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An Enhanced Tabu Search Cell Formation Algorithm for a Cellular Manufacturing System

Vikrant Sharma, Mody University, India*
B. D. Gidwani, Rajasthan Technical University (RTU), Kota, India

ABSTRACT

The major benefit of using cellular manufacturing systems (CMS) is the improvement in efficiency and reduction in the production time. In a CMS, the part families and machine parts are identified to minimise the inter and intracellular movement and maximise the utilisation of machines within each cell. Many scholars have proposed methods for the evaluation of machine cell part layouts with single routes; this paper introduces a modified hybrid tabu search algorithm (HTSA) referred to as hybrid algorithm in this study for machine cell part layouts having multiple routes as well. The primary objective of this paper is to minimise the inter- and intra-cellular movement using a hybrid algorithm. The paper presents a comparative analysis of the existing and the proposed algorithms, proving that the proposed hybrid algorithm is simple, easy to understand, and has a remarkable efficiency with a runtime of 5.6 seconds.

KEYWORDS

Cell Formation and Layout, Enhance Tabu Search Algorithm, Group Technology, Machine Sequencing

1. INTRODUCTION

The Cellular Manufacturing System (CMS) is an innovative manufacturing strategy derived from the group technology (GT) concept. It identifies machinery cells, parts families, and uses these machines to the greatest extent possible to minimise intercellular movement (Chang et al., 2013, Houshyar et al., 2014). A number of companies have favoured CMS with reduced transport time for various parts, cycle time and installation times. It also improved the expertise of operators and human relationships (Gunasekaran, 1994). Cell development, cell layout and intracellular sequencing are key aspects of CMS design (Wu, Low, & Wu, 2004, Imran et al., 2017).

The problem of cell formation (CF) is the division of GT. Grouping of machines and machine parts in a cellular manufacturing process with similar processing methods in all sets of machines is known as the cell formation problem. In certain cases, cell configurations are designed with diversified planning periods for different types of applications. Based on the cell formation process, a fundamental relation will be established among machines and parts. Machine parts would then be assembled to process all parts of the machine family with similar arrangement. There are certain goals to determine

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the feasibility of the cellular manufacturing system, such as minimising inter- or intra-cell movements, increasing machine utilisation and reducing expenses by reducing setup times. CMS design includes numerous interconnection issues, machine grouping, parts family formation, and cell design. Under assembly conditions, GT was used to make manufacturing frameworks more profitable.

Group of GT possesses certain prominent features which needs to be assembled into the part families and an efficient CMS is used for this purpose. CMS offers various advantages such as reduced workloads, decreased computation time, more restrictive lead-time assembly, lower inventory, and increased robustness to withstand internal and external changes such as machine deceptions.

This research presents an enhanced, incredible method of metaheuristic cell development. The problem of cell arrangement is to assemble machines and part of families into cells with an aim of limiting intercellular developments. There is a possibility of considering the decrease of cell load variety and another possibility that consolidates a minimum of cell load variation and intercellular developments. This is addressed by improving the cell system using the metaheuristic. The source can determine the required number of cells of previous and lower and upper cell size limits. This allows the prohibited investigation to adapt to cell development problems. The system of arrangements worked well for large-scale problems tried out and information indexes distributed. The aftereffects of computational tests introduced are extremely reassuring. Various non-customary survey algorithms are available for CMS approach. The aim is to recognise the families of parts and the assembly of machines and to shape the production cells in order to limit the quantity of remarkable components. Although cell assembly offers incredible benefits, the CMS plan is unpredictable for real issues. It is noted that the cell development problem in CMS is one of the NP-hard combination problems. Numerous models and arrangements were developed to distinguish machine cells and part families as it is difficult to achieve ideal arrangements in a satisfactory measure of time, especially in the case of huge, estimated problems. These methodologies can be divided into three main classes: models for mathematical programming (MP), algorithms for heuristic / meta-heuristic arrangement and similarity coefficient methods (SCM). Although the CF has been the focal point of the investigations for a number of years, there are a few variations of the CF merits equivalent considerations on them, such as the CF allowing alternative process. A large portion of the above CF explores the expectation that each part will have an exceptional cycle direction. However, it is noteworthy that there may be options in any degree of a cycle plan. Essentially, only a limited measure of examination with respect to the CF managed machine breakdowns or unwavering quality issues. Customarily, CF and work distribution are carried out, accepting that all machines are 100% reliable. However, this is not generally the case. Their breakdowns could have a significant impact on the framework execution gauges and could have adverse impacts on the performance due date. In order to improve the overall presentation of the framework, machine failure should now be considered during the CMS plan.

