



## Lead Component Method: A Heuristic for Cell Formation

**Shilpa Samak Kulkarni**

*Satara College of Engineering & Management, Limb, Satara, India*

**Neela Ravindra Rajhans**

*Government College of Engineering, Pune, India*

(Received: 28/12/2015; Accepted: 26/04/2016)

---

### Abstract

In any manufacturing unit, raw material is converted into finished product. During this journey, the material undergoes a variety of processes and it has to travel from machine to machine to complete its manufacturing sequence. The manufacturing efficiency largely depends on the layout. Selection of proper layout depends upon variety of the products manufactured and their quantities. If the unit manufactures same kind of products in large quantities, a product layout is preferred. If a large variety of components is to be produced, a process layout is used. Such decisions are taken to minimize the distance travelled by the component. An effective and efficient layout can heavily influence the economics of the manufacturing unit. Over a last few decades, a new method of manufacturing called cellular manufacturing has come into existence. Machines are grouped into cells such that the component completes its manufacturing sequence within single cell. This drastically reduces the distance travelled. A variety of cell formation techniques are already available. Clustering techniques such as rank order clustering, similarity coefficient methods are very popular in this regard. Yet there is a need for simple clustering algorithm. This paper has proposed a very simple yet effective method for clustering which tries to minimize the intracellular movement with maximum grouping efficiency and maximum machine utilization. The proposed algorithm takes into account the similarity of manufacturing sequence and by simple one to one comparison, it clubs together the components. The method does not require any kind of lengthy mathematical calculations. Thorough analysis of the proposed method is done by applying it to various problems available in literature. Comparative values of performance measures are summarized which show that the proposed method is performing well.

**Keywords:** Cellular Manufacturing, Lead Component Method, Group Technology, Performance of layout, Clustering

**JEL Classification:** C6

**Paper Classification:** Research Paper

---

## Introduction

Traditionally, manufacturing units are following either process layouts or product layouts depending upon the variety of the products manufactured and the quantity to be manufactured. In a process layout, machines performing similar operations are located together. Normally, process layout is used when desired production quantity is very less such as in job shops. Product layout is used when machines are located according to the processing sequence of the product. Product layout is used when the desired production quantity is high and an independent production line can be justified to manufacture the product. In process layout, machines are better utilized but the material handling cost is high. In product layout, there is a minimum material handling cost, but comparatively high investment is required in equipments.

With growth of industry, the manufacturers, especially medium scale manufacturers, required a mean of these types of layouts. Over a last few decades, a new method of manufacturing called cellular manufacturing has come into existence. It combines both product layout and process layout. In this method, machines and components are grouped into distinct cells or groups such that all the components assigned to a cell complete their manufacturing sequence within that single cell. Components having similar sequence of manufacturing are clubbed in a single group. Then each cell behaves as independent manufacturing unit. This drastically reduces the distance travelled by the component. Thus cellular layout becomes a multi objective layout which minimizes the cost of transportation and cost of equipments. At the same time controlling of the process becomes easy. Hence cellular manufacturing gained popularity during last few decades.

This paper summarizes various cell formation techniques available via literature review. After defining the problem, a stepwise procedure of proposed algorithm is presented. The proposed algorithm is demonstrated using a problem in the literature. The performance measures already presented in literature are summarized in the next session. The proposed algorithm is then applied to various problems solved in literature and their performance measures are evaluated. The results are compared, summarized and represented graphically. The advantages and limitations of the proposed algorithm are discussed along with conclusions.

## Literature Review

Rigorous research has been carried out in the field of cellular manufacturing. Most of the research is devoted to find an optimum method for cluster formation. Some are based on some mathematical calculations, some are heuristics. Many researchers have summarized all of the existing methods of clustering which shows that a large variety of methods are available for clustering. The researchers have applied their algorithms on some bench mark problems and have analyzed whether their method is compatible or not. While developing the method proposed in this paper, the author has reviewed a lot of research papers which are summarized in this section. The papers are reviewed for clustering techniques used in the paper as well as for the bench mark problems solved in the paper. The books review emphasizes the need of cellular layout.

McCauley (1972) presented and discussed a simple method of grouping machines. It calculated which parts go to each group and how often each machine in a group is visited. It also calculated which machine outside the group is visited by these parts and how often this occurs. King (1980) has developed a clustering technique called rank order clustering which generates diagonalized groupings of the matrix entries. Though this method is quite popular in group technology, its application becomes difficult for larger problems. King and Nakornchai (1982) extended the previously described ROC algorithm with a new relaxation procedure for bottleneck machines.

Waghodkar and Sahu (1984) presented a heuristic approach based on the similarity coefficient which returns minimum number of exceptional elements. Chandrasekharan and Rajgopalan (1986) developed a non-heuristic algorithm which imposed a theoretical upper limit for the number of groups in given binary data and introduced the concept of grouping efficiency. Kusiak and Chow (1987) presented two efficient algorithms for cell formation: cluster identification algorithm and cost analysis algorithm. Wei and Kern (1989) presented a linear algorithm based on the calculation of a commonality score which indicates the similarity between the usages of two machines. Seifoddini (1989) handled the problem of improper machine assignment that arises in the models based on the similarity coefficients using ALC.

Harhalakis, Nagi, and Proth (1990) presented a two phase heuristics for cell formation which reduces the inter cell material movement. Kusiak and Cheng (1990) developed a branch and bound algorithm for solving the group technology problem with bottleneck parts and bottle neck machines. The branching scheme for the GT problem with bottleneck parts is based on removing parts from a machine part incidence matrix. The branching scheme for the GT problem with bottleneck machines utilizes multiple machines.

Chu and Hayya (1991) presented a fuzzy C means clustering algorithm which reveals the specific part family that a part belongs to. Askin, Cresswell, Goldberg, and Vakharia (1991) formulated machine and part ordering as a Hamiltonian Path Problem. Chow and Hawaleshka (1992) also discussed the problem of machine chaining that arises when there is improper machine assignment, which ultimately results in high intercellular movement. They proposed an algorithm based on commonality scores for solving these problems. Kaparathi and Suresh (1992) presented a neural network clustering method based on Carpenter-Grossberg network. Heragu and Gupta (1994) presented a heuristics which attempts to minimize the intercellular movement of parts taking into consideration design constraints. Chen and Cheng (1995) have developed a neural network based cell formation algorithm and tried to eliminate the weaknesses of the adaptive resonance theory by the introduction of a set of supplementary procedures.

