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Cell Formation Heuristic Procedure Considering Production Data

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Abstract: Manufacturing cell formation is one of foremost, and critical aspect of any manufacturing cell design problem. A large number of cell formation methods are developed and research in this area is still in progress. In this paper an attempt has been made by authors to develop a simple, easy to understand and implement cell formation heuristic, having the capability to handle production data viz. operation sequence, production volume, and inter-cell movement cost simultaneously. The results obtained from proposed method are in tune with some highly complex methods, which validates the performance of proposed procedure. To demonstrate its ability to handle other production parameters with little modifications, a modification for consideration to part processing cost in addition to above mentioned production data is developed and explained. Towards the end the procedure to handle alternate process plans in conjugation with production data by the proposed cell formation procedure is also discussed.

Key words: Alternate process plan, cell formation heuristic, inter-cell movement cost, operation sequence, part processing cost, production volume.

1. Introduction

The present era, of increasing global competition, complexity, and high levels of customisation, turn the attention of the industry leaders to critical issues of productivity, quality, efficiency, and manufacturing cost. Cell design is critical to any cellular manufacturing problem. Cell formation (CF) is the first step of cell design. CF is to form the machine cells for the families of parts needed similar manufacturing requirements (Sarker, 1996, Boutsinas, 2013, and Mukattash *et al.*, 2002). Identification of machine cells is most important and basic need in the design of a cellular manufacturing system (Mukattash *et al.*, 2002, Seifoddini, 1998, Venugopal and Narendran, 1994). The purpose of any cell formation technique is to form a set of mutually independent set of machines each capable of fully processing the part families assigned to it (Venugopal and Narendran, 1994). It makes CF a complex and tedious task. The CF techniques developed so far can be categorized into number of categories (Boutsinas, 2013, Yin and Yasuda, 2006, Papaioannou and Wilson, 2010, and Yasuda *et al.*, 2005) (i) similarity coefficient based methods, (ii) mathematical programming based methods, (iii) artificial intelligence based approaches, (iv) heuristics / meta-heuristics, and any combination of these. Among CF techniques similarity coefficient based methods are more flexible and easy to implement (Yin and Yasuda, 2006). Numerous cell formation methods are developed so far and the counting is still raising. No single algorithm can provide all the desired benefits (Mukattash *et al.*, 2002). Work by Yin and Yasuda, (2005), Chu and Tsai, (1990), Shafer and Meredith, (1990), and Miltenburg and Zhang, (1991) may be referred for the comparative study of various CF techniques. The thrust of most CF techniques is to arrange binary part machine incidence (PMI) matrix in such a fashion that maximum possible 1s and minimum possible 0s are arranged inside diagonal blocks (Lokesh and Jain, 2010). Table 1 presents the literature studies related to cell formation. Susanto *et al.* (2009) revealed that about 80% of CF techniques do not consider important production factors like production volume, machine capacity, operation sequence, inter-cell / intra-cell transportation cost, part processing cost, processing time, machine capacity, etc whereas considerations to such production data would make them more

Table 1. Summary of work observed on cell formation with consideration to flexibility and production data

Author & Year	Data considered
Lian *et al.*, 2013	Multiple identical machines, processing time, set-up time, machine capacity, production volume, cell size, alternative routes
Gupta *et al.*, 2012	Operation sequence
Ahi *et al.*, 2009	Operational time, operation sequence
Pandian and Mahapatra, 2009	Operation sequence, operation time
Paydar and Sahebjamnia, 2009	Operation sequence
Susanto *et al.* 2009	Sequence of operations, part-Volume, alternative routes
Kumar and Jain, 2008	Operation sequence, time, production volume
Masmoudi *et al.* 2008	Alternative routes
Kim *et al.,* 2004	Machine sequence, alternative routes
Mahesh and Srinivasan, 2002	Processing time, alternative routes
Mukattash *et al.*, 2002	Multiple parallel machines, processing time, alternative routes
Won and Lee, 2001	Operation sequence, production volume
Nair and Narendran, 1998	Operation sequence
Beaulieu *et al.*, 1997	Intra-cell movement cost, material handling cost, machine cost (alternate machines), alternative routes
Beaulieu *et al.*, 1993	Production cost, work load, machine flexibility, routing flexibility

