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2 authors:

Emad Rabiei Hosseinabad
Northern Illinois University

Muhammad Adib Uz Zaman
University of Florida

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A Brief Review on Cellular Manufacturing and Group Technology

Emad Rabiei Hosseinabad[1*], Muhammad Adib Uz Zaman[2]

[1]*Master of Science, Department of Industrial and Systems Engineering, Northern Illinois University, Illinois, USA*
[2]*Ph.D. Candidate, Department of Industrial, Manufacturing & Systems Engineering, Texas Tech University, Texas, USA*

[*]Corresponding Author Email: z1784372@students.niu.edu

Abstract: The lean manufacturing applications have had significant impact in academia and industrial settings over two decades. However, the application of lean concept in cellular manufacturing has been limited to case studies. There has been a need for summarizing the lean evolution in cellular manufacturing and critical comments on approaches that addressed some of the earlier gaps in the application of lean in cellular manufacturing. By linking the lean trends on cellular manufacturing and interrelated lean research collaborations, this study will establish a unique framework for researchers, academicians and professionals. It is expected to help them understand the evolution of lean in cellular manufacturing not only as a concept, but also its implementation within an organization, and pinpoint possible research area developments in the cellular manufacturing field.

Keywords: Cellular Manufacturing System, GT, Lean Manufacturing, Material Flow, Review Introduction

Introduction

Cellular manufacturing (CM) is a type of manufacturing that helps in implementation of just-in-time manufacturing and lean manufacturing systems. The primary goal of the cellular manufacturing system (CMS) is to provide continuous flow in throughout the system by quickly moving parts and inventory between the processes. CM is sometimes used synonymously with group technology (abbreviated as GT). Group technology is implemented by assigning the same machine(s) to those parts that are similar in geometry, manufacturing process and functions. After investigating on possible areas of cellular manufacturing, it was understood that broadly CMS falls into 4 main categories or themes which are formation of cellular manufacturing, design of cells within the system, the implementation of the different algorithms in terms of cellular manufacturing and the reliability of cellular manufacturing as well as its benefits compared to other manufacturing types. Although, there might be other important areas of in terms of cellular manufacturing, we have tried to investigate on the more important ones. Moreover, the selected themes are utilized more in recent studies; therefore, it is more reasonable to look at the themes that has been considered in the last 15-20 years. This consideration would allow researchers in future to predict the trend in CMS research.

Literature Review Summary

Our collection indicates four major themes related to cellular manufacturing to be discussed in this literature review. These are:

Theme 1: Design of Cellular Manufacturing Systems
Theme 2: Formation of Cellular Manufacturing Systems
Theme 3: Implementation of Cellular Manufacturing Systems
Theme 4: Reliability of Cellular Manufacturing Systems

The following Table 1 illustrates the chronological collection of journals and articles on cellular manufacturing based on the four selected themes.

Table 1. Literature Review (Chronological) Summary Table.

Source	**Theme in Cellular Manufacturing**			
	Design	**Formation**	**Implementation**	**Reliability**
(Chan & Milner, 1982)		√		
(Vakharia & Wemmerlov, 1990)	√			
(Damdaran et al., 1993)	√			
(Olorunniwo, 1997)			√	
(Wemmerlov & Johnson, 1997)			√	
(Choobineh, 1998)	√			
(Co, 1998)	√			
(Bazargan-Lori, 1999)	√			
(Silveira, 1999)			√	
(Diallo et al., 2001)				√
(Gunasekaran et al., 2001)			√	
(Patchong & Willaeys, 2001)				√
(Seifoddini & Djassemi, 2001)				√
(Olorunniwo & Udo, 2002)			√	
(Park & Han, 2002)			√	
(Chakravorty & Hales, 2004)			√	
(Goncalves & Resende, 2004)		√		
(Yin, 2005)		√		
(Das et al., 2006)				√
(Das et al., 2007a)				√
(Das et al., 2007b)				√
(Fraser et al., 2007)			√	
(Murugan & Selladurai, 2007)			√	
(Ameli, & Arkat, 2008)				√
(Mahdavi et al., 2009)		√		
(Pattanaik & Sharma, 2009)			√	
(Rafiee et al., 2011)				√
(Fariborz et al., 2012)		√		
(Jamal et al., 2012)		√		
(Javadi et al., 2012)		√		
(Zheng et al., 2014)		√		
(Mohammadi & Forghani, 2016)	√			
(Xambre et al., 2016)				√
(Renna, 2017)				√
(Tortorella et al., 2017)			√	

The articles selected for analyzing the trend in design of CMS showed good indication and possible research areas in future dated back from 1990 to 2016. Formation of CMS showed great potential through its chronological improvements in various algorithms and solution methods from 1982 to 2014. The articles related to implementation theme were reviewed and most of the authors did a good job in terms of research advances and literature review. Important articles from 1997 to 2017 are presented here so that the gradual advancement in cellular manufacturing implementation becomes evident. In terms of reliability of cellular manufacturing, a trend has been seen from investigating the reliability of individual machines in each cell to optimizing the reliability of the whole cellular manufacturing system which helped to have a better perspective of reliability of a cellular system as a whole.

The following sections will contain detail description of the papers studied in the above-mentioned themes and important point will be highlighted as necessary throughout the whole literature review. This review is organized theme-wise so that the trend is easily understood by the readers. Some necessary figures are also included in the 'Appendices' section as supporting evidences.

Materials and Methods

Design of Cellular Manufacturing Systems

Methodology

'Group technology' is the philosophy that exploits the proximity among the attributes of given objects. Cellular manufacturing is one of the specific applications of group technology in manufacturing. Cellular manufacturing systems have been identified as manufacturing systems which can produce medium-volume/medium-variety parts more economically than other types of manufacturing systems. This involves processing collections of parts (part families) on clusters of machines (cells). These cells are formed to capture the inherent advantages of group technology such as reduced set-up times, reduced in-process inventories, smaller lot sizes, reduction in the number of production equipment, improved productivity and better overall control of operations.

Choobineh (1988) provide the systematic procedure for the design of cellular manufacturing systems. The use of GT in the design of a manufacturing system consist two stages. The first stage identifies the part families. In the first stage, attempt should be made to uncover the natural part families and the decision should be left until second stage. Vakharia and Wemmerlov (1990) also mentioned the detailed study about the part families. In the first stage, they use the mathematical equation and clustering algorithm for finding the part famlies is shown as:

$$S_{ik}(L) = \frac{1}{L}\left[S_{ik}(l) + \sum_{l=2}^{L} \frac{C_{ik}(l)}{N-\ l+1}\right], L \leq N$$

where Cjk(l) is the number of sequences of length I between parts i and k; S'k(L) is the average similarity coefficient of order L between parts i and k, 0 ~ S'k(L) ~ I; and N, is the number of operations of part i; N = minj(N,). The second stage covers machines grouping into cells. In the second stage, Damodaran et al (1993) find the number of cells, assign the part families to the cells and machines to the cells.

