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DYNAMIC CELL FORMATION WITH MACHINE RELIABILITY: GENETIC ALGORITHM APPROACH

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Abstract

Cellular Manufacturing is a major component of lean manufacturing which can be achieved by cell formation of machine types. Several methods have been developed for obtaining efficient cell formation by considering ideal conditions. This paper takes into account machine reliability and breakdown conditions to provide a comparatively more realistic solution. A mathematical model is proposed to minimize the total cost of production considering factors such as operating costs, machine relocation cost (dynamic cell formation), inter-cell material handling cost, and breakdown cost. The breakdown cost takes into account machine reliability. The proposed model is tested on standard problems from literature papers using a Genetic algorithm approach. The various costs considered are material handling cost, operation cost, purchase cost, and breakdown cost. Results validate the effectiveness and efficiency of the proposed model. Further, incorporation of worker assignment and sustainability can improve the proposed approach.

Keywords: Cellular Manufacturing; Cell formation; Plant Layout; Mathematical Model; Machine Reliability; Genetic Algorithm.

1. INTRODUCTION

In the emerging market, quality, speed, efficiency, and efficacy are of utmost importance in the design of any process. The traditional manufacturing methods, such as the shop floor, are ill-equipped to keep up. Manufacturing is crucial for the robust growth of the economy, for exports and for generating substantial relevant employment [1]. The choice of the manufacturing system depends on the design of the parts to be manufactured, the lot sizes of the parts, and market factors such as the required responsiveness [2]. Cellular manufacturing is found to be the most suitable method in recent times [3]. It is an integral part of lean manufacturing. The objective of cellular manufacturing is to design cells of similar machinery such that cycle time, productivity, set up time, and cost of production are optimized. In cellular manufacturing, the machine layout problem is concerned with finding the best arrangement of machines in each cell [4]. According to Tompkins et al. [5], 20-50% of the manufacturing costs are accounted for by the handling of parts. An efficient arrangement of facilities may reduce such redundant expenses by 10-30%.

There are three types of problems in cellular manufacturing. They all include cell formation problems, machine layout problems, and cell layout problems, as well as are NP-Complete optimization problems. Many approaches have been advocated by researchers to obtain optimum or near-optimum solutions to these problems. Papaioannou and Wilson [6] on cell formation problems shows that mathematical programming, heuristic, and metaheuristic methodologies and artificial intelligence strategies are more prominent amongst the researchers. Thanh et al. [7], Ghosh et al. [8], Nouri et al. [9] used a hybrid approach of metaheuristic algorithms for cell formation. Pachayappan and Panneerselvam [10] used hybrid GA for machine component cell formation. GA is effectively used for facility layout design ([11]; [12]). Fuzzy logic, neural networks are also employed to solve cellular manufacturing issues. Dobado et al. [13] proposed a fuzzy – neuro system for part family formation. Josien and Liao [14] combined fuzzy C means, and fuzzy k-nearest neighbors approached for cell formation. Graph neural network approach in cell formation can handle significant scale problems that, too, with fast computation [15]. To design a cellular manufacturing system, Soleymanpour, Vrat, and Shankar [16] proposed a transiently chaotic neural network approach. Kia et al. [17], Wu et al. [18], Khaksar-Haghani et al. [19] addressed issues of group layout design and cell formation. Ho and Liao [20], Bazargan-Lari, Kaebernick, and Harraf [21] solved inter-cell and intra-cell problems simultaneously so that managers will have more extensive choices of selection.

According to Askin [22], any research in the field of cellular manufacturing must consider real-life limitations prevalent in the industry. To best of authors' knowledge, very few papers have considered machine reliability in cellular manufacturing. This paper provides a cell formation and plant layout problem, which also deals with machine breakdown. The paper is to propose a mathematical model based on various costs and machine reliability, implement the mathematical model and, most importantly, and validate this model using a case study. The paper considers the practicality aspect and is also relevant to the industry.

