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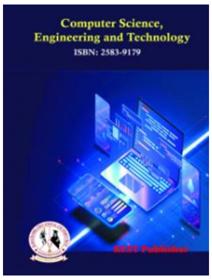

Genetic Algorithm Based Method for Optimizing Machine Arrangement in Manufacturing Cells

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Abstract: *A manufacturing cell that maximizes forward flows and minimizes backtracking flows is expected to achieve a high-performance rating across various measures. Therefore, the primary focus here is on increasing the forward flow distance while minimizing backtracking. In this paper, a genetic algorithm-based method is introduced to determine the machine sequence within each manufacturing cells, aiming to maximize Average Cell Movement Efficiency (ACME). The algorithm was tested, and the results demonstrate superior performance The comparison was made using Cell Movement Efficiency (CME) and ACME, with the proposed algorithm outperforming other methods for the intra-cell arrangement of machines*

Keywords: *Cellular manufacturing Systems, Gnetic algorithm, Intra-cell layout, Forward flows, Cell movement efficiency, Average Cell Movement Efficiency.*

1. INTRODUCTION

Cellular Manufacturing System (CMS) is a key application of Group Technology (GT) in the manufacturing sector. Various methods and algorithms have been developed to enhance the overall efficiency of manufacturing systems using cell design principles. This research aims to introduce a genetic algorithm-based procedure that formulates the intra-cell machine arrangement within a cellular manufacturing system. The algorithm will consider not only the placement of machines within specific cells and the associated forward flows but also the distances between machines, backtracking movements, and jump flows. This approach will help identify new ways to maximize forward flow distance within cells. By utilizing sequence data and part family information as input, the algorithm will create an efficient machine layout sequence within the cells. Building on the strengths of existing models and addressing their shortcomings, this research seeks to offer new methods for improving conditions in the CMS environment.