realistic and effective, but rarely any such similarity coefficient based simple CF technique has been developed so far. The literature reflects the need of efforts to incorporate production and manufacturing flexibility related data (realistic data) in CF procedures in a simple manner. Thus, to abridge this gap, authors in present study developed similarity coefficient / commonality score based simple cell formation heuristic, which possess the capability to handle the production data i.e. operation sequence, production volume, and inter-cell movement cost simultaneously. To demonstrate its ability to handle other production parameters with little modifications, a modification for consideration to part processing cost in addition to above mentioned production data is developed and explained. Towards the end the procedure to handle alternate process plans in conjuction with production data by the proposed cell formation procedure is also discussed.

The outline of the paper is as follows: Section 2 describes development of a commonality score based manufacturing CF procedure. Detailed procedure is explained in section 2.1. A CF problem with production data is solved with proposed CF procedure in section 2.2, followed by comparison of results in section 3. Further, the proposed approach is modified to consider part processing cost along with other production data viz. operation sequence, production volume, and inter-cell movement cost in Section 4. For better understanding of procedure again, one more CF problem is solved in section 4.1. A discussion on the procedure to handle alternate process plans along with above production data is given in section 5. At last the conclusions from the study are drawn and scope for future work is given in Section 6.

2. Development of CF procedure

An exceptional element indicates that part needs to be processed on a machine located outside the manufacturing cell, hence adding towards the inter-cell movement, which in-turn adds to inter-cell movement cost. Total inter-cell movement cost will depend on production volume, per part per move inter cell movement cost, and number of inter-cell moves generated due to exceptional element(s). From a little observation of operation sequence we can infer that a machine could add maximum one inter-cell move per part if it is either at starting or at ending position of the operation sequence of a particular part, otherwise it could add maximum two inter-cell moves (Won and Lee, 1991). Further, while clustering, if two or more machines lie outside the manufacturing cell and they are in consecutive order in operation sequence of a particular part, in this case total inter-cell moves generated by them will be much lesser than the simple sum, for all such cases. It must be taken into consideration while estimating required inter-cell moves or cost accordingly.

Though all similarity coefficients are intuition based and there is no strict reasoning why one of them is better than others (Krushinsky and Goldengorin, 2012). Jaccard similarity coefficient is found the efficient and most stable one among the twenty compared in a comparative study of similarity coefficients made by Yin and Yasuda (2005)**.** For efficiency and stability of proposed CF procedure a variant of Jaccard similarity coefficient is used. Chow and Hawaleshka (1992), claimed that the common source of machine chaining problem seems to be in the implementation of each step of grouping procedure in a disjoint manner**.** To avoid chaining in the proposed CF procedure, the input from a grouping step is used in next grouping step similar to Chow and Hawaleshka (1992).

2.1. Proposed CF procedure

Number of minimum exceptional elements does not guarantee the minimum inter-cell moves / movement cost. The prime motive of any CF procedure is to minimize the number of inter-cell moves / inter-cell movement cost (Sivraj and Sharma, 2012, and Arkat *et al.*, 2012) This is also the basis of proposed CF procedure. The steps of proposed CF procedure is explained by a flow chart in Figure 1 and elaborated below:

Step 1: It is dedicated to convert the pertaining data into maximum possible inter-cell movement cost matrix. The elements of this matrix could be obtained as product of 'production volume of part', 'sum of maximum possible moves could be generated by concerned machine for a concerned part', and 'per unit per move inter-cell movement cost'. The procedure of conversion is explained in four sub steps from '1a' to '1d' detailed below. Any step out of 'step 1b', 'step 1c', and 'step 1d' may be skipped if concerned parameter is not considered.

