RESEARCH ARTICLE

Group Technology for Optimizing Manufacturing Facility Layout

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Abstract: In recent years, the process of cellular manufacturing and group technology have received a lot of attention and popularity in many developed countries. By applying Group Technology (GT), many benefits of flow-line production can be attained in a batch production system. GT improves material handling significantly by reducing material flow time, distance, and setup times. In this paper, an earnest investigative attempt was made to provide valuable information regarding the use of Group Technology by applying to a real world jobshop system. The proposed GT model has the flexibility of choosing the number of cells required, which is very useful in examining different manufacturing cell configurations; or in case the workshop or factory prefers a certain number of work cells. The GT model results were found satisfactory and superior to other techniques in some cases.

Keywords: Group Technology, Cellular Manufacturing, Facility Layout, Optimization.

1. Introduction

A typical company makes thousands of different parts as products, in multiple different batch sizes, which resulted in a variety of different manufacturing operations, processes and technologies. It is beyond the human capabilities to comprehend and manipulate such vast amounts of detailed data. People still need to make decisions regarding how to run a manufacturing company and succeed in today's competitive environment on domestic and foreign markets. For this reason, continuous improvements are needed to increase response times to customer changes. One of the strategies and methodologies is called Group Technology (GT) which focuses on Cellular Manufacturing.

GT offers a substantial benefit to companies that have the perseverance to implement it. The formation of machine cells is one of first important steps in the development and implementation of GT. New achievement in computer technology and artificial intelligence have provided the opportunity to apply more advanced clustering technique to group technology problem.

2. Literature Review

Many researchers have developed techniques for solving the GT problem (Burbidge et al.,1963).

- Rule of thumb techniques: these techniques use some rules of thumb to identity the part families and machines cells. Clearly such techniques are not useful in solving large scale problems, but are relatively easy to use.

- Classification and coding techniques: this group technique parts are based solely on their processing characteristics. Grouping the parts is based on a number of attributes. This technique is sub classified as hierarchical codes, non-hierarchical codes, and hybrid codes.

- Production flow analysis (PFA) techniques: PFA techniques involve the systematic listing of information contained in route cards and identification of part families and machine cells by careful inspection. Some of the later forms of PFA techniques which use a part machine process indicator matrix specify the machining requirements on parts, and then attempt to manipulate the rows and

columns of this matrix to identify clusters. Research simulation studies which use the functional system may be preferable to CMSs.

Han and Ham (1986) classified the GT algorithms in the following ways:

- Peripatetic and ocular technique: these techniques have knowledge concerning the parts and manufacturing systems which are used to determine machine cells and part families. These methods are also not much use in practice.

- PFA technique: (similar as mentioned previously).

- Classification and coding technique: (similar as mentioned previously).

- Mathematical programming technique: These techniques use "fuzzy" mathematics, pattern recognition, cluster analysis, etc. to identify part family and machine cell combinations.

Vakharia (1986) used the following classification:

- Descriptive technique: descriptive technique includes the PFA techniques and other component flow analysis (CFA) techniques.

- Block diagonal technique: this technique is similar to the clustering technique.

- Similarity coefficient technique: (similar as mentioned previously).

Nair and Narendran (1998) proposed the cell formation methodologies based on the similarity (or dissimilarity) coefficient reflecting the operation sequence and production volume the operation and production volumes of parts.

In addition to operation sequence, Won and Lee (2001) consider production volume while grouping machine/parts into cells. This method is suited for medium size problem i.e., problem with machine/parts up to 13 products and machines.

Basically, two approaches have been used to seek the optimal solutions for Facility Layout Problem. These are: the quadratic assignment problem approach and the graph-theoretic approach (Kai-Yin and Meller, 1996). The graph-theoretic approach problems are obtained to maximize the adjacency of departments as objective function. Most known example is SPIRAL (Goetschalckx, 1992).

