EFFECTIVE QUANTITATIVE TECHNIQUES FOR PART-MACHINE FORMATION AND THEIR PERFORMANCE METRICS ON GT CELL OPERATION- A STUDY

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Abstract

The main objective of this study is to analyze the effective part-machine formation and their performances matrices on GT cell operation. Cellular manufacturing is an application of group technology that has recently attracted the attention of manufacturing firms. The part-machine cell formation problem mainly minimizing the inter-cell, intra cell movement and maximize machine utilization. The paper presents a generalized approach for part-machine cell formation from a job shop using quantitative techniques in order to reduce set-up time, work-in-progress and lead times; leading to product quality and customer satisfaction.

Keywords- *Part-Machine Formation, Clustering Techniques, Group Technology, Cell Formation*

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1. INTRODUCTION

The objective of all industries is to increase the efficiency through improved productivity. In order to accomplish this task, there is a wide variety methodologies used in industries. Many manufacturing firms which satisfy their customers while operating job shop production system have recently had to rethink because of the superiority of group technology (GT) philosophy of cellular manufacturing [1]. According to that, in cellular manufacturing system (CMS), group technology (GT) could recognize similar parts and cluster term into part families depending upon its manufacturing designs features and geometric shapes. The Cell Formation problem has long been identified in the concept of Cellular Manufacturing which begins with two fundamental task, 1) machine-cell formation, where similar machines are grouped and dedicated to manufacture part-families,2) part family construction, where parts with similar design, features, attributes, shapes grouped and manufactured within a cell[2]. The CF problems are represented by machine-part incidence matrix, where element presented as 0/1. As shown in **Fig.1**

Various approaches to cell formation have since been reported and fall under one of the six major classification: array-based clustering, similarity coefficient, mathematical programming, graph and network, heuristic and combinatorial optimization. The similarity coefficient approach was first suggested by McAuley. The basis of similarity coefficient is to calculate similarity between each pair of machines and then to group the machine into cells based on their similarity measurements [3]. Machine-part grouping problem is based on production flow analysis, in which the machine-part production cells are formed by permutting rows and columns of the machine-part mapping in the form of {0-1} incidence matrix. Some the methods are rank order clustering, bond energy algorithm etc.

	P1	**P2**	**P3**	**P4**	**P5**
M_1	0	1	1	0	1
M_2	1	0	0	1	1
M_3	0	0	1	0	1

Fig.1 Machine-part incidence matrix

The array based rank order clustering techniques for part-machine formation and their performance metrics used in this study. In group technology, machines used to produce a family of parts should be grouped together in a cell [4]. The process of forming cell is known as machine part grouping. This results in each of the individual part and components families being managed easily in the industries.

