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THE USE OF REALISTIC MATERIALS MOVEMENT DISTANCE IN FACILITIES RELAYOUT EVALUATION

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ABSTRACT

The facilities layout problem is identified to be "ill-structured" and complex. Two major criteria are used in the evaluation of layouts – closeness desirability and materials movement cost. The material movement cost is quantitative in nature and hence it is more acceptable. It is identified that this quantitative criterion is dependent on distance moved by materials. The paper identified the importance of traffic system in layout evaluation; also the most recent layout planning procedures were highlighted. The importance of accurately measuring distance moved by materials was discussed, this is followed by the use of series of tests to establish the influence of fixed cost per journey variable cost per journey and work center cell dominance. Also a brief discussion on the software developed by Author is included and finally comments and conclusions were made on the evaluation criterion and development of computer software.

1. INTRODUCTION:

A more common problem in industries today is that of modifying or totally changing an existing manufacturing layout. The necessity to change an existing layout may be due to changes in manufacturing methods, market situation or product changes. It is this problem that is termed "facilities layout" problem. The facilities layout problem is a very complex one, it involves the consideration of both subjective and quantitative factors as stated by Moore (1) Moore described.

Four possible levels of plant or facilities layout change, each of which will influence the solution approach as:

(i) New layout, no restrictions at all

(ii) New layout to be phased within an existing building.

(iii) New replacement layout, to be phased into an existing layout.

(iv) Extension or reduction of an existing layout

The re-arrangement of an existing layout adds a whole new dynamic character to the layout problem. The dynamic influence arises when considering how to withdraw old manufacturing facilities and install new technology facilities with minimum disruption to production. Evaluating the cost associated with the re-layout problem is a complex process. Typically the following cost are associated with the operation of a manufacturing system-work centre or facility relocation cost, material movement cost, fixed cost and site preparation costs. The material movement cost is quantitative in nature and for the cost to be accurate it is necessary to carry out realistic measurement like distance moved by products or materials during production. The two most common criteria used in facilities layout problem are closeness desirability and materials movement.

Closeness desirability was criticized as a criterion because of the following reason by Driscoll (2):

(i) The selection of scale values and intervals would be difficult to define in scientific manner.

(ii) The process of using only immediate neighbours in the calculation of closeness desirability is suspect.

(iii) The profile of departments could be manipulated to make substantial changes to closeness desirability score.

(iv) Closeness desirability no matter how manipulated is a subjective criterion incapable of conversion to a financial cost and of little use for comparing layouts with marginal differences.

Materials movement was considered to show the greatest promise as a quantitative criterion capable of conversion to a financial cost. The technical process used to calculate total materials movement within the models available at the time was however subject to qualification. These qualifications were:

(i) Material movement consisted of both a fixed and variable elements. Models that ignore the fixed element could be introducing errors as great as twenty-eight percent (in the batch production situation).

(ii) The use of straight line and Cartesian co-ordinates distances would introduce errors where traffic system is in existence.

The review in Driscoll's work supported materials handling cost as having the better prospect for use as a layout evaluation criterion. Also the review by Author (3) summary which is shown in table 1 indicates that materials movement cost is the one that is used mostly by researchers. Material movement cost during anyone time period is calculated using equation (2):

$$M_t = \sum_{k=1}^{P} PQ_K \times \sum_{J=1}^{nk-1} \left(PF_K + PV_K \times D_{J,J+1}\right) \quad (1)$$

Where:

M_{tt} = Materials Movement cost in the period t.

P = Number of products

PQ_k = Number of batches of product k per period

PF_k = Fixed cost of finding, loading and unloading a unit load of product k

$D_{j,j+1}$ = distance from j to j+1 workcentres in product k

n_k = Number of workcentres in the manufacturing sequence for product k

The method of calculating the distance between workcentre facilities is discussed here. Two main types of facility or workcentre (production) layouts were identified. One type without a defined traffic route system and the other type with a well defined traffic route system. Where there is no traffic route system in the layout the distance between workcentres is taken as the rectangular co-ordinate distances between specified materials delivery points. Where a traffic system exists the distances between workcentres is calculated with respect to the traffic system and the calculation is more complex.

DISTANCE MEASUREMENT PROBLEM

Three forms of facility representation were identified by Driscoll (2) as being common amongst quantitative layout programs – point representation, unit area representation and proportional block area which are reproduced in figure 1.