3. Mathematical Model

3.1. Notations

n : number of parts

m : number of machines

p_{min} : minimum number of cells

p_{max} : maximum number of cells

r : index of part type, r = 1,…..n

i, j : index of machine type, 1,…..m

k : index of cells (families), k = 1,…..p

L_f : lower limit on part family size

U_f : upper limit on part family size

L_c : lower limit on machine cell size

U_c : upper limit on machine cell size

A = [a_{ri}], binary PMIM

$$a_{ri} \begin{cases} 1 \ if \ part \ 'r' \ equires \ processing \ on \ machine \ i \\ 0 \qquad\qquad\qquad otherwise \end{cases}$$

n_r : total number of operations required by part 'r'

d_r : production volume of part 'r'

$TOTOP_k$: total number of operations in the kth cell

NOP_k : total number of non – operations (voids) in the kth cell.

3.2. Formulation

$$\text{Min } \sum_{k=1}^{p_{min}} \sum_{r=1}^{n} \sum_{i=1}^{m} \sum_{j \neq 1}^{m} \left(d_r b_{ijr} X_{ijrk} \right) /2 \tag{1}$$

$$b_{ijr} = \begin{cases} 1 \text{ if volume of material flows from machine} \\ \quad 'i' \text{ to machine } 'j' \text{of part } 'r' \\ 0 \text{ otherwise} \end{cases}$$

$$x_{irk} = \begin{cases} 1 \text{ if machine } 'i' \text{of part } 'r' \text{belongs to cell k} \\ 0 \text{ otherwise} \end{cases}$$

$$x_{jrk} = \begin{cases} 1 \text{ if machine } 'j' \text{of part } 'r' \text{belongs to cell k} \\ 0 \text{ otherwise} \end{cases}$$

$$X_{ijrk} = |x_{irk} - x_{jrk}| \tag{2}$$

$$\sum_{k=1}^{p} x_{rk} = 1, \qquad r = 1,\ldots\ldots,n \tag{3}$$

$$x_{rk} = \begin{cases} 1 \text{ if part } 'r' \text{belongs to cell k} \\ 0 \text{ otherwise} \end{cases}$$

$$L_f \leq \sum_{r=1}^{n} x_{rk} \leq U_f, \qquad k = 1,\ldots,p \tag{4}$$

$$\sum_{k=1}^{p} y_{ik} = 1, \qquad i = 1,\ldots\ldots,m \tag{5}$$

$$y_{ik} = \begin{cases} 1 \text{ if machine } 'j' \text{belong to cell k} \\ 0 \text{ otherwise} \end{cases}$$

$$L_c \leq \sum_{i=1}^{m} y_{ik} \leq U_c, \qquad k = 1,\ldots\ldots p \tag{6}$$

3.3. Algorithm

Step 1: Start the process

Step 2: Input the number of machines, **m**

Step 3: Input the number of parts, **n**

Step 4: If no of machines, $m \leq 24$, then $L_{c\,min} = 2$, $L_{c\,max} = \left({no.\,of\,mc's} / {L_{c\,min}} \right)$

Go to Step 6 Else Go to Step 5

(Here the algorithm makes sure that the maximum number of machines that can be allotted is 12)

Step 5: Calculate $L_{c\,min} = \left(\frac{no.of\,mc's}{12} \right)$, $L_{c\,max} = \left(\frac{no.of\,mc's}{L_{c\,min}} \right)$

Step 6: If no. of parts, $n \leq 24$, then $L_{f\,min} = 2$, $L_{f\,max} = \left(\frac{no.\,of\,parts}{L_{f\,min}} \right)$

Go to Step 8 Else Go to Step 7

(Here the algorithm makes sure that the maximum number of parts that can be allotted is 12)

Step 7: Calculate $L_{f\,min} = \left(\frac{no.of\,parts}{12} \right)$, $L_{f\,max} = \left(\frac{no.of\,parts}{L_{f\,min}} \right)$

Step 8: Set Minimum no. of cells, p_{min} = Max ($L_{c\ min}$, $L_{f\ min}$)

Step 9: Set Maximum no. of cells, p_{max} = Min ($L_{c\ max}$, $L_{f\ max}$)

Step 10: Set $L_f = L_{f\ min}$ and $U_f = 12$

Step 11: Set $L_c = L_{c\ min}$ and $U_c = 12$

Step 12: Group the machines using New GT formulation

Step 13: Calculate Intercellular flow count, Bond Efficiency, MH cost

Step 14: Display the result

Step 15: If $p_{min} = p_{max}$, Go to Step 18 Else Go to Step 16

Step 16: Set If pmin = pmin + 1

Step 17: Go to step 9

Step 18: Stop the process

Note: For $L_{c\ min}$ /$L_{f\ min}$, the value should be rounded off to the next higher integer value (i.e., if the value is 2.3 it should be rounded off to 3) and

For $L_{c\ max}$/$L_{f\ max}$, the value should be rounded off the to the lower integer value (i.e., if the value is 2.3 it should be rounded off to 2).