Vakharia and Wemmerlov (1990), However, investigate a cell consist of a set of functionally dissimilar machines which are placed in close proximity to one another and dedicated to the manufacture of a set of part families. In this part, famlies have three major issues involved: the identification of part families, the identification of cell equipment, and the allocation of families to equipment. Choobineh (1988) also identifies the independent cells based on operation sequences and after that they use four stages methodology for identifying on which part is sequentially processed in machines. The first methodology consists the data collection, the second one involves in preliminary analysis of the collected data and third focuses on part grouping and reduce the problem size by decreasing the number of operation sequences involved in clustering process in stage four. Vakharia and Wemmerlov (1990) has also intoduced the symmetric similarity matrix SO which is comuputed for the part grouping without backracks. The similarity measure is defined as follows:

$$SO_{pq} = 0.5\left[\left(\frac{\sum_{i\in C_{pq}} A_{ip}}{\sum_{i=1}^{M} A_{ip}}\right)\right] + \left[\left(\frac{\sum_{i\in C_{pq}} A_{iq}}{\sum_{i=1}^{M} A_{iq}}\right)\right]$$

Where SOpq is similarity between part group 'p' and 'q', i is machine type index (1…, M), Aiq is 1(if machine type I is required to process parts in group 'p' and 0 (Otherwise) and Cpq is a set of machines type whose members appear in both part group OR.

Unlike Vakharia and Wemmerlov (1990), Choobineh (1988) provided a two-stage sequential approach to part grouping and the associated cell formation using clustering techniques and integer programming approaches. Another researcher named Co and Arrar (1988) suggested a three-stage sequential approach for partitioning machines into manufacturing cells. The practical considerations of refixturing and material handling as well as the physical limitation on cell configuration may lead to a trade-off between refixturing and material handling movement, and thereby influencing cell design. Such possibilities will have to be examined when allocating operations to various cells. Damodaran at al. (1993) considered refixturing aspects of production planning problems in developing models of flexible and cellular manufacturing systems. Their primary objective is to consider jointly the issues of refixturing and material handling during cell design. Accordingly, the two mixed integer linear models are developed so as simultaneously to form machine groups and assign part operations to these machine groups considering refixturing, material handling, discounted investment, and operating costs.

Bazargan-Lori (1999) proposed the methodology for the recently developed multi-objective inter- and intra-cell layout in CM environment for dynamic food manufacturing and packaging company in Austria. Because company have problem expressed by the large and unnecessary volume of shop floor material handling cost, difficulties and confusion over production planning etc. furthermore company deeply concern about the increasing number of accident on the shop floor caused by poor layout of machinery. That's why Bazargan-Lori (1999) first objective is to minimize the total inter- and intra-cell material handling cost. He designs the new mathematical model for modify the inter- and intra-cell layout design for the company. That design includes three stages. First stage is grouping part families and production equipment. This stage already finding out with different approach by Choobineh (1988) and Vakharia and Wemmerlov (1990). Second for inter- and facility layout and third for intra-cell and machine layout. Using this stage, he develops one mathematical model for shop floor boundaries, location restrictions, traveling cost. Bazargan-Lori (1999) apply that mathematical model in the food product industry layout shown in Appendix B. That present layout has 8700 km travelling distance per year.

Mohammad et al (2016) also trying present an integrated bi-objective problem to solve the CF, inter- and intra-cell layout problem. On this solution, they consider the different parameter such as part demands, operation sequence, machine dimensions and aisle widths are taken into consideration. One of the parameter operation sequence is already design by different mathematical model by Choobineh (1988) and Damodaran et al (1993). Mohammad et al trying to minimize material handling cost and maximizes the total similarity between machines. Bazargan-Lori (1999) also mentioned reduction of the material handling cost using different mathematical model applies in the food manufacturing company.

Solution and application

Most of the articles and studies the worked-on design of cellular manufacturing system using the mathematical equation, model and solution in terms of different approach applying in the cellular manufacturing system as well as machine and facilities layout based on given example.

Choobineh (1988) define the mathematical model for the part families and machine cell operation. In the part families, they use the number of sequence of length between the parts and number operation after they define value put in the mathematical equation they find out the part families and using the clustering algorithm finding part families. When part families identified the next step is to determine the configuration of the cells and the assignment of the part families to the cells. Combining two identifications of the part families and the cell formation into one stage is most widely reported approach. Using this approach, they arrange the optimum number of each machine type for each cell are shown in the fig. This approach uses a binary machine part matrix are rearranged until if possible block angular form achieved.

Cell k / M/Cq	N^{*}_{qk}		
	1	2	3
1	1	3	1
2	1	6	2
3	2	3	1
4		5	3
5	.1	3	1

$X^{*}_{11} = 1,\ X^{*}_{22} = 1,\ X^{*}_{33} = 1$

Figure 1. Part-family Assignment to Machine Cells Matrix.

Vakharia and Wemmerlov (1990) doing the define part families using four stage procedure. On the first stage gather the data such as machine type, batch size, setup time etc. After the data collection is complete then all the examined based on the operation sequence and dividing into groups of the parts. Then after using the clustering process for the reduce the problem size by reducing the number of operation. Then last composite operation sequences from the clustering process containing no back tracks are merged in descending ordering and get resulting group of part families are obtained. Choobineh (1988) use the same approach but he uses the mathematical equation for finding part families. They also apply this approaches in real life example and they find the which part working on machine cells.

Damodaran et al (1993) design machine cell operation using the mathematical model. On this mathematical model Damodaran et al (1993) are doing the parts and machines selected based on cellularization. After that they consider the situation where new machine procured. Each part type, the total number of units produced may be divided into few batch each following a different process plan. And at last finally number of machines allotted to each cell is given. They take one numerical example and illustrated the example using the refixturing information for each part type for refixturing the setup cost, variable cost, setup time in matrix form. At last they find machine group assign for each operation in each part.