A good cell layout is helpful in reducing the number of intercellular part movements while a proper sequencing of all the cells in the machine will help in the reduction of the part movements within the cells (Moslemipour, 2017). Hence, it can be inferred that the critical factors to be considered in the design of the CMS are the cell layout and the intracellular part movements. Some of the authors considered numerous objectives and introduced a parallel SA algorithm (Su and Hsu, 1998) to minimize the following objectives: (i) machine investment and transportation costs. (ii) inter and intra cellular machine loading unbalance. Pareto-optimality-based multi-objective TS algorithm was presented by Lei and Wu (2005) as a solution to the same problem. Tompkins, White, Bozer, & Tanchoco, (2010) approximated that half of the costs in manufacturing was due to part handling and a proper sequence will help in the cost reduction by 10-30%. Hence the adequate design of the CMS layout is necessary to get maximum output. However, limited research has been done in this area, and one will come across many shortcomings in this area. Sequentially solving the problems of inter, intracell and cell formation may lead to a less efficient CMS system. Certain drawbacks of CMS which limits its usage for real life situations are (i) Minimizing the number of inter and intracellular movements rather than the cost of its material, (ii) not considering the factors of production like process times, processing routings, part demands (Mohammadi, Forghani, 2014).

Due to these drawbacks, this paper develops a modified Hybrid Tabu Search Algorithm (HTSA) referred to as Hybrid Algorithm for machine cell part layouts having multiple routes as well. The main objectiive of this paper is minimising the inter and intracellular movement using the developed hybrid algorithm.

The remainder of this paper is as follows: Section 2 describes a brief literature review and research gap. Section 3 presents methodology and proposed hybrid algorithm. Computational result and discussion is reported in Section 4, and finally study is concluded in Section 5.

2. LITERATURE REVIEW

Various design methods have been suggested by different authors in the design of CMS. An integrated algorithm was proposed to overcome the problem of family-part formation of the machine cell simultaneously along with the issue of inside-cell layout (Akturk, Turkcan, 2000). It was the first study which considered the efficiency of the system as well as the individual cells in financial terms. The proposed method portrayed the operation of the CMS more accurately because it considered processing times, production volumes, alternative routes to assess the impact of capacity constraints Wu et al., (2007) introduced a hierarchical genetic algorithm which formed the cells and determined the group layout simultaneously. The developed algorithm included the hierarchical structure that encoded two decisions regarding cell design. The proposed structure effectively improved the solution quality and accelerating convergence. But this study did not include the intra-cellular sequencing. Chan et al., (2008) was the only one to integrate all the three factors of cell layout, formation, machine sequencing within the cells to design a CMS, but only the linear layout was considered. A two-phase approach was proposed, a mathematical model consisting of a multi-objective function was formed in the first phase, and in the next stage, a different mathematical model which consisted of a lone-objective function was developed to optimize the movements of the cell parts.

The problems pertaining to manufacturing and the formation of the cells were rectified by Wu, Chung, & Chang (2009) by introducing a hybrid simulated annealing algorithm that included a mutation operator. The algorithm explored the solution regions efficiently and expedited the solution searching process. The computational results indicated the proposed method was superior to the others which used maximum density rule.

Javadian et al., (2011) presented a dynamic multi-objective cell formation problem where simultaneous load-varying minimization and different costs were possible. However, in this type of problem, the objectives contradict each other and it is therefore difficult to decide on the ideal solution. As a result, a non-dominated genetic testing algorithm (NSGA II) was developed to determine the Pareto-optimal boundary, which helps the decision-maker to choose the solution. A financially accessible optimization software (Lingo 9) is utilized for solving the problem and then compared to the results of NSGA II for the problems of small sizes. An integrated mathematical model was presented by Mahdavi et al., (2013), which simultaneously considered both cell formation and cell layout and modelled similar elements and their machines in one cell. The developed model also considered forward and backtracked movements. The movements between the cells depending on the distances which were Euclidean or linear among the cell pairs was also measured from this system. Sadeghi, et al., presented a mathematical model for solving the problems of formation of the cell, layout of the cell, assigning the operators and intercell layout simultaneously. The main aim of this study was to reduce the inter and intra cell movements and the cost of machine relocation. But this model had a larger execution time since it is an NP hard model.

Saeidi et al., (2016) developed a programming model for designing the CMS considering the alternative processing plans, operation sequence, machine cost, processing time, volume of production, and redundancy. Fuzzy programming approach was utilized for converting the model that is multi-objective into a single-objective one. Execution of the proposed hereditary calculation is assessed by adopting four issues of the literature. The outcomes demonstrate viability and proficiency of the proposed calculation when compared to those obtained from NSGA II and Lingo. Zeb et al., (2016) developed the hybridization of simulated annealing (SA) with genetic algorithm (GA), wherein the power of GA was explored for broadening the search space and then combined along with the SA's intensification power. Special highlights and points of interest of the proposed techniques are novel hybridization of SA and GA for resolving CFP, and a similar setting of the parameter is utilized for all sizes of issues, giving shake-off to the SA parameters to abstain from getting trapped in nearby minima. Appropriate portrayal of the issue, choice and fine tuning of GA, SA and shake-off parameters are the basic variables to effectively actualize the proposed research work.