- *Step 1a*. Make PMI matrix of size m x n, for 'm' parts and 'n' machines under consideration
- *Step 1b*. Convert it into a matrix indicating maximum possible inter-cell moves for unit production of each part, by considering their respective operation sequence. By using the logic

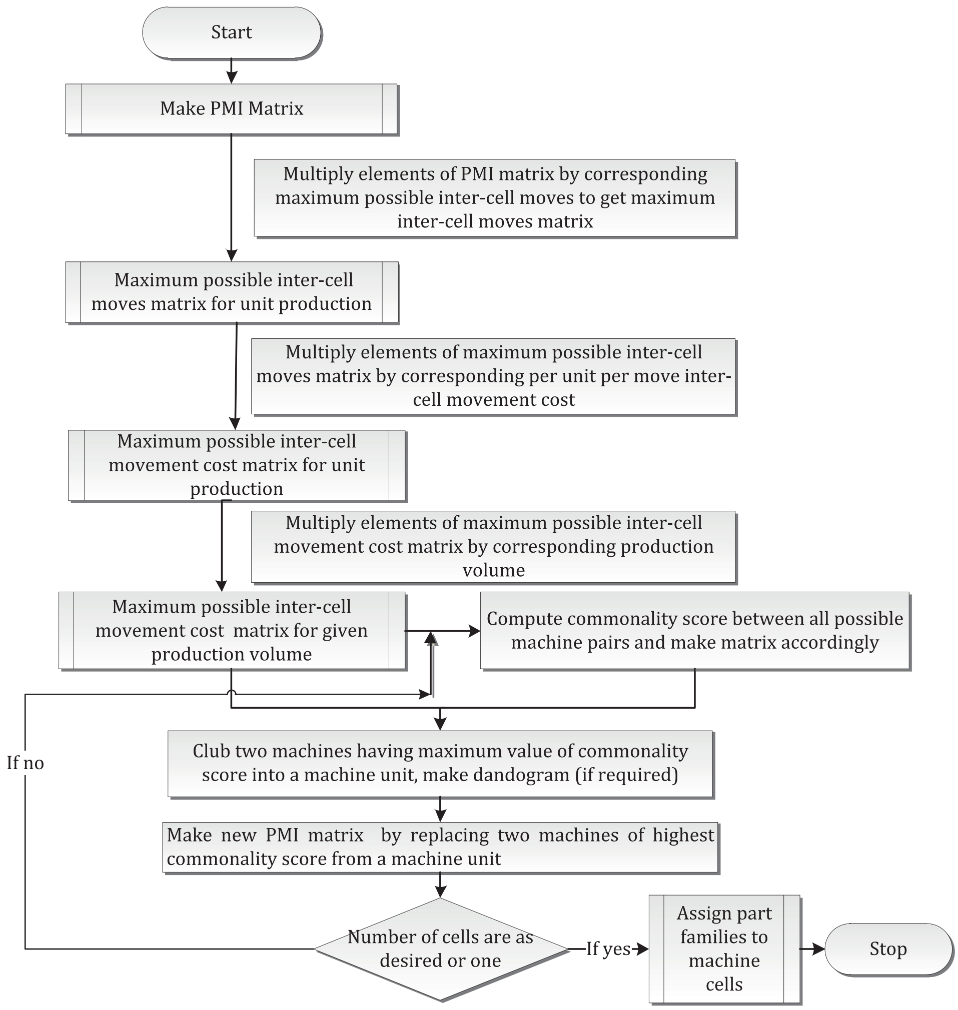

Figure 1. Flow chart for proposed CF procedure

that a machine could add maximum one inter-cell move per part if it is either at starting or at ending position of the operation sequence of a particular part, otherwise it could add maximum two inter-cell moves (Won and Lee, 1991).

- *Step 1c.* Convert this maximum possible inter-cell moves matrix into a matrix containing maximum possible inter-cell movement cost for unit production of each part, by multiplying each element by their respective per part per move inter-cell movement cost.

  Thus obtained matrix may be referred as the maximum possible inter-cell movement cost matrix for single unit production volume**.**

- *Step 1d.* To consider production volume, multiply each element of this matrix by respective production volume. After multiplication with respective production volume this matrix is converted to the maximum possible inter-cell movement cost matrix for given production volume.