Bazargan-Lori (1999) use simple mathematical model for designing layout. In the model, the machine and work center considered as rectangle block. Accordingly, they check if the blocks are overlapping with each other. If blocks are not overlapping to each other then each machine must be fully located inside the associated boundary. They also check the relationship between machines and their design of preliminary layout using reducing travelling cost between the machines. Mohammadi and Forghani (2016) also performed the reduction of material handling cost and maximization of the total similarities between machines. After observing the preliminary solution, they applied some restriction on the inter-cell layout model. That approach has been recently applied to the major and dynamic producer of a diverse range of food products industry layout in Austria. When the approach applied in industry layout (See Appendix. C) they can get the 6081-km travelling distance per year.

Furthermore, Mohammadi and Forghani (2016) introduce the bi-objective problem to solve the CF, inter- and intra-cell layout problem. Considering the proposed problem, they design the new S-shaped layout for the CMS. In their approach, once the allocation of machines to the cells is specified, machines assigned to the same cell are arranged along with a line, from left to right, by considering their length and the horizontal aisle width. The machine cells are also placed on the shop floor from bottom to the top by considering the width of the cells and the vertical aisle width. They suggested the hybrid solution method based on a combination of SA (Simulated annealing) and DP (Dynamic programming) and they get the better result in material handling cost between machines. They compare this approach with the recently developed Krishnan et al (2013) layout approach and they got 98.23% as the accuracy of their model which was more accurate than Krishnan et al (2013) model. By doing so, they proved their applicability of their model in terms of inters and intra-cell layout design.

General and Critical Comments (Pros and Cons)

Considering the proposed approaches by all the literature, this can be assumed that all the researchers use the clustering algorithm for the design of CMS. Nevertheless, those approaches cannot be employed to the enormous size cellular layout problems. Although that some researchers used the unique way to design the CMS such as Mohammadi and Forghani (2016), Feili et al (2014), and Bazargan-Lori (1999), the main objective is to arranging part families using part similarities and considering the sequential operation in machine cell formation.

Vakharia and Wemmerlov (1990) developed the clustering Methodology for design the CMS. That methodology does not consider some stopping rules as well as operating in a sequential fashion where alternative paths are selected based on seemingly reasonable heuristics. That's why Vakharia and Wemmerlov (1990) suggested an algorithm that can rise up some future research to investigate on the candidate cell solutions by imposing constraints on the design process in different order. Moreover, some related area needed to be investigated such as load balancing and flexibility used in clustering process in terms of cellular manufacturing design.

Damodaran et al (1993) developed the model with respect to refixturing aspect of production planning to allow the flexibility of the part to have alternative process plans for its manufacture. However, the proposed algorithm is not implemented for large size problems. Therefore, there is a need to develop heuristic or approximate procedure to overcome this difficulty. Co and Arrar (1988) also discussed refixturing and material handling aspect of cellular manufacturing layout. From investigating their work, it can be said that if refixturing cost associated with an operation of a part in a cell is high, it may be possible to move the part to another cell to perform that operation for a lower total cost of material handling and refixturing. Hence, the need to consider refixturing and material handling together during cell design in future studies is substantial.

Choobineh (1988) and Vakharia and Wemmerlov (1990) use the same clustering algorithm for the part families. Choobineh (1988) use linear integer programming which consider the economic production in cells. That mathematical model can easily be converting into the zero-one integer program and the program can be applied in future for the design of FMS (Total programming manufacturing cell). But Choobineh (1988) approach face difficulty when they applied for the large number of parts.

Mohammadi and Forghani (2016) use the bi-objective CF for the new S-shaped layout and Bazargan-Lori (1999) use the multi-objective layout for the design the CMS. Both researchers tries to minimize handling cost and maximize similarity of parts in part families by the use of different approaches for the design a CMS. Mohammadi and Forghani (2016) suggested S-shaped layout results in some direction for future studies. For instance, process routing and machine capacity constraints can be an interesting area for future research. That innovative approach, helps in dynamic problem when considering the minimization of the total material handling cost plus rearranging the layout design cost of a CMS.

Formation of Cellular Manufacturing Systems

Methodology

A manufacturing philosophy like group technology that attempts to provide some of the operational advantages of a line layout while maintaining some of the strategic advantages of the job shop layout. In designing a productive process that will adopt this manufacturing strategy, one of the primary problems encountered is the formation of component families and production cells. Here we discuss about the various algorithms used for formation of cells.

Chan and Milner (1982) shared their ideas of finding the families and groups by using blocks and rods, and by changing the sequence in which components and machines are listed on the matrix. Systematic procedure is used instead of relying on intuition in determining what row and column rearrangements are required to achieve the desired result. First, we count the number of positive cell entries "K" in each column and row in turn and rearrange the machine component matrix with columns in decreasing order of "K" and rows in increasing order of " K". Step 2 starts with the first column of the matrix, transfers the rows which have positive cell entries in this column to the top of the matrix. Repeat the procedure with the second column, then the other columns, until all the rows are rearranged. In step 3 the current matrix and the one immediately preceding this the same? If yes, go to 6. If no, go to 4. Step 4 Starting with the first row of the matrix, transfer the columns which have positive cell entries in this row to the left-most position of the matrix. Repeat the procedure with the second row, then the other rows, until all the columns are rearranged. In step 5 if the current matrix and the one immediately preceding this the same. If yes, go to 6. If no, go to 2. Step 6 stop. This algorithm can work with any starting form of machine component matrix. The procedure is iterative and the ultimate result will be the same. It will converge in a limited number of iterations, and will find the groups and families directly from the matrix. The algorithm is readily computerized which allows the practical difficulties of data analysis for large matrices to be overcome.

Jamal et al (2012) defined three types of branch and bound algorithms to deal with the cell formation problem. The first algorithm uses a binary branching scheme based on the definitions provided for the decision variables. Based on the structure of the cell formation problem the second algorithm is defined. The last algorithm has a similar structure to the second one, except that it has the ability to eliminate duplicated nodes in branching trees. The simplest (and, perhaps, naive) way to solve the Cell formation problem is to enumerate all such points, discarding the infeasible ones and always recording the feasible solution with the best objective value. When the enumeration is complete, the optimal solution, when one exists, is associated with the best objective value. Branch-and-bound methods have been widely used in various discrete and combinatorial optimization fields and under a variety of names, such as backtrack programming and understood enumeration. The idea is to repeatedly break the set of feasible solutions into subsets (branching) and to calculate bounds on the costs of the solutions contained within them (bounding). The bounds and dominance rules are used to discard entire subsets of solutions from further consideration (fathoming). This simple but effective technique has scored a number of notable successes in practical computations. However, it is rarely possible to establish good bounds on the length of the computation. In the following subsections, three main concepts of the branch & bound method (i.e., branching, bounding, and fathoming) are explained as they relate to the Cell formation problem.

