A Cost-Based Algorithm for Design of Cellular Manufacturing Systems

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This paper describes a cost-based algorithm that deals with the design problems of Cellular Manufacturing Systems (CMS) associated exceptional parts and bottleneck machines. The developed algorithm employes explicitly the main elements of manufacturing costs, such as the fixed machine cost, the production cost, the setup cost, and the material handling cost. The algorithm is based on the minimization of sum of these costs, and considers three alternatives to solve exceptional issues. The first alternative is to try to eliminate the maximum number of intercellular movements from the presently configured manufacturing system by buying and installing extra bottleneck machines into the appropriate cells. The second alternative considers the alternative process plans available and tries to complete the job using the overtime basis in the small machine cells. The third alternative considers the possibility of subcontracting the processing operations of exceptional part(s) to outside vendors to reduce the overall cost for the manufacturing system. The total costs of the three cases are compared and the best alternative for any given problem is identified. In order to illustrate performance of the algorithm developed, a test example is provided.

Key Words: Cellular Manufacturing Systems, Cost-based Algorithm, Manufacturing Cells, Cell Design, Group Technology

Nomenclature

N_m : Number of available machine of type m
C_m : Sum of annual operating cost and depreciation of one machine of type m [$/yr]
D_i : Average annual demand for part i
H_m : Number of hours worked by type of machine m [hrs/day]
O_m : Overtime processing cost for machine m [$/day]
t_{imk} : Processing time for operation k of part i on machine m [min]
R_m : Regular operating cost of machine m [$/day]
S_{fm} : Setup cost for part family f on machine m [$]
S_{imk} : Setup cost for operation k of part i on machine m [$]
W_m : Subcontractor's processing cost for machine m [$/day] (includes processing & setup cost)
D : Number of working days per week [day]
T_i : Intercell handling cost of one unit of part i
X_{mc} : Number of machines of type m and assigned to cell c
P_m : Set of parts to be processed by a machine of type m
E_{imc} : A continuous variable which, if i is assigned to c, will take the value zero, or, if i is assigned to c, will indicate the number of processing hours to be performed by a machine of type m on part i outside of its cell c

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1. Introduction

Group Technology (GT) is a manufacturing concept to achieve higher manufacturing efficiency by identifying similarities of parts based upon their design and manufacturing processes, and grouping them into part families. A major area of GT application is Cellular Manufacturing Systems (CMS) which allow for the multi-product and small-lot-sized production to obtain the mass production effect while retaining the flexibility of the job shop. In cellular manufacturing, the machine-part cell formation problem involving the assignment of parts and machines to manufacturing cells is one of the most important problems to be solved during the design phase.

In the literature, there are two basic methods used for solving the machine-part cell formation problem, which are the classification and coding (CC) system and the clustering methods. Coding systems like OPITZ and MICLASS are used to group parts according to their design attributes, geometric features and machining requirements (Opitz 1972; Houtzeel, 1975), respectively. Clustering methods use the binary machine-part incidence matrix as input, and rearrange rows and columns to minimize the number of exceptional elements, called exceptional parts and bottleneck machines (King, 1980; Khator et al., 1987; Askin et al., 1991). Chadrasekharan et al. (1987), Kusiak et al. (1987), and Boe et al. (1991) suggest similarity coefficients to measure the similarity of parts and to determine a part grouping based on the clustering algorithm. Some mathematical formulations are developed to solve the problem optimally (Boctor, 1991), Kusiak et al., 1992). Sankaran (1990) addresses the issue of developing alternate solutions with respect to conflicting objectives and preferential ordering of different goals with goal programming. Waghodekar et al. (1983) and Offodile et al. (1994) provide a comprehensive review of the various clustering techniques and present an extensive bibliography of part-family and machine-cell formation problems.

Obviously, the effect of these assignment decisions would influence the manufacturing cost of the cellular system. The main elements of manufacturing cost should thus be considered in the assignment of parts and machines to appropriate cells. However, most of these approaches do not explicitly consider the effect of machine and part assignments on costs. Some authors suggest cost functions taking the cost minimization as the main objective. Askin et al. (1987) and Askin et al. (1990) propose methods to assign machines and part families to cell considering the sum of inventory costs, product, setup costs, material handling costs, variable processing costs, and fixed machine costs. Sundaram (1987) consider depreciated capital costs of all machines assigned to each cell. Seifoddini (1989) introduces a cost-based duplication procedure for improving the machine cell efficiency and reducing the intercellular movements by duplicating some bottleneck machines. Kusiak et al. (1988) suggest the cost analysis algorithm to deal with problems associated with subcontracting some works arising from the intercellular movements for exceptional parts. Boctor (1996) and Bajamani et al. (1996) propose assignment decision methods based on the minimization of the sum of machine duplication cost and intercell material handling cost.