This resultant matrix is deduced from the information about operation sequence, production volume, and inter-cell movement cost in addition to the machine(s) required for processing of a particular part.

Step 2: Compute the similarity coefficient among all possible machine pairs from the matrix obtained from 'step 1' by using a variant of Jaccard similarity coefficient. The proposed variant of Jaccard similarity coefficient used here is represented by Eq. 1.

$$\text{Commonality score} = a / (a+b+c) \quad (1)$$

Where, a → sum of elements common to both machines in concerned machine pair (in this case, maximum possible inter-cell movement cost for parts visiting both machines)

$a = \sum_{k=1}^{k=n} a_{(ij)k}$, $a_{(ij)k}$ → elements common to both machines M_i and M_j, for k = 1 to k = n parts

b → sum of values of elements concerned to only first machine in pair (in this case, maximum possible inter-cell movement cost for parts visiting only first machine)

$b = \sum_{k=1}^{k=n} b_{(i)k}$, $b_{(i)k}$ → elements concerned to machine M_i but not machine M_j, for k = 1 to k = n parts

c → sum of values of elements concerned to only second machine in pair (in other terms, maximum possible inter-cell movement cost parts visiting only second machine)

$c = \sum_{k=1}^{k=n} c_{(j)k}$, $c_{(j)k}$ → elements concerned to machine M_j but not machine M_i, for k = 1 to k = n parts

Step 3: Group machine pair having highest value of commonality score, and transform this machine pair into a machine unit M_r having elements $M_{(i,j)r}$

$$M_{(i,j)r} = \begin{cases} a_{i(r)},\ if\ a_{i(r)} \geq a_{j(r)} \\ a_{j(r)},\ if\ a_{i(r)} < a_{j(r)} \end{cases}$$

Where, $M_{(i,j)r}$ → corresponding elements of machine unit M_r, obtained after transformation of machine M_i and machine M_j into a single machine unit

$a_{i(r)}$ & $a_{j(r)}$ → corresponding elements of machine M_i and M_j respectively.

Step 4: Formulate the tree/ dandogram accordingly (optional)

Step 5: Replace machine M_i and M_j with machine unit M_r in the incidence matrix

Step 6: Stop and assign parts to machine cells so as to maximise the work load inside these cells, if the number of machine cells in the new incidence matrix is either only one or desired number of machine cells or , otherwise proceed to step 2.

2.2. Numerical example solved by proposed CF procedure

In this section for a good understanding of proposed procedure, the procedure is implemented on the problem of five machines and five parts adapted from Won and Lee (1991), and given in Table 2. 'P1', 'P2', 'P3', 'P4', 'P5', indicates from part number 1, to part number 5 whereas 'M1', 'M2', 'M3', 'M4', 'M5' indicates from machine number 1 to machine number 5 respectively in order.

Table 2. Initial data for cell formation problem.

Part No.	Operation sequence	Production volume
P1	M2→M4→M2→M4→M5	20
P2	M1→M3	10
P3	M1→M3→M1→M5	50
P4	M4→M2→M4	40
P5	M2→M1→M5→M1→ M2→M1→M5→M1	30

Step 1:

- *Step 1a:* Deduce PMI matrix from the data of problem presented by Table 2.
- *Step 1b:* Matrix for maximum possible inter-cell moves for unit production of each part is formulated by considering the potential of every

machine to generate maximum possible inter-cell moves, by taking care of their respective operation sequence. The resulting matrix is shown in Table 3.

Table 3. Maximum possible inter-cell moves matrix for unit production of each part.

	P1	P2	P3	P4	P5
M1	0	1	3	0	7
M2	3	0	0	2	3
M3	0	1	2	0	0
M4	4	0	0	2	0
M5	1	0	1	0	4

- *Step 1c:* Inter-cell movement cost is not considered, this step may be skipped.
- *Step 1d:* Deduce matrix in Table 3 into the matrix indicating total maximum possible inter-cell moves for given production volume. For this conversion multiply each element of Table 3 by their respective production volume. For example entry corresponding to machine 'M1' and part 'P3' is calculated as 50(3) = 150 i.e. product of 'production volume of part' and 'sum of maximum possible moves could be generated by concerned machine'. Matrix developed by this process is tabulated in Table 4.