The following parts of the paper are organised as follows: A literature review has been explored in Section 2. The proposed model and GA implementation are explained in Section 3. Section 4 details the case study followed by discussion in Section 5. Section 6 gives the conclusion and future scope.

2. LITERATURE REVIEW

This section focuses on understanding the current research work in the area of CMS. The research is carried out in 3 main subcategories: cell formation, machine grouping, and plant layout. There is also research available that solves more than one of the problems simultaneously. The research work on the subcategories has been separately presented in three subsections below.

1.1. Cell Formation Problem

Cell formation has been a favourite of researchers and has been worked on most extensively. There has been much innovation in this area over time, and papers have been studied right from 1976. A wide variety of papers have been studied to observe a trend in the development of the cell formation problem and to identify a gap in the existing research. The earliest method that was studied is the Direct Clustering Algorithm (DCA) ([23]; [24]; [25]; [26];[27]). DCA aims to cluster the machine part factor (marked as '1' is a part is machined on a particular machine, '0' otherwise). Towards the diagonal of a matrix, which has parts as the row and Machine as the column, and vice versa. Exceptional elements (1s not in the cluster) and voids (0s in the cluster) are to be reduced. Initially, these matrices were solved by hand, but with time several heuristics and non-heuristics methods have been developed and used.

1.2. Machine Grouping and Plant Layout

Research in this category is not as extensive as that in cell formation. This is a problem that was taken up slightly later than cell formation, to reduce both intra-cell and inter-cell movement costs. Balakrishnan et al. [28] and Kulkarni and Shanker [29] used hybrid genetic algorithm; Diaby and Nsakanda [30] used large scale capacity heuristics; Drira et al. [31] employed fuzzy formulation; and Kia et al. [17] as well as Allahyari and Azab [32] used simulated annealing to achieve this objective. Unorthodoxly, Kheirkhah and Ghajari [33] converted the problem into a linear form and then solved it on C++. The most elaborate study was done by Anderson et al. [34]. A few varying factors, in addition to the main cost of intra and inter-cellular material handling costs, were selected in these papers.

1.3. Evolutionary Algorithm

There are various evolutionary algorithms available for solving the NP problems of CMS. We referred to the work of Bayram and Sahin [35] to select a suitable tool to solve the mathematical model formulated. Bayram and Sahin [35] have converted the mathematical model to a linear problem and then solved the resulting equations on both Simulated Annealing (SAeLP) and Genetic Algorithm (GAeLP). On comparison of results and ease of solving, we selected GA as the tool for solving our model. Genetic Algorithm (GA) works on Darwin's theory of Survival of the fittest. A set of populations are achieved from a given set of parent populations, and the offsprings giving the best-desired results are selected as the next parent population. This process continues until the parent and offspring population are identical. GA has been selected as the tool for solving the CFP as it can work with even a small parent population to give the best results.

3. METHODOLOGY

After analysing our literature survey, we realized that most of the research is aimed at solving the problems of CF, GF, and PL individually. Even in cases when two problems have been taken up, in most of them, the two problems have been solved sequentially. Thus we worked on a model that takes input from a Rank Clustering method and provides an output such that the cost of production in minimum. This section has been divided into two sub-sections. One explains the model proposed, and the second describes the tool that has been recommended to solve this problem.

3.1. Proposed Model

Defersha and Chen [36] have included a list of factors that affect the Cell Formation Problem (CFP) in their research. We selected the factors most relevant in an industrial scenario, and the factors selected were the minimum required to obtain a solution with maximum accuracy.

To make sure that our model does not overlap and coincide with any existing research, we exclusively referred two papers: Selim, Askin, and Vakharia [37]; Papaioannou and Wilson [6]. These papers focused primarily on summarizing the existing research up to 1997 and from 1997 to 2008, respectively. Apart from this, these papers also provided directions for future research, which were taken into consideration.

A mathematical model can be one that reduces total cost and time or one which maximizes efficiency or profit. The model proposed in this paper minimizes the total cost of production. This has been done by identifying and minimizing the various factors that add to the total cost.