3.4. Performance Measure

Existing Bond Effeciency Formulation:

Existing Bond Efficiency: $\beta = \dfrac{I(I-U)}{I} + \dfrac{(I-q)\sum_{k=1}^{c} TOTOP_k}{\sum_{k=1}^{c}(TOTOP_k + NOP_k)}$

$$I = \sum_{j=1}^{n}(r_j - 1), r_j = \text{maximum number of operations for component j}$$

$$U = \sum_{j=1}^{n}\sum_{k=1}^{r_j-1} xl_{jk}$$

$Xl_{jk} = 0$ if operations k, k +1 are performed in the same cell

$$U = \sum_{j=1}^{n}\sum_{k=1}^{r_j-1} xl_{jk},$$

$Xl_{jk} = 0$ if operations k, k + 1 are performed in the same cell; = 0 otherwise

Compactness of each cell is defined as the ratio of the number of operations within it to the maximum number of operations possible in it.

3.5. Modified Bond Efficiency Formulation

The new method of bond efficiency which minimizes intercellular flow and maximizes the density of 1's is used for determining the cell configuration. Bond Efficiency (β), equation (7) is defined as a weighted average of Compactness (9) and GT efficiency (8)

$$\beta = \dfrac{\dfrac{(I-U)}{I} + \dfrac{\sum_{k=p_{min}}^{p_{max}} TOTOP_k}{\sum_{k=p_{min}}^{p_{max}}(TOTOP_k + NOP_k)}}{2} \tag{7}$$

β is non – dimensional and non – negative

Group Technology Efficiency is defined as the ratio of the difference between the maximum number of inter – cell travels possible and the number of inter – cell travels possible.

$$\text{GT efficiency} = \dfrac{I-U}{I} \tag{8}$$

where,

$$I = \sum_{r=1}^{n} d_r(n_r - 1)$$

$$U = \sum_{r=1}^{n} \sum_{1}^{n_r-1} X_{ijr} \, d_r$$

Compactness of each cell is defined as the ratio of the number of operations within it to the maximum number of operations possible in it.

$$\text{Compactness} = \frac{\sum_{k=1}^{Pmin} TOTOP_k}{\sum_{k=1}^{Pmin}(TOTOP_k + NOP_k)} \qquad (9)$$

For a perfect diagonal block, Compactness takes the value of '1' and NOP_k takes the value of '0'.

4. Approach GT Method on Secondary Data

The process sequence information along with the production volume for 19 products using the 12 machines is shown below in Table 1.

Table 1: Machine sequence information for the all products with production volume

Products	Sequence (Machines)	Production Volume
A	1-4-8-9	2000
B	1-4-7-8-7	3500
C	1-2-4-7-8-9	3600
D	1-4-7-9	1600
E	1-6-10-7-9	4000
F	6-10-7-8-9	5000
G	6-4-8-9	1600
H	3-5-2-6-4-8-9	6300
I	3-5-6-4-8-9	4200
J	4-7-6-8	2000
K	06-11-12	1200
L	11-07-12	1800
M	11-12	1400
N	11-07-10	1500
O	1-7-11-10-12	4000
P	1-7-11-12	4800
Q	11-07-12	1800
R	06-07-10	1500
S	10-11-12	1500

Number of cells calculation

From the algorithm (3.3),

Number of machines, **m = 12**

Number of parts, **n = 19**

Since number of machines, **m ≤ 24, L$_{c\,min}$ = 2**

Lc max = ($^{no.ofmc's}$/L$_{c\,min}$) = (12/2) = 6

i.e. Lc max = 6

Since number of parts, n ≤ 24, L$_{f\,min}$ = 2

L$_{f\,max}$ = ($^{no.ofparts}$/L$_{f\,min}$) = (19/2) = 9.5 = 9 (rounding off to the lower integer value)

i.e. L$_{f\,max}$ = 9

Minimum cells required, P$_{min}$ = Max (L$_{c\,min}$, L$_{f\,min}$) = Max (2,2) **P$_{min}$ = 2**