Since most of the these cost models are developed by assuming that there is only one unique process plan for each part, the creation of independent cells, i. e. cells where parts are completely processed in the cell and no linkages with other cells, may not be possible without duplication of machines. Consequently, all models consider the trade-off between the investment on machines, material handling and operational costs. In practice, a part can have more than one process plan and each operation can be performed on alternative machines. This allows a plan to be processed within a cell without additional investment. Also, subtracting exceptional parts to outside vendor can be considered as one of practical approaches.

The objective of this paper is to propose a cost-based algorithm for assignment of parts and machines to manufacturing cells economically. Part demands, and alternative process plans are taken into consideration while the assignment decision is based on cost alternatives of sum of machine duplication cost, operation cost, material handling cost, and setup cost. The paper is organized as follows. In the second section an explanation of the methodology adopted is given along with the assumptions and limitations considered for this purpose. In the third section, the algorithm and the various mathematical equations for calculation of the costs is addressed. In the fourth section, an example is illustrated to validate the developed algorithm.

2. Methodology

Proposed cost-based algorithm is used to assign parts and machines to appropriate cells after a rank order clustering technique (King, 1980) has been applied. From the part family and machine cells formed by the clustering technique, the "bottleneck" machine(s) and "exceptional" part(s) are identified. This is due that a manufacturing system cannot be divided into small perfect subsystems, and a part may have to be processed in more than one machine cell. This leads to inefficient machine cells and cost increment in intercellular material handling movements.

Three alternatives are suggested to solve these problems. All these alternatives are based on the system in the presently configured manner obtained through the rank order clustering technique. The first alternative is to eliminate the maximum number of intercellular movements by duplicating or buying and installing extra bottleneck machines into the appropriate cells. The second alternative considers the alternate process plans available and tries to complete the job with an overtime basis in the small machine cells. The third alternative considers the possibility of subcontracting exceptional part(s) to an outside vendor to reduce the overall cost for the manufacturing system.

The first step is to group parts into part families and machines into manufacturing cells using a ranker order clustering technique.

The second step is to calculate the total cost of the manufacturing system at this stage. The total system cost of each alternative can be obtained by calculating the following cost components:

1. Fixed machine costs, i. e., capital cost for the machine
2. Production (or processing) costs
3. Setup costs: This cost has two components:
(a) Fixed setup costs for a part-family on a machine
(b) Varying setup costs for different operations depending on refixturing, tools etc.
4. Material handling costs: Only Intercellular material handling costs are considered here.
Intra-cell material handling costs are not taken into account.

The third step is to compare the total costs for the four alternatives, and choose the best alternative for any given problem identified. In this proposed methodology, following cost components linked with cellular manufacturing systems are not being considered: (1) Work-In-Process (WIP) inventory costs, (2) Production cycle inventory costs, and (3) Intra-cell material handling costs.

3. Mathematical Cost Formulation

3.1 Cost components equations

1) Fixed machine costs

Fixed machine costs FMC are calculated as the product of the annual fixed cost (operating cost and depreciation) for each machine and the number of machines of that type in the group. This can be expressed as follows:

$$FMC = \sum_{m} N_m C_m \tag{1}$$

The types of machines and the number of each type of machine may be different in different alternatives being considered.

2) Production costs

The production costs PC are the sum of products of the number of working days of a machine in a machine cell for the part family and the regular operation cost of the machine per day. The amount of time required for a part family is the sum of the times needed to process each of the parts in the part family.

The processing time required by machines to completely process a part is calculated as the sum of the processing time for each operation on the part for each of the required machines.

Mathematically, the production cost can be obtained as follows:

$$PC=\sum_f\sum_i\sum_m \frac{R_m\sum_k t_{imk}}{H_m} D_i \tag{2}$$

3) Setup costs

There are two components of setup costs associated with each part family.

(i) Setup costs for the part family f on machine cell c.

This is the sum of setup cost for a part family f on each machine m of the corresponding machine cell c.