These factors have been identified as operating costs, machine relocation cost (dynamic CFP), inter-cell material handling cost, and breakdown cost. The breakdown cost takes into account machine reliability.

The model has been solved, keeping a few assumptions in mind. These assumptions are listed below:

1. The input to the model has a pre-determined number of parts, operations, machines, and cells. The machines have been allotted to individual cells.
2. Data such as time of operation, cost of operation on an hourly basis, demand for parts in a given period, and the like mentioned in notations used are known beforehand.
3. All the distances for material movement are considered to be of unit value.
4. The batch size for material handling is taken as 20 parts, and the cost for inter-cell movement is taken as $5 based on the reference taken
5. All costs are in dollars, for easy comparison with other research papers.

The notations used and functions thus obtained are listed below:
Sets:

1. Part types, p={1,2,3…,PT}
2. Operations to be performed, o={1,2,3…,NOP}
3. Machine types, m={1,2,3…,MT}
4. Number of cells, c={1,2,3,…,NC}
5. Time periods, T={1,2,3…,P}

Table 1. Input Parameter Terminologies

Term	Input Parameter	Term	Input Parameter	Term	Input Parameter
PT	No. of part types	$I_{m,c}$	No. of machines of type m in cell c initially	C_m	Capacity of machine type m
P	No. of periods	BS	Inter-cell material handling batch size	L	Lower limit of cell size
MT	No. of machine types	PC_m	Purchase cost for 'm' type machine	U	Upper limit of cell size
NC	No. of cells	OC_m	Operating cost for 'm' type machine	a_{opm}	1 if operation o of part p can be done on machine m, else 0
NOP	No. of operations to be done on part p	MHC	Cost per batch for intercell material handling	MFT_m	Mean time between failures for 'm' type machine
t_{opm}	Time to perform operation j of part p on 'm' type machine	IC_m	Installation cost for 'm' type machine	BDC_m	Breakdown cost for 'm' type machine
SD_{pT}	Supply demand of part p in period T	UC_m	Uninstallation cost for'm' type machine	PV	Production volume for part p

$$\text{Minimise } (Total\ Cost) = \sum_{m=1}^{MT} PC_m \times \left\{\sum_{c=1}^{NC} NmcT - Imc\right\} + \sum_{T=1}^{P}\sum_{c=1}^{NC}\sum_{m=1}^{MT}\sum_{p=1}^{PT}\sum_{o=1}^{NOP} SD_{pT} \times t_{opm} \times A_{opmcT} \times OC_m + \frac{1}{2}\sum_{p=1}^{PT}\sum_{T=1}^{P}\left[\frac{SDpT}{BS}\right] \times \sum_{o=1}^{NOP}\sum_{m=1}^{MT} MHC\,|B_{(o+1)pcT} - B_{jpcT}| + \sum_{T=1}^{P}\sum_{m=1}^{MT}\sum_{c=1}^{NC} N^{+}_{mcT} \times IC_m + \sum_{T=1}^{P}\sum_{m=1}^{MT}\sum_{c=1}^{NC} N^{-}_{mcT} \times UC_m + \sum_{m=1}^{MT}\sum_{T=1}^{P}\sum_{p=1}^{PT}\sum_{o=1}^{NOP} A_{opmcT} \times \frac{PV}{MFTm} \times t_{opm} \times BDC_m$$

Such that

$$\sum_{c=1}^{NC} a_{opm} A_{opmcT} = NC \quad (1)$$

$$A_{opmcT} \leq \quad (2)$$

$$\sum_{p=1}^{PT}\sum_{o=1}^{NOP} SD_{pT} \times t_{opm} \times A_{opmcT} \leq C_m \times N_{mcT} \quad (3)$$