Fariborz et al (2012) considered the formation of cells and layouts simultaneously different parameters like forward, number of EE, back Wards transportation, different batch size for different cell size and different sequence of operations are considered. Some assumptions Sequence of process, demand of each part, and distance between two consecutive positions in each cell is equal. Batch size for inter-cell and intra cell movements are different. The electromagnetism algorithm is based on attraction and repulsions of charged particles. It is designed to optimize nonlinear, real valued problems. The charge of each particle is calculated based on its objective value. The formula of each particle is calculated based on its objective values.

$$q_k = \exp\left(-n \times \frac{f(x_k) - f(x_{best})}{\sum_{l=1}^{s}(f(x_l) - f(x_{best}))}\right), \quad \forall k$$

These charged particles influence each other. The force exerted on each point is completed by the formula

$$F_k = \sum_{z \neq k}^{S} \left\{ \begin{array}{ll} (x_z - x_k) \times \frac{q_k q_z}{\|x_z - x_k\|^2} & \text{if } f(x_z) < f(x_k) \\ (x_k - x_z) \times \frac{q_k q_z}{\|x_z - x_k\|^2} & \text{if } f(x_z) \geqslant f(x_k) \end{array} \right\}, \quad \forall k$$

Heidarzade et al (2008) recognized genetic algorithm as a new approach which deals with natural process to create optimize procedures. GA was developed by Holland (1975) as an alternative method for solving optimization problems. Based on machine part incidence Heidarzade et al (2008) number of voids in cell to achieve the highest performance of cell utilization. The EE here are considered as ones falling outside the block diagonal clusters ones. In other words, cell utilization can be said as the number of non-zero value elements of the block elements divided by block- diagonal divided by block-diagonal matrix size of each cell. The main components of GA for implementation identify six components: The scheme for coding. The initial population. An adaptation function for evaluating the fitness of each member of the population. Selection procedure. The genetic operators used for producing a new generation. Certain control parameter values.

Zheng et al (2014) said that the essence of the present algorithm lies in the determination of initial cluster center. Linear assignment model can be formulated based on the determined cluster representatives. The linear assignment initialization, an initial cluster center matrix. Zheng et al (2014) presents a two-phase clustering algorithm for machine-cell and part-family formation in the design of cellular manufacturing systems. The proposed algorithm begins with the determination of initial cluster centers via a linear assignment method using the least similar group representatives in its first phase. A fuzzy C-means clustering method is followed in its second phase for part-family and machine-cell formation using the obtained initial cluster centers. The two-phase algorithm can prepare the problem of clustering irregularity resulting from the fuzzy C-means method with random initializations.

Goncalves and Resende (2004) Presents a new approach for obtaining machine cells and product families. This is a combination of local search heuristic with a genetic algorithm. They also presented computational experience with the algorithm on a set of group technology problems. The approach produced solutions with a grouping efficacy that is at least as good as any results previously reported in literature and improved the grouping efficacy. The genetic algorithm is used to generate sets of machine cells. The process, in the genetic algorithm, is responsible for improving the grouping quality of the sets of machine cells generated. The local search heuristic is applied to the sets of machines cells produced by the genetic algorithm. The objective of the heuristic is to build a set of machine/product groups and improve it, if possible. The heuristic feeds back to the genetic algorithm the grouping efficacy of the set of machine/product groups it constructs.

Solutions and Application

The articles worked on optimizing the formation of the cells in cellular manufacturing and the key issue in production is determining the best formation. The articles also discussed about the time reduction and with large amounts of data obtainable in realistic situations.

Mahdavi et al (2009) tried to cover different sizes, problems with small size, medium size and large size. Minimum utilization are the same for all cells in each problem commonly used. Objectives in cell formation are to minimize intercellular movements and maximize machines. The grouping efficacy of the solution obtained by the proposed method is either better than that of other methods. New mathematical model for the Cell formation problem based on cell utilization concept in CMS is introduced. The proposed model determines the cell configuration with the aim of minimizing the EEs and the number of voids in cells simultaneously. An efficient algorithm was designed to solve the mathematical model based on genetic algorithm.

Algorithm provided by Chan and Milner (1982) considered a machine component matrix. The number of positive cell entries in each column or row is calculated and listed at the end of the respective column or row. The number of positive cell entries in each column or row is calculated and listed at the end of the respective column or row. The same matrix after initial arrangements, the columns and rows are respectively ranked in order of decreasing and increasing values of the number of positive cell entries. This becomes the 9 starting matrices for the iterative algorithm. The first column to be considered is that consisting of machine number 14. The rows which have positive cell entries in this column are components number 9, 4, 3 and 6. These are moved to the top of the new matrix in the same order as they appear in the current matrix. Next, the second column is considered but nothing happens since all the positive entries in this column have already been reallocated. The algorithm applies to the third column consisting of machine number 15 which groups together components number 8, 5 and 2. The other rows are rearranged in a similar manner and the resulting matrix after the first rows rearrangements. Now the algorithm is repeated on the matrix. But this time the columns are arranged instead of the rows. The example matrix after the first columns rearrangements, clustered machine component groups can be identified along the diagonal of this matrix. Applying the iterative algorithm again will not change the pattern of the matrix in Figure 2, therefore it is the finalized form.

COMP NO. / M/C NO	14	9	6	4	1	15	13	8	5	3	12	11	10	2	7
9	x	x	x	x											
4	x	x		x	x										
3	x	x	x		x										
6	x	x	x	x	x										
8						x	x	x	x	x					
5						x	x	x	x	x					
2						x	x	x	x	x					
1											x	x	x	x	
10											x	x	x	x	x
7											x	x	x	x	x

Figure 2. The Part-family Matrix.

Farsijani and Foroutan (2012) Summarized results of the simulation model for the previous state job shop system, the average utilization of workers and machines are 32% and 25% respectively. The average lead time and waiting time are high. The mean wait time is 220 minutes, which shows that the act for the existing system is inefficient and indicates that certain areas need adjustments in order to achieve better system performance. Moving of the cells in parallel positions and dividing the plant into 3 cells and 3 families are considered in the new state, cellular layout based on the proposed method. It is observed that the travelling time of parts has decreased, because the total length of the conveyor is decreased. These achieve better results, and balance worker and process utilization. Furthermore, the space availability for further expansion of the plant is increased to approximately 25%. Witnessing the simulation, summarizing results of two manufacturing models and considering all factors, new state proposed cellular system has significantly better results as compared to previous state predictable job shop system.

