Cellular layout formation by using weighted similarity-based modified flow matrix with process sequence data

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Abstract: Cellular layout formation (CLF) is an important problem in the design of a cellular manufacturing system (CMS). From the previous studies, most of the researchers have used machine part incidence matrix (MPIM) as input in CMS. In this paper, weighted similarity based modified flow matrix is proposed to solve the cell formation problem (CFP) and CLF simultaneously. The objective of our proposed approach is to group dissimilar machines based on the process sequence of different parts. Two well-known benchmark problems are selected from the literature and results are compared based on modified grouping efficacy with the existing methods. The results clearly indicated that our proposed approach outperforms the previously proposed methods.

Keywords: cell formation; cellular layout; cellular manufacturing system; CMS; machine part incidence matrix; MPIM; similarity coefficient; modified flow matrix; MGTE; instant forward movement; instant backward movement; process sequence.

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1 Introduction

Group technology (GT) is a manufacturing philosophy in which parts are grouped based on their geometry, manufacturing process and that parts are manufactured by using a small number of dissimilar machines. Those similar parts are called part family and the dissimilar machines, which are used to manufacture the part family, are called as machine cell. Cellular manufacturing system (CMS) is an efficient approach for implementing the principles of GT in a production environment. Part family classification and machine cell formation are complex problems in CMS. CMS has the following advantages:

1 reduction in setup time
2 reduction in work in progress
3 reduction in material handling cost
4 reduction in material flow distance
5 improvement in machine utilisation
6 reduction in production lead time
7 improve in quality
8 better worker morale.

Cell formation is a complex process and there are numerous approaches for this purpose such as array-based clustering, agglomerative clustering, mathematical programming, graph partitioning, and non-traditional methods. Above-said methods can be classified as cell formation by a binary part-machine incidence matrix and machine cell formation by a sequence of operation data. The array-based clustering methods (Boctor, 1991; Chan and Milner, 1982; King, 1980; King and Akornchai, 1982; Kusiak and Chow, 1987; Mccormick et al., 1972), agglomerative clustering methods (Mcauley, 1972; Tam, 1990; Seifoddini, 1990; Garbie et al., 2005; Yin and Yasuda, 2005, 2006), mathematical programming (Kusiak, 1987; Mahdavi et al., 2007; Srinivasan et al., 1990; Viswanathan, 1995), graph partitioning (Rajagopalan and Batra, 1975; Ferreira et al., 1993) and non-traditional methods (Moon et al., 1999; Asokan et al., 2001; Jayaswal and Adil, 2004; Solimanpur et al., 2004; Suer et al., 2003; Cao and Chen, 2004; Akturk and Turkcan, 2000) have been used to form the machine cell. In this research a weighted similarity-based modified flow matrix approach is proposed to solve the CMS by considering the machine cell formation, cell layout formation, exceptional elements and voids simultaneously. Process sequence of parts and part visits the machine pair data are used as an input to form the machine cell, identifying part families and machine layout formation. In addition, it minimises the inter-cell movement, intra-cell movements and voids. This approach is illustrated by some familiar examples and its performance is measured by modified group technology efficacy (MGTE). It also compares with the well-known approaches CLASS and CASE.

Remainder of this paper is structured as follows: Section 2 introduces a literature review. Section 3 illustrates the problem definition which contains cell formation by operation sequence data and machine cell layout. In Section 4, an overview of CLASS algorithm and flow matrix is presented. In Section 4, the new approach called weighted similarity-based modified flow matrix is proposed and explained by examples and advantages of our approach are also explained. In Section 5, results and comparison of the proposed approach are discussed. Finally, Section 6 concludes and possible future studies are also described.

2 Literature review

Process sequence data and number of parts moving between the machines gives additional information to form the cell and CLF. Important production factor in the design of CMS is the process sequence of parts. The process sequence means an ordering of the machines on which the part is processed sequentially. The number of parts moving between both the machines means a part that is processed by two machines enhances the coefficient value for the two machines. Selvam and Balasubramanian (1985) proposed heuristic-based algorithm for grouping the parts based on the operation sequence. The main criterion of this algorithm is to minimise material handling cost and the machine idle time cost. Wu and Suzuki (2015) developed a new methodology for cellular manufacturing system in two phases. In first stage, an improved similarity coefficient is proposed for identify the part family based an operation sequence and number of repeated operation. In second phase, decomposed mathematical model is based on alternative process routings, capacity of machines, operational time and inter-cell movement cost, to assign machines into part families. An operation sequence-based similarity coefficient was presented to identify the part family by Tam (1988).