Adil and Ghosh (2005) presented a maximum diversity/similarity models and their generalization which can be used effectively in group technology. Venukumar and Haq (2006) formed the manufacturing cells by using Kohonen self-organizing map networks. They applied the method to benchmark problems and effectiveness is checked in terms of various performance measures. Alhourani and Saifoddini (2007) introduced a new similarity coefficient and an algorithm required for machine part grouping for the design in a cellular manufacturing system. Hachicha, Masmoudi, and Haddar (2007) formulated a two phase multivariate approach based on a correlation analysis for solving cell formation problem. Murugan and Selladurai (2011) presented an art modified single linkage Clustering approach (ART-MOD-SLC) to solve cell formation problems in Cellular Manufacturing. Chalapathi (2012) presented a methodology which takes all the available information from the route sheets into consideration. Ghosh, Doloi, and Dan (2014) presented a model considering production factors. Ghosh and Dan (2014) demonstrate a state-of-the-art soft-computing based simulated annealing heuristic to cell formation problems in CMS.

Yan, Wang, and Fan (2014) presented a two-phase clustering algorithm which determines initial cluster centers in its first phase and part-family and machine-cell formation in its second phase. Seifoddini and Djassemi compared the performance of Jaccard's similarity coefficient with the production data-based similarity coefficient.

Pandian and Mahapatra (2009) developed clustering methodology based on adaptive resonance theory (ART) for addressing CF issues. Cheng, Kumar, and Motwani (1994) considered several clustering algorithms. They have discussed various cell formation algorithms with their comparison. According to them, some clustering algorithms require user intervention.

Panneerselvam (2012) discusses about types of plant layouts. He compares various types of plant layout and throws light on group technology techniques. He has explained in detail two popular models for group technology namely rank order clustering and bond energy algorithm. He has also explained mathematical model for machine component cell formation.

Francis and White (1974) also compares product layout versus process layout. They have explained in detail advantages and disadvantages of each type of layout with examples. They have elaborated P-Q chart (production quantity Q to the number of products P) which indicates which layout is justified in which case. According to them, the decision to use a product layout usually results when the required production quantity is very high, the product is easily transported and the procession sequence is similar for all products. On the other hand, if a large variety of products is to be made in relatively small quantities using significantly different processing sequence, then a process layout is selected. Many layouts tend to be a combination of product-process layout. A combination is sought that achieves a compromise in advantages and limitations of each of the layout types.

Tompkins, White, Bozer and Tanchoco (1996) referred cellular layout as group layout or product family layout. According to them, non identical parts may be grouped into families based on common processing sequences, shapes, material composition, tooling requirements, handling storage/control requirements. The product family is treated as a pseudo product and a pseudo product layout is developed. The processing equipment required for the pseudo product is grouped together and placed in a manufacturing cell. The resulting layout typically has a high degree of intradepartmental flow and little interdepartmental flow.

Viswanadham and Narhari (1994) explain the benefits of cellular manufacturing as reduction in processing time, inventory and tooling. Overall manufacturing lead time and material handling times are also reduced. According to them, two major benefits are in tooling development and set up time. Since tooling can be created for a family of parts, tooling efforts get distributed over a family of parts. Because the cell is dedicated to a few different families of part types, fixturing and tooling require a few changeovers and consequently setup time is reduced. As each cell caters to a focused part family, it has other benefits such as high machine utilization and low manufacturing lead time.

## Problem Definition

The literature review shows that there are numerous methods available for clustering the machines or components. A large amount of research has been carried out about formation of cells. Various methods have been proposed by variety of researchers. Each method has its own advantages and disadvantages. Some of the methods involve tedious mathematical calculations. Some require much iteration to reach the best solutions. Some methods can give best solution only for a particular objective. Some methods have size limitations and so on. Existing clustering algorithms impose variety of limitations. Hence the present study has have tried to develop a simple yet efficient algorithm for clustering.

## Objectives of the study

The main objectives of current study are:

1. To develop an efficient clustering algorithm that can cluster the components and machines by comparing the manufacturing processes involved in their production.
2. The algorithm should be free from lengthy mathematical calculations and much iteration.
3. The algorithm should be easy to understand and easy to apply in any clustering situation.

## Research Methodology

### Type of study

The current study involves development of new clustering algorithm and its application on some benchmark problems.

### Data Collection

The data used in the current work is some typical clustering problems solved by various researchers in their papers.

### Hypotheses

Finding the best method of clustering in cellular manufacturing based on reduction in material handling time.

### Research Models used

Rank Order Clustering, Bond Energy Algorithm, Lead Component Method.

## Existing Clustering Techniques

### Rank Order Clustering

This algorithm was developed by King (1980). It considers number of components and component sequences to obtain machine component cells in group technology. Based on component sequences, a machine component incidence matrix is developed. The machines required to process the components are represented by the rows of the matrix represent whereas the component are represented by the columns. Decimal equivalents of each row and column are calculated and the rows and columns are given ranks accordingly. Then they are arranged rank wise. The procedure is repeated until all the rows and columns are arranged rank wise. The final matrix gives clearly distinguished groups or cells.

Though the technique is quite easy to understand, it needs quite a few iterations to reach the solution. Also, the final matrix may not give perfect block diagonal form. Hence some manual disturbance is required to obtain suitable solution.

### Bond Energy Algorithm

It was developed by McCormick (1972). The objective of this algorithm is to form machine component cell in group technology. Bond energies of two columns are calculated first and then bond energies are calculated for rows. Column wise and row wise exchanges are computed

based on bond energies. The matrix obtained after this interchange is considered as final machine component incidence matrix.

There are many other clustering algorithms available such as similarity coefficient method, Neural Networks, Principal Component Analysis, Branch and bound Algorithm, Commonality scores etc which are discussed in literature review.

### Clustering Algorithm

To get rid of the lengthy mathematical calculations, a new algorithm for grouping the components is proposed here. It is based on similarity of manufacturing sequence. The main aim of this algorithm is to minimize the material handling cost, i.e., to minimize intracellular movements.

