4^{th} International Conference on Mechanical Engineering,December 26-28, 2001, Dhaka,Bangladesh/pp. VI 163-168

MACHINE AND ROUTING FLEXIBILITY CONSIDERATION IN CELL FORMATION FOR CELLULAR MANUFACTURING SYSTEMS

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Abstract Fiercely competitive manufacturing scenario, fast changing customer preferences, and shrinking of time-to-market have forced the manufacturer to develop and maintain the capability to tackle these issues with increased flexibility, good quality at low cost and with quick delivery response. Cellular manufacturing is one of the viable options to achieve these objectives in today's globally competitive market. Cell formation is a complex issue in the design of cellular manufacturing system. The consideration of routing and machine flexibilities during cell formation not only gives the improved Block Diagonal Form of part-machine matrix but it also enables the manufacturers to ensure the continuity of production in the face of unexpected demand and machine breakdown. The consideration of these flexibilities improves the performance of Cellular Manufacturing System. This paper presents a heuristic in association with artificial neural network based ART-1 algorithm for the cell formation purposes while considering routing and machine flexibilities.

Keywords: Cellular Manufacturing System, Cell Formation, Machine Flexibility, Routing Flexibility

INTRODUCTION

An increasingly globally competitive environment and ever changing customer preferences have forced the manufacturers to develop just-in-time capability with increased flexibility, productivity, and quality. In this intense competitive environment, need is felt to exploit the time, cost and quality advantages of cellular manufacturing system. Cellular manufacturing is the practical application of GT (Group Technology) manufacturing philosophy. The main concept of Group Technology is to capitalize on similar manufacturing processes and features where similar parts are grouped together into a part family and manufactured by a cluster of dissimilar machines. The cellular manufacturing has been recognized as one of the most effective strategies to the ever-changing world manufacturing scenario and has gained significant popularity in both academic research and industrial applications. The implementation of cellular manufacturing in industries has resulted into significant improvement in areas such as lead times, setup times, work-in-process, quality, machine utilization, simplified and [1]reduced material handling, improved productivity, simplified scheduling and better overall control of operations [4,7,12].

Cell formation is a major issue in the design of cellular manufacturing system. Cell formation consists of identifying part families (PFs) and machine groups (MGs). The part-machine (0-1) matrix is used as input by majority of the researchers for the cell formation purposes. The perfect Block Diagonal Form (BDF) of the machine part matrix is not possible in many cases. The dedication of machines to specific part families is the cause of one of the major benefits of CM (i.e. set-up reduction); it is also the cause of one of the major drawbacks of CM (i.e. loss of pooling flexibility). The use of the routing and machine flexibilities during cell formation not only gives the improved BDF of part-machine matrix but it reduces the adverse effect of CM and also enables the manufacturers to ensure the continuity of production in the face of unexpected demand and machine breakdown. This paper presents a heuristic in conjunction with artificial neural network based ART-1 algorithm for the cell formation purposes while considering routing and machine flexibilities. The flexibility [3] of a manufacturing system has been considered as the ability of a system to adapt quickly to any changes in the relevant factors such as product process, work load or machine failure.

TYPES OF FLEXIBILITY

A classification of different types of flexibility [5] includes:

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- *Machine flexibility:* The ability of a machine to perform different operations required by a given set of part types [11]. The machine flexibility can be measured by the number of different operations a machine can perform without requiring more than a specified amount of effort.
- *Process flexibility*: The ability to produce a given set of part types possibly using different materials, in different ways.
- *Product flexibility*: The ability to change over to produce new products very economically and quickly. It enables the manufacturers to introduce the new products early in the market.
- *Routing flexibility*: The capability of processing a given set of part types using more than one route [11].
- *Volume flexibility*: The ability to operate profitably at different production volumes.
- *Expansion flexibility*: The ability to expand a system without much effort and in a modular fashion.
- *Operation flexibility*: The ability to interchange ordering of several operations for each part type.
- *Production flexibility*: The universe of part types that the manufacturing system can produce.

In this paper, the cell formation problem is considered as the reorganization of an existing shop into GT shops using the routing flexibility (i.e. alternate process plans) and machine flexibility (i.e. the capability of machines to carry out different operations).