Choobineh (1988) developed a two-stage process for the design of cell formation problem based on process routings. In first stage, similarity coefficient was used to form part. An integer-programming model was developed to form machine cells. An operations sequence-based methodology called skip moves and lazy machines (SMLM) was developed for part family formation by Mehmood et al. (2015). Won and Logendran (2015) presented two-phase *p*-median approach for the balanced cell formation (CF). In first phase, process sequence, setup time, processing time, lot size-based *p*-median mathematical model for machine cell formation uses a new similarity coefficient based on non-binary part-machine incidence matrix (PMIM). In second phase, a systematic part assignment process based on the new classification system of part types is used for balancing the workload between the machine cells. Ahi et al. (2009) applied TOPSIS to find the initial solution and then this solution was improved by multiple attribute decision-making (MADM) concepts to determine cell formation, intracellular machine layout and cell layout. Seifoddini and Djassemi (1995) compared two types of similarity namely Jaccard’s coefficient and production volume-based similarity coefficient. The sums of intercellular and intracellular material handling costs were considered as a decisive factor for performance assessment.

Mahdavi et al. (2008) developed a flow matrix-based heuristic algorithm used for cell formation and layout design in a concurrent fashion based on sequence data. Nair and Narendran (1998) proposed a new similarity measure-based non-hierarchical clustering approach to form the machine cell and identifying part family on basis of sequence data. An electromagnetism like (EM-like) algorithm was developed to solve the cell formation and cell layout identification problems by Fariborz et al. (2012). Mahdavi et al. (2013) presented a machine sequence-based integrated mathematical model for cell formation and layout formation. They also developed two performance measures to measure the quality of the solution. A new group technology efficacy for ordinal data was proposed by Lee and Ahn (2013). Chang et al. (2013) developed a two-stage mathematical programming model and tabu search algorithm based on a generalised similarity coefficient for cellular manufacturing system, which considers the alternative process routings, operation sequences and production volume. Kim et al. (2004) developed a two phase multi-objective heuristic algorithm for identifying the part families and machine cells for minimising the inter-cell part movements and maximum machine workload imbalance. Operation sequence and part visiting data-based bacteria foraging algorithm (BFA) was developed by Nouri et al. (2010).

Wu et al. (2009) developed a hybrid simulated annealing algorithm to minimise the inter-cell movement and maximise the grouping efficacy by considering multiple process routing of parts in cell layout formation problem. A two-phase approach was proposed by Chan et al. (2008). In the first phase, multi objective mathematical model was developed to form machine cells and part families. In second phase, single objective mathematical model is used to minimise both inter and intra cell movements. Gohal et al. (2013) have developed a novel operation sequence-based bypassing moves and idle machines (BMIM) similarity coefficient by longest common subsequence (LCS) and the minimum number of bypassing moves and the quantity of idle machines. Inter-cell movement, backward movements, number of voids and number of process-based CLASSPAVI approach for cell formation and cell layout formation was proposed by Raja and Anbumalar (2016b). They also developed a MGTE as new performance measure. Deep and Singh (2015) developed a genetic algorithm-based heuristic to solve the cell formation problem. They considered process time, operation sequence, production volume and alternative process routings to allocate the parts into the cell.

Machine-part incidence matrix with operational sequence-based hierarchical genetic algorithm (HGA) approach was proposed to solve the CF, within cell machine layout design and cell layout design, by Chandrasekar and Venkumar (2013). The effectiveness of the CMS design is measured by grouping efficiency and the grouping efficacy. Ghosh et al. (2013) developed a three stage novel approach used to form the machine cell in cellular manufacturing system. Firstly, a similarity matrix is formed by covariance analysis procedure. Next stage, an eigenvalue and eigenvector based hybrid principal component analysis is used to form the cell. In the last stage, the solution quality and the clustering efficiency are improved by adopting an adjustment heuristic. Raja and Anbumalar (2016a) proposed an operation sequence-based similarity coefficient and Kaiser's rule for feasibility assessment, cell formation and to identify the number of cells.