Maximum cells required, P$_{max}$ = Min (L$_{c\,max}$, L$_{f\,max}$) = Min (6,9) **P$_{max}$ = 6**

Setting L$_f$ = Lf min and U$_f$ = 12, L$_f$ = 2 and U$_f$ = 19 (lower and upper limits on part family size)

Setting L$_c$ = L$_c$ min and U$_c$ = 12, L$_c$ = and U$_c$ = 12 (lower and upper limits on machine cell size)

The From – to chart for all the machines are listed in Table 2.

Table 2: From – to chart for 12 machines

Machines	Parts																		
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1 to 4	500	700		400															
4 to 8	500						400	900	700										
8 to 9	500		600			1000	400	900	700										
7 to 8		700	600			1000													
8 to 7		700																	
7 to 9				400	800														
1 to 6					800														
6 to 10					800	1000													
10 to 7					800	1000	400												
6 to 4								900	700										
3 to 5								900											
5 to 2								900											
2 to 6								900	700										
6 to 4									700										
5 to 6										500									
4 to 7		700	600	400						500									
7 to 6										500									
6 to 8											400								
6 to 11											400		700			1200			500
11 to 12												600		500			600		
11 to 7												600		500			600		
7 to 12															800			500	
7 to 10																1200			
1 to 7															800	1200			
7 to 11																			
11 to 10															800				
10 to 12																			
6 to 7															800			500	
10 to 11																			500
1 to 2			600																
2 to 4			600																

5. Results and Discussion

Since the material handling cost for all the five configuration (2,3,4,5 and 6) account for the same value, the performance measure can be used to select the best configuration. The bond efficiency β of cell

configuration 3 has the highest value (**0.699**) when compared with other configurations, hence we select cell configuration 3 for the given production plan as can be seen in Table 3.

**Table 3:** Performance measure, total material handling cost for different cell configurations.

Cell Configurations	Material handling cost	Performance measure		
		GT efficiency	Compactness	Bond efficiency β
2 cells	9900	0.759	0.564	0.662
3 cells	**12700**	**0.690**	**0.707**	**0.699**
4 cells	22200	0.459	0.818	0.639
5 cells	29300	0/285	0.921	0.603
6 cells	31300	0.237	0.868	0.553

Table 4 is the final table that shows the data from the algorithm that determines the suitable work cells allocation for the jobshop system.

Cell	Machine Types	Qnt	PF1								PF2									PF3	
			PA	PB	PD	PE	PG	PJ	PF	PC	PR	PO	PP	PK	PL	PM	PS	PN	PQ	PH	PI
C1	M1	2	1	1	1	1				1		1*	18								
	M8	1	3	4			3	4	4	5										6*	5*
	M9	1	4		4	5	4		5	6										7*	6*
	M4	3	2	2	2		2	1		3										5*	4*
	M7	1		3,5	3	4		2	3	4	2*	2*	2*		2*			2*	2*		
	M6	1				2	1	3	1		1*									4*	3*
C2	M10	2				3*			2*		3	4					1	3			
	M11	4										3	3	2	1	1	2	1	1		
	M12	1										5	4	3	3	2	3		3		
C3	M2	1							2*											3	
	M5	2																		2	2
	M3	1																		1	1

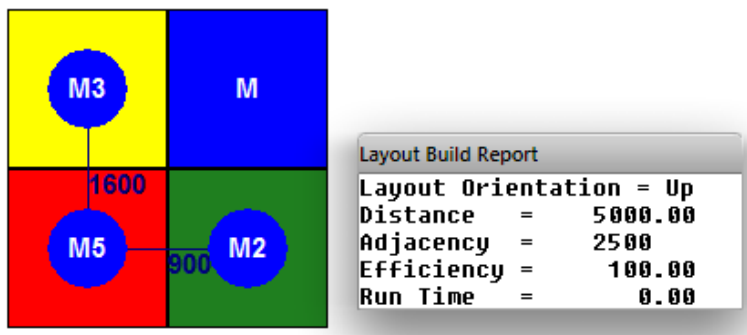**Table 4:** Processing time of machines within cells