Also in the work of Driscoll the conclusion was drawn that point and unit matrix representations were of little use in the layout of batch manufacturing areas, a conclusion supported in the review work of the Author (3). With respect to proportional block area representation

Table 1: Recent layout planning procedure

Program	Author(s)	Discipline	Objective Criterion	Year	Reference
MS-S	Lilly, M.T.	Industrial Engineering	Material movement cost	1985	(3)
S-ZAKY	Abdel-Barr, S.E.Z.	Production Engineering	Materials movement	1987	(4)
Relay 1-Relay 2B	Abdel-Magid, E.E.	Industrial Engineering	Production cost Relocation cost	1980	(5)
Grapple& Dating	O'Brien, C. and Skok, M. J.	Production Engineering	Materials movement	1981	(6)
Slpcalc	Moore J.M	Industrial Engineering	Closeness Desirability	1983	(7)
Calpald	O'Brien,C.and Skok, M. J.	Production Engineering	Materials movement	1983	(8)
GASOL	Hammounche A&Webster, D.B	Industrial Engineering	Closeness Desirability	1983	(9)
Cafl	Mainvannan, S. & Chaudhuri, D.	Industrial Engineering	Material movement	1984	(10)

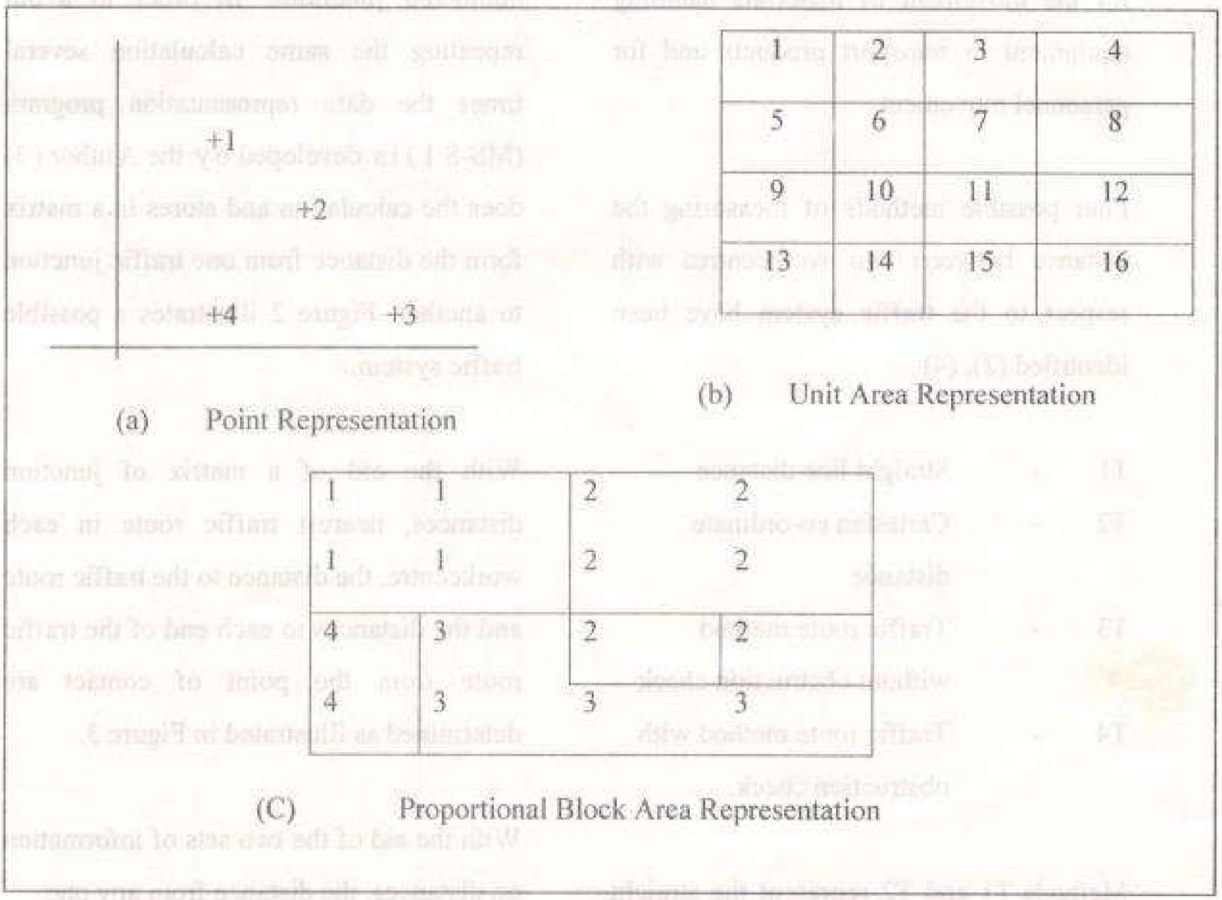

Figure 1 Illustration of Computer Facility Representation (After Driscoll)

conclusion was drawn that whilst useful in the general layout of departments within a factory; it would be unrealistic at the workcentres level for large matrices representing small areas in order to cope with internal obstructions facilities not oriented on the X-Y axes and the subsequent exponential increase in computational time.

