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FACILITY LAYOUT AND MATERIAL HANDLING SYSTEM DESIGN USING HYBRID METHODOLOGY

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Abstract Efficient facility layout design greatly improves the competitive and productive edge through reduction of material handling cost. The usual approach adopted to solve facility layout design problem without considering the material handling aspects has failed to provide an efficient manufacturing environment. Few works has been carried out to integrate the material handling equipment selection with the facility layout design. This paper proposes two distinct methodologies for integrating the determination of materials handling system and facility layout under heavy manufacturing system using knowledge-based and optimization approach. The knowledge base consists of facts and rules that determine the feasibility of using particular materials handling equipment for a given move. The optimization model considers minimization of material flow cost for developing the machine layout. Many practical aspects are considered to make a cost effective system. The application of the proposed methodology is illustrated with test problem involving 6 machines, 30 moves and 12 material handling equipments. The results obtained under two different methodologies are presented with encouraging results.

Keywords: Facility layout, Material handling system, Optimization and Knowledge-based.

INTRODUCTION

An efficient material handling system to transport materials between processing centers greatly improves the competitiveness of a product through a reduction of material handling cost. It is reported that materials handling accounts for 30% to 55% of the cost of a product [Apple, 1977]. Facility layout deals with the arrangements of different physical items that exist in a manufacturing environment in order to achieve maximum profitability and productivity. The selection of material handling equipment (MHE) is directly related to the design of facility layout. The determination of material handling system (MHS) involves both the selection of material handling equipments and the assignment of moves to each individual item of material handling equipment. Traditionally, the experts who analyze few alternatives based on their knowledge and experience have solved this selection problem [Gabbert and Brown, 1990]. Selection of accurate material handling system in line with layout requires extensive analysis of the material-handling problem. The selection of MHE is based on guidelines [Apple, 1977] [Apple, 1984]. The cost and quality of the product are directly affected by the facility design. Facility layout is the physical arrangement of production machines and equipment, workstations, people, location of materials of all kinds and stages. Material handling is defined simply as moving of materials (move). The problem of facility layout is to decide the proper position of a collection on a plan. The facility layout problem is not a detached design problem. The relationships can be summarized as shown in figure 1. Muther and Webster have illustrated in their literature that facilities design projects can be achieved by considering the following cases:

- Layout is already fixed and Material handling system is to be selected and
- Material handling system is already fixed and Layout is to be selected.

The usual approach adopted to solve facility layout is to simplify the problem by considering the determinations of the layout and MHS as separate individual problem. Since the determination of the layout and the material handling are interrelated issues, both problems need to be integrated. Very few attempts have been reported in the literature, which consider the selection of material handling equipment as well as development of facility layout. Most of the earlier models of FLP and MHS have not considered the machine configuration, orientation, pickup/drop-off location, actual move length and Material handling cost. This is because the material handling cost depends on the location of facilities and the type of MHE assigned for the move. In flexible manufacturing system situations, knowledge based machine layout is developed, which consider both layout and material

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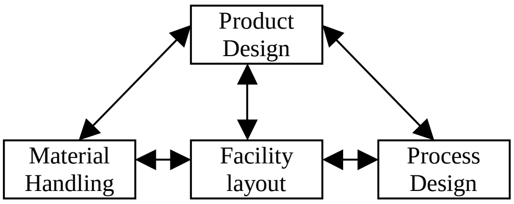

Fig .1 Communication links of facility layout design

handling system [Heragu and Kusiak, 1990]. The procedure requires the user to input either the layout type or material-handling carrier. The integrated expert system approach [Abdou and Dutta, 1990] determines the MHS first to determine the layout. The work presented in this paper is the development of machine layout and selection of optimal set of MHE in order to achieve the minimum material handling cost by using knowledge based and optimization approach. A hybrid model in general works better than the conventional analytical model. Moreover, it is very difficult to express the mathematical formulation of integrated facility layout design problem, which is basically complex and unstructured by nature [Deb et al, 2001]]. Therefore this research paper presents two distinct methodologies for determining layout and material handling system through the development of a hybrid model that takes the advantage of knowledge base and optimization system.