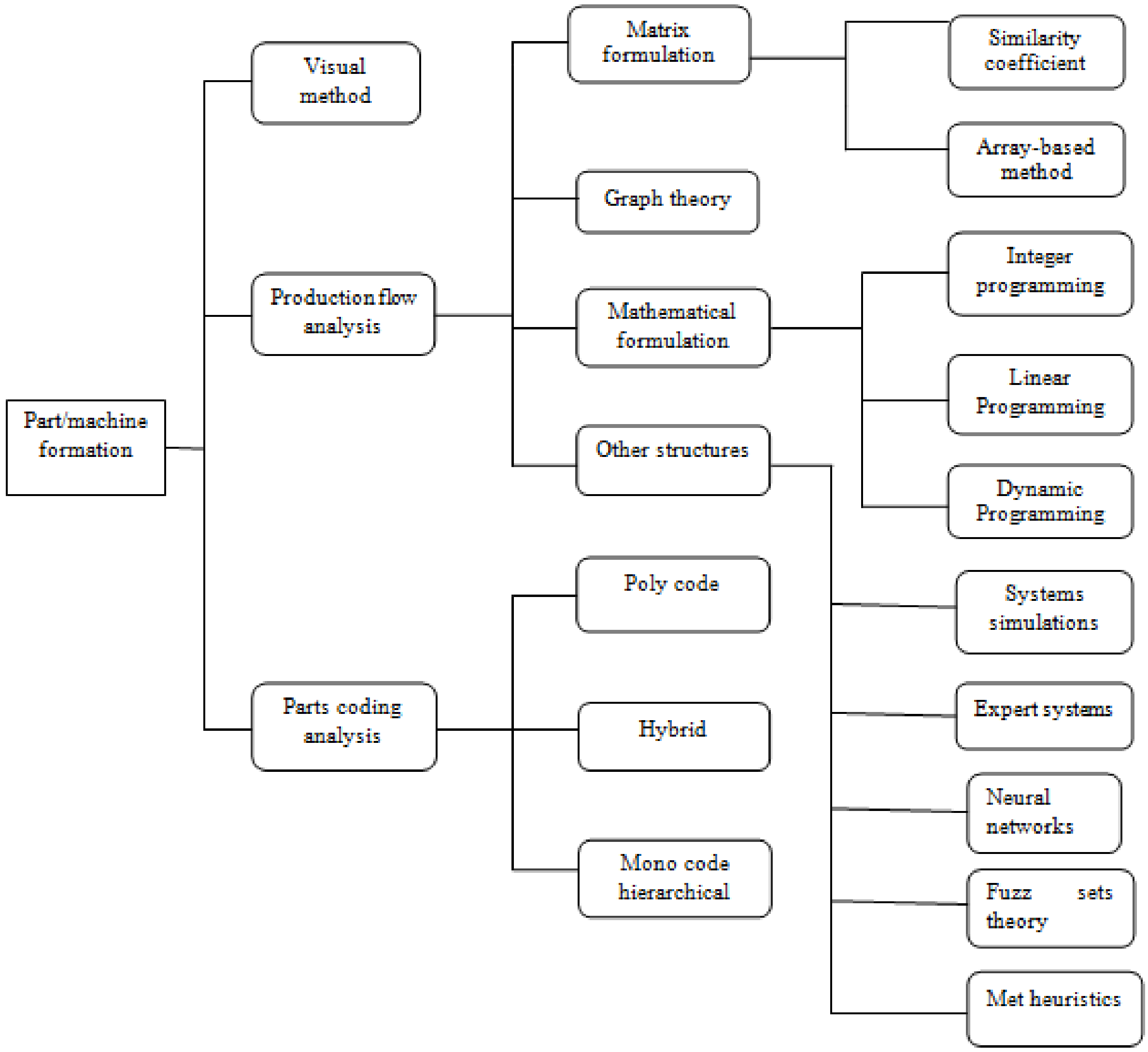

Fig.2 Methods of group formation

2. METHODOLOGY

2.1 Rank order cluster (ROC) algorithm

The ROC algorithm was developed by J.R. King (1980) and is based on the concept of production flow analysis. The effective methodology and part family/machine cell formation problem using rank order clustering algorithm [5].It is an efficient and easy to use algorithm for grouping machines into cells. ROC works by reducing the part-machine incidence matrix to a set of diagonalized blocks that represent part families and associated machine groups. The algorithm consists of the following steps:

Steps in ROC algorithm

- Each row, assign binary weights and calculate decimal equivalent.
- Rank the rows in order of decreasing valve. That is, the rows with the highest decimal equivalent are considered to have the highest rank 1 among the rows and so on.
- Numbering from top to bottom, check whether the current order of rows is the same.
- Rearrange the rows of the matrix rank wise.
- For each column, assign binary weights and calculate decimal equivalents.
- Rank the column in order of decreasing valve.
- Numbering from left to right, check whether the current order of column.Rearrange the column of the matrix rank wise
- The final part-machine incidence matrix. Stop and print.

2.2 Problem 1

Effective ten parts and five machine formation using rank order clustering technique

Table-1: Initial part-machine incidence matrix

Machines	**Parts**									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
M_1	1	1	1	1	1		1	1	1	1
M_2		1	1	1					1	1
M_3	1				1	1	1	1		
M_4		1	1	1				1	1	1
M_5	1	1	1	1	1	1	1	1		

Step 1: For each row, calculate decimal equivalent and binary weights. Then rank the rows in order of decreasing valve

Table-2: calculating the ranking of rows and decimal equivalent

Machines	**Parts**										**Decimal equivalent**	**Rank**
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**		
	Binary weights											
	2^9	**2^8**	**2^7**	**2^6**	**2^5**	**2^4**	**2^3**	**2^2**	**2^1**	**2^0**		
M_1	1	1	1	1	1		1	1	1	1	1006	2
M_2		1	1	1					1	1	450	5
M_3	1				1	1	1	1			572	3
M_4		1	1	1				1	1	1	454	4
M_5	1	1	1	1	1	1	1	1			1020	1

Step 2: From table 2, noted the decimal equivalent and rank

Table-3: Row arrangement

Machines	**Parts**									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
5	1	1	1	1	1	1	1	1		
1	1	1	1	1	1		1	1	1	1
3	1				1	1	1	1		
4		1	1	1				1	1	1
2		1	1	1					1	1

Step 3: Rearrange the rows in rank wise

Table 4: Calculating decimal equivalent and rank column

Machines	**Parts**										**Binary weight**
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	
5	1	1	1	1	1	1	1	1			2^4
1	1	1	1	1	1		1	1	1	1	2^3
3	1				1	1	1	1			2^2
4		1	1	1				1	1	1	2^1
2		1	1	1					1	1	2^0
Decimal equivalent	28	27	27	27	28	20	28	30	11	11	
Rank	2	3	3	3	2	4	2	1	5	5	