Steps Involved:

1. List all the processes required by each component.
2. Calculate the total number of processes for each component.
3. Arrange all the components as per descending order of number of processes.
4. Mark first component in the list as 'Lead Component'.
5. Consider next component in the list. (component 2) Compare its processes with the 'Lead Component'. If all the processes of component 2 are present in the process set of lead component, component 2 will enter the group. If not, component 2 will become second lead component.
6. Consider next component in the list. (component 3). Compare its processes with the 'Lead Component 1'. If all the processes of component 3 are present in the process set of lead component 1, component 3 will enter the group. If not Compare its processes with the 'Lead Component 2'. If all the processes of Component 3 are present in the process set of lead component 2, component 3 will enter the group. If not, component 3 will become third lead component.
7. The process can be repeated until all the components either enter any group or become lead component.
8. If too many components are becoming lead components, restrict the number of lead components using following equation:

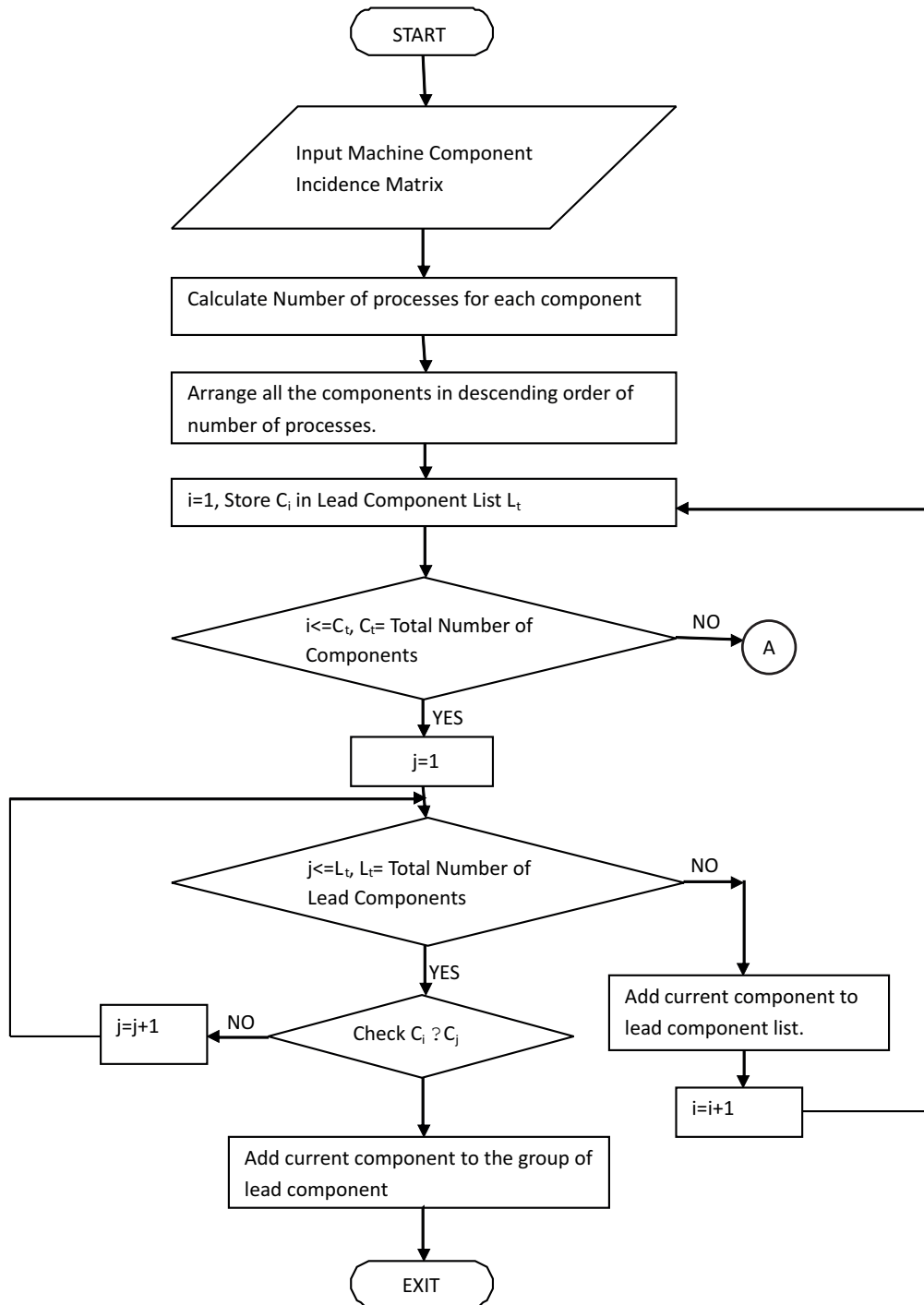
$$\text{No of cells} = \frac{(\text{Number of 1's in incidence matrix})}{(\text{Number of components} \times \text{number of machines})} \quad \text{eq. 1}$$

Restriction on number of cells using this formula may need elimination of some of lead components in other cells.

9. Place the lead component to be eliminated, in a cell where it will create minimum exceptional elements.
10. If the lead component to be eliminated created equal number of exceptional elements in any two cells, place it where it will produce minimum void cells.
11. If numbers of voids created by this component are also same, then place it in a cell where it will have minimum size of the cell.

12. If a component follows more than one lead component, place it in a cell where it will produce minimum void cells.

The flowchart of proposed algorithm is as shown in Figure 1.