According to Zheng et al (2014), comparative studies on many benchmark data sets are brief where the performance criteria with asterisks on the right denote the best results in the works. The study consists of benchmark problems with performance criteria for each one. Among the total 75 performance indexes, 51 are equal, 12 are better, and 9 are almost equal, the best-known results. Particularly, the two-phase clustering algorithm is effectual in terms of percentage of exceptional elements (PE). The results of the relative study validate that the two-phase clustering algorithm is efficient and effective for solving machine-cell and part-family formation difficulties.

Fariborz and Babak (2012) said random problems were generated randomly to compare the performance of the EM-like algorithm with heuristic local search and hierarchical GA. The model parameters which are used in the problem demonstrates the final parameters that are used in the algorithms and the termination condition of the algorithms. The problems are categorized in small, medium and large size problems to have better overview on the performance of the algorithms. The results are that each problem was run 100 times. NP, NM and MC represent number of parts, number of machines and least number of cells that are allowed to be created. For both objective functions, same weights are considered. F-bound and F-best denote the objective bound and the best objective value which are obtained in the reported time. B&B algorithm gives the global optimum on the first two problems third problem the algorithm was run for more than 62 hours but still the global optimum was not obtained the rest of the problems the B&B algorithm was run for 3 hours. For the medium size and large size problem the B&B algorithm could not reach the feasible solution space within 3 h, thus no lower bound and best objective value are reported. The EM-like algorithm gives the global optimum in the first two. On the other the best objective values of EM-like algorithm are better than GA except in one problem and the mean values of EM-like algorithm is always better than GA mean value. Applying GA can reduce the CPU time in comparison with EM-like algorithm but as it can be seen for large size problems EM-like algorithm has better CPU time in comparison with GA. The comparison has been illustrated in the figure (See Appendix A) to get a better idea.

Jamal et al (2012) presents a number of numerical examples to confirm the effectiveness of proposed Branch and bound algorithms. The first set which consists of ten randomly generated instances is to compare three branch and bound algorithms in terms of the efficacy of branching scheme and the tightness of bounds. The sizes of these problems vary from small to large sizes. We consider a maximum two hours of time when running each B&B

algorithm. In other words, if an algorithm fails in obtaining the global optimum for a numerical example within 2 hours then the best solution found yet will be reported (Jamal et al., 2012). illustrates the results for the first example set. The improved CF-based B&B has always outperformed the other two schemes in terms of the quality of the best solution and running time.

Yong and Kazuhiko (2005) Performance results under the condition of different Radio of expectations ratios. All similarity coefficients perform best under a low RE ratio. Only a few of similarity coefficients perform well under a high RE ratio Sokal and Sneath 2 is very good for all RE ratios. Again, the four similarity coefficients: Hamann, Simple matching, Rogers and Tanimoto, and Sokal and Sneath, perform badly under high RE ratios.

In summary, three similarity coefficients: Jaccard, Sorenson, and Sokal and Sneath 2 perform Coefficients for its stability. For all problems, literately generate and for all levels of both REC and RE ratios, Jaccard similarity coefficient is constantly the most stable coefficient among all 20 similarity coefficients. Another finding in this study is four similarity coefficients: Hamann, Simple matching, Rogers and Tanimoto, and Sokal and Sneath are inefficient under all conditions. So, these similarity coefficients are not recommendable for cell formation applications.

Goncalves and Resende (2004) tested the hybrid genetic algorithm on 35 GT instances collected from the literature. The selected matrices range from dimension 5! 7–40! 100 and comprise well-structured, as well as unstructured matrices. The matrix sizes and their sources are presented. These six approaches provide the best results, found in the literature, for the 35 problems used for comparison. The procedure obtained solutions that are at least as good as the ones found the literature. For 57% of the problems, the algorithm improved the previous solutions, in some cases by as much as 12%.

General and Critical Comments (Pros and Cons)

The main requirement of Cellular Manufacturing is to ensure that all equipment required for production are operating at 100% efficiency at all times. Through short daily inspections, cleaning, lubricating, and making minor adjustments, minor problems can be detected and corrected before they become major problems that can shut down a production line.

Mahdavi et al (2009) proposed a new mathematical model for the CFP based on cell utilization concept in CMS. The proposed model determines the cell configuration with the aim of minimizing the EEs and the number of voids in cells simultaneously. An efficient algorithm based on GA was designed to solve the mathematical model. In order to verify the performance of the GA approach.

Chan and Milner (1982) Cluster data from any given machine component matrix, but also can effectively deal with exceptional elements and bottleneck machines. The algorithm provides a feasible approach to group formation in cellular manufacturing. Based on the same principle, the algorithm can be used in conjunction with a data field matrix for grouping similar characteristics from a range of objects, when no classification is suitable for coding the attributes relevant to the analysis. In fact, the Direct Clustering Algorithm can serve as a means of universal classification. The Direct Clustering Algorithm is a powerful tool for group formation, and therefore can be used in many areas.

Cellular manufacturing system (CMS) is a production technique that leads to increasing productivity and efficiency in the production floor. The design of CMS consists of machine-part family formation problem. Continually, researchers attempt to find a better solution for solving it. In this paper, a 0-1 quadratic programming model based on the Minkowski distance measure for solving the machine-part family formation problem is applied. The proposed method is implemented in a hypothetical manufacturing facility in terms of conventional job shop layout with 10 machines and 15 parts. The results that are shown in section 5, indicates that the cellular layout based on the proposed method is more efficient than the previous state, job shop layout. The conclusion cannot be generalized, as the result is dependent upon data and size of the problem. An extension of this study would be to include other optimization models for solving the machine-part family formation problem.

Zheng et al (2014) discussed in this paper, an efficient two-phase clustering algorithm for part-family and machine-cell formation in the design of cellular manufacturing systems. The approach utilizes the combination of a linear assignment program and a fuzzy C-means algorithm. One distinctive advantage of the two-phase clustering algorithm is that it is deterministic with constant clustering results. The present algorithm is demonstrated to be effective and efficient according to the experimental results of an extensive comparative study.

Fariborz and Babak (2012) study developed an EM-like algorithm for CM design and layout problem to minimize the cost of handling and number of exceptional elements. A heuristic local search algorithm was presented to improve the performance of the proposed algorithm. It was demonstrated the proposed heuristic results in better answers in comparison with two other local search method. To verify that issue some statistical tests were developed. The influence of different levels of parameters, in EM-like algorithm and GA has been studied by developing some statistical tests. The performance of EM-like algorithm was compared with that of GA algorithm proposed by Wu et al (2007) and B&B algorithm.