Mathematically, this can be calculated as follows:

$$SCO=\sum_m N_{fm} \tag{3}$$

(ii) Varying setup costs for each individual operation k, of part i, on machine m.

This is computed as the sum of setup costs for each operation k of part i (in part family f), on machine m (of machine cell c, corresponding to f).

Mathematically, this cost SCV can be expressed as

$$SCV=\sum_i(\sum_m\sum_k S_{imk})D_i \tag{4}$$

Therefore, the total setup cost SC can be given by

$$SC=\sum_f(\sum_m S_{fm}+\sum_i(\sum_m\sum_k S_{imk})D_i) \tag{5}$$

4) Material handling costs

The material handling costs MHC of a given part depends only on the characteristics of this part (weight, volume, shape, fragility, etc.) and the number of units to be handled. This means that the effect of some factors like the intercell distances or part routings on this cost can be neglected. This is the most sensitive to these assumption as, in some practical cases, it may lead to inaccurate cost estimations.

Mathematically, MHC can be expressed as follows:

$$MHC=\sum_m\sum_{i\in P_m}\sum_c(T_i/\sum_k t_{imk})E_{im} \tag{6}$$

3.2 Costs formulation of Alternatives

The total cost of a manufacturing system for each alternative is determined by the sum over the adapted cost components mentioned on the previous section. Mathematically the total cost TC can be represented as follows:

$$\begin{aligned}TC=&\sum_m N_mC_m+\sum_f\sum_i\sum_m\frac{R_m\sum_k t_{imk}}{H_m}D_i\\&+\sum_f(\sum_m S_{fm}+\sum_i(\sum_m\sum_k S_{imk})D_i)\\&+\sum_m\sum_i\sum_c(T_i/\sum_k t_{imk})E_{imc}\end{aligned} \tag{7}$$

According to this equation, the cost equations utilized in the suggested alternatives are described as follows;

1) Additional machine based alternative

In this alternative, the problems associated with the "bottleneck" machines and the "exceptional" parts are solved by buying one or more of the bottleneck machines to reduce or remove the intercellular movements, and thus reduce the transportation cost, as also make the machine cells more efficient.

Since the number of machines of type m to be purchased can be obtained from $\{\sum_c X_{mc}-N_m\}$, the annual fixed cost of the newly purchased machine(s) is expressed as follows:

$$\sum_{m\in NP}C'_m\{\sum_c X_{mc}-N_m\} \tag{8}$$

where C'_m indicates sum of annual operating cost and annual depreciation of newly purchased machine of type m, and NP indicates set of newly purchased machines.

The fixed machine cost FMC_A for this alternative can be obtained by adding costs associated with these additional machines to the current fixed machine cost. This term can mathematically be represented as follows:

$$\begin{aligned}FMC_A=&\sum_m C_mN_m+\sum_i C'_m\{\sum_{m\in NP}X_{mc}\\&-N_m\}\end{aligned} \tag{9}$$

The setup cost will also be increased due to the installation cost of the new purchased machine. Mathematically the setup cost SCA is represented as follows:

$$SC_A=\sum_f(\sum_m S_{fm}+\sum_i(\sum_m\sum_k S_{imk})D_i)$$
$$+\sum_f\sum_{m\in NP}S_{fm} \tag{10}$$

The first term represents the original setup cost, and the second term gives the installation cost of newly purchased machines.

The material handling cost is reduced by assigning newly purchased machines into suitable cells and hereby reducing or removing movements between two cells. The reduction in the transportations cost will be subtracted from the material handling cost in the given configured manufacturing system. Then, the material handling costs MBC_A of this alternative will be modified as follows:

$$MHC_A=\sum_m\sum_{i\in P_m}\sum_c(T_i/\sum_k t_{imk})E_{im}$$
$$-\sum_{m\in NP}\sum_{i\in P_m}\sum_c(T_i/\sum_k t_{imk})E_{im} \tag{11}$$

The production cost taking new machine(s) into consideration is the same as that of a given configured manufacturing system and can be obtained from Eq. (2).