$$L \leq \sum_{m=1}^{MT} N_{mcT} \leq U \quad (4)$$

$$N_{mc(T-1)} + N^{+}_{mcT} - N^{-}_{mcT} = N_{mcT} \quad (5)$$

$$I_{mc} + N^{+}_{mc1} - N^{-}_{mc1} = N_{mc1} \quad (6)$$

1.2. Genetic Algorithm Implementation

Genetic Algorithms (GA) have been used primarily as an alternative to solve numerical optimization problems [18]. It is beneficial in cases where the data sample space is high, as GA does not get stuck in local optima. The initial set of data is set as the initial population, which is then manipulated for subsequent populations. The offspring (data in subsequent generations) are checked using the fitness function, which is defined for the problem. The best offspring become the parent population for the next set of iterations, and this continues until the parent population for current iteration matches with the offspring of the previous generation. Thus the GA method manipulates the solution space in a way that better outputs are obtained in the strings that follow [38].

We have solved the model using the 'GAtoolbox' feature on MATLAB 2015. This was the tool of choice as MATLAB is capable of choosing its population that eventually funnels to the best result. Also, the minimum knowledge of this evolutionary algorithm is required. Only the fitness function needs to be inputted, and the software provides optimum results in return. The algorithm for the function is as follows:

Step 1: Input the number of operations, parts, machines in individual cells, and periods.

Step 2: Input the data concerning various costs such as hourly operating cost, purchase cost, breakdown cost, and other data such as time of operation on a particular part on a particular machine in a given period and demand of the part in a given period.

Step 3: Set number of iterations to be performed (the software automatically sets default value)

Step 4: Set lower and upper bounds for the values.

Step 5: Call the fitness function

Step 6: The optimum (minimum in this case) total cost is obtained for given data.

1. **USE CASE: Cellular Manufacturing**

The sample problem in consideration has been taken majorly from Bayram and Sahin [35]. The problem has two parts, with three operations to be performed on these parts using three machines. A maximum of 2 cells can be formed with not more than three machines per cell and not less than one machine per cell. Since all the factors considered in our model were not all considered in Bayram and Sahin [35]; Chung et al. (2011). They were considered for data only on Machine Reliability. The data used from both papers have been compiled and shown in a tabulated format.

Table 2. Demand in a given period

D_{pT}	P=1	P=2
T=1	400	300
T=2	500	200

Table 2 contains the number of pieces of each part required in a particular period. This data is required to calculate the total operating cost, as the data of the cost of operation per hour and time required for operation is available for a single part. Also, it is required to calculate the total material handling cost. Since the batch size is fixed, the demand is necessary. To determine the number of trips required from one machine to the other, and the cost of material handling is available for each trip made.

Table 3. Machine information

Machine No.	Purchase cost	Fixed operating cost	Installation cost	Uninstallation cost	Variable operating cost ($/hr)	Capacity (hours)
M=1	18,000	1800	450	450	9	500
M=2	15,000	1500	375	375	7	500
M=3	16,000	1600	400	400	6	500

Table 3 contains all the data that is necessary for the three machines. The initial purchase cost has been included in our model. The fixed operating cost is the cost incurred during every operation. Installation cost and uninstallation cost are of relevance during the dynamic CFP, as machines need to be uninstalled from one location and reinstalled at another location. The variable operating cost is the cost incurred per hour of operation of the machine. Higher the time of operation, the more the variable cost of operation. The capacity is the upper bound for operation time for any machine. We have not assumed the machines to have the infinite operating capacity. The total time of production for each machine should not exceed the total capacity of that machine.

Table 4. Processing times

Machine No.	P=1			P=2		
	R=1	R=2	R=3	R=1	R=2	R=3
M=1	0.54	0.79	-	-	0.8	-
M=2	-	0.53	-	0.45	-	0.76
M=3	0.77	-	0.33	-	0.91	0.8

Table 4 gives the time required for each operation to be done on the part of a particular machine. The unit of the time mentioned is in hours. If a particular operation is not being carried out on a part, it is denoted by '-.'

