. Stochastic properties of demand should be accounted for and sensitivity of optimum layout changes analyzed.

3. Reference was made to the three major costs: production setup, inventory holding, and material handling costs. The author was unable to find any algorithm, in the literature, which would minimize the sum of these three costs. The formulation of such an algorithm would certainly be beneficial.

4. The principles of relative location are independent of a particular system or process. The relative location problem, therefore, has equal application in such activities as offices, cafeterias, hospitals, libraries, and supermarkets. The criterion, however, may be modified as warranted by the system under investigation. That is, for cafeterias and/or supermarkets the criterion might be the minimization of time customers spend in the system. Investigation into these other areas appears to be fruitful.

APPENDIX I

Total Cost = Production Setup Cost + Inventory Holding Cost

$$TC = \sum_{i=1}^{n} \left[\frac{R_i A_i}{Q_i} + \frac{Q_i}{2} C_i I \right]$$

where:

R_i = yearly demand of item i

Q_i = production lot size of item i

A_i = setup and/or ordering cost of item i

C_i = unit cost of item i

I = Inventory carrying cost per year based on a percentage of unit cost (I=27%)

n = number of items.

Differentiating the above equation with respect to Q_i, and equating to zero:

$$\frac{\partial TC}{\partial Q_i} = - \frac{R_i A_i}{Q_i^2} + \frac{C_i I}{2} = 0$$

Solving for optimum Q_i^*:

$$Q_i^* = \left[\frac{2 A_i R_i}{C_i I} \right]^{\frac{1}{2}}$$

The optimum number of lots is:

$$L^* = \frac{R_i}{Q_i^*} = \left[\frac{R_i C_i I}{2 A_i} \right]^{\frac{1}{2}}$$

Optimum number of lots for each item and interdepartmental flow matrix were determined using an IBM 1410 computer.

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