Then, the total cost TC_B for this alternative can be calculated as follows:

$$TC_A=\sum_m N_mC_m+\sum_{m\in NP}C'_m\{\sum_c X_{mc}-N_m\}$$
$$+\sum_f\sum_i\sum_m\frac{R_m\sum_k t_{imk}}{H_m}D_i$$
$$+\sum_f(\sum_m S_{fm}+\sum_i(\sum_m\sum_k S_{imk})D_i)$$
$$+\sum_f\sum_{m\in NP}S_{fm}$$
$$+\sum_m\sum_i\sum_c(T_i/\sum_k t_{imk})E_{imc}$$
$$-\sum_{m\in NP}\sum_{i\in P_m}\sum_c(T_i/\sum_k t_{imk})E_{im} \tag{12}$$

2) Over time based alternative

In this alternative, the material handling costs for intercellular movements can be reduced by carrying out the further operations on the part, on an overtime basis within the same machine cell (s). This is possible, if and only if alternate process plans for the concerned operations and machines are available.

The fixed machine cost will remain the same because no machines are being added to the already existing ones. The varying component of the setup cost will be different for each process plan case, and the setup cost can be modified as follows:

$$SC_B=\sum_f(\sum_m S_{fm}+\sum_i(\sum_m\sum_k S_{imk'})D_i) \tag{13}$$

where k' indicates operation modified by a new process plan.

Additional production cost will result from processing the part on overtime basis. This cost can be calculated in a manner similar to regular time processing cost.

$$\sum_f\sum_i\left(\sum_m\frac{O_m\sum_k t_{imk'}}{H_m}\right)D_i \tag{14}$$

where, f, m, i, k' are considered only with respect to the overtime operations concerned.

The total production cost for this alternative will exclude the processing cost incurred for further processing of the exceptional parts. This can be given by

$$\sum_f\sum_i\left(\sum_m\frac{R_m\sum_k t_{imk'}}{H_m}\right)D_i \tag{15}$$

where, f, m, i, k', are considered only with respect to the new redundant number of operations affected because of the overtime processing.

Then the total production cost PC_B for this alternative can be given by

$$PC_B=\sum_f\sum_i\sum_m\frac{R_m\sum_k t_{imk}}{H_m}D_i$$
$$+\sum_f\sum_i\left(\sum_m\frac{O_m\sum_k t_{imk'}}{H_m}\right)D_i$$
$$-\sum_f\sum_i\left(\sum_m\frac{R_m\sum_k t_{imk'}}{H_m}\right)D_i \tag{16}$$

The material handling cost will be reduced as the number of intercellular movements will be either reduced or removed completely due to the availability of alternate process plans and overtime processing (that is, if this is possible). The material handling cost can be obtained as follows:

$$MHC_B=\sum_m\sum_{i\in P_m}\sum_c(T_i/\sum_i t_{imk})E_{im}$$
$$-\sum_m\sum_{i\in P_m(p)}\sum_c(T_i/\sum_k t_{imk'})E_{im} \tag{17}$$

where k' indicates operation modified by a new process plan and $P_m(p)$ indicates new set of parts to be processed by a machine of type m reconfigured by a process plan p.

Then, the total cost for Alternative-C will be given as follows:

$$TC_B = \sum_m C_m N_m + \sum_f (\sum_m S_{fm} + \sum_i (\sum_m \sum_{k'} S_{imk'}) D_i) + \sum_f \sum_i \sum_m \frac{R_m \sum_k t_{imk}}{H_m} D_i + \sum_f \sum_i \Big(\sum_m \frac{O_m \sum_{k'} t_{imk'}}{H_m} \Big) D_i - \sum_f \sum_i \Big(\sum_m \frac{R_m \sum_{k'} t_{imk'}}{H_m} \Big) D_i + \sum_m \sum_{i \in P_m} \sum_c (T_i / \sum_k t_{imk}) E_{im} - \sum_m \sum_{i \in P_m} \sum_c (T_i / \sum_{k'} t_{imk'}) E_{im} \tag{18}$$

3) Vendor utilization based alternative

In this alternative, the material handling costs, production costs, and setup costs associated with the bottleneck machines and exceptional parts can be reduced by subcontracting the processing operations resulting in the intercellular movements.

These operations, and the machines in which these operations have to be carried out should be identified from the first clustering technique. Then the operations resulting in intercellular movements, and all the further operations on the parts can be given to an outside vendor on a subcontracting basis. This may save some internal material handling costs, setup costs, and processing costs associated with these operations.

The total cost for this alternative can then be calculated based upon the subcontractor's cost for processing and setup. The fixed machine cost will remain the same as no machines are being added to the already existing ones.