Table 5. Breakdown information

Machine No.	Break down cost	Meantime between failures (hr)
M=1	900	90
M=2	2000	51
M=3	1600	60

Bayram and Sahin [35] paper did not consider the breakdown information. Table 5 shows the assumed breakdown cost and mean time between failures. The breakdown cost is the cost incurred to the company to fix the machine and get it back into running condition. The loss incurred due to the stoppage of production during this period has not been taken into account. The mean time between failures is the average time for which the machine runs without any failure or sign of failure. More significant the mean time between failures, the higher is the reliability of the machine.

3. RESULTS AND DISCUSSION

On solving the mentioned data as per the algorithm mentioned above on gatoolbox in MATLAB (Fig. 1), we obtained the results, as shown in Fig 2.

The variables chosen to pass to the fitness function were:

1. Number of parts (lower bound 1, upper bound 2)
2. Number of operations (lower bound 1, upper bound 3)
3. Number of periods (lower bound 1, upper bound 2)
4. Number of machines (lower bound 1, upper bound 3)

The different graphs in Figure 2 each have their significance. They have been mentioned below:

1. The average distance between individuals denotes the dispersion of the result. The dispersion is initially high and then reduces. This denotes that the software has converged to the final result, and the best fit had been obtained.
2. The score histogram has the highest score for the final result, which means that the final result is the best.

The optimum cost was obtained after 102 iterations, the value of which was $ 779,639. The cost was further divided into categories such as Purchase cost, , Material handling cost, Operation costand Machine Breakdown cost.

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1. The average distance between individuals denotes the dispersion of the result. The dispersion is initially high and then reduces. This denotes that the software has converged to the final result, and the best fit had been obtained.
2. The score histogram has the highest score for the final result, which means that the final result is the best.