CELL FORMATION CONSIDERING ROUTING AND MACHINE FLEXIBILITY

A large number of cell formation procedures (heuristics as well as non-heuristics) are available in the literature. Majority of the procedures uses a part-machine matrix as input and attempts to obtain a BDF. Beaulieu et. al.[4] have proposed a heuristic method that provides a good solution for the cell formation and machine selection during design stage. It takes into consideration the machines and material handling costs, machine capitalization and the different alternative routings of each operation. Sofianopoulou [9] has considered that part types can follow alternative routes resulting from the existence of multiple copies of each machine type. Ang and Wiley [2] have shown that inter cell work load transfer through alternative routes can improve the CMS performance. Adil et.al.[1] have suggested a good cell formation procedure by considering alternate routings by using a non-linear integer programming model. Wu [12] has given a new approach to deal with the cell formation and assignment of identical machines concurrently.

In this paper attempt is made to develop a procedure for the cell formation by considering the routing flexibility (i.e. alternate process plans) and machine flexibility (i.e. by using the capability of the machines to carry out different operations and their unutilized capacity). For this purpose an algorithm is developed to select the suitable process plans for the part-machine matrix and then using improved ART-1 algorithm, the BDF of the matrix is achieved. In some cases the BDF of the part-machine matrix is not perfect. The partitioned matrix can still have some *Exceptional Elements (EEs*) and *Voids*. Voids and exceptional elements are not desirable for the effective CMS operations. A void indicates that a machine assigned to a cell is not required for the processing of the part in the cell. Presence of voids leads to inefficient large cells. This results into increased intra-cell material handling cost. An exceptional element is one, which requires machining outside its allocated cell. The exceptional elements increase the inter-cell material handling cost significantly. In order to get rid of exceptional elements the machine flexibility is used in this paper. The machine flexibility is used in the sense that if a particular part needs processing outside its parent cell, and if the allocated machine in the cell itself has the capability to perform the required operation and the machine remains under utilized in the cell, than the EEs can be processed within its allocated cell.

Improved ART-1

The ART-1 artificial neural network [07] has the capability of classifying a set of binary vectors into groups, each group containing similar vectors based on a specified degree of similarity. The flow chart of the ART-1 algorithm is shown in Fig.1. The improved ART-1 approach proposed by Dagli [06] incorporates a few changes in the basic approach. To deal with the problems of representative pattern getting sparse with more number of patterns instead of storing the AND of the vectors, the vector with a higher number of ‘1’s is stored as representative vector. This eliminates the possibility of improper classification of later parts due to its comparison with sparse representative patterns. Also to deal with the problem of sensitivity of the obtained classification to the sequence in which parts are applied. Pre –processing of the input vectors is done prior to training. The vectors are applied in the decreasing number of ‘1’s. This results in the sparse vectors absorbed into the ‘denser’ vectors. With these changes the modified ART-1 (ANN) algorithm involves the following steps [06].

1. Arrange the column vectors by the decreasing number of ‘1’s.
2. Perform grouping with exemplars created by storing the denser patterns (higher number of ‘1’s) i.e. part families are formed using original ART-1 algorithm.
3. Reorder rows of the immediate matrix according to the decreasing number of ‘1’s.
4. Similarly group rows, as in step 1, i.e. perform machine grouping by using original ART-1 algorithm.

Select Plan Algorithm

This algorithm is used to select the process plans which give a good and compact cell formation with the minimum number of EEs and voids.

It involves the following steps:

1. Select the part process plan with the maximum number of ‘1’s and ignore the remaining process plans of that part type for the cell formation purposes.
2. Select the process plan which should have the similarity elsewhere in the input machine-part matrix i.e. at least two part process plans should have similar routings. In that case all the similar plans will be selected for the cell formation purposes.
3. In case if the similarity does not exist for part process plans of a particular part type then select the process plan with lowest index number.

SOLUTION

Two problems have been taken for the cell formation purposes considering alternate process plans (adapted from Adil et. al .[01]).

The first problem data set is of 5 parts and 4 machines problem as shown in Fig.2. The select plan algorithm selects the process plans i.e. part no. [process plan no.] and subsequently for the selected process plan the cell formation is carried out by using improved ART-1 algorithm. The result obtained matches the one obtained by Adil [01] et.al. using 0-1 integer programming as shown in Fig.3.