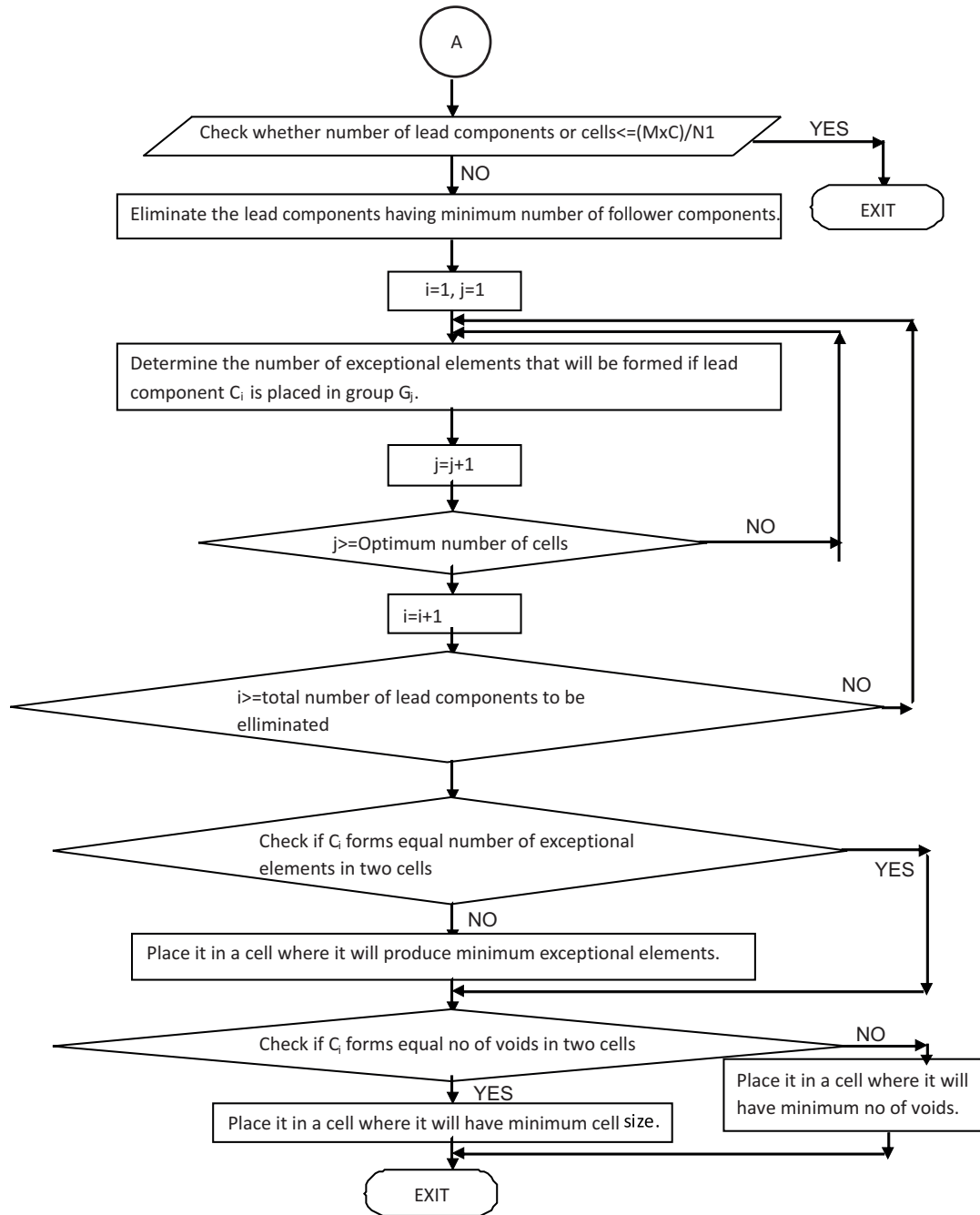


Figure 1. Flowchart showing proposed algorithm

### Numerical Example

Example 1: Consider an example with 8 parts and 7 machines as shown in Table 1(Murugan Selladurai, 2011)

**Table 1: Initial machine-component incidence matrix**

	C1	C2	C3	C4	C5	C6	C7	C8
M1	0	1	0	1	0	0	0	0
M2	1	1	0	0	0	1	1	1
M3	0	0	1	0	0	1	0	1
M4	0	0	0	1	0	0	1	0
M5	1	0	1	0	0	1	0	1
M6	0	0	0	1	0	0	1	0
M7	1	1	0	0	1	1	1	1

The solution to this problem can be obtained by following these steps:

Step 1. Arrange the matrix in such a way that, the components will be in rows and machines/ processes will be in columns.

Step 2. Sum up the total number of processes for each component and arrange all the components as per descending order of number of processes.

Step 3. First component in the list i.e. C6 is the first lead component. Consider next component in the list, i.e., C7. All the processes of C7 are not included in the processes set of first lead component. Hence C7 becomes the second lead component.

Step 4. Consider next component, i.e., C8. All the processes of C8 are included in the process set of first lead component and are different from second lead component. Hence C8 enters the first group. Similarly C1 and C3 also enter the first group. C2 and C4 become third and fourth lead components.

Step 5. Now there are four lead components, viz., C6, C7, C2, and C4. Components C1 and C3 are assigned to group 1. Component C5 is yet to be assigned as it shows complete similarity with the three lead components. Thus there is no clear solution yet.

Step 6: Following equation 1, the number of cells should be restricted.

The total numbers of elements in the given matrix are  $7 \times 8 = 56$ .

The total numbers of positive entries are 24.

Hence number of cells  $= 56/24 = 2.33 \approx 2$

Thus, only two cells have to be formed, which means, that the present study needs to eliminate two lead components.

Step 7: Lead component C4 does not have any element similar to first lead component whereas lead component C2 and C7 shows some similarity with both C6 as well as C4. Hence these two are eliminated from the list of lead components. The final lead components are C6 and C4.

Step 8: The three components remaining are C2, C5, and C7. As C5 shows complete similarity with first lead component, it enters the first group. C2 will cause 2 exceptional elements if placed in group 2 and 1 exceptional element if placed in group 1. Hence it is placed in group 1. C7 will cause 2 exceptional elements with both the groups. But it will increase total number of voids if placed in group 1. Hence it is placed in group 2.

Thus the final solution obtained by the Lead Component method is as shown in Table 2.

**Table 2: Final Solution using LCM**

	M5	M2	M7	M3	M1	M4	M6
C6	1	1	1	1	0	0	0
C8	1	1	1	1	0	0	0
C1	1	1	1	0	0	0	0
C3	1	0	0	1	0	0	0
C5	0	0	1	0	0	0	0
C2	0	1	1	0	1	0	0
C7	0	1	1	0	0	1	1
C4	0	0	0	0	1	1	1

Table 3 shows solution to the same problem by rank order clustering (ROC) and ART modified single linkage clustering algorithm which is given in literature.

**Table 3: Solutions using ROC and ART-MOD-SLC. (Murugan and Selladurai, 2011)**

	M6	M8	M1	M7	M2	M3	M5	M4
C2	1	1	1	1	1	0	0	0
C7	1	1	1	1	1	0	1	0
C5	1	1	1	0	0	1	0	0
C3	1	1	0	0	0	1	0	0
C1	0	0	0	0	1	0	0	1
C4	0	0	0	1	0	0	0	1
C6	0	0	0	1	0	0	0	1

	M6	M3	M8	M5	M1	M7	M4	M2
C2	1	0	1	0	1	1	0	1
C3	1	1	1	0	0	0	0	0
C4	0	0	0	0	0	1	1	0
C7	1	0	1	1	1	1	0	1
C5	1	1	1	0	1	0	0	0
C6	0	0	0	0	0	1	1	0
C1	0	0	0	0	0	0	1	1

Comparison of the solutions obtained by proposed method and that in literature shows that proposed method is better. To prove its goodness, some performance measures are used which are discussed in the following session.