2. LITERATURE REVIEW

Research in cellular manufacturing using sequence data has primarily focused on two areas: identifying suitable similarity measures for the cell formation problem and developing new algorithms for cell formation using sequence data. Selvam and Balasubramanian (1985) [1] were the first to report the use of sequence data for cell formation through a heuristic procedure based on the set covering technique to identify cells. Suresh et al. (1999) [2] applied a fuzzy neural network approach to cell formation using sequence data. Other significant works in cell formation using sequence data include studies by Nair and Narendran (1998) [3], Vakharia and Wemmerlov (1990) [4], and Harhalakis et al. (1990) [5]. Park and Suresh (2003) [6] compared the performance of fuzzy neural networks with other clustering methods. One approach to solving the grouping and layout problem involves assuming a specific layout structure and developing a solution methodology to arrive at the optimal design. Vakharia and Wemmerlov (1990) [4] proposed a heuristic approach for machine cell design, where machines within each cell are arranged along a linear flow line. Arvindh and Irani (1994) [7] introduced an iterative approach to designing a cellular manufacturing system, where one loop focuses on machine and part grouping, and another loop adjusts the number of cells to find the best design. Heragu and Kakuturi (1997) [8] worked on integrating machine grouping and layout problems. Their approach forms machine cells using a heuristic, then constructs near-optimal intra-cell and inter-cell layouts using a hybrid simulated annealing algorithm. Chiang and Lee (2004) [9] developed a genetic-based algorithm for cell formation in a bi-directional linear flow layout, with the goal of minimizing the actual inter-cell flow cost, rather than optimizing the number of inter-cell movements. Meanwhile, the layout problem has been addressed independently by researchers for a long time. Houshyar and McGinnis (1990) [10] applied a graphic approach to facility layout, aiming to minimize the travel distance of work-in-process. Other significant contributions to the use of sequence data in cell formation include the works by Kim et al. (2004) [11] and Yin and Yasuda (2004) [12]. Mourtzis et al. (2020) conducted research on adaptive scheduling in CMS and proposed an algorithm that provides near real-time support for machines, workforce, and production managers. Additionally, Motahari et al. (2022) [14] developed a multi-objective model to optimize weighted completion time, travel cost, and idle time of machines in a multi-product environment. Kazerooni et al. (1997) [15] applied the genetic algorithm (GA) multiple times to address cell formation design problems, particularly those involving alternative routing, process sequence, and production volume. In their research, they determined the best alternative routing for each part, then identified part families and machine cells by calculating part similarity and machine similarity, respectively. Nouri et al. (2010) [16] explored a bacteria foraging algorithm that uses operation sequences for cell formation. Similarly, Yin and Yasuda (2002) [17] studied cell design by considering various production factors, especially operation sequences, alternative process routings, operation times, and production volume. Wu and Salvendy (1993) [18] incorporated operation sequences in their network analysis method to solve the cell formation problem (CFP). Furthermore, Won and Currie (2006) [19] proposed a P-median model to determine the optimal number of machine cells and associated part families, using real-world production factors such as sequence data and production volume. Mahdavi et al. (2012) [20] addressed the CFP using a three-dimensional machine-part-worker incidence matrix. Seifoddini (1989) [21] considered duplication cost and the reduction of inter-cell material handling costs in making decisions about machine duplication. Vakharia and Chang (1997) [22] focused on minimizing the total cost of inter-cell moves and machine investments, while also considering operation sequence, machine replication, production volume, and cell size. Su and Hsu (1998) [23] solved the CFP with the goal of minimizing machine costs, intra-cell, and inter-cell moves. Sequencing machines within cells and organizing the cells themselves plays a crucial role in reducing total intra-cell and inter-cell part movement distances. The use of sequence data assists designers in achieving this objective by defining the processing order of jobs in a manufacturing setup (Harhalakis et al., 1990) [5]. While some researchers, such as Won and Lee (2010) [24], have explored CMS in relation to factors like production volume and operation sequences, only a few have examined the sequence of machines within the cells (intra-cell layout) and the sequence of formed cells (inter-cell layout) (Chaieb and Korbaa, 2003) [25]. A well-designed facility layout can reduce material handling costs, lead time, and throughput time, ultimately boosting productivity and efficiency. On the other hand, a poor layout can lead to inefficient material handling and significant accumulation of work in process (WIP) (Ariafar and Ismail, 2009) [26]. Addressing these issues, which arise from the cell layout problem (CLP), can significantly minimize both inter-cell and intra-cell part movements. Chaieb and Korbaa (2003) [25] conducted a study focusing on a micro-level view of CFP, specifically investigating intra-cell machine layout. However, this study was limited to intra-cell configuration and did not consider broader aspects, such as machine sequencing. Al-Hakim (2000) [27] conducted a similar study, while Bazargan-Lari et al. (2000) [28] proposed a three-phase method to address three key design challenges: machine-part grouping, intra-cell layout, and inter-cell layout problems. Jajodia et al. (1992) [29] introduced a new approach using simulated annealing (SA) to tackle both intra-cell and inter-cell layout issues in CMS. Additionally, Adil and Rajamani (2000) [30] addressed cell compactness and independence by discussing the inter-cell and intra-cell move costs and clarifying the trade-off between these costs. In recent years, several studies have addressed both Cell Formation Problems (CFP) and Cell Layout Problems (CLP) to better align with real-world manufacturing systems. Mahdavi and Mahadevan (2008) [31] developed an algorithm called CLASS, which uses sequence data as an input to identify machine cells and the arrangement of machines within each cell. The layout is assumed to follow a linear arrangement, and valuable information about job flow patterns in the manufacturing system is utilized to derive performance measures for cell design and layout. However, their study did not consider inter-cell movements. Chan et al. (2006) [32] proposed a two-stage method to solve both CFP and CLP. In the first stage, a mathematical model is used to solve the CFP, followed by a second stage that optimizes intra-cell and inter-cell part movements using another mathematical model. The CFP model's output is then used to solve the CLP, taking into account the sequence of part operations. Machine and cell layouts are treated in a linear form, but sequence data is not used in the first stage. While their research covers both intra-cell and inter-cell layout problems, it does not integrate these into a unified mathematical model. Mahdavi et al. (2013) presented an integrated model for solving both cell formation and cell layout problems simultaneously, introducing concepts like cell movement efficiency to measure forward and backward movements within a cell. Shiyas and Pillai (2014) [33] proposed a procedure focusing solely on the number of forward flows to explicitly solve the cell layout problem, while Mahdavi et al. aimed to maximize forward flows and distances in their model. In a more recent study, Rahimi et al. (2020) [35] incorporated intra-cell layout issues into their model to minimize total time. However, while these solution methods may correctly identify the machines for each cell, arbitrarily placing machines within each cell without considering part sequence data can lead to suboptimal machine layouts. The sequence in which machines should be arranged within each group is often unclear from the solution. Many of the approaches mentioned above have high problem and solution complexity, limiting their ability to handle large-scale problems. It is also noted that the measure of performance for a cell design cum cell layout problem is not the pure "inter-cell" moves, but also other measures pertaining to flow patterns within each cell, and the distances between different machines according to sequence of arrangement (in a machine cell). Moreover, GA used rarely to address such problems The goal of this research is to develop an algorithm and establish a suitable performance measure that accounts for these requirements, addressing the gaps in the existing literature and helping to find a solution that is as close to the optimal as possible using the current resources available. From the literature review, several conclusions can be drawn. Primarily, only a limited number of methods for the cell formation problem that utilize sequence data have tackled the layout issue. In the present research we consider two performance measures, namely CME (Cell Movement Efficiency), and ACME (Average Cell Movement Efficiency (Mahdavi et al. 2013). The CME is a powerful index for evaluating performance of solutions obtained from the considered problem. This method is based on distances of machines in a cell. The CME index equals 1 when there are only forward flows in a cell and no backtracking movements exist. In such a condition, all of intra-cell moves are forward ones. The average of cell movement efficiency (ACME) is the weighted average of CMEs in all cells.