Problem No.01:

		Machines
Part(Process plans)	1[1]	0011
	1[2]	0101
	2[1]	0110
	2[2]	1010
	3[1]	1001
	3[2]	0101
	4[1]	1001
	4[2]	1010
	5[1]	0011
	5[2]	1000
	5[3]	1110

Fig. 2 Initial part-machine matrix

The selected part process plans {part no.[process plan no.]} are 1[2], 2[2], 3[2], 4[2], and 5[3]. Two clusters are obtained with one exceptional element and two voids. The clusters formed are {1,3} and {2,4}. The problem of exceptional element can be tackled by considering the machine flexibility during cell formation i.e. by taking into consideration the capability of machines to perform different operations and unutilized capacity of the machines in the cells.

		Machine Groups	
		1122	
		1324	
Part families	5(3)	1110	1
	2(2)	1100	1
	4(2)	1100	1
	3(2)	0011	2
	1(2)	0011	2

Machine group 1: Machines 1,3
Machine group 2: Machines 2,4
Part Family 1: Parts 2,4,5
Part Family 2: Parts 1,3

Fig. 3 Cell formation after using ART-1 and alternate routing

In Table-1, O_{11} (15) indicates that machine 1 can process part 1 and 15 % efficiency of the machine is utilized in that particular operation. Whereas ‘0’ in the row of machine 2 indicate that part type 4 can not be processed by machine 2 as per part process plan shown in Fig. 2.

EE-1: Part type 5

In the above example of *Problem No.1* the part type 5 need processing outside its cell i.e. on machine 2 (see Fig. 3). The part type 5 can be processed within its own cell if the machines 1 and 3 have the capability to machine part type 5 and there exists the unutilized capacity of the machines of that cell i.e. available capacity of machines 1 or 3 is equal to or more than that is required by part type 5 on machine 2.

By using equation (1)

$$\left\{1-\left(\sum_{j=1}^{k} CO_{ij}\right)\right\} \geq \sum_{i`=1}^{n} CO_{i'j'} \quad \text{---- -----(1)}$$

Where

CO_{ij} =utilized capacity of the i^{th} machine for j^{th} part type inside the cell

$CO_{i'j'}$ =utilized capacity of the *i’ th* machine for *j’ th* part type outside the cell

$i`$ = the machine required by the part type outside the allocated cell

$j`$ = the part type that need processing outside the allocated cell

From the Fig. 3 and Table-1 we get

$i`=2$ and $j`= 5$

CO_{25} is the capacity utilized by the part type 5 on machine 2 (see Table-1). ~ CO_{25}=15 %.

Therefore the utilized capacity of the machine 2 for part type 5

CO_{25}=15 %. ------------(2)

The unutilized capacity of the machine 1 is given by

$$1-\left(\sum_{j=1}^{k} CO_{ij}\right)$$

Where j = (1,2,3------k) and k is the total number of parts to be processed by the machine i in the cell.

In the present case k = 3 as the machine 1 is used to process three part types i.e. part type 2, 4, and 5 respectively.

Therefore unutilized capacity of the machine 1 is

$\{1-(CO_{12} + CO_{14} + CO_{15})\}$

{1- (20+15+10)}= 55%

The unutilized capacity of machine 1 is =55 %

Similarly, unutilized capacity of machine 3 is 30 %.

As the unutilized capacity of machine 1 is more than that of the machine 3 therefore the machine 1 can be used to process part type 5 in addition to processing of part type 5 already assigned to the machine 1.

The second problem data set is of 10 parts and 10 machines problem as shown in Fig. 4 with 24 process plans under consideration.