MATERIALS HANDLING SYSTEM MODEL

The material handling system mainly consists of three factors (1) Material, (2) Move and (3) Method. The main objective of material handling equipment selection is the utilization of proper 'method' for 'material' transportation for a particular 'move'. The material handling system selection is based on the concept of minimizing the total material handling cost and aisle space requirements under a manufacturing system. For this purpose two efficient models are required (1) Cost model to estimate cost coefficients and (2) Mathematical model to optimize the objective function in order to place the rectangular block at minimum material handling cost position.

Cost model

The parameters involved in the MHE selection are annual investment cost of equipment, annual operating cost per unit load distance. The investment cost depends on many factors such as variable path, fixed path equipment etc. the example of variable path equipments are mobile crane, tow-tractor, AGV, fork lift etc.

[1]Investment cost for variable path equipment (IC):

$$C_j^I=C_j^1+C_j^2*C_j^L$$

where C_j^I is the investment cost of variable path MHE, C_j^1 is the fixed cost associated with the equipment, C_j^2 is the cost per unit load carrying capacity and C_j^L is the load carrying capacity.

[2]Investment cost for fixed path equipment (IC):

$$C_j^I=C_j^1+C_j^2*C_j^L*S$$

where C_j^2 is variable cost depending on span (S) and load carrying capacity. Examples are bridge crane and gantry crane.

[3]Investment cost of conveyors (IC):

$$C_j^I=C_j^1+C_j^2*W_i*d_i$$

where W_i is the width of unit load associated with move I and d_i is the distance associated with the move i.

The operating cost is linearly proportional to operating time. The operating time is defined as the time for which a MHE is engaged to a move. The operating costs include the cost of electricity; cost of operators, cost of maintenance, cost of spare parts etc. In general, the operating cost is given by

[4]Operating cost (OC)

$$C_j^O=C_j^3*T_{ij}$$

where C_j^3 is the operating cost of MHE [j] per unit operating time, T_{ij} is the operating time of MHE[j] required for move i. In general the operating time is dependent on the speed of the equipment, flow volume and the distance associated with the move. Thus, the operating time can be defined as:

$$T_{ij}=2*d_i*F_i/v_j$$

where d_i is the rectilinear distance, Fi is the flow volume in unit loads and v_j is the sped of the material handling equipment [j]. The loading and unloading times are not considered separately. The speed of the MHE can be adjusted to consider the effect of loading and unloading time. In general, the MHE returns to the source empty after completing a move, hence the multiplication factor 2 is applied in the expression.

[5]Penalty cost (PC)

$$C_j^P=A_j*P_c$$

where A_j is the space requirement for MHE[j]. It is the product of aisle width and distance moved. Most of the MHE needs aisle space except bridge crane.

Material handling cost of move i by MHE [j]

$$MC_{ij}=C_{ij}+C_j^3*U_{ij}*T+P_c*A_j*d_i$$

where C_{ij} is the apportioned annual investment cost of MHE(j), A_j is the aisle width of MHE(j) associated with move i and P_c is the penalty cost coefficient i.e. cost of per unit aisle area.

$$C_{ij}=C_j^I*Uij/t_j^L$$

where $U_{ij}=T_{ij}/T$ is the utilization of MHE [j] by the move i, T is the annual working time available and t_j^L is the lifetime of the MHE [j].

Thus, $C_{ij}=(C_j^I*T_{ij})/(t_j^L*T)$

$$MC_{ij}=(C_j^I*U_{ij})/tj^L+C_j^3*T_{ij}+P_c*A_i*d_i$$

$$=(C_j^I*T_{ij})/(t_j^L*T)+C_j^3*T_{ij}+P_c*A_i*d_i$$

Thus, the available time(T) and the unit penalty cost(P_c) can be considered as a parameter that influence the selection of material handling equipments. In the present research paper, three parameters (1) Available time, (2) Penalty cost and (3) Weights of bi- criterion objective function are varied to obtain number of layouts and material handling system selection.