In any well organized engineering layout there exists a well defined traffic system for the movement of materials handling equipment to transport products and for personnel movement.

Four possible methods of measuring the distance between two workcentres with respect to the traffic system have been identified (2), (4):

T1	-	Straight line distance
T2	-	Cartesian co-ordinate distance
T3	-	Traffic route method without obstruction check
T4	-	Traffic route method with obstruction check.

Methods T1 and T2 represent the straight line and rectangular co-ordinate distance from workcentre location to workcenter location; these two methods are the most commonly used ones in many existing computer programs for facilities layout. Method T4 is not employed due to the very high levels of calculation that would be generated.

Method T3 determines the shortest distances between workcentres through the traffic systems. The traffic system is considered to be circular or straight line in the shape or a combination of both and is considered to be continuous with numbered junctions. In order to avoid repeating the same calculation several times the data representation program (MS-S 1) is developed by the Author (3) does the calculation and stores in a matrix form the distance from one traffic junction to another. Figure 2 illustrates a possible traffic system.

With the aid of a matrix of junction distances, nearest traffic route in each workcentre, the distance to the traffic route and the distances to each end of the traffic route from the point of contact are determined as illustrated in Figure 3.

With the aid of the two sets of information on distances, the distance from any one workcentre to another, which is the shortest of the four routes is determined. If both centers are on the same route the distance from the i to Workcentre j is:

$$D_{i,j} = C_i + C_j + \text{Absolute}\,(A_i + A_{jj}) \quad (2)$$

For workcentres on two different routes the distance from one to the other is the sum of the minimum of the distances using routes including the junctions at each end of the two routes nearest to the workcentres. Using Figure 3 as an example the minimum distance from workcentre1 to workcentre 4 is

$$C_1 + C_4 + B_1 + B_4 \quad (3)$$

The basic T3 model was implemented in the UA1 – UA3 (2) Software.

The modifications to the method of measuring movement distances that are original to this work (programs MS-S3 and MS-S4) include circular traffic routes (for automated guide vehicle (AGV systems) and specified pickup and placing locations (3).

The materials movement cost consists of two components the distance dependent part called variable cost and the distance independent part called fixed cost. The transportation of a product involves finding and raising, moving it from its former position to a new one and then lowering it at the new position.

The fixed cost term in the equation for materials movement cost evaluation model eliminates the problem of generating a flow matrix representing inter-workcentre movement where potentially large numbers of workcentres may be involved. Also the model enables the fixed and variable costs to be selected to suit the physical requirements of individual products. Another modification adopted is the elimination of cost of materials movement performed by machine operators.

When workcentres are closed to each other and the physical size of product batches is small, some percentage of materials movement will be undertaken by machine operators; hence the need to modify the materials movement cost equation. This saving of movement cost results from those product movements involving small distances, hence a boundary distance (E) is introduced to account for the minimum distance required for the cost to be included in the evaluation model. So for movements less E their corresponding costs are not included in the cost model, this concept being carried forward from the UA1 – UA4 programs. With this

