DEVELOPMENT OF MACHINE LAYOUT ALGORITHM AND ITS PARAMETRIC ANALYSIS

S.K.Deb*, B.Bhattacharyya, S.K.Sorkhel
Producton Engineering Department
Jadavpur University.
Calcutta-32.
West Bengal, India.

Abstract Most of the facility layout model and algorithm found in the literature are meant for general facilities layout planning (FLP). In this paper, a hybrid construction algorithm for facility layout under manufacturing environment is developed. The model considers many practical possibilities such as loading/unloading, machine dimensions, orientations and configurations along with the different quantifiable and non-quantifiable links between machines. The selection order of machines is made using a knowledge base and the placement of the machines in open continual plane is made using an optimization approach which searches several candidate points along the periphery of the existing block to locate the best placement of the new facilities to minimize the material flow cost (FC), minimum required area of layout (MRAL) and dead space (DS). Several alternatives are generated by varying the weights of objective function and number of candidate points on the machine periphery. Alternatives are ranked to select a set of efficient alternatives according to decision maker's preference. The suggested procedure is coded in C language and implemented in a personal computer. The experimental results with test problems is illustrated with encouraging results.

Key words: Facility Layout , Flow cost, Minimum required area of layout, Dead space.

INTRODUCTION

Faclity layout deals with the selection of the most effective arrangements of physical facilities in a production plant to allow greater efficiency and productivity. Plant layout problems are now faced by manufacturing industry more frequently due to a change from mass production towards more flexible batch production. The objectives that are considered in determining the layout [Tomkins and White,1974] [Francis and White, 1992] are minimizing the material handling cost , minimizing the overall production time, minimizing the investment of equiptments and effective utilization of space, emplyee safety, flexibility for arrangement and operations etc. An efficient layout generally involves competitive edge through reduction of material handling costs and efficient utilization of space, Owing to the complex and unstructured nature of facility layout, many researchers have proposed various approaches which have not been very successful to deal with the practical issues of manufacturing system. Manufacturing facility layout has gained less attention compare to general facility layout problems. The facility layout problem has been modeled in several ways e.g. quadratic assignment problem, a linear integer programming problem, a non-linear programming problem, and graph theoretic problem [Heragu and Kusiak,1990]. Several computerized heuristic algorithms have been developed and these algorithms deal with two basic jobs: 'construction' of new layouts and 'improvement ' of existing layouts. Some of the well known computerized layout planning routines that have been reported in he literature are the computerized relative allocation of facilities techniques (CRAFT) (Buffa et al. 1964), the computerized relationship layout planning (CORELAP) (Lee and More 1967), the automated layout design program (ALDEP) (Seehaf and Evans 1967), the plant layout analysis and evaluation technique (PLANET) (Apple and Deisenroth 1972), the computerized facilities design (COFAD) (Tomkin and Reed 1976). O'Brien and Barr (1980) considered distinct pickup and drop-off points of machines in their proposed interactive improvement type faclity layout. Ligget (1981) has proposed in their report that a combination of analytical and knowledge base procedure would provide a better layout. Kumara et al. (1988) has presented an expert system for facility layout, Joshi and sadananda (1989) presented a analytical and knowledge base approach for developing layout. More recently, Al-Hakim (1991) presented graph theory based improvement type heuristic methods .Banerjee et al. (1992) presented a reasoning based interactive facilities design method to improve the layout. Heragu and kusiak (1990) contains specific

E-mail: *debskd2000@rediffmail.com

information that solution of machine layout formulation is computationally inefficient. All the categories above have strength and weaknesses of the analytical systems, improvement algorithm needs a starting solution, while a construction algorithm starts without any initial solutions. Moreover most of the earlier approaches are based on the quadratic assignment formulation, which divides the space into a rectangular grid where each cell is assigned to a facility. This has resulted in irregular shapes for the facilities. In general it is reported in the literature that a hybrid system performs better than individual system. The better fundamental techniques whether construction or improvement would result in an efficient hybrid system to cover the practical issues of facility layout [Deb et al, 2001]. Therefore, continued research on developing better construction and improvement methods for facility layout is highly important in order to achieve the desired level of manufacturing productivity and profitability.

PROBLEM FORMULATION

The generation of model for layout construction is a critical step because of its unstructured and vast nature. Most of the earlier approaches used the concept of area under rectangular grid system and distance covered from center to center of the blocks. As a result the usability and practicability of these approaches has been limited to general facilities layout planning. The methods could not address the development of machine layout which are characterized by dimension of length and width, input and output points and orientation of machines for making loading and unloading closer in aisle.