The computational results denoted that the solutions of the proposed EM-like algorithm are superior to those of GA in small, medium and large sizes problems. Beside the convergence diagrams for two problems were plotted to compare EM-like algorithm and GA convergence process. Based on our knowledge, we presented EM-like algorithm for CM design and layout problem for the first time in the literature. It can be a good opportunity for further researches to improve presented EM-like algorithm by combination of other meta-heuristic algorithms.

Jamal et al (2012) proposed that a CF-oriented B&B algorithm has the potential to be utilized in more complicated cell formation problems (that is, CF problems considering various production data). Moreover, the proposed problem-oriented B&B algorithms can be used in various similar clustering problems that involve the assignment of distinct objects in indistinguishable groups (such as k-means, k-median and k-center problems). The branching process is applied to the binary decision variables involved in the mathematical model. However, due to the large number of variables in the CF problem, the number of nodes in the branching tree increases exponentially; hence, this branching scheme fails to find global optimum solutions even for small-sized CF problems. Another difficulty that arises in this B&B algorithm is the high probability of infeasibility and repeatability for complete or incomplete solutions (nodes). The branching process for the second B&B algorithm is performed based on the structure of the CF problem. In other words, instead of branching on binary variables, the branching process is performed on the cell numbers for machines. Although the second B&B algorithm prevents the generation of infeasible solutions, there is still the possibility of having indistinguishable solutions in the last level of the branching tree. The last B&B algorithm is developed by introducing a relatively simple modification into the branching scheme applied in the second algorithm. This adjustment enables the last B&B algorithm to eliminate the repetitive solutions in the last level of the branching tree.

Yong and Kazuhiko (2005) discussed that the initial problem in the design of cellular manufacturing systems is the cell formation problem. One methodology to form manufacturing cells is the use of similarity coefficients. 2 experimental factors were proposed and used for generating experimental problems. 9 performance measures were used to judge the solutions of the tested problems. The numerical results showed that three similarity coefficients are more efficient and four similarity coefficients are inefficient for solving the cell formation problems. Another finding is that Jaccard similarity coefficient is the most stable similarity coefficient. Comparative studies in consideration of some production factors, namely production volumes, operation sequences, etc. of parts.

Goncalves and Resende (2004) proposed a new approach for obtaining machine cells and product families has been presented. The approach chains a local search experimental with a genetic algorithm. The genetic algorithm uses a random keys alphabet, a selection strategy, and a uniform limit. Experience with the algorithm, on a set of 35 GT problems from the literature, has shown that it performs remarkably well.

Implementation of Cellular Manufacturing Systems

Methodology

Olorunniwo (1997) categorized success of cellular manufacturing implementation; 50% or more improvement on performance matrices like production lead time, throughput, reworked items indicate the successful implementation of CM. Wemmerlov and Johnson (1997) continued the work where several process categories were identified and data were collected from them. Silveira (1999) described a three-phase implementation methodology involving preparation, definition and installation. Each phase contains necessary sub-phases concerning cell formation, data collection, cell design among other aspects. This paper is merely an integrated approach of previously presented concepts and structures of the CM implementation. Gunasekaran et al (2001) implemented CM using the trial method in a manufacturing firm. The methodology for implementation is divided into two phases that contained the design of GT cells, formation of part/product and machine grouping and implementation of individual cells. A survey on past literature revealed the importance of GT implementation in small to medium size enterprises (SME). They categorized the implementation into three categories- qualitative/quantitative techniques, analytical techniques (simulation) and trial method, the first two of which were discussed in the papers already mentioned above.

Olorunniwo and Udo (2002) stated three different regression models that were used to determine the most influential variables in CM implementation. Addressing the human resource issues, the authors used sociotechnical systems (STS) theory. Fraser et al (2007) introduced a multi-phase model to incorporate both technical and human aspects of cellular manufacturing implementation. In a recent article, Tortorella et al (2017) considered STS factors as per the past literature review study. Though the authors originally focused on the application of lean principles in a toy manufacturing company, several papers referred by them showed that the implementation in terms of Socio-technical Ergonomics (SE) in different other companies would be successful as well.

Park and Han (2002) used 4 steps in their study to assess the performance obstacles in cellular manufacturing implementation. Summed rating for all the obstacles were obtained and compared to find out the most vital ones. Analysis of variance (ANOVA) showed significant factors (obstacles) affecting the overall implementation performance. Chakravorty and Hales (2004) studied A lean manufacturing improvement related case thoroughly and data were collected based on that. There are several elements discussed which correspond to initial cell design decisions. Murugan and Selladurai (2007) with the help of a three-cell formation algorithm in a pump industry, optimized and implemented cellular manufacturing. The process depends on several clustering algorithms namely Rank Order Clustering (ROC), Direct Clustering Analysis (DCA) etc. Pattanaik and Sharma (2009) relied on a cell formation technique based on binary machine-part incidence matrix and introduced it in the paper to identify machine cells for a certain given part. Multi-objective optimization technique was used to maximize utilization and minimize waste.

Solutions and Application

Olorunniwo (1997) opined that delivery response (DR) and quality cost (QC) are the most important dimensions. Their methodology focuses on more improvement in DR than QC. According to Wemmerlov and Johnson (1997), there exist five reasons to start CM. Customer response time is important. After a few years, Olorunniwo and Udo (2002) detected 19 sociotechnical variables were identified and grouped into four major factors. Altogether, 7 major sub-variables showed the highest impact. Two of the major factors were ‘Management initiated cell implementation’ and ‘Cross training machine run.’ Under these two factors, most of the major sub-variables were studied. The response variables were delivery response (DR) and quality cost (QC). In addition to that, Park and Han (2002) mentioned several crucial factors including training and education, teamwork skill, supervision and scheduling were most important for a successful CM implementation. The next update on the implementation takes place when Murugan and Selladurai (2007) took a different implementation approach and analyzed results from all the clustering algorithms like ROC, DCA etc. All the results were compared with each other to find out the best choice of clustering for the implementation process that is DCA. So, their cellular layout model was based on that. Recently, Tortorella et al (2017) consolidated improvement opportunities for LM practices. The following Figure 3 showed 5 of 19 factors (namely takt time, goal oriented teams, flexible manpower etc.) which were the most critical ones for LM implementation.