Problem No.2

		Machines: 12345678910
Part (process plan)	1(1)	1101000000
	1(2)	0001010000
	1(3)	0011000001
	2(1)	0000001101
	2(2)	1000110011
	3(1)	0010001100
	3(2)	1000101000
	4(1)	0010001010
	4(2)	0010001100
	5(1)	1000100001
	5(2)	0100100011
	6(1)	1100000000
	6(2)	0010001100
	7(1)	0101010000
	7(2)	1101000000
	7(3)	0001001100
	8(1)	1000101011
	8(2)	1000000011
	9(1)	0010001100
	9(2)	0010001010
	10(1)	1010000100
	10(2)	0010001100

Fig. 4 Initial part-machine matrix (10*10)

The selected process plans i.e. Part No.[Process Plan No.]are: [1], 2[2], 3[1], 4[2], 5[2], 6[2], 7[2], 8[1], 9[1], 10[2]

	Machine Group 1112223333 73812491056	
2(2)	0001001111	1
8(1)	1001001110	1
5(2)	0000101110	1
4(2)	1110000000	2
6(2)	1110000000	2
3(1)	1110000000	2
9(1)	1110000000	2
10(2)	1110000000	2
7(2)	0001110000	3
1(1)	0001110000	3

MG1: Machines 3,7,8
MG2: Machines 1,2,4
MG3: Machines 5,6,9,10
PF1: Parts 2,5,8
PF2: Parts 3,4,6,9,10
PF3: Parts 1,7

Fig. 5 Cell formation after using ART-1 algorithm and using alternate routings.

Three cells formed are {1,2,4}, {3,7,8} and {5,6,9,10} and three part families formed are {3,4,6,9,10}, {2,5,8} and {1,7} as depicted in Fig. 5. Three parts need processing outside their allocated cells namely parts 2, 5 and 8. Part type 2 needs processing on machine 1, type 5 needs processing on machine 2 and type 8 needs processing on machine 7 and 1. This problem of exceptional elements can be overcome by using the machine flexibility in terms of their unutilized capacity and their capability to process the required part types. For example, part type 2 needs processing on machine 1 whereas the capacity required to machine part type 2 is 10%. The part type 2 belongs to MG3 i.e. cell 3 where the machines allocated are 5, 6, 9 and 10. Therefore using the equation (1) the unutilized capacity of all the machines can be calculated from Table-2.

EE-1: Part type 2

Utilized capacity for the part type j'=2 on machine i'=1 is given by

$$CO_{i'j'} = CO_{12} = 10\%$$

Where as the unutilized capacity of machine 5 can be determined by using equation 1.

Here i=5 and k=3

(as machine 5 is used to process part 2, 5 and 8)

Unutilized capacity of machine 5 is

={1-(15+15+30)} =40%.

Similarly the unutilized capacity of machine 6

= {1-(25)} =75%

The unutilized capacity of machine 9

= {1-(35+15+15)}=35%

The unutilized capacity of machine 10

={1-(20+10+25)}=45%

Since out of the machines 5, 6, 9 and10 the maximum unutilized capacity (75%) is of machine 6, the part type 2 can be processed within the cell.

EE –2: Part type 8

Part type 8 needs processing outside its cell on machines 7 and 1.

Utilized capacity of part type 8 on machines 1 and 7 = $CO_{18} + CO_{78}$

= 15+15 =30%

Now, unutilized capacity of machine 5 is

= {1-(15+15+30)} =40%.

Similarly, the unutilized capacity of machine 6

= {1-(25+25*)} =50%

{ Capacity assigned on machine 6 for part type 2(part type2 is the EE)}*

The unutilized capacity of machine 9 is

= {1-(35+15+15)}=35%

The unutilized capacity of machine 10 is

={1-(20+10+25)}=45%

Again, the machine 6 has the maximum unutilized capacity in the cell. Therefore the machine 6 can be used to provide the alternate means to process the part type 8 within the cell.

EE –3: Part type 5

Utilized capacity of machine 2 for part type 5 is CO_{25}= 25%

And unutilized capacities of machine 5,6,9 and 10 are 40%, 20%, 35% & 45% respectively. Therefore the part type 5 can be processed on machine 10 as this machine has the capability to process the part type 5 as well as it is having the maximum unutilized capacity.

CONCLUSION

In this paper attempt has been made to get the cell formation by using routing flexibility (alternate routings) and machine flexibility so that all the parts of a particular part family can be processed within the allocated cell of the part family. This will result in the effective utilization of the machines in the cell. As in problem no.2, initially the machine 6 is allocated to process only one part type. But by using its unutilized capacity and capability it can also machine part type 8. By changing the values of similarity coefficient (vigilance parameter) ART-1 algorithm enables to get the different cell formation sizes.