Mahdavi and Mahadevan (2008) developed a CLASS algorithm to form cell and machine layout simultaneously. They formed the machine cell and machine layout based on operation sequence data of parts. They only considered the specific satiations. They did not considered inter-cell movements, exceptional elements and voids. In this paper, a new weighted similarity coefficient is proposed for cell formation and cell layout formation in cellular manufacturing system. This proposed approach is used to minimise intra-cell movements, inter-cell movements, number of exceptional elements and number of voids in cell formation problem.

3 Problem definition

3.1 Cell formation with ordinal data

CFP involves the relocation of its columns and rows to form machine cell and part families. Let *P* be the set of parts and *M* the set of machines. Every part has its own sequence, every part's manufacturing sequence is expressed as a part-machine incidence matrix of size ($n \times m$), where 'n' represents a row (machine) and 'm' represents a column (parts). Each part is to be processed based on the operation sequence. Inter-cell movements of parts will increase material handling distance, cost of material handling, manufacturing lead-time and inventory, which also causes low utilisation of machines. Cluster the parts based on their process sequence, and associated machines are grouped into machine cell is called cell formation. CFP takes the machine-part incidence matrix as input. The aim of the CFP is to minimise backward movement, inter-cell movement and intra-cell movement. A greater number of backward movements affects the machine cell performance. In the final matrix, number of positive entries outside the cell is called exceptional elements; number of blanks inside the cell is called voids.

3.2 An overview of class algorithm and flow matrix

The definition and shortcomings of flow matrix are explained in this section. Mahdavi and Mahadevan (2008) and Mahdavi et al. (2008) have proposed the CLASS algorithm and flow matrix-based heuristic algorithm for cell formation and machine layout formation simultaneously. They have formulated a flow matrix on the basis of number of successive forward movements of parts between the machines and use it as the input for the grouping of machines and intra-cell machine layout problem. They have not considered number of exceptional elements, number of voids and inter-cell movements of parts. In this proposed approach, cell formation, cell layout formation, reducing inter-cell movement, reducing intra-cell movement, minimising the voids and exceptional elements are included.

Table 1 5 × 7 initial machine part incidence matrix

Machines	*Parts*						
	1	*2*	*3*	*4*	*5*	*6*	*7*
1	1	2	1	1		3	
2			2	2	1		1
3	2	1		3		1	
4	3	3				2	
5			3		2		2

The flow matrix is explained by using example 1. Table 1 shows 5 × 7 initial PMIM. Each entry in the part-machine matrix indicates operation sequence for parts.

Table 2 Result of flow matrix for example 1

Machines	*Machines*				
	1	*2*	*3*	*4*	*5*
1	0	2	1	1	0
2	0	0	1	0	3
3	1	0	0	2	0
4	1	0	0	0	0
5	0	0	0	0	0

From the result of flow matrix, highest threshold value is 3 in the machine location m_2 and m_5. Assign machines 2 and 5 in first cell based on highest threshold value. The next highest value is 2 in the machine locations m_1 and m_2. Assign the machine 1 in the first cell. The next highest value is 2 in the machine locations m_3 and m_4. Assign machines 3 and 4 in the next cell. Rearrange the parts based on number of operations inside the cell. Results are indicated in Tables 3 and 4.

Table 3 Solution of CLASS algorithm

Machines	*Parts*						
	3	*4*	*5*	*7*	*1*	*2*	*6*
1	1	1	-	-	1	2	3
2	2	2	1	1			
5	3	-	2	2			
3		3			2	1	1
4					3	3	2

Table 4 Result of CLASS algorithm

Cell	*Machine*	*Parts*	*No. of exceptional elements*	*No. of voids*	*No. of inter-cell movement*	*No. of operations*	*Backward movements*
1	1, 2, 5	3, 4, 5, 7	1	3	4	9	0
2	3, 4	1, 2, 6	3	0	1	6	0