The amount of work subcontracted will be done by a vendor at a cost quoted by the vendor. The cost associated with the subcontractors includes both the processing and the setup costs. The additional costs can be expressed as follows for the work done by the subcontractor:

$$\sum_{i \in f} \Big(\sum_m \frac{W_m \sum_{R \in i} t_{imk'}}{H_m} \Big) D_i \tag{19}$$

where, m, i', k' are considered only with respect to the operations affected because of subcontracting work to a vendor outside.

The work that is subcontracted outside will reduce the production cost of present configured manufacturing system. This reduced production cost can be computed as follows:

$$\sum_{i \in f} \Big(\sum_m \frac{R_m \sum_{k' \in i'} t_{imk'}}{H_m} \Big) D_{i'} \tag{20}$$

where, m, i', k' are considered only in regard to the new redundant number of operations affected because of subcontracting the work outside.

The total production cost for this alternative can be given by

$$PC_C = \sum_f \sum_i \sum_m \frac{R_m \sum_k t_{imk}}{H_m} D_i + \sum_i \Big(\sum_m \frac{W_m \sum_{k'} t_{imk'}}{H_m} \Big) D_i - \sum_i \Big(\sum_m \frac{R_m \sum_{k'} t_{i'mk'}}{H_m} \Big) D_{i'} \tag{21}$$

The setup cost will change from the original setup costs. The overall setup cost for part family f of a machine cell c will remain unchanged. However, the varying setup cost will be reduced because of some of the operations being subcontracted outside. The reduced value of the varying setup costs can be given as follows:

$$\sum_{i \in f} \sum_m \sum_{k' \in i'} S_{i'mk'} \tag{22}$$

These are to be considered only for the operations being performed in-house. Therefore, the total setup cost for this alternative can be given by

$$SC_C = \sum_f (\sum_m S_{fm} + \sum_i (\sum_m \sum_k S_{imk}) D_i) - \sum_{i \in f} \sum_m \sum_{k \in i'} S_{i'mk'} \tag{23}$$

Since some of the work is subcontracted to reduce the number of intercellular movements, there will be a reduction in the total material handling cost in a similar manner to overtime based alternative.

The total cost for this alternative will then be given as follows:

$$TC_C = \sum_m C_m N_m + \sum_f (\sum_m S_{fm} + \sum_i (\sum_m \sum_k S_{imk}) D_i) - \sum_{i \in f} \sum_m \sum_{k \in i'} R_{i'mk'} + \sum_f \sum_i \sum_m \frac{R_m \sum_k t_{imk}}{H_m} D_i + \sum_i \Big(\sum_m \frac{W_m \sum_{k'} t_{i'mk'}}{H_m} \Big) D_{i'}$$

$$
\begin{aligned}
&-\sum_{i}\left(\sum_{m}\frac{R_m\sum_{k'}t_{i'mk'}}{H_m}\right)D_{i'} \\
&+\sum_{m}\sum_{i\in P_m}\sum_{c}\left(T_i/\sum_{k}t_{imk}\right)E_{im} \\
&-\sum_{m}\sum_{i\in P_m(p)}\sum_{c}\left(T_i/\sum_{k'}t_{imk'}\right)E_{im} \qquad (24)
\end{aligned}
$$

3.3 Algorithms

Step-0: The machine cell/part family clusters are obtained by using the rank order clustering technique.

Step-1: Identify the "bottleneck" machine(s) and the "exceptional" part(s) leading to difficulties in separating the clusters into clear independent machine cells, and resulting in avoidable intercellular material handling moves.

Step-2: Calculate the total cost of the present configuration by considering

- Fixed machine costs (Eq. (1))
- Production costs (Eq. (2))
- Setup costs (Eq. (3), (4), & (5))
- Material handling costs (Eq. (6))

Calculate the total cost TC of the presently configured manufacturing system using Eq. (7).

Step-3: Consider first alternative in which the possibility of buying extra machine(s) to overcome the "bottleneck" machine(s) problem is explored. Use Eqs. (8) to (12), to compute the total cost for second alternative, i. e., compute TC_A.

Step-4: Consider second alternative in which the alternate process plans are explored (i. e., if such are available for the "exceptional" part(s) & "bottleneck" machine(s), then the possibility of processing the work for exceptional part(s) with a machine cell with overtime basis is tested). The total cost for this alternative is computed using Eqs. (13) to (18), i. e., calculate TC_B.

Step-5: Consider third alternative in which the possibility of subcontracting the work due to the exceptional part(s)/bottleneck machine(s) is explored. The total cost for this alternatives calculated using Eqs. (19) to (24), i. e., calculate total cost. TC_C.