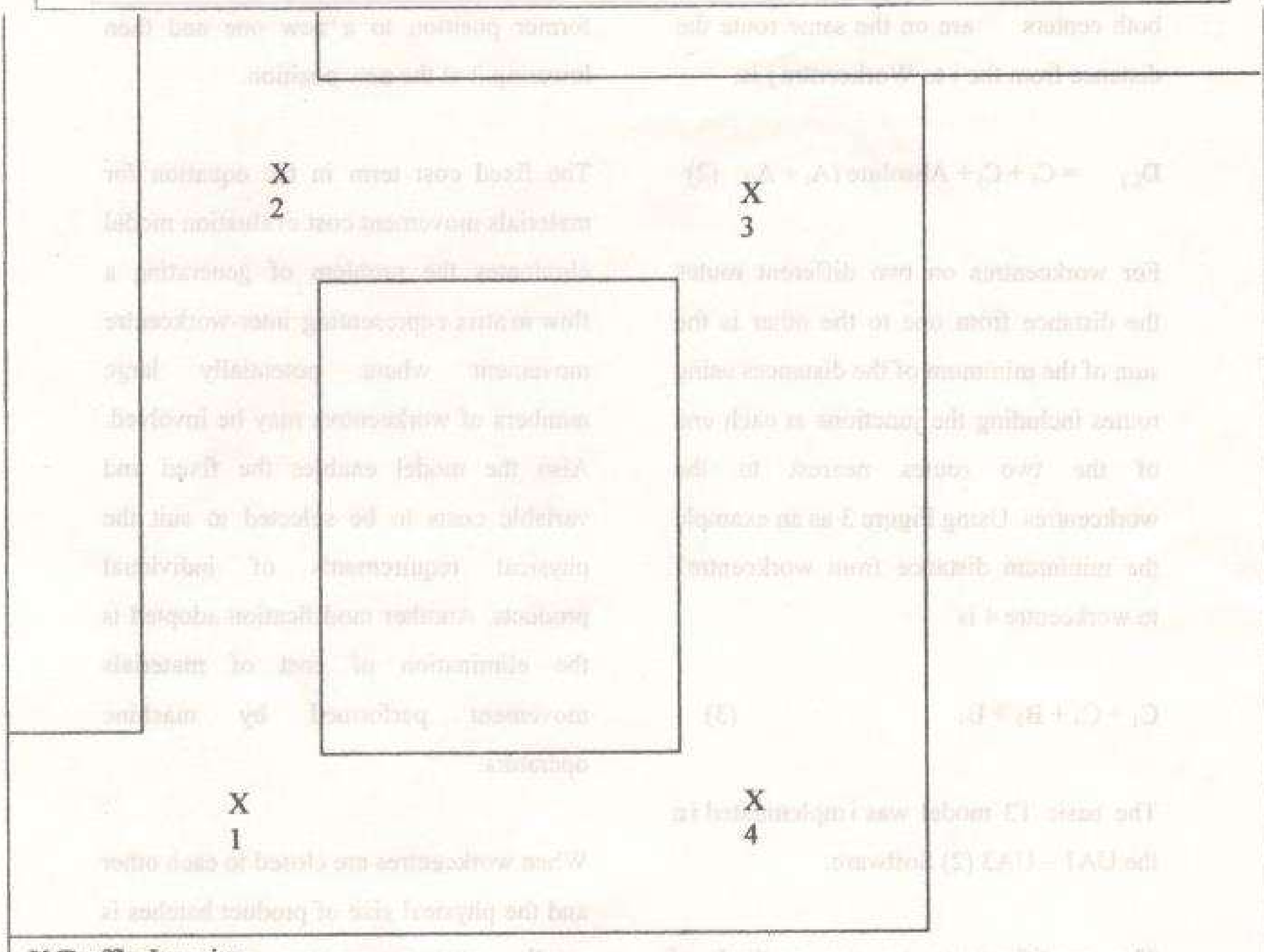

FIGURE 2. TRAFFIC SYSTEM

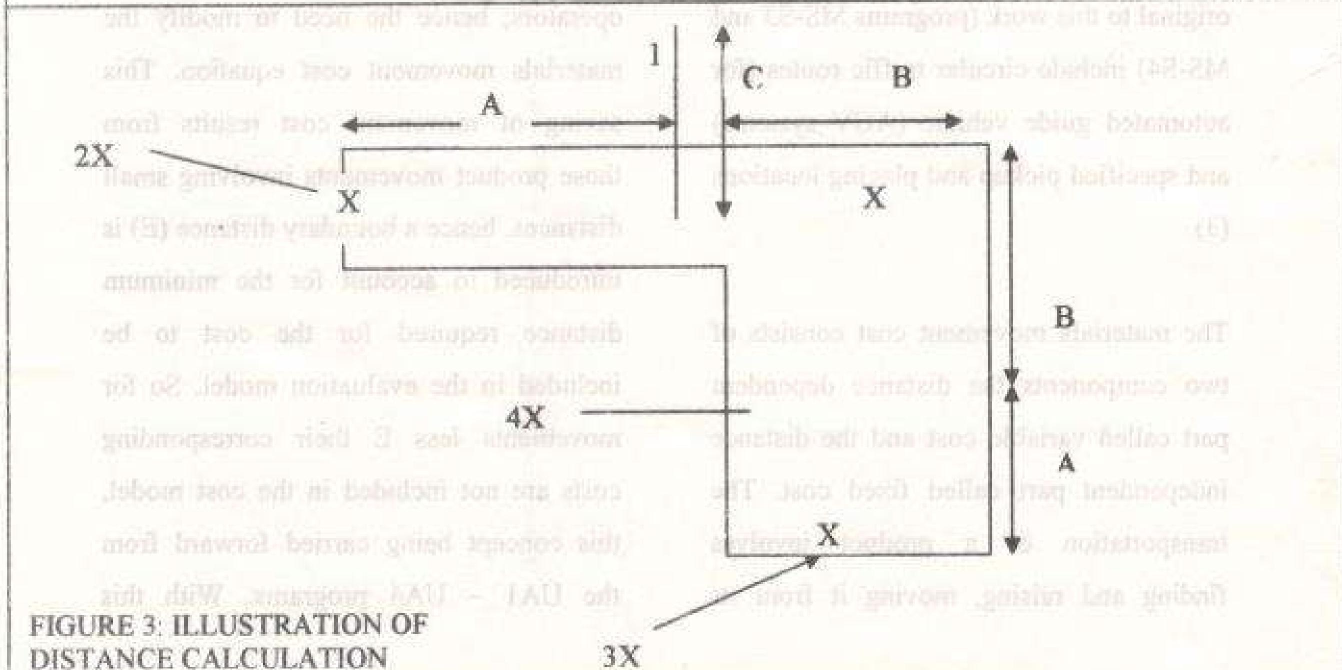

FIGURE 3: ILLUSTRATION OF DISTANCE CALCULATION

modification the materials movement cost equation becomes a non-linear one. The saving in materials movement cost required by the model is calculated using the equation:

$$GMCST_t = M_0 - m_t \quad (4)$$

Where:

$M_0 =$ Materials movement cost in initial layout

$M_t =$ Materials movement cost in period t as in equation 1

$GMCST_t =$ Materials movement savings in period t

TESTING OF INFLUENCE OF DISTANCE MOVEMENT

The traffic system forms an important part of materials movement evaluation process and is recoded therefore in some detail as a series of connected traffic routes with known width, length, (center for circular routes) and junction points.

This representation can be used for either conventional materials movement models or for the design of flexible manufacturing system (F.M.S.) EMPLOYING automated guide vehicles (AGV's). When an independent FMS subsystem is to be included in the new layout area provision is made for identifying separately the FMS sub-area and FMS traffic subsystems. Hence a computer program was developed to take care of the required realistic calculation. Figure 4 shows the arrangement of the programs. Four data files are initially created and coded as follows:

MS-F1 for general project data
MS-A1 for layout data
MS-W1 for workcentre data and
MS-M1 for production data

File MS-W1 contains information on each workcentre involved in a layout project, whether it is obsolete and to be phased out, to be transferred from the old layout to the new layout or it is a new workcentre and awaiting placement in the new layout, twenty four sets of values were given. These values identify the w orkcentre a nd its condition; shape, location and materials delivery point, disconnection and connection times, relocation cost and also indicates alternative equivalents and replacement workcentres.

Finally manufacturing programme data i s provided for each to be produced and it is stored in file MS-M1. This data includes the identification number of each product, its batch size, production volume, materials handling, equipment code number, fixed and variable costs of moving and producing each batch of the product, financial gain in producing each unit. Also included in this data file is the sequence in which the product batch moves through listed workcentres, stages of production, set-up time of each workcentre, production time at each workcentre and the proportion of work done at each stage of production. The combination of the workcentre data and the production program information provided the opportunity to consider a more realistic evaluation model (11). The present limits applicable to the major data value input to the three main data files are shown in table 2.

Once data has been inputted the program MS-S1 will carry out a number of data validation checks (twenty-seven checks in number shown in Table 3), create workcentre cells data and maximum cost spanning tree data and will prepare the MS-C1 data file for the later design and simulation processes.

TEST CASES

The main significant criterion in the design of facility layouts is the materials movement cost used in the graph theory spanning tree model. The first series of tests are therefore designed to vary three of the controlling influences on materials movement cost; the fixed cost per journey –PF, the variable cost per journey –PV and the Workcentre cell dominance -WCD. The Workcentre cell dominance is defined by the equation (5)

$$WCD = \frac{\sum_{j=1}^{N} PW_j \times \sum_{j=1}^{} WO_{ij} / WT_{ij}}{M} \qquad (5)$$

Where:

PW_j = PO_J x ($FCOST_j$ + $PROFIT_j$)

PO_j = Full production volume of product j period.

$FCOST_j$ = Fixed cost per unit of product j

$PROFIT_j$ = Profit margin per unit of product j

W_j = The number of workcentres in the manufacturing sequence of product j

N = The number of products

M = The number of workcentre cells to be relocated

WTij = The number of workcentre cell in product j at the sequence position I

= 1 when workcentre cell is to be relocated

= 0 when workcentre cell position is fixed.