Need statement: The present paper states to develop a construction model and algorithm for facility layout which can be used under general as well as manufacturing environment with the following assumptions and constraints,

(I) the size of the block should be compatible with length and width of a machine. A block is represented by using the corner points of it's diagonal.

(II) input and output points of a block should have the same relative positioning as the machine which the block represents and it may be designed along the perimeter of the four sides of the block as shown in Figure number 1.

(III) The configuration of a block is defined as the style in which it is placed at the candidate points. It can be placed horizontally or vertically in three or more different ways as shown in Figure number 2.

(IV) The blocks should not overlap with each other. The non-overlapping condition for blocks B[i] and B[j]

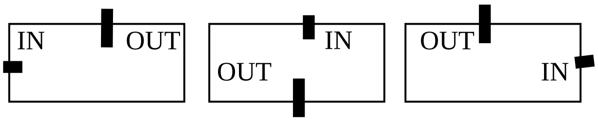

Fig. 1 Different input/output points of block with respect to configuration

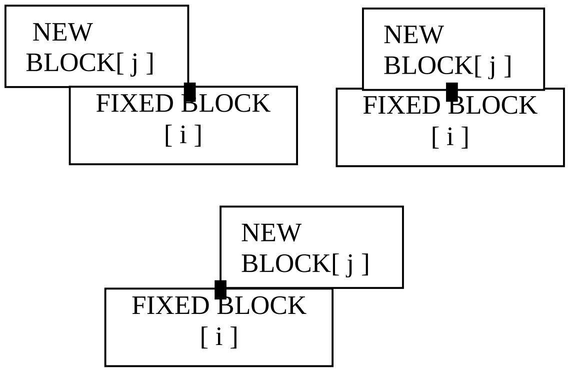

Fig. 2 Horizontal configurations of new block placement to a fixed block.

as shown in Figure number 3

either $(x_{jt} - x_{ib}) \times (x_{jb} - x_{it}) \geq 0$

or $(y_{jt} - y_{ib}) \times (y_{jb} - y_{it}) \geq 0$

where (x_{jt}, y_{jt}) and (x_{jb}, y_{jb}) top right and bottom left corner point of the jth block.

(V) The candidate points C (X_c , Y_c) for placement of new blocks should be on the boundary of the already fixed block and it's feasible quarter for new block placement should satisfy the expressions given in figure number 4 . A candidate point is expressed in terms of corner points and dimensions of blocks.There

either $(x_c - x_{it}) \times (x_c - x_{ib}) \geq 0$

or $(y_c - y_{it}) \times (y_c - y_{ib}) \geq 0$

where (x_{it}, y_{it}) the top left *and* (x_{ib}, y_{ib}) bottom right corner point of the ith block.

may be any number of candidate points on a selected block.

(VI) Dead space is defined as the difference of minimum required area of layout and total area of blocks i.e. DS=(Max $\{x_b\}$-Min $\{x_t\}$)*(Max$\{y_b\}$-Min$\{y_t\}$)-∑L*W.

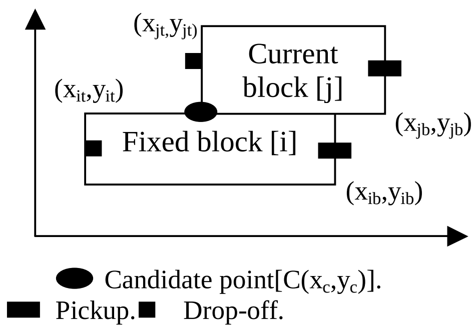

Fig. 3 Fixed and current block with P/D point.

Objective function

The objective of the procedure is to determine the location of blocks , their configurations and orientations of input and output points such that the total flow cost and dead space is minimized. Since the procedure selects and locate blocks sequentially, the objective has to be revised so that its configuration and orientation of the selected block can find the best location byminimizing flow cost and dead space of a bicriteron objective function. The objective function associated with placing of current block B[j] with respect to a set of already placed blocks B[i] is given in Appendix 1.

DEVELOPMENT PROCEDUR

The procedure determines the optimum location of facilities depending on a placement order. The procedure needs the computations of decision variables like coordinates of the diagonal , input and output points of the blocks. The procedure consists of mainly two steps as follows.