3.3 Modified group technology efficacy

The performance measure is more important to measure the quality of the proposed approaches. Raja and Anbumalar (2016b) have developed a MGTE for measuring the quality of the solution. MGTE considers backward movements, intercellular movements, compactness within the cells and actual possible intercellular movements. It is defined by equation (1).

$$\text{Modified group technology efficacy} = [1-(\mu+\beta)]/(1+\varphi) \quad (1)$$

$$\mu = \frac{\text{Number of actual intercellular movements}}{\text{Total number of possible intercellular movements}}$$

$$\beta = \frac{\text{Number of backward movements with the cells}}{\text{Total number of possible intercelluar movements}}$$

$$\varphi = \frac{\text{Number of voids within the cells}}{\text{Total number of operations within the cells}}$$

$$\begin{aligned}\text{Total number of movements} \\ &= \text{Total number of operations of the system} - \text{Total number of parts} \\ &= 19 - 7 = 12\end{aligned}$$

$$\begin{aligned}\text{MGTE} &= [1-(5/12)+(0/12)]/(1+(3/15)) \\ &= 0.486 = 48.6\%\end{aligned}$$

4 Weighted similarity-based modified flow matrix

The objectives of our proposed approach are to group the machines and parts simultaneously, minimise the exceptional elements and voids, and reduce the inter-cell movements and intra-cell movements. To defeat the disadvantages of flow matrix, we propose a weight similarity-based modified flow matrix based on the number of successive forward movements between a pair of machines and number of parts visits between the machines, and the number of backward movements of parts. Weighted similarity is calculated by following formula:

$$WS_{mm} = \sum_{p=1}^{p} W_{mnp} S_{mnp} + \sum_{p=1}^{p} I_{mnp} \tag{2}$$

Notations

WS_{mn} weighted similarity between machine *m* and *n*

W_{mnp} forward movement coefficient for part *p* between machine *m* and *n*

S_{mnp} similarity for part *p* between machine *m* and *n*

I_{mnp} instant forward movement coefficient for part *p* between machine *m* and *n*

p index of parts

m index of machines

C index of cells.

4.1 Modified flow matrix

Successive forward movements between the machine pair and number of parts visits between the machines are a perfect indicator of the improved solution, which provides particular information for goodness of the solution. We developed a weighted similarity-based modified flow matrix, which considers the successive forward movement between the machine pair and number of parts visits between the machines for grouping the machines and machine layout design.

where W_{mnp} is unit forward movement coefficient for a part (p) between machines m and n. S_{mnp} is the similarity for a part (p) between machines m and n, I_{mnp} is the unit instant forward movement coefficient for a part (p) between machines m and n, V is the modified flow matrix ($M \times M$), WS_{mn} is the part visit weighted similarity coefficient between machines m and n.

Let us consider a machine pair m and n. If a part p has forward movement between machines m and n then there is one unit forward movement between the pair of machines, i.e., W_{mnp}. If a part p has backward movement between machines m and n, there is half unit (0.5) forward movement between the machine pair, i.e., W_{mnp}. If part p is processed in both machines, then there is a unit similarity between machine pair, i.e., S_{mnp}. Similarly, if part p visits both machines m and n in instant forward movement then there is also one unit of movement, i.e., I_{mnp}.

To evaluate the total number of movements of all the parts visiting a machine pair, we can find based on forward or backward flow of parts between the pair of machines, part visit between the machine pair and successive forward flow between machine pair. After calculating all WS_{mn} values for each machine pair in the MPIM, the modified flow matrix is created $V = [WS_{mn}]$. This algorithm selects the highest threshold value of WS_{mn} for assigning equivalent machine pair in the new cell. According to the high value of WS_{mn}, selected linked machines are located one by one. Find if any machine in the machine pair is already present in any one of the cells, insert the other machine into that cell. If any machine from the selected machine pair is not allocated in any cells, a new cell in formed. After allocating the entire machine into cell, corresponding part families can be formed.

4.2 Algorithm

Step 1 Compute $V = [WS_{mn}]$ from machine part incidence matrix.

Step 2 Construct modified flow matrix based on weighted similarity values.

Step 3 Locate maximum similarity value from modified flow matrix.

Step 4 Create a new cell.

Step 5 Assign linked machines in cell c.