KNOWLEDGE BASE AND OPTIMIZATION

The facility layout problem by nature is a complex and unstructured system whose mathematical formulation is very critical. The complexity of the problem becomes unmanageable when the size of the problem and number of departments increases. It is very difficult to obtain optimal solution of the FLP that are expressed commonly as quadratic assignment or mixed integer programming problem. The optimization technique involves some part of artificial decision making that are very difficult to express mathematically. A hybrid becomes very effective under such unclear situation. Hybrid modeling could be explained as a system design approach for handling complex and unstructured problem whose mathematical formulation is very critical. It takes the advantage of using two or more different logic and concept to solve the problem conveniently and yet to work mathematically strict and vigorous way. In the present paper, a knowledge-based system and heuristic optimization procedure is adopted for integrating FLP and MHS as shown in Figure 2.

Optimization part

The objective of the procedure is to determine the location of blocks, their configurations and orientations so that the total flow cost and dead space are minimized. Hence, the objective function associated with placing of a current block B_j with respect to a set of already placed blocks B_i ξ S for finding the decision variables is expressed as a bi-criterion objective function. The non-overlapping condition for machine blocks B_i and B_j with top and bottom coordinates (X_{it} ,Y_{it},X_{ib} ,Y_{ib}) and (X_{jt} ,Y_{jt},Xj_b ,Yj_b) are either $(X_{jt}-X_{ib})*(X_{jb}-X_{it})\geq 0$ or $(Y_{jt}-Y_{ib})*(Y_{jb}-Y_{it})\geq 0$ The incoming machine blocks are located at a candidate point for a particular configuration and orientation which give the minimum flow cost and dead space to be generated during development of manufacturing facility design process. The decision variables of the objective function are coordinates of the machine block, pickup/drop-of points. The move is measured between the pickup/drop-off points of the machine blocks. The dimensions of the machine blocks are taken as the length and width of several combinations.Based on the above information the problem of designing the efficient facility layout from a number of moves can be expressed in the following form:

Knowledge base part

The mathematical model presented requires some Boolean values. A knowledge manager having facts and rules logically supports these values for every move. When optimization part is over the corresponding moves are known completely. The data associated with a move are mainly (1) Material and (2) Methods i.e. equipments.

Material (F1, F2, Fi, type, nature, weight, size, move, path, load, others)
Here, F1=Source from, F2=Destination to, Fi=flow volume of move i
The MHE data involves the objective as well as subjective attributes. The cost coefficients are represented objective factors and the safety, life etc are considered as subjective
parameters influencing the MHE selection. The data that associated with a move are written as follows:

Equipment (N_i, Mi, C1, C2, C3, velocity, capacity, life, aisle, maintenance, safety, special features)
Here, N_i=Equipment number, M_i=Name of equipment, C1, C2 and C3 are cost coefficients.
Rules are developed for obtaining a feasible set of MHE, which can be directly selected from the rules. The rules developed are in the form of:

Rule1 If (Mat.Type! =Bulk) and (Mat.Nature!=Sturdy)
and(Path=Horizontal)
Then (Mhe selection) is Roller Conveyor.

Rule 2 If (Mat.Type=Unit) and (Weight=Heavy) and
(Speed! =Uniform)
Then (Mhe selection) is Gantry crane etc.

MATHEMATICAL MODEL

The objective is to select a MHS for which the investment cost, operating cost and penalty cost for using aisle space are minimum. The objective function is supported by the artificial intelligence with the help of a knowledge-based part. Thus, the objective function is defined as

MINIMIZE $\sum$ (IC+OC+PC)

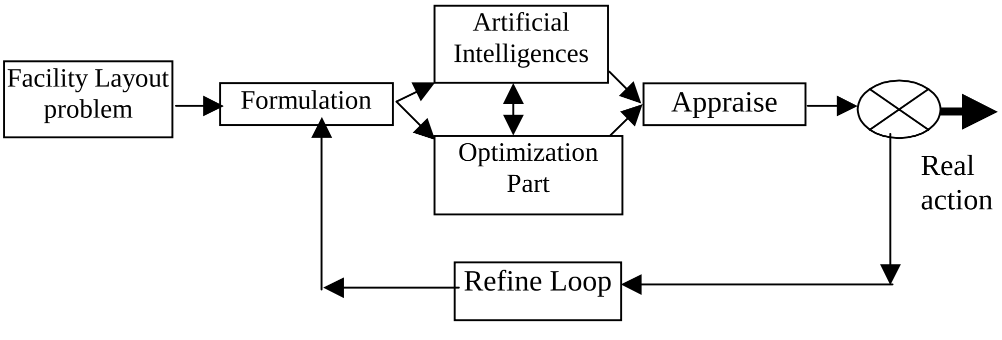

Fig. 2 Design analysis process under hybrid system.