Eguia, et al., (2017) dealt with the designing and loading a CMS when multiple periods of time and alternative routing is present. These systems consisted of machining cells which are reconfigurable. The problem of cell design is modified as an Integer Linear Programming formulation taking into account various processes. For the problem of loading the cell a mixed integer linear programming model (MILP) is designed. But computation of a solution which is optimal for the designed kind of MILP is impractical for the problems whose size is large due to the increase in computation time. Imran et al., (2017) developed a mathematical model to reduce the value-added work in the process of cell formation in a CMS. The developed mathematical model was implemented by integrating the simulation and the genetic algorithm. This technique reduced the cost values by 9.01% but idle time of the machine was large thus increasing the overall runtime of the process. (Sharma et al., 2019) proposed an implementation model for visualizing the prioritization of cellular manufacturing system (CMS) employing analytic hierarchy process (AHP) and analytic network process (ANP) techniques. In the proposed research four enabler dimensions and 17 CM attributes were evaluated and two efficient models such as AHP and ANP are proposed to evaluate the implementation dimension. The effectiveness of the proposed research was verified by carrying out sensitivity analysis. The proposed research provides a simplified analysis for effectively analyzing CMS. The proposed AHP and ANP approaches play a prominent role in selecting a potential strategy for implementing CMS. These two techniques provided similar outcomes and are capable of considering the required essentialities of any organization using its own accessible potential. (Bansal,2020) presents five metaheuristic improvement algorithms to discover near-optimal Golomb ruler (OGR) arrangements in a reasonable time. To improve search space and further improve assembly speed and accuracy of metaheuristic algorithms, improved algorithms are proposed depending on the transformation system and Lévy-Flight Search Appropriation. These two procedures help the metaheuristic algorithms leap out of the nearby ideal, enhancing the world's research capacity to maintain a wide variety of populations.

(Bansal,2019) proposes five late ways to find close ideal Golomb ruler (OGR) successions in a reasonable time depending on nature-propelled algorithms. Ideal Golomb ruler sequences have been discovered in a canal allotment strategy that can hide crosstalk from the optical wavelength multiplexing (WDM) frameworks by means of a four- wave mix (FWM).

(Bansal, Gupta and Singh,2017) proposes the use of three late nature-motivated calculations, in particular Bat inspired algorithm(BA), Cuckoo Search Algorithm (CSA), Flower pollination algorithm (FPA) and its adjusted structures for the discovery of Golomb ideal or narrow ideal rulers in an appropriate time and their display contrasting customary and nature calculations for close OGR's. The intention of using natural metaheuristic calculations was not really to produce fantastic results, but to produce close to ideal results in the limits of the results. This paper presented 3 algorithms based on nature (BA, CSA and FPA) as well as their modified structures (MBA, CSAM and FPAM) to address the close issue of OGRs. The proposed calculations have been approved and contrasted in close proximity with other existing OGR algorithms.

In (Bansal,2018), two nature-motivated multi-target optimizing algorithms (MOAs) and their crossover structures are proposed to locate optimal Golomb rulers (OGRs) at a reasonable time. The

OGRs can be used as a channel-distribution algorithm that allows the crosstalk blending of four waves to be hidden in multiplexing frames for optical frequency division. The results introduced assume that the proposed MOAs beat current ordinary old style and nature-enlivened based algorithms to discover close OGRs in terms of ruler length, complete optical transfer speed, data transmission development factor, algorithm time, and computational intricacy. So as to discover the prevalence of proposed MOAs, the exhibitions of the proposed calculations are additionally dissected by utilizing measurable tests. (Bansal, Gupta and Singh,2016) proposes a unique multi-object Bat Algorithm (MOBA) and its all-encompassing structure, to be a specific, new multi-objective parallel hybrid Bat algorithm (PHMOBA) to create the shortest Golomb ruler length at a reasonable algorithm time.

2.1 Research Gap

Majority of the studies discussed above attempted to reduce the inter and intra cell movements in a CMS, however, the developed techniques had lesser efficiency and longer computation time thus increasing the overall runtime of the process. To the best of our knowledge, no effective technique exists for reducing the inter and intracellular movements. Moreover, the time and efficiency can be considered as a major gap. Hence there is a need for developing an effective technique with higher efficiency and lesser time consumption.

3. RESEARCH METHODOLOGY

3.1 Problem Definition

CMS is generally developed for enhancing the flexibility as well as efficiency of production. It involves identifying the machine cells and part families for minimizing the intercellular movements as well as maximizing the use of machines inside the cells. Chang, et al., (2013) developed a mathematical model consisting of two stages for designing the CMS. But the developed algorithm was only for machine cell parts having single routes. This algorithm can further be modified for parts having multiple alternative routes in turn reducing the ICMD value which further improves the efficiency of the complete system.

3.2. Proposed Solution

Chang, Wu, Wu, (2013) proposed a two-stage mathematical programming model for the design of a CMS. This model integrated the important issues of cell formation, layout and machine sequences among its cells by considering the volume of production, sequences of operations and alternatively routed processes. But this algorithm developed a machine cell-part layout for parts having single routes. The proposed method is an improvement of this algorithm for the development of the machine cell parts having multiple alternative routes.

3.2.1 Layout Formation

We consider the layout employed by Chang, Wu, (2013) for our proposed scheme. The hybrid algorithm which we propose will be applied to the layout and the performance of the same is estimated. Table 1 shows the layout considered in our research.