Step-6: Compare the total costs of each of the 4 alternatives to determine the lowest cost, i. e., find lowest(TC_A, TC_B, TC_C)

Step-7: Recommend the alternative giving the lowest total cost, then STOP.

4. Results and Discussions

In most of the approaches for the design of CMS, with a few exceptions, the cost aspect is not considered while forming part families and machine cells. Moreover, the main objective in CMS is to form a set of mutually independent machine cells. In practice, however, parts need to be processed in more than one cell due to the processing requirements which lead to a large number of intercellular moves and fewer efficient machine cells, and hence an increased total cost. There are alternatives available for reducing this total cost, and forming smaller and more efficient machine cells. Some of the alternatives are: (i) Duplication machines in cells, (ii) Exploring the possibility of using alternate process plans and working overtime in smaller machine cells, and (iii) Subcontracting some of the work to reduce the costs. These alternatives have been considered in this paper, and a methodology in the form of an algorithm with requisite equations for total cost calculations for each of the alternatives are proposed here.

In order to illustrate the performance of the suggested mathematical cost models and algorithm, a test example considering 12 products and 6 machines is used. The test-problem data is outlined in Table 1. The other needed values for calculating costs are as follows: W_m=\$ 1,600/yr; O_m=\$ 1,200/day; S_{imk}=\$ 1/unit; S_{fm}=\$ 1,000, H_m=8hr.

First, the rank order clustering technique applies to the machine-part incidence matrix interpreted from processing time matrix in Table 1(a), and results in the cell formation matrix as illustrated in Table 2. However, machine C is recognized as the bottleneck machine.

As a solution of this problem associated with exceptional parts and a bottleneck machine, first alternative suggested is trying to buy a bottleneck machine type C, and install into cell 2. In second alternative, the operations of parts formed into part family 2 performed by machine type C are carried out on an overtime basis. The third alter-

Table 1 Test example data.

(a) Processing times matrix

machine	Part 1	2	3	4	5	6	7	8	9	10	11	12
A	0.7			0.5	0.4		1					
B	0.5		0.5	0.8	0.3							
C	0.2		0.5	0.8	0.5	0.5	0.7	1		0.6	0.8	
D		0.3				0.5			0.7	0.5		
E			0.3		0.1		0.5					
F		0.1						1	0.7	0.2	0.8	1

(b) Demand and intercell handling cost

Part i	1	2	3	4	5	6	7	8	9	10	11	12
D_i	1000	1800	500	500	1000	500	700	1000	500	700	800	1200
T_i	0.4	1.0	0.3	0.5	0.6	0.8	0.4	1.0	1.5	0.4	0.8	0.7

(c) Annual fixed cost and regular operating cost

machin m	A	B	C	D	E	F
C_m	100,000	100,000	5,000	10,000	10,000	5,000
R_m	800	700	600	800	700	600

Table 2 Machine Cell formation.

	Part famil 1					Part family 2							
part / machine	1	4	3	7	5	11	2	6	9	8	12	10	
B	0.5	0.8	0.5		0.3								
A	0.7	0.5		1	0.4								
E			0.5	0.3	0.5								
C	0.2	0.8	0.5	0.7	0.5	0.8		0.5		1		0.6	cell 1
F						0.8	0.1		0.7	1	1	0.2	
D							0.3	0.5	0.7			0.5	cell 2

Table 3 Costs calculated for three alternative.

	First alternative	Second alternative	Third alternative
Fixed machine Cost	55,000	50,000	50,000
Production Coast	1,107,875	1,281,125	1,396,625
Setup Cost	32,100	31,000	28,100
Material handling Cost	0	0	0
Total cost	1,194,975	1,362,225	1,474,725

native suggests exceptional parts 6, 8, 10, and 11 are reduced by subcontracting the processing operations. The results of evaluating the three alternatives are summarized in Table 3. With reference to the Table, first alternative buying a new machine type is recognized as the appropriate solution.

5. Conclusion

A mathematical cost formulation and algorithm that deal with the design problems of Cellular Manufacturing System was developed in this study and tested the performance of the algorithm by applying it to an example.