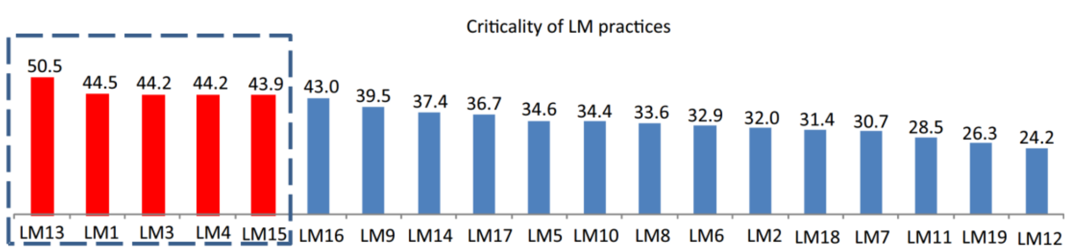

Figure 3. Factors effecting LM practices & their degree of criticality by Tortorella et al (2017).

Silveira (1999) revealed that different performance measures showed benefits from this implementation process. Rework and WIP showed huge reductions of 83% and 92% respectively after CM implementation. Likewise, Gunasekaran et al (2011), noticed significant reduction in WIP storage after the implementation. The bottlenecking stations were identified after the implementation of CM. Fraser et al (2007) proved that the reductions in both labor costs and lead-times were achieved. WIP also went down resulting in a quality increase of nearly 10%. In the study by Chakravorty and Hales (2004), the CM implementation results showed 50% improvement in production lead time in millwork manufacturing company after maintaining it for 5 years. The proposed implementation was built based on direct clustering and it has been shown that 20.21 % increase in productivity could be achieved if this algorithm is used for implementation of cellular layout. In a more recent study, Pattanaik and Sharma (2009) reported that the proposed future state generated a net increase of 11% to value added (VA) activities and net decreases of 12.20% and 2.8% for non-value-added activities (NVA) and necessary non-value added (NNVA) respectively.

General and Critical Comments (Pros and Cons)

Olorunniwo (1997) only focused on two dimensions. More dimensions might have been scrutinized but the paper was presented as an earlier version of future advancement. Wemmerlov and Johnson (1997) indicated that their suggested strategies worked well with many firms but some of the firms failed to achieve any results. This was partially because of the simplification of the supply chain concentrating only on labor cost optimization. This area needs to be investigated further. The methodology explained by Silveira (1999) seemed to be working fine in the case of toy manufacturing. But it might not be very useful where a fixed position layout is needed. The CM implementation worked well because of the well-known simplified process in the mass production. Gunasekaran et al (2001) became successful to identify many essential work stations for other stations to perform smoothly. Those stations should be placed strategically. The low improvement on revenues and return on invested capital of Textron (a company studied by the authors) should be addressed and dealt with as well.

It was observed in the article by Olorunniwo and Udo (2002) that the R^2 values for the regression models were low and this shows a poor prediction in most of the cases. The sample sizes were also very small. There are definite scopes to improve on this study in future. While in the research paper by Park and Han (2002), their survey might show biased results based on the focus groups involved. The implementation was based on developed countries which should not be generalized for other developing or under-developed countries. Chakravorty and Hales (2004) suggested ways that lead towards worker reduction in the long run, might be avoided. Slight gradual increase shown in the WIP should affect the overall system in future.

In the article by Fraser et al (2007) There are many other factors along with STS that have been ignored and left out. A total overview of lean manufacturing implementation should include as many factors as possible from real life manufacturing operation sequences. The study by Murugan and Selladurai (2007) is based on one product only which is the simplest case for any manufacturing companies. More than one product or even product mixes should have been tried out to see if the algorithm (DCA) can improve productivity. Pattanaik and Sharma (2009), In their implementation method, overlooked the issues involved with load levelling (heijunka) or high utilization of resources which are very important for any manufacturing industry and vital to its competitiveness. Improvement of cellular layout and corresponding effect to value stream could have been presented in detail. Tortorella et al (2017) failed to incorporate technical issues in their model (which would have been more realistic and appropriate) that are crucial for any manufacturing practice. Also, the method is a preliminary step to start the implementation process and likewise it needs many other steps to be improved and sustainable.

Reliability of Cellular Manufacturing Systems

Methodology

Reliability is one of the substantial factors affecting the performance of manufacturing system. It can cause disturbances and delay in production rate. Although that the reliability of manufacturing systems including job shop, cellular manufacturing, and mass production has been discussed by several researchers, the reliability of cellular manufacturing is a topic that has been taken into account recently comparing to other themes of cellular manufacturing system (CMS). The focus on the reliability of machines in manufacturing is mentioned in number of papers, but the reliability of machines in cellular manufacturing systems started in early 2000. Previously, in many CMS research and studies, such as Ameli and Arkat (2008), it was assumed that machines are perfectly reliable in cellular manufacturing which was far from the real world.

Patchong and Willaeys (2001) were among the pioneers in the field of cellular manufacturing and machine reliability within the cells. Previously, research and studies in terms of cellular manufacturing was only limited to its formation, implementation, and the obstacles of generating cellular manufacturing systems. Based on our research it is determined that most of the methods appeared in the literature to consider the reliability of CMS problems use mathematical programming procedures that take large amount of computational calculation. Among them, Patchong and Willaeys (2001) has introduced the basic parameters of an isolated machine and its performance in flow line machine, then he discussed the probability of failures, efficiency, and repair rate of those machines with mathematical equations in a cellular manufacturing system.

$$\lambda_i = \frac{1}{Pw_i} \sum_{j=1}^{J_i} \lambda_{ij} Pw_{ij} \prod_{k \neq j} (1 - Pd_{ik})$$

Which l is average failure rate of M_i, Pw_i is the probability that machine i is working (utilization rate), and Pd_{ik}

is the probability of machine i being down. There are other formulas that derived from the average failure rate formula.

Seifoddini and Djassemi (2001) and Das et al (2006) have created a mathematical model that was used as a reference in next studies which focused on investigating the performance measures at different quality index (QI). The technique used the same performance measure introduced by Patchong and Willaeys (2001) to replacing each parallel-machine stage by a single equivalent machine in order to obtain a classically-structured reliability rate with machines in series. Since Patchong and Willaeys (2001) considered the reliability of machines in different cases such as when machine works solely, when machine works in a production flow, and when machine is not subject to idleness; therefore, the model that they came up with was more comprehensive that could be used by others as a reference.