Here in the above layout, we have formulated the cells based on the machine position and the various parameters considered are mentioned below:

PN: art number
PV: Production volume
RN: Routing number
M1-M10: Number of machines employed

Table 1. Input cell that requires optimization

PN PV RN	P1 150			P2 95		P3 130			P4 80		P5 120		P6 95			P7 135			P8 145		P9 100		P10 150	
	R1	R2	R3	R1	R2	R1	R2	R3	R1	R2	R1	R2	R1	R2	R3	R1	R2	R3	R1	R2	R1	R2	R1	R2
M3			1						1	1			3	1							1	1	2	1
M7				2		3				3				3				3			3		3	3
M8				1		2	3		2	2				2	3			2	3		2	2		2
M2	2	2				1		2				1	2			1	2							
M4	3	1	2													2	3	1						
M6		3													2	3								
M1	1				1		1	1			1		1		1		1		1	1			1	
M5			3		4			3			3	4							5	3	4			
M9					3				3			3							4	2		3		
M10					2		2				2	2							2					

3.2.2 Similarity Matrix

In manufacturing systems similarity coefficient-based techniques are used extensively in the cell formation process. The similarity matrix is calculated using Sorenson's similarity coefficient:

$$s_{ij} = \frac{2a_{ij}}{2a_{ij} + b_{ij} + c_{ij}} \tag{1}$$

where:

S_{ij} = Similarity among machines i,j

a_{ij} = No. of parts handled by i,j machines

b_{ij} = No. of parts handled only by i machine

c_{ij} = No of parts handled only by j machine

The similarity matrix among the every machine pair is calculated using equation (1).

The machine cell linking the individual machines or subgroups of machines, is formed taking the similarity matrix as the input. From p,q cells the r cell is formed. The no. of r cell machines is denoted by n_r. Equation (2) is used to compute the centroid linkage:

$$d\left(r,s\right) = \left\| x_r - x_s \right\|_2 \tag{2}$$

where:

$$x_r = \frac{1}{n_r} \sum_{i=1}^{n_r} x_{ri} \tag{3}$$

The part family is formed with the help of equation (4):

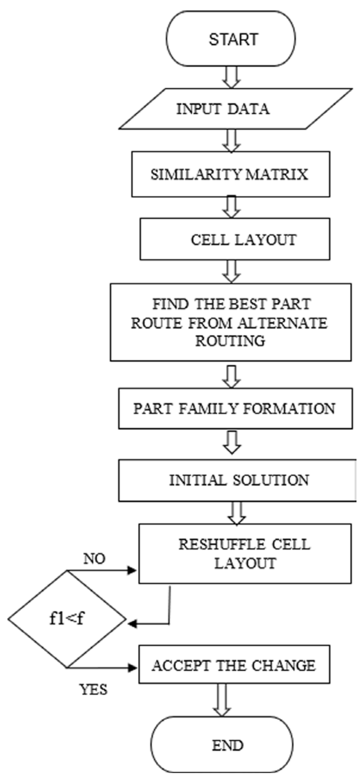
$$D_{cj} = \frac{N_{cj}}{m_c} \times \frac{N_{cj}}{n_j} \times \frac{1}{v_c} \tag{4}$$

where:

c - cell, j - part
c - cell, j - part
D_{cj} = j to c Membership index
N_{cj} = No. of machines of c cell which handles j
m_c = all the machines of c cell
N_j = all the machined needed by j
M_{cj} = No. of c cell machines that does not handle j
v_c = No. of c cell voids

The flow diagram for the proposed scheme of cellular layout optimization is given in the below fig 1.

Figure 1. Flowchart of the proposed algorithm



3.2.3 Hybrid Tabu Search Algorithm (HTSA)

In our proposed Hybrid algorithm, we combine centroid based linkage clustering (CLCA) algorithm with tabu search to improve the optimization. Here the clustered parameters are employed to enhance the search process that adds in improving the efficiency. The algorithm pseudocode is given below:

```
Input:
    Set: Incidence matrix A of the machine part as input
Step - 1 Procedure similarity ()
        Step 1.1: Compute the similarity values among machine pairs
        Step 1.2:  Calculate the similarity matrix Sm.
End

Step - 2 Procedure CLCA ()
        Step 2.1: Set the loop
        Step 2.2: Compute the Euclidean distance among the cell centroids
        Step 2.3: Construct a matrix of size size (m-1)x3 using
         hierarchical structure of the tree
        Step 2.4: Set the loop
        Step 2.5: Create machine cells for computing the
         similarity coefficient of highest level
End

Step - 3 Procedure part_family_formation_heuristic ()
        Step 3.1: Read the machine assignment for every part of
         the routing selection
        Step 3.2: Assign the cells to each part which results in
         the lowest sum of different voids
        Step 3.3: Assign the part to the cell with lower voids, if
         the result is same for two cells
        Step 3.4: Repeat step 3.2 till all the cells are assigned with parts
Step - 4 Optimization of the obtained solution
        Step 4.1: The assigned machine parts to the cell are
         changed in the obtained solution
        Step 4.2: Calculate the objective function
        Step 4.3: Accept the arrangement if f1 < f, else swap the
         part with another cell
        Step 4.4: Repeat Step 4 for every part assigned to the cell
        Step 4.5: Terminate the execution after reaching the maximum iteration
End
```

Based on the employed hybrid algorithm the cell formation is optimized and performance is evaluated. Here we compared our algorithm with various existing algorithms. Results obtained are explained in the next section.