Selection procedure

In this step the sequence at which the facilities are to be placed is calculated fron the flow matrix and other qualitative parameters dictating the importances of adjacency. The first facility to be selected for placement is the one which has the maxium value of flow or interactions with he other departments.If the flow matrix is unsymetrical i.e. two way flow

The first facility to be selected for placement will be the facility K for which value of flow is maximum. Next facility to be selected is the one which has the maximum flow value with the facility already selected and the procss is repeated for all other facilities to include them in the sequencial placement.order.It is similar to PLANET (Apple and Deisenroth, 1972), COFAD(Tomkin and Reed, 1976).

PLACEMENT PROCEDURE

The first block is placed at the center of a plane continum horizontally (may be vertically). The method for the placement of next blocks is to evaluate the value of objective function at each candidate point on the already placed block for two configurations, two rotations and three styles i.e. twelve possible ways as referred in figure number 2. Searching is carried out through all candidate points on the four edges of the block for that particular combination of candidate ,configuration, orientation and style for which objective function value is minimum and the block is placed. The process is repeated for the remaining facilities.

Generalised representaton of rotation

The new block to be placed is given rotation to have several combinations of input and output points and the rotation for which the value of the objective function is minimum is preserved. The coordinates of any point on four edges of a block is generalised with respect to the

For horizontal position

$X_i = x_{it} + x_i$

$Y_i = y_{it} + y_i$

For vertical position

$X_i = x_{it} + w_i - y_i$

$Y_i = y_{it} + x_i$

For horizontal 180 rotation

$X_i = x_{it} + l_i - x_i$

$Y_i = y_{it} + w_i - y_i$

For vertical 180 rotation

$X_i = x_{it} + y_i$

$Y_i = y_{it} + l_i - x_i$

where

x_{it} and y_{it} are top left corner points of the ith block

l_i and w_i are length and width of the machine block,

x_i, y_i are the coordinates of any input or output point.

point with respect to top left corner point of ith block.

top left corner point of the block and it is tabulated below.The coordinates of any point on four edges of a block is generalised with respect to the top left corner point of the block and it is tabulated below.

STEPS OF ALGORITHM

Step 1.Find the selection order as discussed in section 3.
Step 2.Locate the first block at the center horizontally.
Step 3.Select the next block for placement according to placement order.
Step 4.Select the candidate point and check the feasible quarter. If not feasible go to step 7, else go to next step.
Step5.Locate the block according to placement possibilities and check for non-overlapping. If not satisfied repeat next possible placement as explained in Section 3., else go to step 6.
Step 6.Calculate the value of objective function ,if it is better than previous update Configuration and objective function value. Go to step 5 for next searching other possibilities at the candidate point.
Step 7.Select next candidate point If all candidate points of the selected block are considered, go to step 8, otherwise go to step 4.
Step 8.Select the next block. If all blocks are selected go to step 9 else go to 3.
Step 9 Locate the block which provide the best value of objective function and update the value of decision

variables like x_t, y_t, x_b, y_b, and find the final value of flow cost and dead space.

GENERATING ALTERNATIVES AND RANKING

Malakooti (1989) analysed the use of weighting method to handle multiple objectives in the facility layout. Therefore, several alternatives layout can be genarated by varying the weightage of flow cost and dead space in the objective function. The multiobjective evaluations of alternatives, with or without incorporating the decision maker's preferrence is done by transforming the scores of alternatives according to how the scores turn out for the whole set of alternatives. Each objective value of the alternatives are transformed into Z-score and N-score. The value score for the alternatives can be expressed as weighted average ;

$$S_{ij} = (s_{ij} - \mu_j) / \delta_j$$

$$Z_i = \sum_{j=1}^{n} w_{ij} \times S_{ij}$$

$$\forall \quad i = 1, 2, ...m.$$

$$nS_{ij} = (s_{ij} - \min\{s_{ij}\}) / (\max\{s_{ij}\} - \min\{s_{ij}\})$$

$$N_i = \sum_{j=1}^{n} w_{ij} \times nS_{ij} \qquad \forall \quad i = 1, 2...m$$

where

s_{ij} = score of alternative i for criteria j;

μ_j = mean ; δ_j = standadr deviation;

S_{ij} and nS_{ij} are standardized and normalized score of alternative .

Z_i and N_i are $Z-$ value and $N-$ value of the ith alternative .