### Performance Measures

For evaluation of the cells formed, some performance measures are necessary. Various performance measures are defined in literature. Yin and Yasuda (2005) have listed nine performance measures viz. number of exceptional elements, machine utilization index, grouping efficiency, group efficacy, clustering measure, grouping index, bond energy measure, grouping capability index, and alternative routing grouping efficiency. The first four performance measures are mostly used by various researchers for comparing the clusters. Hence the current study also uses these four parameters for comparing the solutions.

### Number of exceptional element

Exceptional elements are movements of parts from one cell to another. Cell formation mainly emphasizes on reducing the total material handling cost. Hence, EE is the simplest measure for evaluating the cell formation solution. The exceptional elements appear as positive entries outside any cell. The number of exceptional elements should be minimum or nil.

### Machine Utilization Index

It shows how many of times the machines within the group are used for production. It is expressed in percentage.

$$\text{Here, } MU = \frac{N1}{\sum_{i=1}^c M_k N_k}$$

N1 is the number of positive entries in the diagonal blocks,

M<sub>k</sub> is the number of machines in the kth cell,

N<sub>k</sub> is the number of parts in the kth cell, and

C is the number of cells.

The higher the value of MU, the better the machines is being utilized

### Grouping Efficiency

It considers both the above said performance measures simultaneously. It considers the weightage given by the analyst to exceptional elements and machine utilization, which reveals the relative importance of each of the two criteria. Unless specified, this weight is taken as 0.5 which treats both the measures equally.

$$\eta = p \frac{N1}{\sum_{i=1}^c M_k N_k} + (1 - p) \frac{NE}{MN - \sum_{i=1}^c M_k N_k}$$

M = number of machines

N = number of parts

N1 = number of 1s in the machine-part matrix

NE = number of exceptional elements in the solution

The higher the grouping efficiency, the better the clustering results.

### Grouping Efficacy

$$\tau = \frac{1 - \phi}{1 - \emptyset}$$

where φ is the ratio of the number of exceptional elements to the total number of elements; φ is the ratio of the number of 0s in all the cells to the total number of elements.

These performance measures are used to compare the solution obtained by lead component method with the solution in literature. In literature, ART modified single linkage clustering approach is used for cell formation.

**Table 4: Comparison of results**

S.No.	No. of cells	Exceptional Elements	Machine Utilization	Grouping Efficiency	Group Efficacy
LCM	2	12.50	70.00	80.71	63.64
Literature Method	2	16.67	58.82	73.86	52.63

### Problem Sets

The same algorithm is applied to various problems selected from available literature. 30 problems are considered for study considering the number of machines involved, density of the machine-component incidence matrix and popularity of the problem amongst researchers.

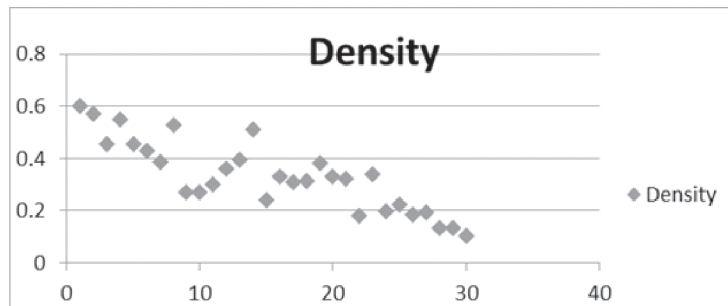
### Density

Density of the matrix is the ratio of total number of positive entries in the machine component incidence matrix and the size of the matrix. A little consideration will show that problems having density below 0.3 are difficult to solve. Maximum numbers of problems from this region are selected. The classification of problems selected based on density is shown in following Table 5:

**Table 5: Classification based on density**

Density	No. of problems	%
0.1 to 0.2	7	23.33
0.2 to 0.3	5	16.67
0.3 to 0.4	10	33.33
0.4 to 0.5	3	10
>0.5	5	16.67

The classification of the test problems based on density is represented graphically in Figure 2.



**Figure 2. Densities of test problems**

### Number of machines involved

With the increase in the number of machines, the complexity of the problem increases. Still it is found that, in many problems involving fewer numbers of machines it becomes a tough task to get an efficient solution. The current study, tries to make sure that all problems get equal representation. The classification of selected problems based on number of machines involved is given in following Table 6:

**Table 6: Classification based on number of machines involved**

Machines	No. of problems	%
<8	12	40
8<M<16	12	40
>16	6	20

The classification of the test problems based on number of machines involved is represented graphically in Figure 3.

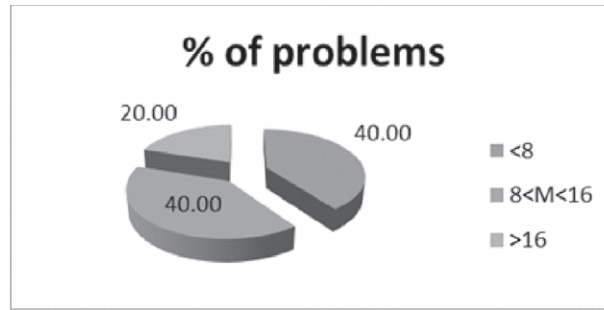


Figure 3. Percentage of test problems based on number of machines

### Results

The proposed algorithm is tested for selected 30 problems and evaluated using the performance measures defined in previous sessions. The below table 7 shows the results:

Table 7: Comparison of performance measures

S. No.	Matrix Size	Machine Utilization		% of exceptional elements		Grouping Efficiency		Efficacy		Author
1	4 x 5	90	80	25	33.33	81.36	73.33	69.23	57.14	Ghosh, Doloi, and Dan
2	5 x 7	84.2	84.2	20	20	81.58	81.58	69.57	69.57	Ghosh and Dan
3	5 x 7	82.4	82.4	12.5	12.5	85.62	85.62	73.68	73.68	Waghodekar, Sahu
4	7 x 7	72	66.7	33.3	40.74	71.48	66.67	52.94	45.71	Ghosh, Doloi, and Dan
5	5 x 11	75.9	75.9	12	12	83.39	83.39	68.75	68.75	Chow and Hawaleshka
6	7 x 8	70	58.8	12.5	16.67	80.71	73.86	63.64	52.63	Murugan, et al
7	7 x 10	83.3	66.7	25	40	79.17	65.94	65.22	46.15	Ghosh and Dan
8	7 x 10	80	76.2	13.5	13.51	98.93	96.43	71.11	68.09	McAuley
9	7 x 11	76	76	9.52	9.524	86.28	86.28	70.37	70.37	Hachichaa et al
10	7 x 11	76	73.1	9.52	9.524	86.08	84.58	70.37	67.86	Venukumar and Haq
11	7 x 11	70.8	60.7	26.1	26.08	79.75	74.23	56.67	50	Kusiak and Chow
12	8 x 10	96.4	96.4	6.9	6.897	96.33	96.33	90	90	Yan, Wang, and Fan
13	9 x 9	92.6	92.6	21.9	21.88	89.81	89.81	73.53	73.53	Chu and Hayya
14	5 x 18	85.4	85.4	10.9	10.87	86.76	86.76	77.36	77.36	Seifoddini
15	10 x 10	67.6	67.6	4.17	4.167	83.17	83.17	65.71	65.71	Murugan, et al
16	10 x 10	81.8	81.8	18.2	18.18	86.8	86.8	69.23	69.23	Chen and Cheng
17	12 x 10	80	76.2	13.5	13.51	98.93	96.43	71.11	68.09	McAuley
18	10 x 15	88	88	6.38	6.383	92.58	92.58	83.02	83.02	Chalapathi
19	8 x 20	100	100	14.8	14.75	95.83	95.83	85.25	85.25	Chandrasekharan et al
20	19 x 12	51.2	47.6	12	0	71.04	73.78	47.83	42.67	Heragu and Gupta
21	11 x 22	81.7	80.7	14.1	14.1	87.42	86.9	72.04	71.28	Hachichaa et al

(Continued)

22	14 x 24	68.6	67.4	1.67	3.333	84.1	83.32	67.82	65.91	Askin
23	15 x 25	88.4	88.4	10.2	10.24	91.7	91.7	80.28	80.28	Saeedi et al
24	20 x 20	81.3	76.2	17.7	18.99	84.29	80.2	69.15	64.65	Harhalkis et al
25	18 x 24	61.1	59.2	28.1	34.38	76.81	75.16	49.29	45.65	Seifoddini et al
26	16 x 43	61.8	50.2	2.38	0.794	80.7	75.02	60.89	50	King and Nakorchari
27	20 x 35	75.4	73	2.22	0	80.23	78.38	74.15	72.97	Kaparthi and Suresh
28	24 x 40	91.6	91.8	9.23	30.77	95.09	93.62	83.69	65.22	Kusiak and Cheng
29	25 x 40	65.6	44.2	22.6	20.3	81.02	70.31	55.08	39.7	Pandian, et al
30	40x100	91.2	91.2	8.57	8.57	95.1	95.1	82.88	82.88	Yan, Wang, and Fan

The figures in grey are the values obtained by using the proposed algorithm where as the other columns show best values in literature.

The results in Table 7 are represented graphically in following figures.

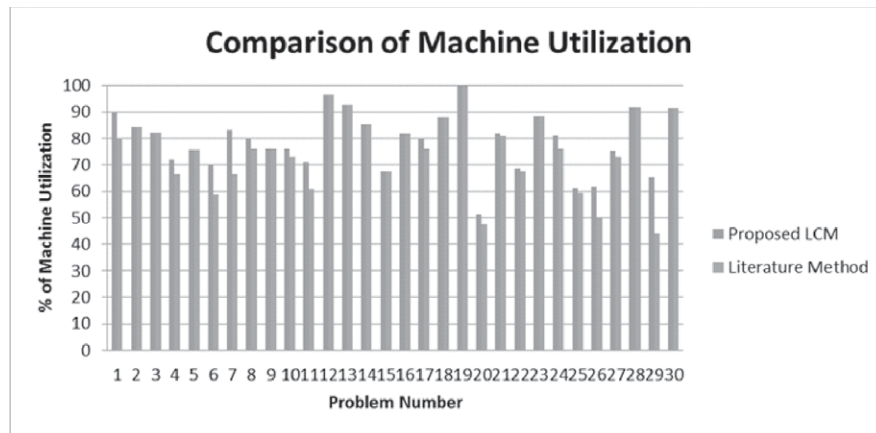


Figure 4. Comparison of % Machine Utilization by Proposed method & Literature Method