4. RESULTS AND DISCUSSION

4.1 Similarity Matrix

From the given matrix, the similarity matrix is calculated for the machines and the parts that required processing. The formation of a similarity matrix is the basic step for the process of machine cell formation. For this process the elements of the similarity matrix have to be divided into similar elements and then clustered. This process is continued until the required number of clusters is formed. These clusters will be the machine cells for the problem considered in this paper.

4.2 Machine Cell Formation

The machine cell formed, and the machine cell layout is shown in figures 2 and 3 respectively. From the figures it can be understood that machines 3,7,8 are in the first cell and 2,4,6 are in the second cell and 1,5,9,10 are in the third cell.

Figure 2. Machine cell formation

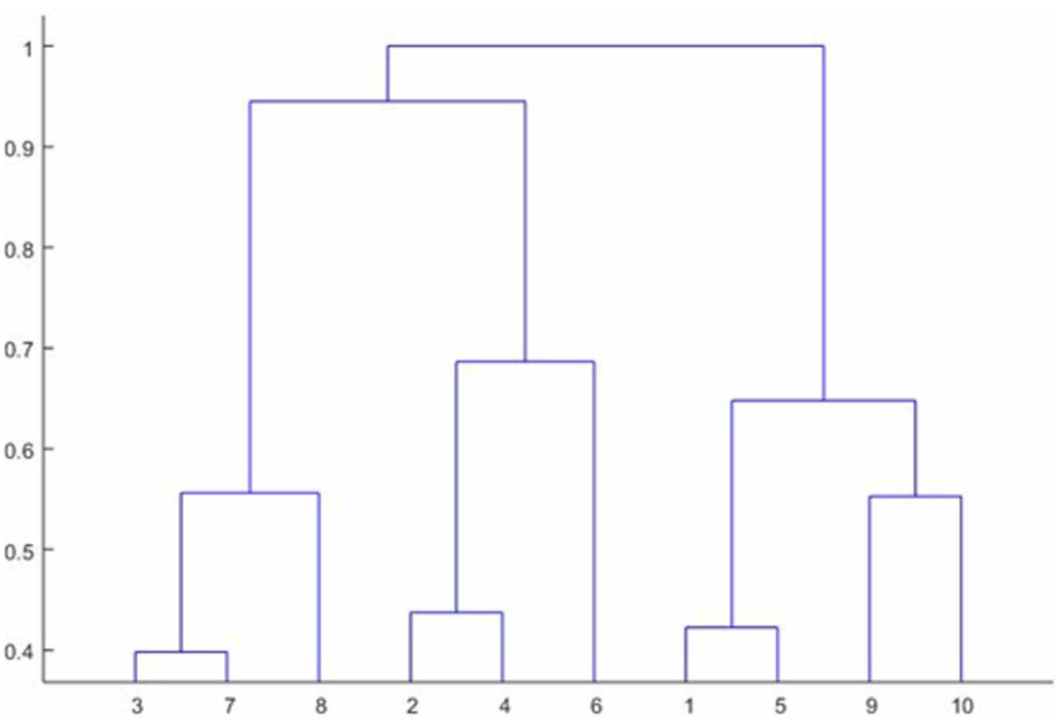


Figure 3. Machine cell layout

```
cell_layout{1} = 3
cell_layout{1} = 7
cell_layout{1} = 8
cell_layout{2} = 2
cell_layout{2} = 4
cell_layout{2} = 6
cell_layout{3} = 1
cell_layout{3} = 5
cell_layout{3} = 9
cell_layout{3} = 10
```

4.3 Part Route Allocation

From the developed code, the variable icmd2 gives the distance of intercellular movement for each route. From this variable the best route for all the parts which has more than one route is extracted. The extracted route is shown in figure 4. It is seen that the best route for 1st part is 2nd one from the three alternate routes proposed. And for 2nd is the 2nd one from the given routings and so on.

4.4 Part Family Formation

The total number of voids and exceptional elements for all the three cells is calculated and the allocation of the part to the part families is done on the basis of the sum of the voids and exceptional elements. Lowest sum of elements and voids is a result of allocating the machine to the cells. Three part families are formed after the allocation. From figure 5 it can be understood that the 1st part is assigned to the machine cell 2 and the 2nd part is assigned to the machine cell 3 and so on.

4.5 Formation of the Initial Solution

The matrix that appears after the arrangement of the part families according to the machine cells is shown in figure 6. The total icmd obtained for the initial solution is found to be 330.

4.6 Improvement of the Initial Solution Using the Proposed Hybrid Algorithm

In this step the machine cell is altered and the new total_icmd is found to be 230, which is less than the previous one.