Based on the above discussion the objective function of selecting a material handling equipment can be expressed in the following form

$$Min\ Z = \sum_{j=1}^{n} \left\{ \alpha_j (C_j^I + C_j^O) + \sum_{i=1}^{m} P_c \times b_j \times d_i \times \beta_{ij} \right\}$$

$$subj\ to\ \ \sum_{j=1}^{n} \gamma_{ij} \times \beta_{ij} = 1 \qquad \forall\ i = 1, 2, ...m$$

$$\beta_{ij} \le \alpha_j \qquad \forall\ for\, all\ \ i,\ \ j.$$

$$\sum_{i=1}^{m} T_{ij} \times \beta_{ij} \le \delta_j \times T \qquad \forall\ j = 1, 2, ...n$$

$$\beta_{ij} \le \gamma_{ij} \qquad \forall\ for\ all\ \ i,\ j$$

$$C_j^O = \sum_{i=1}^{m} C_j^3 \times T_{ij} \times \beta_{ij} \qquad \forall\ for\, all\ i,\ j$$

$$\alpha_j = \{0,1\},\ \ \delta_j \ge 0 \qquad \forall\ j = 1, 2, ...n$$

$$\beta_{ij} = \{0,1\} \qquad \forall\ for\, all\ i,\ j$$

$$where\ \gamma_{ij} = \begin{cases} 1 & if\ \ MHE[j] can\, be\, used\ \ for\, move\, i \\ 0 & otherwise \end{cases}$$

$$\alpha_{ij} = \begin{cases} 1 & if\ MHE[j] is\, selected\, in\ feasible\, set \\ 0 & otherwise \end{cases}$$

$$\beta_{ij} = \begin{cases} 1 & if\ move\, i\, is\, assigned\ to\, MHE[j] \\ 0 & otherwise \end{cases}$$

$$\delta_j = Number\, of\ units\, of\ MHE[j]\ required$$

$$b_j = Aisle\, width\, of\ MHE[j]$$

PROCEDURE AND ALGORITHM

The design of machine layout and material handling equipment selection is integrated mainly in three steps (1) The selection of a set of possible material handling equipments for each move using knowledge base, (2) Selection of the feasible material handling equipment associated with the move using material handling cost calculation and (3) Development of layout using the optimization model for getting the best location of the incoming machine blocks by minimizing the value of bi-criterion objective function. The steps of the algorithm for the computer design of layout and MHE selection under two options as discussed in section 1 are given in two sub-sections.

First MHS then layout (case 1)

Step1 Find the selection order of machine block placement.
Step2 Store the move number as per selection order in a list.
Step3 Compute the string of move characteristic in the list.
Step4 Take move number 1 and select a list of possible MHE based on knowledge base.
Step5 Repeat step 4 for all the moves.
Step6 Consider mean operating time, available time and penalty cost coefficient.
Step7 Consider move 1 with first possible MHE and compute the total material handling cost.
Step8 Repeat step 7 for next possible MHE.
Step9 Select the minimum cost MHE for move 1.
Step10 Go to step 7 for next move.
Step11 Update each move with the minimum cost MHE from the set of MHE for each move.
Step12 Place the first block at the center of the open field.
Step13 Place the second block at the first configuration of first candidate point and compute objective function.
Step14 Repeat the same for the next configuration. If Z is less than previous value, update Z with current value.
Step15 If all configurations are considered, repeat step 13 for next candidate point and update Z with min {Z}.
Step16 If all candidate points are chosen, repeat step 13 for next block and update the value of Z, coordinates of the top and bottom of the incoming block.
Step17 Compute total flow cost and penalty cost.