Step 4: For each column, calculate decimal equivalent and assign binary weights. Then arrange the rank of column in decreasing valve

Table 5: Rearranging column

Machines	**Parts**									
	H	**A**	**E**	**G**	**B**	**C**	**D**	**F**	**I**	**J**
5	1	1	1	1	1	1	1	1		
1	1	1	1	1	1	1	1		1	1
3	1	1	1	1				1		
4	1				1	1	1		1	1
2					1	1	1		1	1

Step 5: Rearrange the column

2.3 Iteration 2

Table 6: Calculating decimal equivalent and ranking of rows

Machines	**Parts**										**Decimal equivalent**	**Rank**
	H	**A**	**E**	**G**	**B**	**C**	**D**	**F**	**I**	**J**		
	Binary weights											
	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0		
5	1	1	1	1	1	1	1	1			992	2
1	1	1	1	1	1	1	1		1	1	1019	1
3	1	1	1	1				1			964	3
4	1				1	1	1		1	1	571	4
2					1	1	1		1	1	596	5

Step 6: For each row, calculate decimal equivalent and assign binary digit. Then arrange the rank in decreasing valve

Table 7: Rearranging rows

Machines	**Parts**									
	H	**A**	**E**	**G**	**B**	**C**	**D**	**F**	**I**	**J**
1	1	1	1	1	1	1	1		1	1
5	1	1	1	1	1	1	1			
3	1	1	1	1				1		
4	1				1	1	1		1	1
2					1	1	1		1	1

Step 7: Rearrange the rows

Table 8: Calculating the decimal equivalent and ranking columns

Machines	**Parts**										**Binary weights**
	H	**A**	**E**	**G**	**B**	**C**	**D**	**F**	**I**	**J**	
1	1	1	1	1	1	1	1	1			2^4
5	1	1	1	1	1	1	1		1	1	2^3
3	1	1	1	1				1			2^2
4	1				1	1	1		1	1	2^1
2					1	1	1		1	1	2^0
Decimal equivalent	30	28	28	28	27	27	27	20	11	11	
Rank	1	2	2	2	3	3	3	4	5	5	

Step 8: From table 8, it noted that column order differ above matrix

Table 9: Rearranging column

Machines	**Parts**									
	H	**A**	**E**	**G**	**B**	**C**	**D**	**F**	**I**	**J**
1	1	1	1	1	1	1	1	1		
5	1	1	1	1	1	1	1		1	1
3	1	1	1	1				1		
4	1				1	1	1		1	1
2					1	1	1		1	1

Step 9: Rearrange the column

Table 10: Part-machine formation

Machines	Parts										Decimal equivalent	Rank
	H	A	E	G	B	C	D	F	I	J		
	Binary weights											
	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0		
1	1	1	1	1	1	1	1	1			1020	1
5	1	1	1	1	1	1	1		1	1	1019	2
3	1	1	1					1			900	3
4					1	1	1		1	1	597	4
2					1	1	1		1	1	595	5

Step 10: From table 10, it noted that part and machine formation

Table 11: Machine-parts groupings

Group No	Machine cluster	Components family
1	**Cell 1:** 1,5,3	**Part family 1:** H,A,E,G and B
2	**Cell 2**: 4,3	**Part family 2:** C,D,F,I and J

2.4 Performance metrics in cell operations

Some of the equation developed in industry operation can be adapted to the operation of group technology cells. Suppose the cell consists of of n machines (work station) and produces a family of parts with n_f family members. Let i=a subscript to identify machines (i=1, 2, 3…..n), and let j=a subscript to identify family members (j=1, 2…n_f).[6] The production time of family member j on machine I is given by T_{pij} which is determined as follows

$$T_{pij}=\frac{T_{suij}+Q_jT_{cij}}{Qj} \quad (1)$$

Where T_{suij}= the setup or change over time to prepare for family member j on machine *i*, min; T_{cij}= operation cycle time for family member j, pc. Unlike conventional batch production, one would expect the T_{suij} valve to be minimal; in the ideal case, there would be no lost time for changeover in cellular manufacturing (T_{suij}=0). Similarly, batch quantity Q_j would be low, perhaps a batch size of one (Q_j=1). With these valves, $T_{pij}=T_{cij}$. However, equation (1) allows for changeover time between different family member, and for the family members, and for the family members to be run in batches if there is a change over time [7].

The production rate R_{pij} for family member j on machine *i* is the reciprocal of production time, multiplied by 60 to express it as an hourly rate:

$$R_{pij}=\frac{60}{T_{pij}} \quad (2)$$

Let f_{ij} = the fraction of time during steady state operation that machine *i* is processing family member j. under normal conditions, it follos that for each machine *i*.