Step 6 Select the next maximum value and linked machines. Check whether any one of machine is already allotted to cell c. If yes, allocate to the cell c and insert the new machine in front of the existing machine. If no, create a new cell and assign the machines in it. If the current maximum value is exists, continue in the same procedure.

Step 7 If all machines are assigned go to Step 10 otherwise go to Step 3.

Step 8 Locate the next maximum value and linked machines. Create a new cell and allocate the machine pairs in it, if selected machines are not linked to existing cell, otherwise go to Step 6. Continue Steps 3 to 8 until all the machines are assigned.

Step 9 If all machines are assigned go to Step 10 otherwise go to Step 3.

Step 10 Part family identification. Based on maximum intra-cell movement, parts are allocated to the cell.

4.3 Illustrated example

In order to demonstrate the proposed approach, two benchmark problems were solved, which were selected from Nair and Narendran (1998). The first set of problems has seven parts and five machines and second problem contains 20 parts and eight machines. To measure the quality of the solution by using MGTE proposed by Raja and Anbumalar (2016b), the solution offered in Mahdavi and Mahadevan (2008) and Nair and Narendran (1998) is compared with our proposed solution.

First problem is taken from Nair and Narendran (1998) (example 1). This problem contains seven parts and five machines. Table 5 shows the operational sequence based MPIM. The weighted similarity value is calculated by using equation (2).

Table 5 Initial machine part incidence matrix (example 1)

Machines	*Parts*						
	1	*2*	*3*	*4*	*5*	*6*	*7*
1	1	2	1	1		3	
2			2	2	1		1
3	2	1		3		1	
4	3	3				2	
5			3		2		2

The weighted similarity is calculated for machine 1 and 3 as follows,

$$\begin{aligned} WS_{13} &= \left[\left(W_{131} \times S_{131}\right) + I_{131}\right] + \left[\left(W_{132} \times S_{132}\right) + I_{132}\right] + \left[\left(W_{133} \times S_{133}\right) + I_{133}\right] \\ &\quad + \left[\left(W_{134} \times S_{134}\right) + I_{134}\right] + \left[\left(W_{135} \times S_{135}\right) + I_{135}\right] + \left[\left(W_{136} \times S_{136}\right) + I_{136}\right] \\ &\quad + \left[\left(W_{137} \times S_{137}\right) + I_{137}\right] \\ WS_{13} &= [(1 \times 1) + 1] + [(0.5 \times 1) + 0] + [(0 \times 0)] + 0 + [(1 \times 1) + 0] + [(0 \times 0) + 0] \\ &\quad + [(0.5 \times 1) + 0] + [(0 \times 0) + 0] \\ &= 4 \end{aligned}$$

In similar manner, the weighted similarity between the machines are calculated and tabulated. Table 6 shows the weighted similarity-based modified flow matrix.

Table 6 Proposed weighted similarity-based modified flow matrix

Machines	*Machines*				
	1	*2*	*3*	*4*	*5*
1	0	4	4	3.5	1
2	1	0	2	0	6
3	4	0.5	0	5	0
4	3	0	1.5	0	0
5	0.5	1.5	0	0	0

Table 6 shows the proposed weighted similarity-based modified flow matrix for five machines. The maximum weighted similarity value is 6, which is belongs to machines m_2 and m_5. Allocate the machines 2 and 5 in first cell. Next highest value is 5 in machine locations m_3 and m_4. None of these machines (m_3, m_4) belongs to cell 1. So, allocate the machine 3 and 4 in second cell. Next highest value is 4, which is belongs to machines 1, 2 and 1, 3. The weighted similarity value between machines 3 and 1 is also 4. But this value for machines 2 and 1 is 1. So, allocate the machine 1 in cell 2, because, both machine locations 1, 3 and 3, 1 have same value that is 4. The first cell consists of machines 2, 5 and second cell consist of machines 1, 3 and 4. C1 = [2, 5] and C2 = [1, 3, 4]. The parts are assigned to the cells based the maximum inter-cell movement. For example, the part 1 has to process in machines 1, 3 and 4. So, locate part 1 in C2. Similarly all the parts are allocated to the cell. The result for example 1 is shown in Table 7.