Table 4. Matrix for maximum possible inter-cell moves for given production volume.

	P1	P2	P3	P4	P5
M1	0	10	150	0	210
M2	60	0	0	80	90
M3	0	10	100	0	0
M4	80	0	0	80	0
M5	20	0	50	0	120

Step 2: Construct the commonality score matrix on the basis of data available in the resultant matrix from step 1. The similarity coefficient matrix is represented in Table 5.

Table 5. Commonality score matrix based on data in Table 4.

	M1	M2	M3	M4	M5
M1	1	{90/(280+140+90} = 0.176	0.297	0	0.436
M2		1	0	**0.56**	0.355
M3			1	0	0.2
M4				1	0.061
M5					1

Step 3: Machines 'M2' and 'M4' have the highest value of Commonality score, therefore they must be clubbed to form a machine unit.

Step 4: It is simply the construction of dendogram or tree. The step may be skipped.

Step 5: A new data matrix by clubbing machine 'M2' and 'M4' in a single machine unit is developed and represented in Table 6.

Table 6. New data matrix considering machine 2 and machine 4 as a single machine unit.

	P1	P2	P3	P4	P5
M1	0	10	150	0	210
M2,4	80	0	0	80	90
M3	0	10	100	0	0
M5	20	0	50	0	120

At this stage (Table 6) the number of machine cells are neither optimum nor one, hence, proceed to step 2.

Final clustered maximum possible movement based machine part incidence matrix is represented in Table 7 and machine cells are encircled by bold lines.

Table 7. Final clustered maximum possible movement based machine part incidence matrix.

	P3	P5	P2	P1	P4
M1	150	210	10	0	0
M5	50	120	0	20	0
M3	100	0	10	0	0
M4	0	0	0	80	80
M2	0	90	0	60	80

After clustering machines as per the scheme tabulated in Table 7, we can find the maximum number of possible inter-cell moves is 110 (i.e. 90+20). Machine 'M5' is only at the end of operation sequence of part 'P1', in this case maximum possible inter-cell moves are same as total inter-cell moves required. Machine 'M2' is neither at the start nor at the end of operation sequence of part 'P5', and machine 'M5' is used only once in the operation sequence of part 'P5', in this case also maximum possible inter-cell moves are same as total inter-cell moves required. Hence, total inter-cell moves required for given production volume will be 110. This is also an optimum solution and in the tune of Won and Lee (1991).

3. Comparison of results

The results from proposed procedure is compared with the results of some well-known methods. These well-known methods were compared and found better than several other methods in the studies made by their respective authors. Basically, the clustering of these CF problems are same as those found by their respective authors. The comparison of results is summarized in Table 8.

Table 8. Comparison of results.

Source of problem	Size of problem (part×machine)	Exceptional elements: Proposed procedure	Exceptional elements: Source author's method	Required inter-cell moves from both methods	Remarks
Elbenani and Ferland (2012)	8 × 6	6	6	-------	Same groups as Elbenani and Ferland (2012), 0/1 matrix only
Pandian and Mahapatra, (2009)	7 × 5	6	6	5 for unit production volume	Same clustering as of source author
Ahi, *et al.*, (2009)	20 × 8	**10**	**14**	16 for unit production volume from proposed method	Machine cells are same as Ahi *et al*. (2009)
Won and Lee (2001)	5 × 5	2	2	110 for given production volume	Same clustering as Won and Lee (2001)
Nair and Narendran (1998)	20 × 6	9	9	16 for unit production volume	Same clustering as Nair and Narendran (1998), and Paydar and Sahebjamnia (2009)

4. Proposed CF procedure with consideration to part processing cost

The proposed procedure is corrected for consideration to part processing cost along with operation sequence, production volume, and inter-cell material handling cost by a little modifications in deduction of cost matrix for computation of commonality score. The desired modification is limited only to step 1 of proposed procedure, and all other steps remain same. The procedural step of deduction of cost matrix (step 1) is explained with the help of a flow chart in Figure 2.