Figures 1,2 and 3 show the results for three cell using Spiral software package.
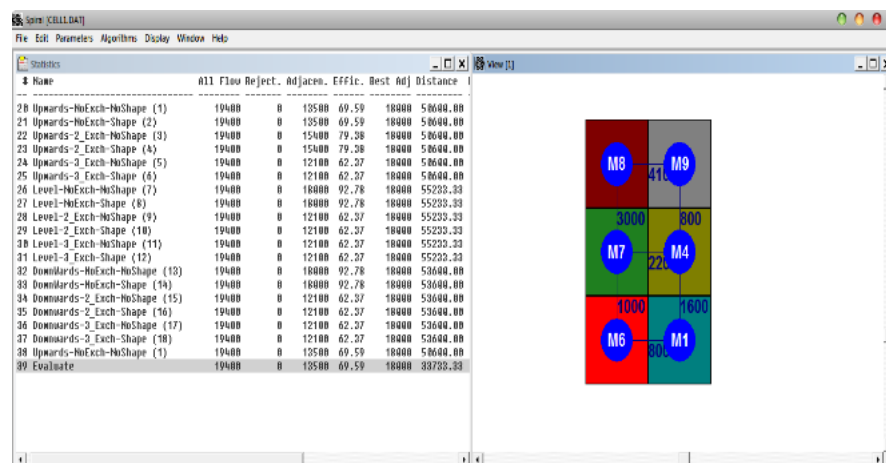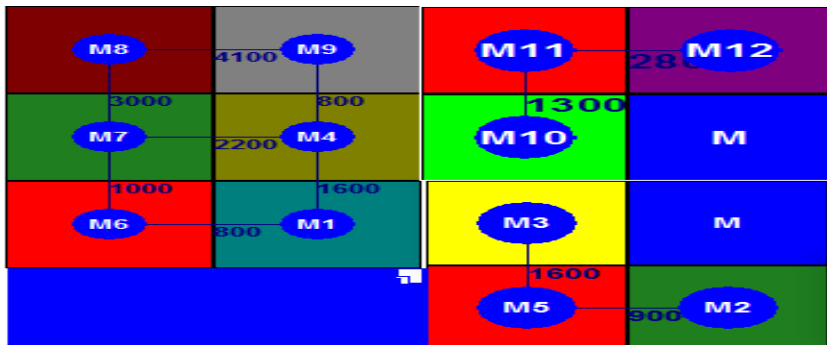

Figure 1: Cell 1 configuration result
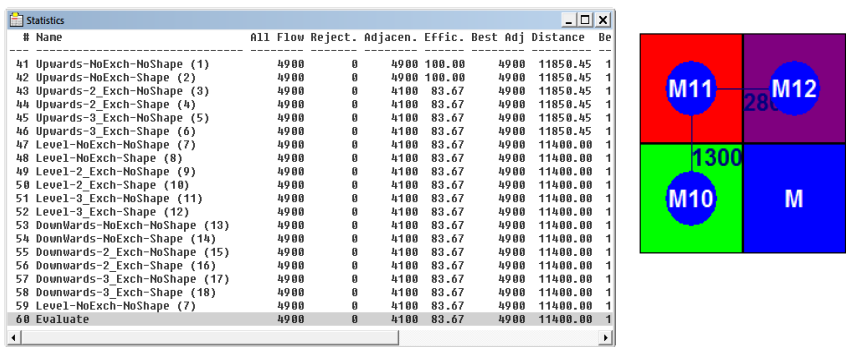
Figure 2: Cell 2 configuration result

Figure 3: Cell 3 configuration result

Figure 4: Final layout

6. Conclusion

From the study results, it is concluded that the proposed methodology can be used to solve facility layout problems using Group Technology and Spiral software package. The developed model proved to be efficient irrespective of the size of the problem considered, even after inclusion of details such as machine sequence, production volume and machine revisits along with the performance measure for the cells formed. By restricting the number of cell configurations between an upper and lower limit, the model eliminated the possibility of unwanted configurations that increases the complexity of the problem. The proposed method can be used to get the actual number of intercellular movements between cells and also can be used to select the best configuration for a given production plan using reduced material handling cost as the criteria.

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