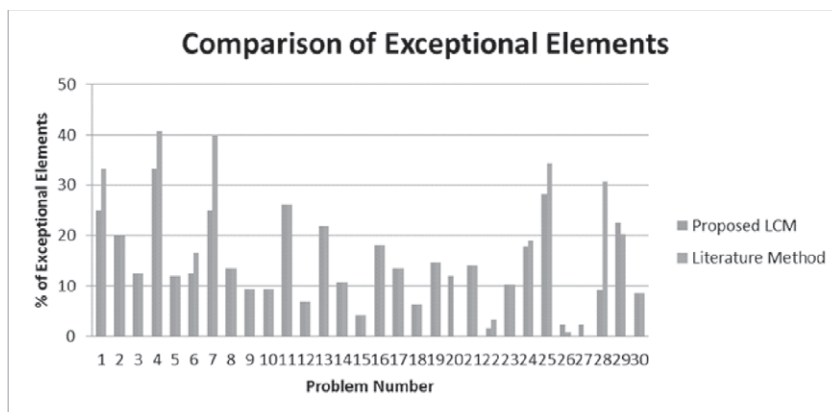


Figure 5. Comparison of % exceptional elements by Proposed & Literature Method

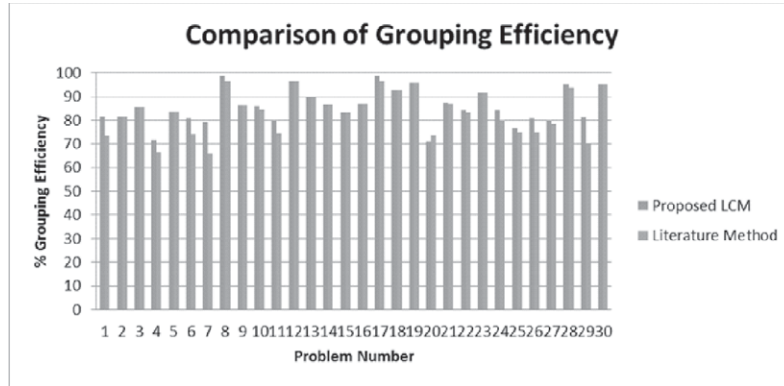


Figure 6. Comparison of % grouping efficiency by Proposed & Literature Method

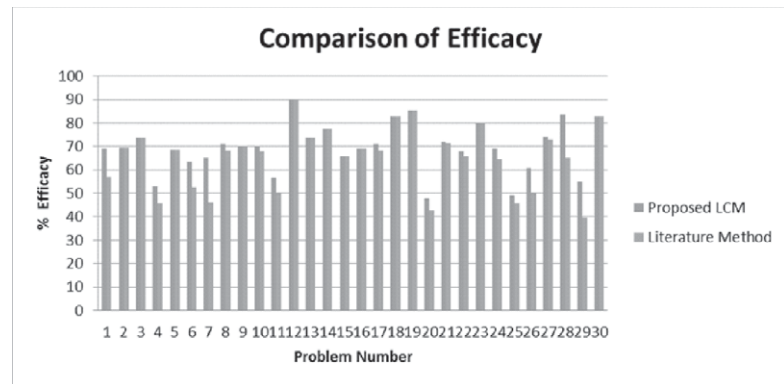


Figure 7. Comparison of % efficacy by Proposed & Literature Method

The statistical performance of the proposed method is summarized in table 8:

Table 8: Statistics showing performance of proposed algorithm

	MU		PE		GE		Efficacy	
	No. of Problems	%	No. of Problems	%	No. of Problems	%	No. of Problems	%
Worse	1	3.33	4	13.33	1	3.33	0	0.00
Equal	13	43.33	18	60.00	13	43.33	13	43.33
Better	16	53.33	8	26.67	16	53.33	17	56.67
	30		30		30		30	

From Table 8, it is clear that the proposed algorithm is performing well in almost all the problems studied. In majority of cases, the proposed algorithm shows improvement in performance measure. In some cases, it shows equality and there are a few exceptional cases where the proposed algorithm shows reduction in machine utilization or increase in percentage of exceptional elements. But Table 8 shows that, when the proposed algorithm shows reduction in machine utilization by a very small amount, it shows decrease in percentage of exceptional elements by a very large amount.

Out of all 30 problems, 13 problems show equality in all performance measures when calculated using proposed LCM and literature methods whereas 12 problems show that proposed method is superior in terms of every performance measure.

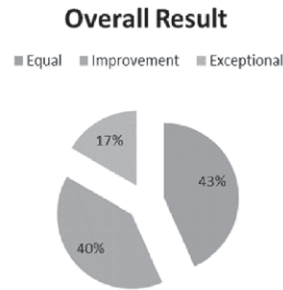


Figure 8. Overall Result

Out of 30 problems, 5 problems show some exceptions with proposed method. Out of four performance measures, efficacy is improved in all five cases. Other performance measures show reduction in one measure with improvement in other. Following table summarizes the exceptions.

Table 9: Exceptional cases

Problem No.	Increase in MU	Reduction in EE	Increase in GE
20	3.601815	-12	-2.744547001
26	11.60824	-1.5873016	5.679770393
27	2.455598	-2.2222222	1.85019305
28	-0.23368	21.5384615	1.467724231
29	21.43843	-2.2556391	10.7161708

From Table 9, it is clear that, when the proposed method shows reduction in one performance measure, it shows considerable increase in other. In problem 26, the number of exceptional elements has increased by about two percent with twelve percent increase in machine utilization and six percent increase in grouping efficiency. Also in problem 28, the machine utilization shows very small reduction with large reduction in number of exceptional elements.

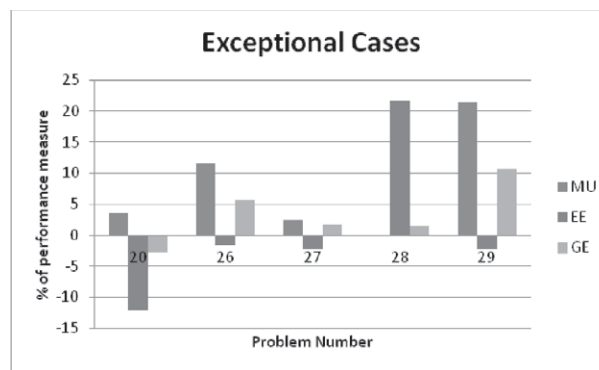


Figure 9. Values of Performance Measures of Exceptional Cases

Thus, these exceptional cases can be considered as improvement cases.

The average values of improvements in performance measures obtained by proposed algorithm are shown in following Table 10:

**Table 10: Overall improvement by the proposed algorithm**

% Improvement in			
MU	PE	GE	Efficacy
6.34	1.31	3.13	8.22

## Conclusions

Though there are numerous methods available for cell formation in group technology, no method can guarantee an optimum solution. Considering this situation, the author has tried to develop a new algorithm which is very simple and flexible. The proposed method is tested on almost all types of problems available in literature. In every situation the proposed method is performing well. In current work, Application of LCM to machine-part incidence matrix has been demonstrated successfully which forms the groups of a machines and part families.

The results are compared with popular existing algorithms and found that the LCM solution is superior to others. The proposed method has not been tested against any particular cluster formation approaches, but the method is applied to problems which have been solved in literature using variety of techniques. The solutions obtained by these methods are evaluated using the performance measures already defined. The LCM method gives improved average values of the four performance measures, PE, MU, GE and efficacy.

## Advantages

The proposed method is very simple yet effective. It is free from sequential constraints. Whatever may be the sequence of components and processes in the initial matrix, the algorithm arranges it in descending order of number of processes. Hence the final solution does not get influenced by initial incidence matrix. Very low computational effort is required compared with all other algorithms.

## Limitations of the Study

Firstly, construction of large size machine part incidence matrix is at times tedious. However it can be simplified using worksheet on computer. Secondly, the algorithm is tested on bench mark problems, some real life problems need to be tested and solved. Thirdly, the algorithm is purely based on reduction in material handling time, however some other criteria such as machine movement restriction, process sequence, etc. may also be considered. Finally, resource sharing is not considered.

## Scope for Future Research

The algorithm may further be extended by adding constraints such as resource sharing, process sequence to be followed, etc. The various alternatives obtained may then be simulated to identify optimal solution.