4.1. Numerical example with modified CF procedure

For illustration part processing, and inter-cell movement costs are introduced arbitratrly to problem adopted from Won and Lee (1991), discussed in section 2.2. The revised problem is given in Table 9. Part processing cost per operation is 10, 40, 30,

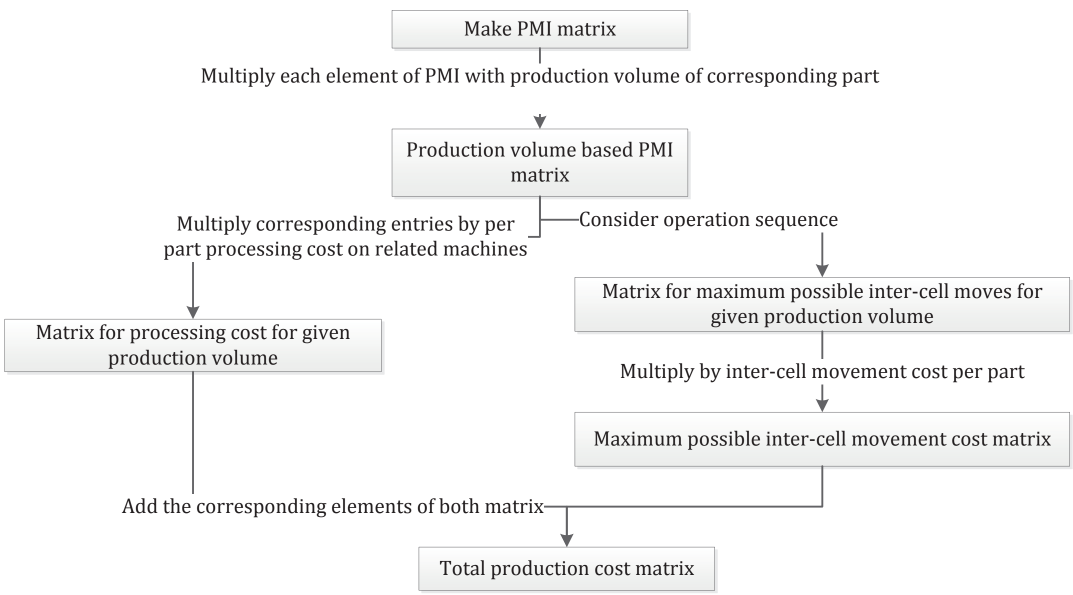

Figure 2. Flow chart for modifications required (step 1) to accommodate processing cost.

Table 9. Modified data for cell formation problem.

Part	Operation sequence	Production volume	Inter-cell movement cost / part / move
P1	M2→M4→M2→M4→M5	20	2 unit
P2	M1→M3	10	1 unit
P3	M1→M3→M1→M5	50	2 unit
P4	M4→M2→M4	40	1 unit
P5	M2→M1→M5→M1→M2→M1→M5→M1	30	3 unit

25, 20 units on machine ‘M1’, ‘M2’, ‘M3’, ‘M4’, ‘M5’ respectively. In this illustration part processing cost is same for all parts processed on a particular machine but this cost may be different for different part for a particular machine. Matrix obtained at various stages of proposed procedure are given from Table 10 to Table 14.

After completing the procedure the final clustered matrix is obtained as detailed in Table 14. From final clustered matrix the followings inferences can be deduced: Exceptional elements = 2, Required Inter-cell moves = 110, Required inter-cell movement cost = 310 unit, Processing cost for parts processed outside manufacturing cells = 1490 units, and Total production cost of exceptional elements for entire lot =1910 units.

Table 10. Matrix for processing cost for given production volume.

	P1	P2	P3	P4	P5
M1	0	100	500	0	300
M2	800	0	0	1600	1200
M3	0	300	1500	0	0
M4	500	0	0	1000	0
M5	400	0	1000	0	600

Table 11. Maximum possible inter-cell movement cost matrix.