The graph in figure 11 is a plot between the iterations and ICMD. The graph starts from 330 as the initial solution was 330. In the second iteration the ICMD was found to be 230 and in the subsequent

Figure 4. Part route allocation

1	2	3	4	5	6	7	8	9	10
2	2	1	2	1	2	1	2	1	2

Figure 5. Part family allocation

	1	2	3	4	5	6	7	8	9	10
1	2	3	1	1	3	1	2	3	1	1

Figure 6. Initial solution

	1	2	3	4	5	6	7	8	9	10
1	3	3	3	3	3	0	0	0	0	0
2	2	2	2	2	2	0	0	0	0	0
3	1	1	0	1	1	0	0	0	0	0
4	0	0	1	0	0	2	1	0	0	0
5	0	0	0	0	0	1	2	0	0	0
6	0	0	0	0	0	3	3	0	0	0
7	0	0	0	0	0	0	0	1	1	1
8	0	0	0	0	4	0	0	4	3	3
9	0	0	0	0	0	0	0	3	0	2
10	0	0	0	0	0	0	0	2	2	0

Figure 7. Obtained optimum cell layout

```
cell_layout{1} = 2
cell_layout{1} = 4
cell_layout{1} = 6
cell_layout{2} = 3
cell_layout{2} = 7
cell_layout{2} = 8
cell_layout{3} = 1
cell_layout{3} = 5
cell_layout{3} = 9
cell_layout{3} = 10
```

Figure 8. Part routing obtained by the hybrid algorithm

	1	2	3	4	5	6	7	8	9	10
1	2	2	1	2	1	2	1	2	1	2

Figure 9. Part family allocation obtained by the hybrid algorithm

	1	2	3	4	5	6	7	8	9	10
1	1	3	2	2	3	2	1	3	2	2

Figure 10. Final solution obtained for the considered problem

	1	2	3	4	5	6	7	8	9	10
1	3	3	0	0	0	0	0	0	0	0
2	2	1	0	1	0	0	0	0	0	0
3	1	2	0	0	0	0	0	0	0	0
4	0	0	1	0	1	1	1	0	0	0
5	0	0	3	3	3	3	3	0	0	0
6	0	0	2	2	2	2	2	0	0	0
7	0	0	0	0	0	0	0	1	1	1
8	0	0	4	0	0	0	0	4	3	3
9	0	0	0	0	0	0	0	3	2	0
10	0	0	0	0	0	0	0	2	0	2

step it rises to 330 and in the final step it goes back to 230 again. Hence the best solution is obtained for the two machine cell configurations. The graph in figure 12 is a plot between the total ICMD and group efficiency. It is seen from the graph that for the same icmd value of 230 two efficiency values are obtained. Hence it can be concluded that the best machine cell layout is the one with the higher efficiency. The highest efficiency is obtained with least ICMD for the second iteration which is the final solution obtained.

Here we employ the same approach in the below case study and respective performance of the hybrid algorithm will be measured. Here the below table shows the case study considered.