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Table-1

Machines	Part type 1	Part type 2	Part type 3	Part type 4	Part type 5
Machine 1	O_{11} (15)	O_{12} (20)	O_{13} (20)	O_{14} (15)	O_{15} (10)
Machine 2	O_{21} (20)	O_{22} (15)	O_{23} (20)	0	O_{25} (15)
Machine 3	O_{31} (10)	O_{32} (25)	0	O_{34} (35)	O_{35} (10)
Machine 4	O_{41} (20)	0	O_{43} (25)	O_{44} (15)	O_{45} (15)

Table-2

M/cs	Operations to be performed by the machine (utilized capacity)									
M1	O_{11}(05)	O_{12}(10)	O_{13}(05)	0	O_{15}(10)	O_{16}(10)	O_{17}(05)	O_{18}(15)	0	O_{110}(05)
M2	O_{21}(10)	0	O_{23}(05)	0	O_{25}(25)	O_{26}(05)	O_{27}(05)	0	0	0
M3	O_{31}(10)		O_{33}(10)	O_{34}(10)	0	O_{36}(05)	O_{37}(05)	0	O_{39}(10)	O_{310}(05)
M4	O_{41}(25)	0	0	0	0	0	O_{47}(15)	0	0	0
M5	0	O_{52}(15)	O_{53}(10)	0	O_{55}(15)	0	0	O_{58}(30)	0	0
M6	O_{61}(15)	O_{62}(25)	0	0	O_{65}(10)	O_{66}(10)	0	O_{68}(30)	0	0
M7	0	O_{72}(05)	O_{73}(10)	O_{74}(15)	0	O_{76}(15)	O_{77}(10)	O_{78}(15)	O_{79}(05)	O_{710}(05)
M8	0	O_{82}(10)	O_{83}(05)	O_{84}(10)	0	O_{86}(10)	O_{87}(05)	0	O_{89}(05)	O_{810}(05)
M9	0	O_{92}(35)	0	O_{94}(15)	O_{95}(15)	0	0	O_{98}(15)	O_{99}(05)	0
M10	O_{101}(10)	O_{102}(20)	O_{103}(10)	0	O_{105}(10)	0	0	O_{108}(25)	0	0

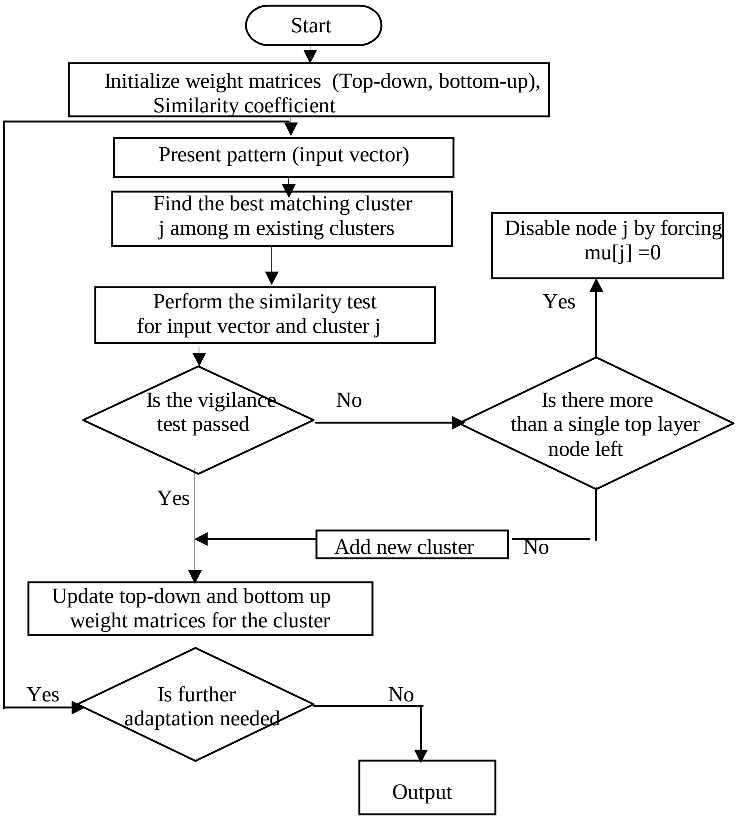

Fig. (1) Flow Chart for ART-1 Algorithm