3. THE PROPOSED ALGORITHM

The Objective of the present work is to Maximize the Average Cell movement efficiency by Minimizing the backward flows and maximizing the forward flows inside a cellular manufacturing system

Maximize

$$ACME = \frac{\sum_k NF_k \times CME_k}{\sum_k NF_k}$$

Where NF_k is total number of flows in cell k

And

Cell movement efficiency: The cell movement efficiency of a cell k is given as

$$CME_k = \frac{DF_k}{DF_k + DB_k}$$

DF_k total intra-cell movement distance of forward moves in cell k

DB_k total intra-cell movement distance of backtracking moves in cell k

(Here a forward flow distance means the distance between the machines when they are arranged in particular cell as taken in Mahdavi et al (2013) [34])

The proposed method, is based on Genetic Algorithm (GA). GA is a random search method that follows the natural evolution process. The GA operations are similar to the genetic operations in nature. GA starts with a random set of populations initially and after applying operations like reproduction, crossover and mutation search for optimum solution the solution space. The characteristics of GA used here is discussed below

3.1 Chromosome structure

Coding decision variables in the form chromosome is an important part of GA. Here the chromosome represented by a sequence of numbers and each position denotes the position of a machine type and the number represents the machine type for a single cell. In the model the number of cells and the machine type incorporated in each cell is already known and is the basic input to the model. Hence each chromosome will have a length of the number of machine types representing the arrangement in each cell.

For example, suppose there are 3 cells in a CMS with the Follo **Average Cell Movement Efficiency (ACME)**wing machines

Cell 1: Machine 3 and 7

Cell 2: Machine 1 and 6

Cell 3: Machine 2, 3 and 5

The chromosome structure will be

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The first two digit represents cell 1, The third and fourth represents cell2 and remaining cell 3

Reproduction

Reproduction is the process of finding out the set of chromosomes taken for crossover and mutation. Here a roulette wheel selection procedure is used. There the possibility of a good chromosome to come to the meeting pool is high and at the same time retaining the chance of lower fit chromosomes also.

Fitness function

Here the objective is to maximize the average cell movement efficiency. Hence the fitness function is same as the objective.

Crossover and mutation

Single point crossover w is used as the crossover operator. Here one location of two chromosomes is randomly selected and the right portion is swapped and a repair function is employed to change infeasible chromosomes. The mutation operator is SWAP mutation. New off Springs are created through these operations.

Termination

Termination criteria used to hear is maximum number of generation rule or the algorithm stops when the best solution is repeated for a fixer number of generations.

Selection of the new generation

The present generation and the old generation are combined together and the best chromosome equal to the size of the population is taken for the next genetic corporations

The genetic algorithm parameter values are

Crossover probability = 0.85
Mutation probability = 0.05
Population size = 2 × chromosome length
Maximum number of generations = 1000
Fixed value for best fitness repetition =50

The performance of the proposed algorithm is compared to existing methods in the literature. For this, we will consider two performance measures, namely CME (Cell Movement Efficiency), and ACME and CME were taken.

4. RESULTS AND DISCUSSIONS

Table I and Table II shows 2 different problems and are already organized into cells as given in Mahdavi et al. 2013 [34]. and the result from the proposed algorithm is given in Table III, and Table IV.

TABLE 1. Problem 1

Part No.	Route	Part No.	Route	Part No.	Route	Part No.	Route
1	6 5	6	2 4 7 8 5	11	7 3 1	16	1 3
2	1 3	7	8 4 7 2	12	5 4 6	17	3 5 1
3	2 1 7 8 4	8	1 3	13	7 3 1	18	4 2 8 7
4	2 4 7 8	9	1 6 3	14	1 2 3	19	1 3
5	6 5	10	5 3 2	15	5 6	20	4 2 6 7 8

Here a three-cell organization is taken as given in Mahdavi et al (2013)
Cell1: Machines 1, 3
Cell2: Machines 2, 4, 7, 8
Cell3: 5, 6

TABLE 2. Problem 2

Part No.	Route	Part No.	Route	Part No.	Route	Part No.	Route
1	12 1 9 18 20	6	11 14 16 17 5	11	11 14 3	16	15 7 6 18
2	11 3 2	7	5 16 17	12	9 18 5 12 1	17	9 1 12
3	8 20 19	8	15 13 7 9 4	13	6 7 15 17	18	8 19 20 10
4	3 11 2 10	9	18 9 11 1 12	14	8 10 1 2	19	3 2 11 5
5	4 15 6 7	10	19 20 8	15	13 14 17 16	20	18 10 1 12