APPLICATION OF METHODOLOGY

The algorithm was coded in Turbo C language and the problem was run on IBM Pentium III, 550 MHz machine. The relavent data of machine dimension and flow matrix are taken from literature and presented in table 5 and table 6 respectively. Several experimentation was carried out in broad spectrum to explore the impact of design parametric change on the proposed methology. The experimentation of earlier researchers was limited for four candidates points at the centre of eah edge of the block and discrete pickup and dropoff points. To analyse the influence of candidate points on flow cost, dead space and minimum required area of layout five different sets of candidate points are considered that are given as follows

- A=C1M :One candidate point at the moddle of each edge.
- B=C1C: One candidate point at each corner of the block.
- C=C2C: Two candidate points at the extreme end of each edge.
- D=C2C/C1M: Combination of (1) and (3) i.e 12 candidate points.
- E=C2C/C3M: Two candidate points at the end along with three intermediate points at each edge i.e. 20 candidate points.

Table 1. List of alternatives for W_1=1.0, W_2=0

Alt. No	Candidate Number	Flow cost	Dead space	MRAL	Ranking	
					Z	N
1	A	6059	1856	3325	3	3
2	B	6170	2661	4130	2	2
3	C	6124	2056	3525	4	4
4	D*	5820	1751	3220	1	1
5	E	6088	1751	3220	2	2

Table 2. List of alternatives for W_1=0, W_2=1.0

Alt. No	Candidate Number	Flow cost	Dead space	MRAL	Ranking	
					Z	N
1	A	11154	556	2055	4	4
2	B	11890	371	1840	5	5
3	C	11214	371	1840	2	2
4	D*	11214	371	1640	1	1
5	E*	11193	371	1640	1	1

Table 3. List of alternatives for W_1=0.3, W_2=0.7

Alt. No	Candidate Number	Flow cost	Dead space	MRAL	Ranking	
					Z	N
1	A	6901	407	1876	4	5
2	B	7298	253	1722	3	2
3	C	6428	531	2000	2	3
4	D	6428	531	2000	2	4
5	E*	6730	281	1750	1	1

* Best alternative of the set obtained by varying weight.

Table 4. Values of flow cost and dead space obtained by varying weightage and candidate points.

Weightage		C1M		C!C		C2C		C2C/C1M		C2C/C3M	
W1	W2	FC	DS	FC	DS	FC	DS	FC	DS	FC	DS
0.9	0.1	5841	2206	6021	2171	6044	2056	6195	2171	6023	1716
0,8	0.2	5823	1122	5809	2051	6044	1681	6044	1681	6016	1681
0.7	0.3	6065	1751	6065	1331	6044	1681	6070	1571	6016	1681
0.6	0.4	6263	1821	6065	1331	6611	720	6650	1183	6628	1183
0.5	0.5	6351	1401	6501	871	6819	907	7225	481	7225	481
0.4	0.6	6812	502	6802	949	6427	531	7847	208	7830	208
0.3	0.7	6901	407	7298	253	6423	531	6417	531	6729	281

These five set of candidate points are used to develop facility layout under three separate objective functions(1) Minimization of flow cost(i.e. W_1=1), (2) Minimization of dead space(i.e. W_2=1) and(3) Minimization of flow cost as well as dead space(i.e.W_1=0.3, W_2=0.7) The values of the flow cost and dead space for the three cases are shown in table 1, table 2 and table 3 respectively. Experimentation was further carried out to develop several alternatives by varying the weight of bi-croterion objective function under five set of candidate points to analyze the variation of weight parameter on flow cost and dead space. Table 4 shows the values of flow cost and dead space under different set of candidate points and weights. The average and standard deviation of the values of each set of candidate points are represented in the corrosponding column.To overcome the difficulty of selecting a superior layout from the various alternatives, a Z-ranking and N-ranking method is followed under the consideration of flow cost and dead space and these are presented in end column of Table1, table2 and table3. The efficient layouts obtained from the present design parametric analysis are shown in table 6 and layouts are shown in figure 4 and figure 5 for efficient alternative 1 and 4.

DISSCUSSION AND CONCLUSION

It is very difficult to analyze the better layout from the experimental table because of the conflicting nature of evaluating parameters i.e. flow cost and dead space are inverse in nature. The results of table 1 is based on the minimization of flow cost. The inherent characteristics of developing a layout under open field system is the generation of dead space. The value of flow cost (5820) is minimum for candidate set D and the value of dead space is minimum for candidate set D as well as E. The best layout under this category is obtained under candidate set D that gives both flow cost and dead space minimum. Table 2 shows the results based on minimization of dead space for several candidate set. The flow cost is minimum for candidate set C and D. but the dead space is minimum for the candidate set except A. Thus the best layout can be considered either D or E. The results of bi-criterion objective function(table 3) reveals that flow cost is minimum at candidate set C and D. But the dead space is minimum for candidate set B. Thus, it is very difficult to evaluate better layout under such conflicting multi-parameters.