	P1	P2	P3	P4	P5
M1	0	10	300	0	630
M2	120	0	0	80	270
M3	0	10	200	0	0
M4	160	0	0	120	0
M5	40	0	100	0	360

Table 12. Combined (total production) cost matrix.

	P1	P2	P3	P4	P5
M1	0	110	800	0	930
M2	920	0	0	1680	1470
M3	0	310	1700	0	0
M4	660	0	0	1120	0
M5	440	0	1100	0	960

5. Handling of multiple process plans along with production data by proposed CF procedure

In the case, when multiple process plans are to be considered along with operation sequence, production volume, inter-cell material handling cost, and part processing cost. The CF procedure will remain similar as explained above, the only difference is first consider all process plans as process plans for different parts, form manufacturing cells by considering all process plans in the line of Mukattash *et al.* (2002). After cell formation, accept only one process plan for each part, which needs minimum inter-cell movement cost / processing cost for part outside manufacturing cell, and reject all other process plans for that part.

5.1. Numerical example solved by proposed modified CF procedure

For considerations of alternate process plans, the same are added to the above discussed numerical problem arbitrarily, rest of other data remains same, as detailed in Table 15. It becomes a 5 machines, 5 parts, and 10 process plan problem. Final clustered matrix obtained from proposed CF

Table 13. Commonality score matrix (first iteration).

	M1	M2	M3	M4	M5
M1	1	0.187	0.31	0	0.663
M2		1	0	0.437	0.271
M3			1	0	0.323
M4				1	0.115
M5					1

Table 14. Final clustered combined cost matrix.

Part	P3	P5	P2	P1	P1
M1	800	930	110	0	0
M3	1700	0	310	0	0
M5	1100	960	0	0	440
M2	0	1470	0	1680	920
M4	0	0	0	1120	680

Table 15. Data for cell formation problem.

Part No.	Process plan	Operation sequence	Prod. vol.	Inter-cell movement cost /part / move
P1	1	M2→M4 →M2→M4→M5	20	2
	2	M2→M1 →M2 M3→M5		
	3	M3→M1 M5→M3→M4		
P2	4	M1→M4	10	1
	5	M3→M5		
P3	6	M1→M3 M1→M5	50	2
	7	M1→M5→M1→M4		
P4	8	M4→M2→M4	40	1
	9	M4→M2 →M3		
P5	10	M2 →M1→M5 →M1M2→M1 →M5→M1	30	2

procedure is given in Table 16. Results deduced from final clustered matrix are as follows: Exceptional Elements = 2, Required total Inter-cell moves = 110, required inter-cell movement cost = 220 unit, processing cost for parts processed outside manufacturing cells = 1600 units, and total production cost of exceptional elements for entire production = 1820 units. A little consideration of results obtained without alternate process plans (Table 14), and with alternate process plans (Table 16), it is clear that procedure selects the process plan which ultimately reduces the total production cost.

Table 16. Final clustered combined cost matrix with alternate process plan.

Part	P1	P2	**P3**	P4	P5
Process plan	6	10	**5**	1	8
M1	800	720	0	0	0
M5	1100	840	210	440	0
M3	1800	0	310	0	0
M4	0	0	0	660	1080
M2	0	1380	0	920	1680

6. Conclusion

The proposed CF heuristic procedure is simple, easy to understand, and implement. It has the ability to use the production data such as production volume, operation sequence, and inter-cell movement cost simultaneously. It produces the results which commensurate with some highly advanced and complex cell formation methods requiring very high computational power. The modifications for part processing cost, and alternate process plans demonstrates its ability to handle other production parameters too. The proposed procedure could also be implemented if part processing, and inter-cell movement costs are replaced by part processing, and inter-cell movement time respectively. The procedures would be highly beneficial for a low to mid-size flexible manufacturing system.

Future work may be carried out in the development of more realistic and efficient formulations with considerations to more realistic parameters such as setup cost, machine capacity, multiple identical machines, decisions on number of manufacturing cells & size, reliability, work imbalance, and various manufacturing flexibility related parameters, etc for large-size CF problems.

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