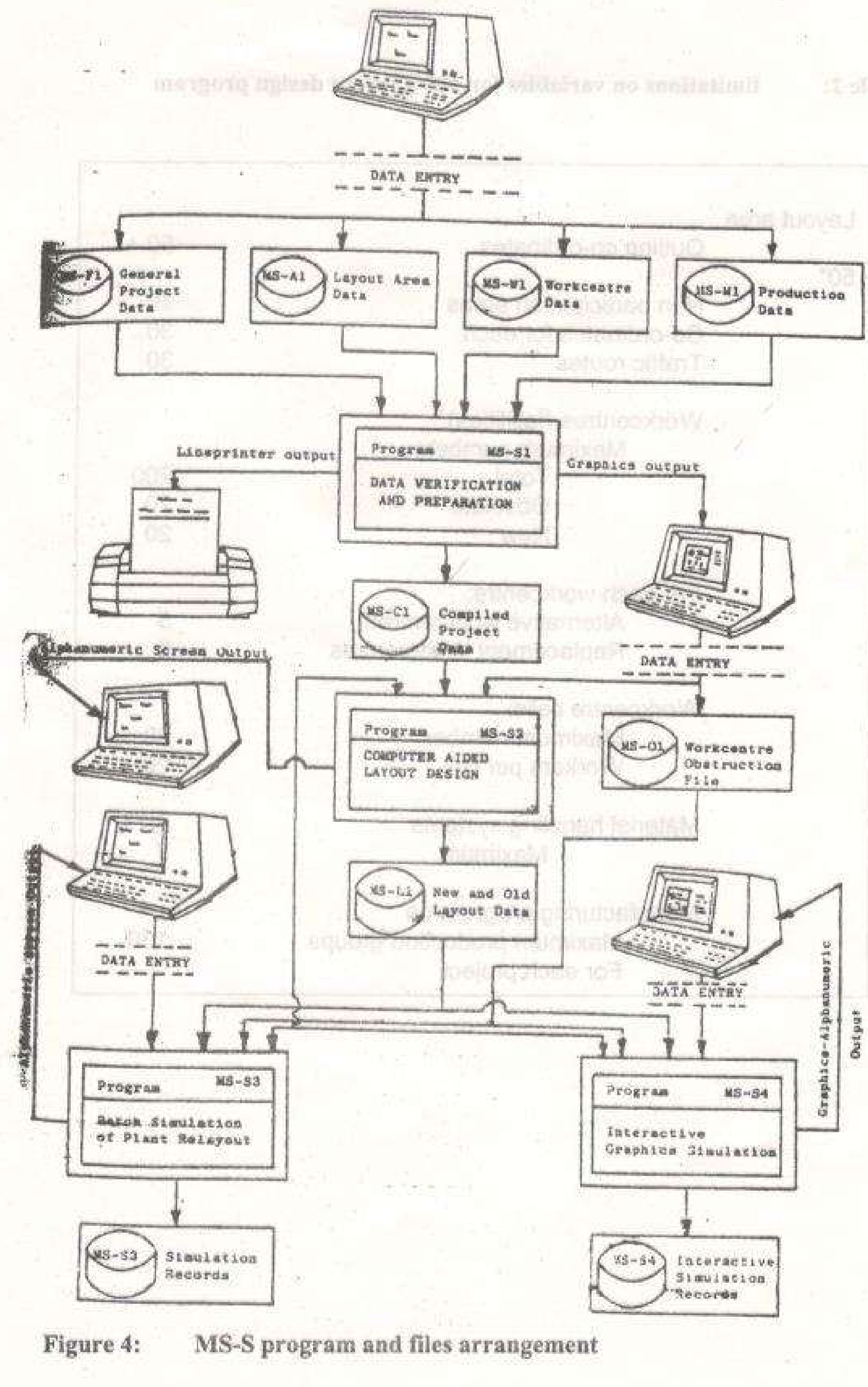

Figure 4: MS-S program and files arrangement

Table 2: limitations on variables for MS-S layout design program

Layout area	
Outline co-ordinates	50 +
50*	
Non participation areas	30
Co-ordinates for each	30
Traffic routes	30
Workcentres (facilities)	
Maximum numbers:	
Total	200
Obsolete	20
New	20
For each workcentre:	
Alternative workcentres	5
Replacement Workcentres	5
Workcentre cells:	
Maximum number	60
Workers per cell	20
Material handling systems	
Maximum	7
Manufacturing programme	
Maximum production groups	100
For each project	

Table 3: Data Check List

1.	Number of routine points in range 3 to 50
2.	Number of non-participation areas less than 50
3.	Number of traffic routes less than 30
4.	Non-outline-non-participation area violation
5.	No violation of non-participation areas
6.	Initial area point on extreme left
7.	Each traffic point has a minimum of two traffic points
8.	Co-ordinates of each traffic point the same
9.	Traffic system continuous and sequentially numbered
10.	Number of workcentre less than 200
11.	Workcentre type is 1 or 2 and correct data
12.	Workcentre orientation less than 90 degree
13.	Workcentre in the range 1 to 60 and minimum 1 fixed one
14.	Workcentre is dummy, candidate for relocation, new or obsolete
15.	Workcentre inside modified outline
16.	Workcentres outside modified non-participation area
17.	Workcentres outside traffic routes
18.	New workcentres not more than 20
19.	Obsolete workcentres to be phased out not more than 20
20.	Sum of new workcentres is equal to input value
21.	Sum of obsolete workcentres is equal to input value
22.	Number of products in the range 1to 100
23.	Product quantity and batch size greater than zero
24.	At least two workcentres in workcentre sequence
25.	No zero workcentre entry
26.	Spanning tree contains required number of edges
27.	All vertices included in spanning tree