Three alternatives available for reducing this total cost, and forming smaller and more efficient machine cells are proposed, and these alternatives are: (i) Duplication machines in machine cells, (ii) Exploring the possibility of using alternate process plans and working overtime in smaller machine cells, and (iii) Subcontracting some of the work to reduce the costs. These alternatives have been considered in this paper, and a methodology in the form of an algorithm with requisite equations for total cost calculations for each of the alternatives are proposed here.

The mathematical cost model and algorithm should be an available method of reducing the total cost in the manufacturing system, and should be expected to use in the industry. For the future work, these cost models can employ the interacell material handling cost to increase the accurate of developed cost models, and the method can be extended to assign parts and machines to cells simultaneously.

References

Askin, R. G., and Chiu, K. S., 1990, "A Graph Partitioning Procedure for Machine Assignment and Cell Formation in Group Technology," *International Journal of Production Research*, Vol. 28, pp. 1555~1572.

Askin, R. G. and Cresswell, S. H., Goldberg, J. B. and Vakharia, A. J., 1991, "A Hamiltonian Path Approach to Reordering the Part-machine Matrix for Cellular Manufacturing," *International Journal of Production Research*, Vol. 29, pp. 1081~1100.

Askin, R. G. and Subramanian, S. P., 1987, "A Cost-Based Heuristic for Group Technology Configuration," *International Journal of Production Research*, Vol. 25, pp. 101~113.

Bajamani, D., Singh, N., Aneja, Y. P., 1996, "Design of Cellular Manufacturing Systems," *International Journal of Production Research*, Vol. 234, pp. 1917~1928.

Boctor, F. F, 1991, "A Linear Formulation of Machine Part Cell Formation:," *International Journal of Production Research*, Vol. 29, pp. 343~356.

Boctor, F. F., 1996, "The Minimum-Cost, Machine-Part Cell Formation Problem," *International Journal of Production Research*, Vol. 34, pp. 1045~1063.

Boe, W. J. and Cheng, C. H., 1991, "A Close Neighbour Algorithm for Designing Cellular Manufacturing Systems," *International Journal of Production Research*, Vol. 29, pp. 2097~2116.

Chandrasekharan, M. P., Rajogopalan, R., 1987, ZODIAC: An Algorithm for Concurrent Formation of Part-Families and Machine-Groups," *International Journal of Production Research*, Vol. 25, pp. 835~850.

Houtzeel, A., 1975, "An Introduction to the MICLASS System," *Proceedings of Computer Aided Manufacturing International*: Seminar of CAPP Applications, CAM-1, pp. 159~178.

King, J. R., 1980, "Machine-Component Grouping in Production Flow Analysis: An Approach Using a Rank Order Clustering Algorithm," *International Journal of Production research*, Vol. 18, pp. 213~232.

Khator, S. K., Irani, S. A., 1987, "Cell Formation in Group Technology: A New Approach," *Computers and Industrial Engineering*, Vol. 12, pp. 131~142.

Kusiak, A. and Chow, W. S., 1988, "Efficient Solving of the Group Technology Problem," *Journal of Manufacturing Systems*, Vol. 6, No. 2, pp. 117~124.

Kusiak, A. and Cho, m., 1992, "Similarity Coefficient Algorithms for Solving the Group Technology Problem," *International Journal of Production Research*, Vol. 25, pp. 2633~2646.

Kusiak, A. and Heragu, S. S., 1987, "Group Technology," *Computers in Industry*, Vol. 9, pp. 83~91.

Offodile, O. F., Mehrez, A. and Grznar, J., 1994, "Cellular Manufacturing: A Taxonomic

Review Framework," *Journal of Manufacturing Systems*, Vol. 3, pp. 196~220.

Opitz, H., 1972, *A Classification System to Describe Workpieces*, Part Ⅰ and Ⅱ, New York: Pergamon Press.

Sankaran, S., 1990, "Multiple Objective Decision Making Approach to Cell Formation: A Goal Programming Model." *Mathematical Computer Modelling*, Vol. 13, No. 9, pp. 71~82.

Seifoddini, H., 1989, "Duplication Process in Machine Cells Formation in Group Technology," *IIE Transactions*, Vol. 21, No. 4, pp. 382~388.

Sundaram, R. M. and Fu, S. S., 1987, "Group Technology Cell Formation-Some New Insights," *Computers in Industrial Engineering*, Vol. 13, Nos. 1-4, pp. 267~276.

Waghodekar, P. H. and Sahu, S., 1983, "Group Technology: A Research Bibliography," Opsearch, Vol. 29, pp. 225~249.