First layout then MHS (Case 2)

Step1 Find the selection order of machine block placement.
Step2 Locate the first block at the center horizontally.
Step3 Select the next block for placement according to placement order.
Step4 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, else step 6.
Step6 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.
Step7 Select next candidate point If all candidate points of the selected block are considered, go to step 8, otherwise go to step 4.
Step8 Select the next block. If all blocks are selected go to step 9 else go to 3.
Step9 Locate the block, which provide the best value of objective function.
Step10 Update the move with finally placed rectilinear distance.
Step11 Initialize the available time, cost of penalty coefficient and span for finding the MHS.
Step12 Consider move number 1 and select a set of possible MHE using knowledge base.
Step13 Calculate the total material handling cost for each set of possible MHE for move 1.
Step14 Select the MHE that has the minimum material handling cost.
Step15 Repeat steps 12 to 14 until all moves are considered and find Min{ TC_{ij} } and store the corresponding MHE for that move.
Step16 Calculate the total material handling cost ($\sum TC_{ij}$) and total penalty cost ($\sum PC_{ij}$).

Step 17 Stop for final material handling selection and cost.

EXPERIMENTATION AND RESULTS

The methodology proposed has been implemented using Turbo C language on a Pentium III, 550 MHz machine. A machine layout problem involving 6 machines and 30 moves having several combinations of length and width, Pickup and drop-off points are considered to demonstrate the applicability of the methodology. The machine dimensions and specifications are shown in table 1. Table 2 shows the list of relevant information of the material handling equipments considered for the present problem. The data associated with 30 moves are represented in table 3. The experimentation was carried out for 5 sets of parametric combinations by changing the values of weights, available time (T) and penalty cost (P_c). The values of material handling cost, penalty cost and minimum required area for layout are presented in table 4 and 5 for case 1 and case 2 respectively. The list of MHE selection and the corresponding moves are shown in table 6 and 7 respectively. The selection of material handling equipments for case 1 depends on some preliminary estimation of the mean time of operation of MHE. As operating cost is linearly dependent on the operating time, the selection of feasible MHE for each move highly depends on the estimation of the average operating time assessed by the designers. In the present research paper the value of average operating time is varied in the range [20,60].

Table 1: Machine dimensions and P/D points

M/a	M 1	M2	M3	M4	M5	M 6
L	60	30	120	48	72	54
W	30	30	30	36	24	36
P	00 15	00 15	60 00	24 00	00 12	27 00
D	60 50	30 15	60 30	24 00	36 00	00 18

Table 2: Material handling equipment data

M_i	C_j^1 Rs $*10^5$	C_j^2 Rs *1o^5	C_j^3 Rs 10^5	V_j M/ hr	C_j^L In T	A_j In M^2	t_j^L Hrs 10^2
F1	1.2	0.25	200	150	2	4	50
F2	2.4	0.15	250	160	4	5	60
B1	4.3	0.11	210	100	6	0	50
B2	5.1	0.15	300	120	8	0	60
G1	5.7	0.30	350	120	6	6	65
G2	6.2	0.25	400	130	8	6	50
A1	1.5	0.13	100	110	2	2	70
A2	2.2	0.14	200	120	3	3	80
IT	1.4	0.08	150	100	1	3	85
TC	2.3	0.12	120	130	2	2	60
TT	2.5	0.26	140	125	2	3	70
RC	1.8	0.16	090	120	2	2	60

EQN=Equipment number, F=Fork lift, B=Bridge crane, C=Gantry crane, A=Automate guided vehicle, IT=Industrial truck, TT=Tow-tractor, TC=Tow-conveyor RC=Roller conveyor, C_j^1=Fixed investment cost Coefficient C_j^2=Variable investment cost coefficient, V_j=Speed), C_j^L=Load carrying capacity, A_j=Aisle width, t_j^L=Lifetime of the equipment

DISCUSSIONS AND CONCLUSIONS

One of the primary problems faced by the facility designer is the selection of accurate material handling equipment in line with the layout. In general this problem has received much less attention from researchers than its counterpart as the layout design problem. The real problem of integrating facility layout and material handling system design is due its vast and complex structure. It is very difficult to express in mathematical programming. Under such circumstances, the proposed methodology has been very effective in designing both

Table 3: Details of move data.