TABLE 5: LAYOUT DESIGN TEST SERIES

A1. Variation of PF **PV = 0.1**

$$PF = PV*D_{av}\%$$

	PF					
	1	2	3	4	5	6
PROBLEM	0%	25	50	100	200	400
L1	1	4	7	10	13	16
L2	2	5	8	11	14	17
L3	3	6	9	12	15	18

A2. Variation of PV **PV = 0.0**

	PV					
	1	2	3	4	5	6
PROBLEM	0.0	0.1	0.2	0.3	1.0	2.0
L1	19	22	25	28	31	34
L2	20	23	26	29	32	35
L3	21	24	27	30	33	36

A3. Workcentre Cell Dominance Variation (WCD)

PROBLEM 1.1

TEST	*QUANTITY*					*WCD*
Cell number 27	6	7	8	9	10	1.0
38	1	1	1	1	1	2.0
39	8	3	3	3	3	3.0
40	6	1	1	1	1	4.0
41	16	11	1	1	1	5.0
42	100	1	1	1	1	5.0
43	1	100	1	1	1	5.0
44	1	1	100	1	1	5.0
45	1	1	1	100	1	5.0

In other to vary relationship between PF and PV it is necessary first to calculate the average distance moved (D_{av}) between workcentres in the production programme

$$D_{av} = \sum_{I=1}^{18} X \sum_{j=1}^{NPS} D_{ij} / N \qquad (6)$$

Where:

D_{av}	=	Average distance covered
18	=	Number of products
NPS	=	Number of production stages in the production sequence of each product
D_{ij}	=	Distance between work-centres I and j
N	=	Number of Workcentres in the production programme

Three test case layouts having the parameters shown in Table 4 are used to test this research work. In all 45 tests were carried out at this stage. Having calculated the average journey using rectangular co-ordinate movement as 15.2, 30.0 metres respectively for layouts L!, L2, and L3, the average variable cost can be calculated. Using a constant PV value of 0.1 for each test the average variable cost component of each layout is 273.60, 545.40 and 414.00 respectively for layouts L1 to L3.

A series of tests were then ran setting the fixed cost per journey as a percentage of the average variable cost i.e. 0, 25, 100, 200, and 400 of variable cost for each of the layouts and consequences examined are shown in Table 5.

The results for all three layouts showed an identical spanning tree order through each test. The explanation for this requires an understanding of how the materials handling model operates. Consider the first test on each layout, where PF = O and therefore generate the order of cells. As PF is increased the key factor is that the number of journeys to each cell is balanced in the manufacturing programme and therefore PF is simply adding the same constant value to each cell movement cost. Consequently the same cell order is maintained. The conclusion can be drawn therefore that in order for variation of PF to be significant the number of journeys by each must vary i.e. cell dominance has to exist.

VARIATION OF PV

The second set of validation tests on layout design software consisted or reducing the influence of fixed cost per journey to zero and scaling the variable cost per unit distance moved over a geometric progression value 0.0, 0.1, 0.2, 0.5, 1.0, and 2.0. The results are shown in Table 6. When the fixed and variable costs are zero there will be no movement cost and

TABLE 6: WORKCENTRE CELLS RELOCATION ORDER FOR PROBLEMS L1 TO L3

A1. Variation of PF

D_{av}= 15.2 for problem 1.1

No.	TESTS 1	4	7	10	13	16
PF	0.0	0.38	0.76	1.52	3.04	6.08
1	1	1	1	1	1	1
2	9	9	9	9	9	9
3	2	2	2	2	2	2
4	5	5	5	5	5	5
5	7	7	7	7	7	7
6	4	4	4	4	4	4
7	6	6	6	6	6	6
8	8	8	8	8	8	8
9	10	10	10	10	10	10
10	3	3	3	3	3	3

D_{av}= 30.3 for problem 1.2

No.	TESTS 2	5	8	11	14	17
PF	0.0	0.76	1.52	30.04	6.08	12.16
1	3	3	3	3	3	
2	12	12	12	12	12	12
3	2	2	2	2	2	2
4	4	4	4	4	4	4
5	2	2	2	2	2	2
6	8	8	8	8	8	8
7	7	7	7	7	7	7
8	6	6	6	6	6	6
9	10	10	10	10	10	10
10	11	11	11	11	11	11
11	5	5	5	5	5	5
12	9	9	9	9	9	9

D_{av}=23.0 for problem 1.3

No.	TESTS 1	4	7	10	13	16
PF	0.0	0.38	0.76	1.52	3.04	6.08
1	5	5	5	5	5	5
2	7	7	7	7	7	7
3	12	12	12	12	12	12
4	15	15	15	15	15	15
5	14	14	14	14	141	14
6	1	1	1	1	1	1
7	8	8	8	8	8	8
8	4	4	47	4	4	4
9	13	13	13	13	13	13
10	11	11	11	11	11	11
11	10	10	10	10	10	10
12	3	3	3	3	3	3
13	6	6	6	6	6	6
14	9	9	9	9	9	9
15	2	2	2	2	2	2

therefore no spanning tree cell order across each test series on each problem. This confirms the consistency of the spanning tree models as well as providing software test cases as shown in Table 7.