Figure 11. Plot for total_icmd

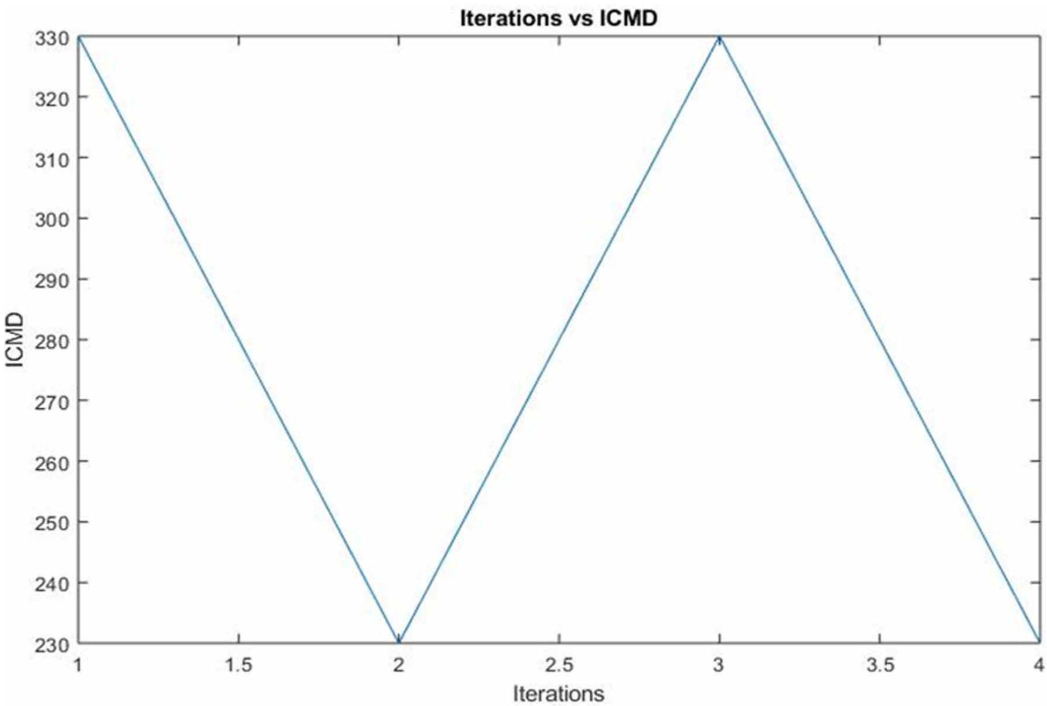


Figure 12. Plot for efficiency

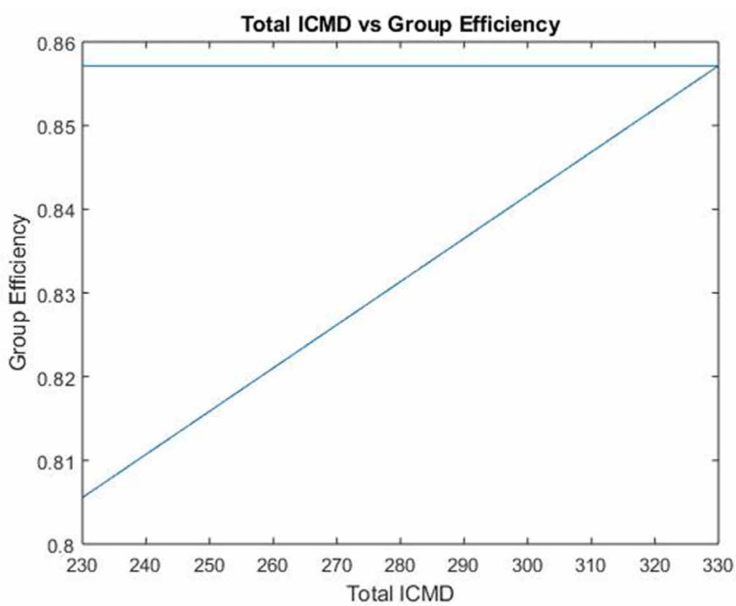


Table 2. Final optimum cell part layout

Cell No.	PN	P1	P7	P9	P3	P4	P10	P6	P2	P8	P5
	PV	150	135	100	130	80	150	95	95	145	120
	RN	R2	R2	R1	R2	R1	R1	R1	R2	R1	R2
1	M2	3	3	0	0	0	0	0	0	0	0
1	M4	2	1	0	1	0	0	0	0	0	0
1	M6	1	2	0	0	0	0	0	0	0	0
2	M3	0	0	1	0	1	1	1	0	0	0
2	M7	0	0	3	3	3	3	3	0	0	0
2	M8	0	0	2	2	2	2	2	0	0	0
3	M1	0	0	0	0	0	0	0	1	1	1
3	M5	0	0	4	0	0	0	0	4	3	3
3	M9	0	0	0	0	0	0	0	3	2	0
3	M10	0	0	0	0	0	0	0	2	0	2

Table 3. Case 2: Input cell that requires optimization

PN	P1		P2			P3		P4			P5		P6			P7		P8			P9			P10	
PV	06		18			20		14			20		06			18		14			12			06	
RN	R1	R2	R1	R2	R3	R1	R2	R1	R2	R3	R1	R2	R1	R2	R3	R1	R2	R1	R2	R3	R1	R2	R3	R1	R2
M1						1		2	1	2						3	1				3	4			
M2	5		2		2		2				4	1	4	4	3				2	1				5	
M3	3			3	1	4	3			3	2	4	2	2	1		4		5	4		1	1	3	3
M4	1	1				2	4	3	2						4		2				4				
M5			3	1	3						5	2		5				2	3	2				1	
M6	2	2				3	5	4	3	4						5	3	5		3	5		2	4	
M7		3			5		1		4							1					1	3	3		
M8	4	4				5		1	5							2		4			2	2	4		4
M9			1	4						1	3	5	3	3	2			3	1						1
M10			4	2	4						1	3	1	1	5	4		1	4					2	2

The optimized cell is given in Table 4.

4.7 Time Period

The model proposed in this paper required 5.6 seconds for the code to run in the workstation with configurations of RAM-8GB processor INTEL CORE i3. While the existing model took 9.26seconds to run the code on the workstation with configurations Intel(R) 2.40 GHz personal computer with 3.24 GB RAM.

Table 6 and Figure 13 gives the comparison of the proposed algorithm with the existing algorithms in terms of ICMD and the time taken by the CPU to run the algorithms of different authors. The present study did not emphasize on HTFSC algorithms since ILOG and LINGO were advanced when compared to the former algorithm. From the table it can be seen that the proposed hybrid algorithm has the least ICMD and CPU runtime values. Therefore, the proposed method is the most suitable algorithm for designing the CMS.