Fig. 1. Screenshot of GAToolbox on MATLAB

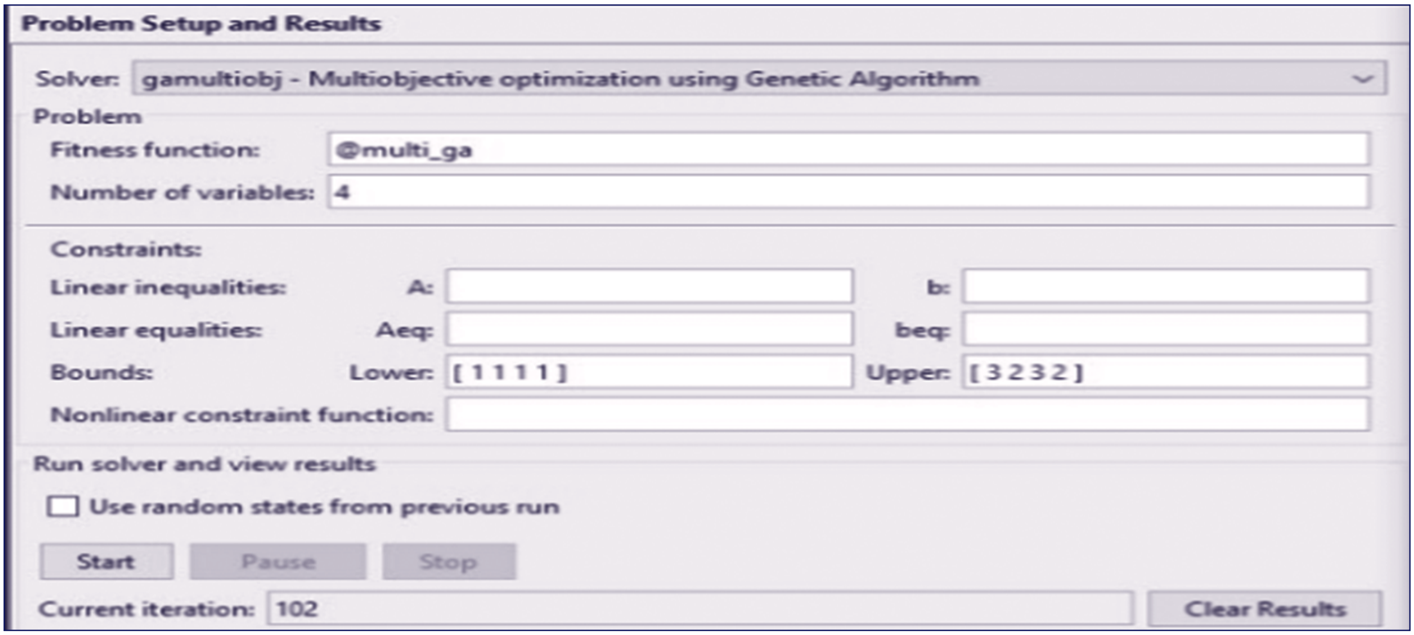

Fig. 2. Graphical representation of the outputs obtained

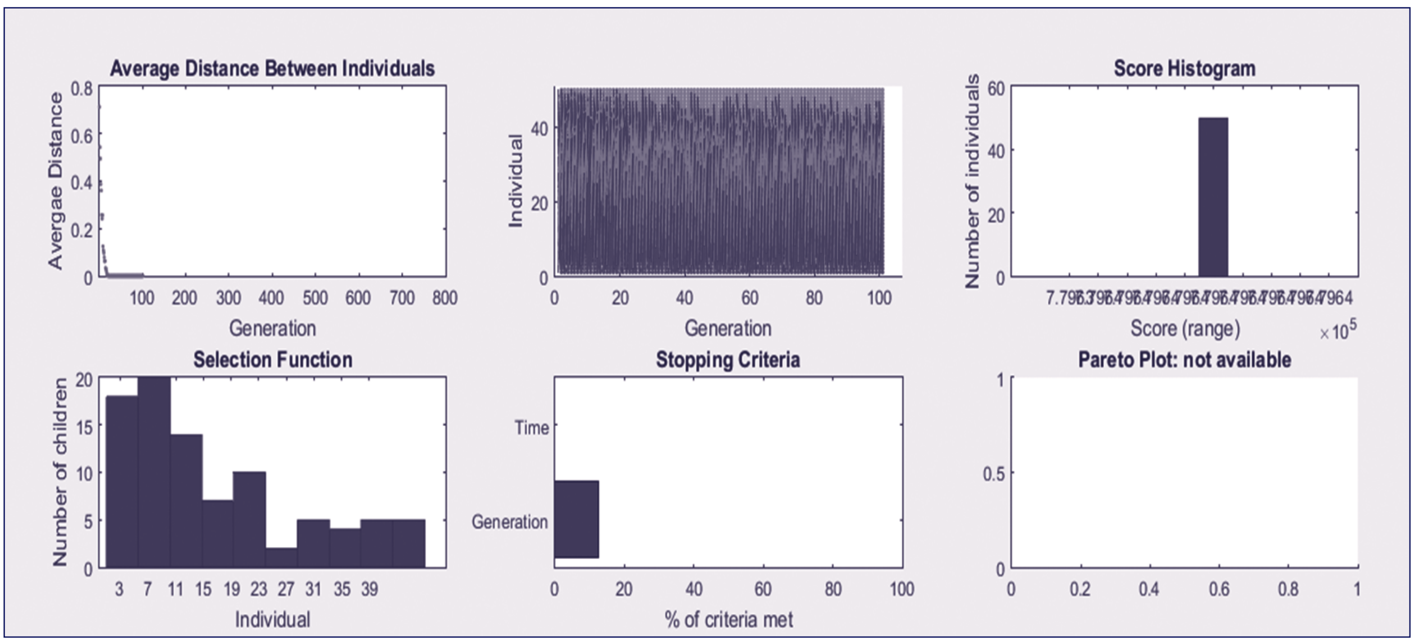

Table 6. Comparison of Results

Sr. No.	Particular	Bayram and Sahin (2015)	Our model
1	Purchase cost	$ 80,000	$ 49,000
2	Operation cost	$ 52,249.6	$ 38,019
3	Material Handling cost	$ 17,950	$ 17,500
4	Breakdown cost	Not Applicable	$ 8250
Total cost		**$ 150,199.6**	**$112,769.0**

In Table 6, the various costs considered by Bayram and Sahin [35] and our model are compared. The costs considered are purchase cost, material handling cost, operation cost, and breakdown cost. All these costs are added up to obtain the total cost. We will now discuss why there is a contrast observed in these individual costs.