$0 < \Sigma f_{ij} < 1$ where $0 < f_{ij} < 1$ for all *i*. (3)

The valve of Σf_{ij} for each machine is the utilization of that machine within the cell. That is,

$$U_i=\sum_J f_{ij} \quad (4)$$

Where U_i = utilization of machine *i*. if Σf_{ij} = 1, the machine is fully utilized. More likely, Σf_{ij} will be less than 1 for at least some of the machines in the cell. The average utilization of the cell is the average of the machine utilization:

$$U=\frac{\sum_{i=1}\sum_{j} fij}{n}=\frac{\sum_{j} U_i}{n} \quad (5)$$

Each family members is processed through n_{oj} operations (machines) in the cell. The production rate of the cell is given by

$$R_p=\sum^{n}_{i=1}\sum_{j}\frac{f_{ij}R_{pij}}{n_{oij}} \quad (6)$$

Where R_p = average hourly production rate (pc/hr) of the cell; n_{oj} = the number of operations required to produce family member j, and the other terms are defined earlier.

One of the advantages of cellular manufacturing is reduced lead time to get parts through the cell compared to a job shop. The manufacturing lead time is the sum of setup time, run time, and nonoperation time. The nonoperation time consists of waiting time and move time within the cell [8]. For any family member, this can be expressed as follows:

$$MLT_j=\sum_{i=1}^{n_{oj}}(T_{suij}+Q_jT_{cij}+T_{noij}) \quad (7)$$

Where MLT_j = manufacturing lead time for part family member j, min; T_{suij}= setup (changeover) time for operation I on family member j,min; Q_j= batch quantity of family member j being processed in the cell, pc; T_{cij}= cycle time for operation I on family member j, min/pc; T_{noij} = nonoperation time associated with operation I, min; and i= indicates the operation sequence in the processing: i=1,2,…., n_{oj}, one would expect the setup time to be minimal in a group technology cell, depending on how similar the family members are. The nonoperation time in a GT cell would also be expected to be significantly less than in a conventional job shop or batch production situation. The average manufacturing lead time for the part family is given by the following [9]

$$MLT = \frac{\sum_{j=1}^{nf} MLT_j}{n_f} \quad (8)$$

Where MLT =average manufacturing lead time for the n_f family members and MLT_j = lead time for family members j from above equation

The work-in-progress manufacturing within the cell can be determined from the production rate and manufacturing lead time.

$$WIP = R_p\,(MLT) \quad (9)$$

Where WIP= work-in-progress in the plant, pc; R_p = average hourly production rate from above equation

2.5 Problem 2

A group technology cell has three machines and is used to process a family of four similar parts. The table below lists production quantities (Q_j), production times (T_{pij}) and machine fractions for each family (f_{ij}). Assuming the nonoperation times (T_{no}) is all the same at 30 min per machine

		Machine 1		Machine 2		Machine 3	
Part	Q_j	T_{P1} (min)	F_{1j}	T_{p2} (min)	F_{2j}	T_{p3} (min)	F_{3j}
A	1	3.0	0.2	4.5	0.3	2.25	0.15
B	1	2.0	0.2	4.0	0.4	3.0	0.3
C	1	5.0	0.25	4.0	0.2	3.0	0.15
D	1	4.0	0.3	1.333	0.1	2.667	0.2

2.6 Solution

Hourly production rate for each machine and family member were computed using equation (2). The quantities of each family member produced in 1hr were $Q_{ij}=f_{ij} R_{pij}$. The total for each column represents the hourly output of all parts from each machine (17.5 pc/hr).

The MLT values were obtained from $MLT_j = T_{p2j} + T_{p2j} + T_{p3j} + T_{no.}$

R_{p1}	R_{p2}	R_{p3}	Q_1	Q_2	Q_3	MLT
20.00	13.33	26.67	4.00	4.00	4.00	99.75
30.00	15.00	20.00	6.00	6.00	6.00	99.00
12.00	15.00	20.00	3.00	3.00	3.00	102.00
15.00	45.00	22.50	4.50	4.50	4.50	68.00
			17.50	17.50	17.50	398.75
Average MLT = 99.7						

3. RESULT AND CONCLUSION

a) Hourly production rate for each machine and for the cell R_p = **17.5 parts/hr**
b) Average manufacturing lead time MLT= 99.7 min
c) Utilization for each machine is given byΣf_{ij} for each machines i. Thus, U_1=0.95, U_2= 1.0, U_3= 0.80. Average cell utilization U= 0.917
d) Average work-in-process WIP=(17.5 parts/hr) (1.661 hr) =**29.1 Parts**

This paper tells about the part-machine formation problem using rank order clustering, Pearson's correlation coefficient and performance metrics on GT operation. The proposed method obtains better quality solutions by consuming lesser time and the above result shows that proposed measures has the ability to perform its productivity efficiently.

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BIOGRAPHIES

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