## References

- Adil, G. K., & Ghosh, J. B. (2005). Maximum diversity/similarity models with extension to part grouping. *International Transactions in Operational Research*, 12, 311-323.
- Alhourani, F., & Saifoddini, H. (2007). Machine cell formation for production management in cellular manufacturing systems. *International Journal of Production Research*, 45(4), 913-934.
- Askin, R. G., Cresswell, S. H., Goldberg, J. B., & Vakharia, A. J. (1991). A Hamiltonian path approach to reordering the part machine matrix for cellular manufacturing. *International Journal of Production Research*, 29(6), 1081-1100.
- Chalapathi, P. V. (2012). Complete design of cellular manufacturing systems. *International Journal of Advanced Engineering Technology*, 3(3), 67-71.
- Chandrasekharan, M. P., & Rajgopalan, R. (1986). An ideal seed non-hierarchical clustering algorithm for cellular manufacturing. *International Journal of Production Research*, 24(2), 451-464.
- Chen, S. J., & Cheng, C. S. (1995). A neural network based cell formation algorithm in cellular manufacturing. *International Journal of Production Research*, 33(2), 293-318.
- Cheng, C. H., Kumar, A., & Motwani, J. (1995) A comparative examination of selected cellular manufacturing clustering algorithms. *International Journal of Operations & Production Management*, 15(12), 86-97.
- Chow, W. S., & Hawaleshka, O. (1992). An efficient algorithm for solving the machine chaining problem in cellular manufacturing. *Computers Industrial Engineering*, 22(1), 95-100.
- Chu, C. H., & Hayya, J. C. (1991). A fuzzy clustering approach to manufacturing cell formation. *International Journal of Production Research*, 29(7), 1475-1487.
- Francis, R. L., & White, J. A. (1974). *Facility Layout and Location*. New Jersey: Prentice Hall Inc.
- Ghosh, T., Doloi, B., & Dan, P. K. (2014). A novel cell formation technique in cellular manufacturing system based on Production factors. 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR) IIT, Guwahati, Assam, India. Retrieved from <http://www.iitg.ernet.in/aimtdr2014/PROCEEDINGS/papers/169.pdf>.
- Ghosh, T., & Dan, P. K. (2014). Taguchi's Orthogonal Design based soft computing methodology to solve cell formation problem on production shop floor. *ACTA Technica Corviniensis - Bulletin of Engineering*, 4, 81-88.
- Hachichaa, W., Masmoudi, F., & Haddar, M. (2007). Formation of machine groups and part families in cellular Manufacturing systems using a correlation analysis approach. *International Journal of Advanced Manufacturing Technology*, 36(11-12), 1157-1169.
- Harhalakis, G., Nagi, R., & Proth, J. M. (1990). An efficient heuristic in manufacturing cell formation for group technology applications. *International Journal of Production Research*, 28(1), 185-198.
- Heragu, S. S., & Gupta, Y. P. (1994). A heuristic for designing cellular manufacturing facilities. *International Journal of Production Research*, 32(1), 125-140.
- Kaparthi, S., & Suresh, N. C. (1992). Machine-component cell formation in group technology: a neural network approach. *International Journal of Production Research*, 30(6), 1353-1367.

- King, J. R. (1980). Machine component grouping in production flow analysis: an approach using a rank order clustering algorithm. *International Journal of Production Research*, 18(2), 213-232.
- King, J. R., & Nakornchai, V. (1982). Machine component group formation in group technology: review and extension. *International Journal of Production Research*, 20(2), 117-133.
- Kusiak, A., & Chow, W. S. (1987). Efficient solving of group technology problem. *Journal of Manufacturing System*, 6, 117-124.
- Kusiak, A., & Cheng, C. H. (1990). A branch and bound algorithm for solving the group technology problem. *Annals of Operations Research*, 26, 415-431.
- McCauley, J. (1972). Machine Grouping for Efficient Production. *The Production Engineer*, 2, 53-58.
- Murugan, M., & Selladurai, V. (2011). Formation of Machine Cells/ Part Families in Cellular Manufacturing Systems Using an ART-Modified Single Linkage Clustering Approach – A Comparative Study. *Jordan Journal of Mechanical and Industrial Engineering*, 5(3), 199 – 212.
- Pandian, R. S., & Mahapatra, S. S. (2009). Manufacturing cell formation with production data using neural networks. *Computers & Industrial Engineering*, 56(4), 1340-1347.
- Panneerselvam, R. (2012). *Production and Operations Management*. New Delhi, India: PHI Learning Private Limited.
- Seifoddini, H. (1989). A note on the similarity coefficient method and the problem of improper machine assignment in group technology applications. *International Journal of Production Research*, 27(7), 1161-1165.
- Seifoddini, H., & Djassemi, M. (1991). The production data-based similarity coefficient versus jaccard's similarity coefficient. *Computers & Industrial Engineering*, 21, 263-266.
- Tompkins, J. A., & White, J. A., Bozer, Y. A., & Tanchoco, J. M. A. (1996). *Facilities Planning*. John Wiley and Sons.
- Venukumar, P., & Haq, A. N. (2006). Complete and fractional cell formation using Kohonen self-organizing map networks in a cellular manufacturing system. *International Journal of Production Research*, 44(20), 4257-4271.
- Viswanadham, N., & Narhari, Y. (1994) *Performance Modelling of Automated Manufacturing Systems*. Prentice Hall India.
- Waghodkar, P. H., & Sahu, S. (1984). Machine-component cell formation in group technology: MACE. *International Journal of Production Research*, 22(6), 937-948.
- Wei, J. C., & Kern, G. M. (1989). Commonality analysis: A linear cell clustering algorithm for group technology. *International Journal of Production Research*, 27(12), 2053-2062.
- Yan, Z., Wang, J., & Fan, J. (2014). Machine-cell and Part-family Formation in Cellular Manufacturing Using a Two-phase Clustering Algorithm. Preprints of the 19th World Congress The International Federation of Automatic Control Cape Town, South Africa. 2605-2610. Retrieved from <http://www.nt.ntnu.no/users/skoge/prost/proceedings/ifac2014/media/files/0950.pdf>.
- Yin, Y., & Yasuda, K. (2005). Similarity coefficient methods applied to the cell formation problem: a comparative investigation. *Computers & Industrial Engineering*, 48, 471-489.

*Authors' Profile*

**Shilpa Moreshwar Samak-Kulkarni**, is heading the Department of Mechanical Engineering at GECT's Satara College of Engineering & Management, Satara, India. She has published several research papers in the area of industrial engineering. She is currently working on a project of layout improvement of a medium scale company.

**Neela Ravindra Rajhans** is a Professor of Production Engineering at Government College of Engineering, Pune, India. She has a total of 25 years of teaching experience and has 60 publications in national and international journals to her credit. Her areas of research interest are ergonomics and industrial engineering. Her current projects include designing bed to avoid bed sores, layout improvement of a medium scale company, spare part inventory optimization of a bus company and vehicle routing problem.

---