Purchase cost is the cost incurred while purchasing machines for the plant. For the three machine problems, we have purchased one machine of each type, whereas Bayram and Sahin [35] have considered two identical machines of type 2 and 3, which increases the total purchase cost to $80,000. However, since the total machine hours were not exceeding the machine capacity, we have considered only one machine of each type, hence getting a machine purchase cost of only $49,000. The installation costs in both cases have been ignored. Operation cost in our model takes into account the total cost incurred due to the running of the machine on an hourly basis. There is also a fixed cost which is incurred every time an operation is carried out. This is added to the variable machining cost to obtain the Operation cost. This value has been optimized in our model.

The material handling cost is the cost of taking crude inventory from one work station to the other in a batch size of 20 at a time. Since we have considered all inter-machine distances to be unity, there is a slight difference observed in our cost and the cost of Bayram and Sahin [35]. The unique feature of our model is the Breakdown cost. This breakdown cost is the cost which is incurred in repairing the damaged machine since machines do not have 100% reliability and run time. This cost of single repair work is multiplied with the frequency of machine breakdown.

The frequency helps to determine the total number of breakdowns that occur and thus helps to compute the Total Breakdown cost. This is a factor that Bayram and Sahin [35] have not considered. Hence, it cannot be compared. The data is an extract from the work of Chung et al. [39]. However, since the data other than breakdown cost from our model did not match the data in Chung et al. [39], no comparison between these two papers have been made. As is evident from Table 6, that there is only a slight difference in the values obtained in the literature and the values obtained in our paper. A significant difference can be observed in operation cost, where the maximum optimization is observed. One reason for this difference is also that the authors in the literature survey have considered different distances between locations. In contrast, the distances in our paper are assumed to be unit.

Thus the main factor that makes the mathematical model proposed in this paper unique is the fact that the number of real-time industry factors has been considered in this model. Breakdown cost has not been considered by Bayram and Sahin [35]. Though the total cost for our model is higher owing to breakdown cost considered, the cost of only the first three factors (Purchase cost, material handling cost, and operation cost is lower in our model ($ 104,519) than the literature in comparison ($ 150,199.6). The comparison made between the two papers has been made solely on the criteria of the Total Cost of production as determined by solving the model. The total cost for our model is lesser by $ 37,430.6 (24.92 %) better than Bayram and Sahin [35], even though our model considers break down cost ($ 8250).

5. CONCLUSION AND FUTURE SCOPE

Cellular manufacturing is a stepping stone to achieve world-class manufacturing status. Cellular manufacturing allows fitting a lengthy series of operations into a limited space. Also, it becomes easy to organize supplies such as materials, products, or special services. The salient features of the proposed model are that it considers real-life factors such as machine reliability. The model also takes into account dynamic cell formation and provides a minimum cost of production on the implementation of CMS to the plant. To the best of authors' knowledge, very few papers consider a combination of the factors proposed in this paper. Simulation results and comparison shows that the proposed model better in terms of the total cost, purchase cost, and operation cost. The findings of this paper can be successfully implemented in MSMEs and upcoming businesses as discussed in Narkhede[40] to improve the firm performances in these environments. The effects of this implementation on the plant performance can then be measured and validated based on the discussion in Narkhede, Nehete and Mahajan [41]. Future scope also includes solving different sizes problems , real life industry problems, and to validate its results with the proposed method. Also, incorporating merging sustainability with CMS and worker assignment with learning ability can improve the proposed model. In the modern scenario where the shop floor workers are considered to be important while making decisions. In cellular manufacturing where each worker is responsible for their own respective cells, it is important to have employees who are trusting and motivated. This has been studied by Sahu and Narkhede [42] and something like a worker motivation factor can further be incorporated in the model.

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