5. CONCLUSION

The paper proposed a simple, easy to understand algorithm to design the cellular manufacturing systems which produced the same results as the existing method effectively. From the results obtained it can be concluded that the hybrid algorithm used to develop the cellular manufacturing system is more efficient when compared to the existing method with respect to time consumption. The grouping

Table 4. Case 2: Final optimum cell part layout

Cell No.	PN	P4	P7	P9	P3	P1	P10	P6	P2	P8	P5
	PV	06	18	12	20	14	06	06	18	14	20
	RN	R3	R2	R1	R2	R1	R1	R1	R2	R1	R2
1	M1	2	3	0	0	0	0	0	0	0	0
1	M6	4	1	0	1	0	0	0	0	0	0
1	M9	1	2	0	0	0	0	0	0	0	0
2	M3	0	0	1	0	1	1	0	0	0	0
2	M7	0	0	3	3	3	3	0	0	0	0
2	M8	0	0	2	2	2	2	0	0	0	0
3	M2	0	0	0	0	0	0	3	1	1	1
3	M5	0	0	4	0	0	0	1	4	3	3
3	M4	0	0	0	0	0	0	2	3	2	0
3	M10	0	0	0	0	0	0	1	2	0	2

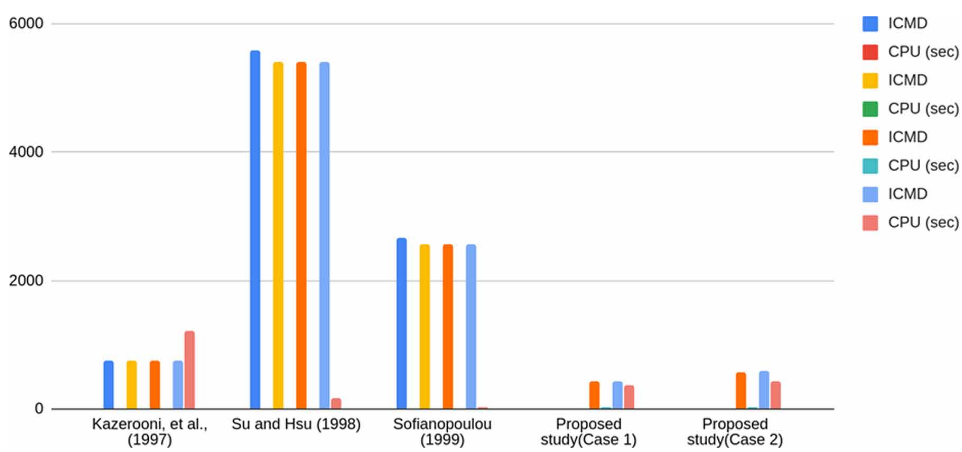
Table 5. Comparative analysis of the existing and proposed method

Authors	Production data	Layout	No of cells	Algorithm/ Mathematical Model
Chung et al., (2011)	Operation sequences and alternative routings	Inter cell layout	Auto determined	Tabu search algorithm
Chang et al., (2013)	Operation sequences and alternative routings	Inter and intra cell layout	Auto determined	Hybrid algorithm
Sadeghi et al., (2015)	Operation sequences	Inter and intra cell layout	Auto determined	Linear Programming model
Imran, et al., (2017)	Operation sequences and alternative routings	Inter cell layout	Prescribed	Hybrid genetic algorithm
Moslemipour, (2017)	Operation sequences	Inter and intra cell layout	Auto determined	Simulated Annealing algorithm
The current study	Operation sequences and alternative routings	Inter and intra cell layout	Prescribed	Hybrid algorithm

Table 6. Comparison of the proposed and existing algorithms

Author	Algorithms											
	HTSFC (linear single-row layout)		HTSFC (linear double-row layout)		ILOG CPLEX (dynamic search)		LINGO (branch and bound		Modified Binary Digit Grouping Algorithm		Hybrid algorithm (proposed method)	
	ICMD	CPU (sec)	ICMD	CPU (sec)	ICMD	CPU (sec)	ICMD	CPU (sec)	ICMD	CPU (sec)	ICMD	CPU (sec)
Kazerooni, et al., (1997)	760	1.22	760	1.16	760	18.16	760	1222	-	-	-	-
Su and Hsu (1998)	5595	2.05	5402	1.74	5402.7	1.62	5402.7	172	-	-	-	-
Sofianopoulou (1999)	2670	0.82	2561.6	0.63	2561.6	0.53	2561.6	20	-	-	-	-
Proposed study(Case 1)	-	-	-	-	430	21.23	433.2	371	-	-	330	9.26
Proposed study(Case 2)	-	-	-	-	567	26	594	425	-	-	390	12.22

Figure 13. Graphical representation of comparative performance analysis



efficiency calculated in this method will help in the decision making when a tie occurs between the two methods. The algorithm was initially used only for developing the cell-part layout for the parts having single route but this paper improvised the algorithm to develop the cell part for the parts having multiple routing. The proposed method has higher efficiency and lesser ICMD hence more beneficial when compared to the existing methods.

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Vikrant Sharma is working as an Assistant Professor in the Department of Mechanical Engineering, Mody University of Science and Technology, Lakshmangarh, Rajasthan. India. He was graduated in Production Engineering from the University of Pune in the year 2004. He obtained a Master's degree in Manufacturing System Engineering from MNIT Jaipur. He has research and teaching experience of about 13 years and about 10 publications in international journals of repute. His research interests include Industrial engineering, production, and operations management, plant layout, and multi-criteria decision making.

B. D. Gidwani has completed a Doctorate from A.K. Technical Univ., Lucknow, presently working as an Associate Professor in Dept. of Mechanical Engineering, Rajasthan Technical University Kota, India. His research interest includes Productivity Improvement, Performance Measurement, Operations Management, Lean and Cellular Manufacturing. He has published many research papers in international and national journals.