The quality of proposed solution is measured by MGTE, which was proposed by Raja and Anbumalar (2016b). The MGTE is calculated by equation (1). From Table 8, number of actual inter-cell movements is 3 and total number of possible inter-cell movement is 12. The number of backward movements and number of voids are 2 and 1. The total number of operations within the cells is 17. The complete solution of the proposed approach is shown in Table 8 and comparison between CLASS and proposed approach is in Table 9.

$$\begin{aligned}\text{The MGTE} &= [1-(3/12)+(2/12)]/[1+(1/17)] \\ &= 0.551 = 55.1\%\end{aligned}$$

Table 7 Solution of proposed approach

Machines	*Parts*						
	3	*5*	*7*	*1*	*2*	*6*	*4*
2	2	1	1				2
5	3	2	2				
1	1			1	2	3	1
3				2	1	1	3
4				3	3	2	-

Table 8 Complete solution of proposed approach

Cell	*Machine*	*Parts*	*No. of exceptional elements*	*No. of voids*	*No. of inter-cell movement*	*No. of operations*	*Backward movements*
1	2, 5	3, 5, 7	1	0	1	6	0
2	1, 3, 4	1, 2, 6, 4	1	1	2	11	2

Table 9 Result comparison between CLASS and proposed approach

Approach	*No. of cells*	*No. of exceptional elements*	*No. of voids*	*No. of inter-cell movement*	*No. of operations in the cell*	*Backward movements*	*MGTE %*
CLASS	2	4	3	5	15	0	48.6
WS	2	2	1	3	17	2	55.1

Table 10 Initial machine part incidence matrix (example 2)

Parts	*Machines*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1					2	1		
2	1		2					
3	2	1		5			3	4
4		1		2			3	4
5					2	1		
6		1		2	5		3	4
7		4		2			3	1
8	1		2					
9	1		3			2		
10				2	3	1		
11	3		2				1	
12					1	3	2	
13	1		2					
14	1	2	3					
15					1	2		
16	1		2					
17	3		1		2			
18		2		1			4	3
19	1		2					
20		2		1		3	4	5

Table 11 Weighted similarity-based modified flow matrix (example 2)

Machines	*Machines*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	0	2.5	13	1	0.5	2	2.5	1
2	2.5	0	2	6.5	1	2	5.5	6.5
3	6.5	0.5	0	0	2	0.5	0.5	0
4	0.5	6.5	0	0	3	1.5	8.5	5
5	2	0.5	0.5	1	0	4.5	2.5	0.5
6	0.5	0.5	2	2.5	6	0	2.5	1
7	1.5	4.5	2	3.5	1.5	2.5	0	9
8	0.5	3.5	0	6	2	0.5	5	0

Table 12 Solution of proposed approach (example 2)

Parts	*Machines*							
	1	*3*	*2*	*4*	*7*	*8*	*6*	*5*
2	1	2						
8	1	2						
9	1	3					2	
11	3	2			1			
13	1	2						
14	1	3	2					
16	1	2						
17	3	1						2
19	1	2						
3	2		1	5	3	4		
4			1	2	3	4		
6			1	2	3	4		5
7			4	2	3	1		
18			2	1	4	3		
20			2	1	4	5	3	
15							2	1
1							1	2
5							1	2
10				2			1	3
12					2		3	1

4.4 *Example 2*

Second example is taken it from Nair and Narendran (1998), which consists of eight machines and 20 parts and its operation sequence is shown in Table 10. The weighted similarity-based modified flow matrix is shown in Table 11. From that matrix, the highest weight similarity value is 13 in the machine locations m_1 and m_3. Allocate the m_1 and m_3 in cell 1. Next maximum value is 9, which is belongs to m_7 and m_8. None of these machines (m_7 and m_8) was assigned to cell 1. So, locate both machines in cell 2. The next maximum value is 8.5 and linked machines are m_4 and m_7. Machine 7 is already in cell 2. Assign m_4 before m_7 in second cell. Next maximum weighted similarity value is 6.5 in the machine locations m_2, m_4 and m_2, m_8. The weighted similarity value for m_4, m_2 is also 6.5. But, this value for m_8, m_2 is 3.5. So, allocate the machine 2 before the machine 4, which is already located in cell 2. The next maximum value is 6, which belongs to m_6, m_5 and this machines (m_6, m_5) are not belongs to cell 1 and cell 2. Now assign the machines 6 and 5 in cell 3.