Variation Cell Dominance (WCD)

The dominance of a particular workcenter cell in production programme will seriously affect the order of relocations of workcenter cells determined from the maximum spanning tree; hence it has a direct effect on the generation of spanning tree. The cell dominance tests were carried out on only one layout, layout L1, and the value of cell dominance were generated by manipulation of the manufacturing programme. With five main cells (excluding five dummy input output cells) a ten product manufacturing programme was generated. By showing two products per cell and introducing equal manufacturing sequences then cell dominance can be said to be a function of the number of loads per product.

With this fixing of number of products and the length of each product sequence the WCD equation simplifies to:

$$WCD = \frac{Q_{\max}}{\sum_{i=1}^{n} Q_j / n} \qquad (7)$$

Where:

WCD = Workcentre Cell Dominant Ratio

Q_{max} = The maximum quantity in the production programme

Q_j = The quantity of materials through workcentre cell j

N = Number of Workcentre cells in the production programme

In the WCD test series dominance was varied from 1.0 to 5.0 (actual 4.8) and the 5.0 dominance was moved from cell, producing the results shown in Table 8.

Variation of workcentre cell dominance

The results again show the strong ordering characteristics of maximum spanning tree for a s the dominance of cell 6 was increased it remained the first cell in the selection order and as significant dominance was rotated through cell 6 to 10 the order of cell selection varied in direct response.

COMMENTS AND CONCLUSIONS

- The facilities relocation problem is ill-structured and required the consideration of both subjective and qualitative factors.
- Two main factors used in layout evaluation are closeness

A2. Variation of PV PF = 0.0

Problem L1

TABLE 7: WORKCENTRE CELLS RELOCATION ORDER FOR PROBLEMS L1 TO L3

No. PV	TESTS 19	22	25	28	31	34
	0.0	0.1	0.1	0.5	1.0	2.0
1	NO SPANNING TREE	1	1	1	1	1
2		9	9	9	9	9
3		2	2	2	2	2
4		5	5	5	5	5
5		7	7	7	7	7
6		6	6	6	6	6
7		4	4	4	4	4
8		8	8	8	8	8
9		10	10	10	10	10
10		3	3	3	3	3

Problem 1.2

No. PF	TESTS 20	22	26	29	32	35
	0.0	0.1	0.2	0.5	1.0	2.0
1	NO SPANNING TREE	3	3	3	3	3
2		12	12	12	12	12
3		1	1	1	1	1
4		4	4	4	4	4
5		2	2	2	2	2
6		8	8	8	8	8
7		7	7	7	7	7
8		6	6	66	6	6
9		10	10	10	10	10
10		11	11	11	11	11
11		5	5	5	5	5
12		9	9	9	9	9

Problem 1.3

No. PF	TESTS 21	24	27	30	33	36
	0.0	0.1	0.2	0.5	1.0	2.0
1	NO SPANNING TREE	5	5	5	5	5
2		7	7	7	7	7
3		12	12	12	12	12
4		15	15	15	15	15
5		14	14	14	14	14
6		1	1	1	1	1
7		8	8	8	8	8
8		4	4	4	4	4
9		13	13	13	13	13
10		11	11	11	11	11
11		10	10	10	10	10
12		3	3	3	3	3
13		6	6	6	6	6
14		9	9	9	9	9
15		2	2	2	2	2

Table 8: Workcentre cell relocation order for problem L1

Test	Cell Order				WCD	
37	6	10	7	8	9	1.0
38	6	10	7	8	9	2.0
39	6	10	7	8	9	3.0
40	6	10	7	8	9	4.0
41	6	10	7	8	9	5.0
42	7	10	6	8	9	5.0
43	8	10	7	6	9	5.0
44	9	10	7	6	7	5.0
45	10	7	6	8	9	5.0

desirability and materials movement cost

- Materials movement cost is quantitative and is more realistic
- A realistic measurement of distance covered by materials in manufacturing industries is very important.
- Introduction of traffic system in the analysis makes the work a worthwhile venture.
- There are four possible methods of measuring the distance between two workcentres where a traffic system exists.
- The materials movement cost consists of two components - the distance dependent part called the variable cost and the distant dependent cost called the fixed cost.
- The introduced traffic system caters for conventional, AGV's and FMS system.
- The limitations and data checks on test cases are reasonable and realistic.
- The controlling influences on materials movement cost are fixed cost per journey, the variable cost per journey and workcentre cell dominance.
- The test cases confirmed the influence of the controlling factors on the materials movement cost.

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