Move (i-j)	M F	MT	MN	LV	DS	PT
1-2	1	B	F	H	120	FX
2-1	5	I	NF	H	147	V
1-3	2	U	S	H	187	V
3-1	2	B	NF	NH	125	V
1-4	1	U	S	NH	121	FX
4-1	4	B	NF	H	315	FX
1-5	2	U	F	H	621	FX
5-1	1	B	F	H	222	FX
1-6	3	I	F	H	314	V
6-1	0	B	NF	H	613	V
2-3	1	B	NF	NH	312	V
3-2	3	B	S	NH	311	FX
2-4	2	B	S	NH	331	FX
4-2	0	B	S	H	411	V
2-5	1	B	S	H	119	V
5-2	2	B	F	H	237	V
2-6	2	B	F	H	113	FX
6-2	2	B	F	H	113	FX
3-4	3	B	NF	H	311	FX
4-3	0	B	NF	H	423	FX
3-5	2	B	S	H	501	V
5-3	0	U	S	H	124	V
3-6	1	U	S	NH	215	V
6-3	0	I	F	H	332	V
4-5	1	I	F	NH	131	FX
5-4	5	I	F	NH	313	FX
4-6	2	B	F	NH	314	FX
6-4	2	B	S	H	423	FX
5-6	1	B	NF	NH	511	V

MN = Material nature, DS = Distance, V= Variable, NF = Not fragile. PT=Path. LV =Level, B =Bulk, F =Fragile, S =Sturdy, FX=Fixed, H=Horizontal, U =uniform, I =individual, NH=Not horizontal

Table 4: Test results of MEC, PC and MRAL for A

Parametric Combination	MC (Rs Lakh)	PC (Rs Lakh)	MRAL
w1=1,P_c=500	19.42	6.43	31806
w1=.5,P_c=500	19.26	5.59	22320
w2=1, P_c=500	19.88	5.63	14580
w1=. 5,P_c=100	19.11	10.59	22320
w1=. 5,P_c=400	18.90	44.78	22320

layout and material handling system, which give equal importance to both. It is observed from the experimental results of table 4 that the values of flow cost (MHC), penalty cost (PC) and MRAL are directly affected with the change of design parameters. The experimental results do not give lower MH cost with the higher weight of the material flow cost in the objective function. Keeping the mean time, available time and penalty cost coefficient same, the MH cost is found to be less in case of W1=W2=0.5 when compared with that of W1=1. The higher value of Penalty cost coefficient does not produce a high penalty cost. It is observed that penalty cost is less in case of test run 1,2 and 3 than its value at test run 4 and 5. One of the interesting observation made from the experimental results that the effect of parametric change on the material handling cost is comparatively less than the other evaluating criteria. Sets of alternatives are generated through different combinations of parameters. The decision maker may select layout on his choice, which will satisfy the desirability of shop floor level. The proposed distinct methodology is simple, although more detailed and more realistic than models exist in previous analytical methods.

Table 5: MHES and moves (type A)

MHE	Moves assigned with the MHE
FL 2	[3-2]
BC 1	[I-2][2-1][1-3][2-3][6-2][4-6]
BC 2	[3-1][4-1][5-1]
GC 2	[5-4]
AGV2	[1-5][1-4][5-2][6-5]
IT	[1-6][2-4][2-5][2-6][3-4][3-6][6-4][5-6]

Table 6. MHEStion and moves (Project B)

MHE	Moves assigned to the MHE
FL 2	[2,1][3,2][4,1][5,1][3,2][3,5]
BC 1	[4,6]
BC 2	[5,6]
GC 1	[2,3]
AGV2	[1,4][1,5][5,2][4,5][6,5] [5,4]
IT	[1,2][1,3][1,6][2,4][2,5][2,6][3,4][4,5][6,4]
RC	[6,2]

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