Here a five-cell organization is taken as given in Mahdavi et al (2013)

Cell1: Machines 8, 10, 19, 20
Cell2: Machines 1, 9, 12, 18
Cell3: Machines 5, 14, 16, 17
Cell4: Machines 4, 6, 7, 13, 15
Cell5: Machines 2, 3, 11

TABLE 3. Solution to Problem 1 using Proposed Model

Cell No.	1	2	3
Machine Sequence	1-3	7-2-4-8	6-5

TABLE 4. Solution to Problem 2 using Proposed Model

Cell no.	1	2	3	4	5
Machine Sequence	8-19-20-10	1-9-18-12	16-14-5-17	15-4-6-13-7	3-11-2

The new method is compared with two existing models from the literature, and the comparison is presented in Tables V and VI. The selection of problem data and comparison methods was based on the availability of results under the same input conditions and the feasibility of using a common performance measure for comparison. As shown in the performance results, the new algorithm provides solutions that outperform those obtained by the two other existing techniques. The performance measures presented in Table V indicate that the algorithm outperforms the integrated model developed by Mahdavi et al. (2013) and surpasses the CASE algorithm in solving the model formulated by Nair and Narendran (1998). The ACME value achieved by the proposed algorithm is superior to that of the integrated mathematical model, which is significantly more complex and resource-intensive. For Problem 2, the proposed method also yielded better solutions based on CME values and ACME. In Cell 3, the proposed method showed a slight decline in CME, but for all other cells, the new algorithm demonstrated greater efficiency in terms of CME compared to the integrated model. However, the ACME obtained for the entire solution was still higher than those achieved by other methods. In summary, the proposed algorithm outperforms in all the problems considered, and since the procedure is relatively simple, it allows for easier incorporation of new situations and parameters, which could further improve the algorithm and lead to better solutions for the cell layout problem

TABLE 5. Solution to Problem 2 using Proposed Method

Cell no.	CASE [5]				Integrated model by Mahdavi et al. [34]				Proposed model			
	DF_k	DB_k	NF_k	CME	DF_k	DB_k	NF_k	CME	DF_k	DB_k	NF_k	CME
1	1	5	6	0.17	5	1	6	0.83	5	1	6	0.83
2	15	12	16	0.55	9	9	16	0.5	17	13	16	0.56
3	1	2	3	0.33	2	1	3	0.66	2	1	3	0.66
ACME	0.4256 (From Mahdavi et al. [34])				0.60 (From Mahdavi et al. [34])				**0.636**			

TABLE 6. Solution to Problem 2 using Proposed Model

Cell no.	CASE [5]				Integrated model by Mahdavi et al. [34]				Proposed model			
	DF_k	DB_k	NF_k	CME	DF_k	DB_k	NF_k	CME	DF_k	DB_k	NF_k	CME
1	5	3	6	0.625	6	4	8	0.6	9	3	8	0.75
2	16	16	13	0.5	5	5	10	0.5	12	8	10	0.6
3	8	5	9	0.61	6	2	7	0.75	9	5	7	0.64
4	6	7	7	0.46	9	4	9	0.64	14	7	9	0.66
5	2	4	6	0.33	6	2	6	0.75	6	2	6	0.75
ACME	0.4256 (From Mahdavi et al. [34])				0.60 (From Mahdavi et al. [34])				**0.673**			

5. CONCLUSION

Determining the cell layout is a crucial step in designing a cellular manufacturing system. While many studies have focused on CFP as a significant topic, few have addressed CLPs, and even fewer have considered both CLP and CFP together. Although CFP is beyond the scope of this paper, it aims to explore the topic and methods for solving the CLP problem using various criteria. The key takeaway from this paper is the development of an efficient solution for the cell layout problem, incorporating backtracking and distances alongside forward flows—an approach that has rarely been explored by previous researchers. The proposed algorithm aims to maximize forward distances within a cell. In real-world applications, forward flows are preferred over backtracking, which should be minimized as much as possible. To validate the proposed model, two performance measures, CME and ACME, are calculated and compared with those from existing literature. These indices evaluate the effectiveness of the solutions by considering intra-cell movements, with a focus on optimizing forward flow distance. Since this paper addresses only the cell layout problem, inter-cell performance measures are not considered. After experimentation and evaluation, the proposed model has proven to be competitive with existing models, as demonstrated by performance indices such as CME and ACME. It has outperformed established models like CASE and the integrated model when tested in the same environment. Looking ahead to future research opportunities, it would be valuable to develop mathematical models of varying complexities that address both CFP and CLP simultaneously. Additionally, models that account for exact distances between cells, travel distances between machines, entry and exit points, as well as factors like part demand and multi-period planning, could be explored. These enhancements would make the model more realistic, better reflecting practical scenarios, and enable its application to a broader range of problems.

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