Table 5. Data table for machine configuration.

M	M 1	M 2	M3	M 4	M 5	M6
L	60	30	120	48	72	54
W	30	30	30	36	24	36
P	0,15	0,15	60,0	24,0	0,12	27,0
D	60,15	30,15	60,30	24,0	36,0	0,18

Table 5. Flow matrix of the problem.

M	M 1	M 2	M3	M 4	M 5	M6
1	0	1	2	1	2	3
2	5	0	1	2	1	2
3	2	3	0	3	2	1
4	4	0	0	0	1	2
5	1	2	0	5	0	1
6	0	2	0	2	10	0

Table 6. Efficient layouts and design parameters.
(Selection Order: 5-6-4-1-2-3)

Alt No.	Optimum design parameters	Flow cost	MRAL
1	D: C2C/C1M(w1=1, w2=0)	5820	3220
2	D: C2C/C1M(w1=0, w2=1)	11214	1640
3	E:C2C/C3M(w1=0,w2=1)	11193	1640
4	E:C2C/C3M(w1=.3,w2=.7)	6730	1750

To determine the efficient layout under such condition a multi-criteria evaluation technique is adopted to rank the alternatives. By applying Z-ranking method, the best layout is obtained for candidate set E. Thus it is observed that the best layout is obtained either at D or E of candidate set that signifies that the development of layout would be better as the number of candidate points incrases having combination of both corner and middle points of the edges of the blocks already fixed. The results of table 4 shows that the average and standard deviation of flow cost is minimum for candidate set E. The average value of dead space is minimum for E but the standard deviation value is minimum at candidate set C(626.73). The value of SD for candidate set E is very near to that of C. Thus it can be concluded that the deviation of results for varying the weights is minimum for tha candidate set E signifying the best set of candidate point combinations for developing an efficient layout under bi-criterion objective function.

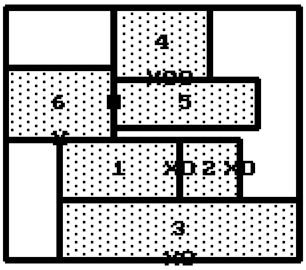

Fig. 4 C graphics of Layout for alternative 1.
D: C2C/C1M, w1=1, w2=0, FC=5820, MRAL=3220

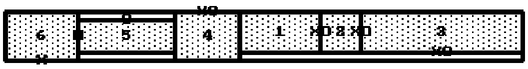

Fig. 5 C graphics of Layout for alternative 4.
E:C2C/C3M, w1=.3,w2=.7, FC=6730,MRAL=1750
X=Pickup , O=Drop off , XO=P/D at the same point.

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APPENDIX 1

*Minimization of flow cost

$$\text{Minimize } Z_j^1 = (f_{ij}(|x_j^p - x_j^d| + |y_j^p - y_j^d|) + f_{ji}(|x_j^p - x_j^d| + |y_j^p - y_j^d|)) \quad \forall \quad j = 2,3,.......n.$$

*Minimization of dead space

$$\text{Minimize } Z_j^2 = (x_b^i - x_t^i) \times (y_b^i - y_t^i) - \sum_{i=1}^{j} l_i \times b_i \quad \forall \quad j = 2,3,....... n.$$

*Minimization of minimum required area of layout

$$\text{Minimize } Z_j^3 = (x_b^i - x_t^i) \times (y_b^i - y_t^i)$$

$$\text{where } x_b^i = \text{Max}\{x_{bi}\} \quad \forall \quad i = 1,2,........n.$$

$$x_t^i = \text{Max}\{x_{ti}\} \quad \forall \quad i = 1,2,........n.$$

$$y_b^i = \text{Max}\{y_{bi}\} \quad \forall \quad i = 1,2,........n.$$

$$y_t^i = \text{Max}\{y_{ti}\} \quad \forall \quad i = 1,2,........n.$$

*Minimization of flowcost, MRAL and deadspace

$$\text{Minimize } Z_j = W_1 \times Z_j^1 + W_2 \times Z_j^2 + W_3 \times Z_j^3$$

Where

W_1 , W_2 and W_3 are weights of flowcost (FC), deadspace (DS) and minimum required area of layout (MRAL).

(x_i^p, y_i^p) is the pickup coordinate of ith m/c.

(x_i^d, y_i^d) is the dropoff coordinate of ith m/c.