The first cell consists of machines 1, 3, second cell consists of machines 2, 4, 7 and 8 and third cell consists of machines 6 and 5 (C1 = [1, 3]; C2 = [2, 4, 7, 8] and C3 = [6, 5]). After all the machines are assigned into the cell, the parts are assigned to the cell based on the maximum inter-cell movement. For example, part 1 has to be processed in machines 1, 3. Locate the part 1 in C1. Similarly all the parts are allocated to the cell and that parts 2, 8, 9, 11, 13, 14, 16, 17, 19 are allocated to C1, parts 3, 4, 6, 7, 18, 20 are assigned to C2, parts 15, 1, 5, 10, 12 are assigned to C3. The result for example 2 is shown in Table 12. Table 13 shows machine cell, part families, number of exceptional elements, number of voids, inter-cell movements, backward movements and number of operations in the cell. The result comparison between proposed approach and other approaches is shown in Table 14. From Table 14, the proposed approach MGTE is better than the CASE approach and equals to CLASS algorithm.

Table 13 Complete solution of proposed approach (example 2)

Cell	*Machine*	*Parts*	*No. of exceptional elements*	*No. of voids*	*No. of inter-cell movement*	*No. of operations*	*Backward movements*
1	1, 3	2, 8, 9, 11, 13, 14, 16, 17, 19	4	0	7	18	1
2	2, 4, 7, 8	3, 4, 6, 7, 18, 20	3	0	5	24	6
3	6, 5	15, 1, 5, 10, 12	2	0	4	10	1

Table 14 Result comparison between propose approach and other approaches (example 2)

Approach	*No. of cells*	*No. of exceptional elements*	*No. of voids*	*No. of inter-cell movement*	*No. of operations in the cell*	*Backward movements*	*MGTE %*
CASE	3	9	0	16	52	13	29.3
CLASS	3	9	0	16	52	8	41.5
WS	3	9	0	16	52	8	41.5

5 Results and discussion

Four machine part incidence matrices are selected to compare the performance of proposed weighted similarity (WS) approach with other approaches. In Table 15, the proposed approach is compared with CASE and CLASS approach based on number of cells, number of voids, number of exceptional elements and MGTE. For dataset 3, the number of voids for CLASS algorithm is 54 and it is reduced to 15 in the proposed approach. It indicates that, the cell utilisation is increased. Based on MGTE, our proposed approach is better than the other approaches and it means that the proposed approach is better than CLASS and CASE algorithm. Performance of weighted similarity modified flow matrix has been evaluated based on these well-known examples and approaches. From this analysis, we understand that operation sequence and parts visits the pair of machines data are more important to form the cell, cell layout, minimise the inter-cell movement and increase the cell utilisation.

Table 15 Proposed approach compared with CLASS and CASE approach

Dataset	*Source*	*Size*	*Approach*	*No. of cells*	*No. of voids*	*No. of exceptional elements*	*MGTE %*
1	Nair and Narendran (1998)	5 × 7	CLASS	2	3	4	48.6
			WS	2	1	2	55.1
2	Nair and Narendran (1998)	8 × 12	CLASS	3	0	9	41.5
			CASE	3	0	9	29.3
			WS	3	0	9	41.5
3	Harhalakis et al. (1990)	20 × 20	CLASS	4	54	25	22
			WS	5	15	14	37.1

6 Conclusions

In designing a cellular manufacturing system, machine cell formation, parts allocation and cell layout formation are important and complex problems. Most of the researchers have discussed about CFP, only a few researchers have focused on cell formation problem and cell layout problem simultaneously. In this paper, a weighted similarity-based modified flow matrix simultaneously considers machine cell formation, intra-cell layout, inter-cell layout and voids issues in the CLF problems by operation sequence and parts visits between machine pairs. The proposed approach has formed the machine cell and cell layout to minimise inter-cell movement and voids and increase the cell utilisation. The performance of the proposed approach is measured by MGTE and our approach is compared with two well-known approaches. In future the alternative process routings, processing time, scheduling, human resources and various production factors may be included.

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