Seifoddini and Djassemi (2001) attempted to calculate the reliability changes with simulation at different QI. For the simplicity of their work, exponential distribution was introduced for measuring the reliability of machines performing in a CMS. The performance measures they considered was mean flow time and work-in-process inventories. Seifoddini and Djassemi (2001) also attempted to investigate to see that in which type of manufacturing system the impact of reliability variation is more significant. They proposed a parallel reliability configuration in general manufacturing system. By the means of simulation, they have concluded that in which type of manufacturing system reliability changes is more sensitive. As mentioned earlier, Seifoddini and Djassemi (2001) used and compared two performance measures in their analysis (mean flow time, WIP inventories) that was considered and applied in future works of Das et al (2007), Das et al (2007) Xambre et al (2016), Das et al (2007) and Renna et al (2017) have evaluated the different machine reliability based on WIP, mean flow time and throughput in CMS and subsequently, suggested the preventive maintenance policies in order to hinder machine failure. However, Xambre et al (2016) compare the performance measures of machines in a CMS by building a Decision Supporting System (DSS). He indicated that the DSS for checking the reliability of machines is dependent on the cell formation, as well as the performance of the machines individually. The DSS structure proposed by Xambre et al (2016) in terms of reliability of machines in CMS showed below in Figure 3.

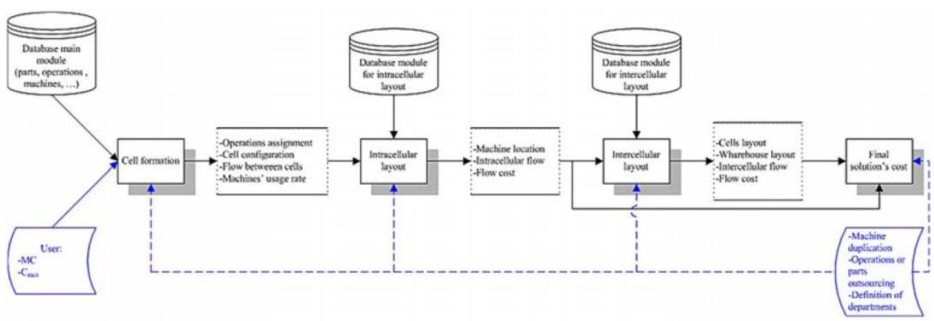

Figure 4. The structure of DSS

Diallo et al (2001) has discussed a platform in cellular manufacturing system (CMS) that could increase the reliability of machines. They performed the reliability analysis of individual machines in the presence of unreliable machines flexible design of cellular manufacturing systems. They have utilized Markov chain model which is a way of simulation to build efficient configuration when the disturbances resulting from unreliable machines are considered in the model.

Das et al (2006) and Das et al (2007), however, built their model without considering the flexible design of manufacturing cell which was performed by Diallo et al (2001) previously to investigate the reliability of machines based on the overall reliability not just an individual machine in a CMS. They have had huge contribution through developing the reliability of machines and its preventive maintenance in CMS. Das et al (2006), Das et al (2007) and Das et al (2007) have all developed a model that aims to have highest overall reliability a CMS with presence of unreliable machines by minimizing the total cost and maximizing the individual reliability of each machine in the system. Das et al (2006) also used a simulated annealing-based solution algorithm in 2006 which was considered for machine availability for investigating the machine reliability in 2007. Moreover, they proposed a reliability-based model in the same year with almost the same assumptions for a common preventive maintenance planning in the cellular manufacturing system. While it has been perceived that the preventive maintenance and reliability is mostly used in cellular manufacturing, Renna (2017) and Sarwar, and Zaman (2017) represented that preventive maintenance also can be used interchangeably in job shop environment.

Ameli and Arkat (2008) proposed a unique linear integer formula to minimize the intercellular movement of machines with reliability consideration. Their model follows Das et al (2006) assumptions to have optimum balance between minimization of cost of machines movement within a cell and maximization of the reliability of individual machine. They also had the same assumption as Seifoddini and Djassemi (2001) did that breakdown time of machines follows exponential distribution.

Rafiee et al (2011), however, proposed a cell formation by considering the existence of unreliable machines in the cell since moving from "in control" state to "out of control" state makes the situation more realistic. They also considered all costs associated with the production in a dynamic condition. As mentioned before, Xambre et al (2016) have tested a Decision Support System (DSS) in CMS to propose a conceptual map in terms of dealing with reliability of machines in the system.

Recently, researchers concentrate more on the role of preventive maintenance (PV) in routing of machines in the system. As such, Renna (2017) suggested a simulation environment to assess the impact of PV policies in maintaining the flexibility routing. He highlights two performance measures of the maintenance policy and that the parameters have positive effects on improving the performance measures. His works was initially performed by Seifoddini and Djassemi (2001). However, Seifoddini and Djassemi (2001) estimate the performance measures at different quality index.

Solutions and Application

Most of the articles and studies worked on the overall reliability of machines or individual machines in cellular manufacturing system (CMS) attempt to verify their mathematical models, equations, and solutions in terms of different aspect of reliability of CMS by proposing examples to show that their results also get credits in real world practices.

That is why providing a numerical example in terms of reliability of the formation and design of a CMS has become institutionalized in the studies. First type of papers utilized simulation environment to show the solutions, results, and applications associated with reliability of CMS problems. Among them, Patchong and Willaeys (2001), Das et al (2007) and Renna (2017) can be mentioned. Patchong and Willaeys (2001) has used ARENA software to simulate the results, Das et al [4] has utilized an annealing-based approach simulation to show the solutions of simulation, and Renna (2017) has used Simul8$^{@}$ discrete event simulation to apply the achieved the multi-objective linear models into real life numeric example to evaluate the reliability of intercellular machines in CMS.

Patchong and Willaeys (2001) performed the simulation for two case scenarios one slow parallel machines two redundant parallel machines to investigate the reliability of each layout in CMS. Their results are used in estimating the reliability of any series-parallel flow line that because of its simplicity and applicability of implementation had been referred broadly. Their method also being credited by being implemented in the industry.

Das et al (2006), however, attempts to calculate the mean time between failure for machine (MTBF) and mean time to repair for machine (MTTR) as two of most important machine reliability indicators related information by a simulation approach. They also investigated on routing flexibility of CMS in general that resulted in getting information about the frequency of machine non-availability. Then they compared their answers with Genetic Algorithm (GA). They have also come to know that the suggested algorithm can be performed in practical-size of CMS problems to gain reasonable solutions.

Renna (2017) also utilized MTTR and MTBF and preventive maintenance to investigate the reliability of machines in CMS. The minimum and maximum amount of MTTR and MTBF was chosen the same as Das et al (2006), Das et al (2007a) and Das et al (2007b) did in their work. They also come up with the same results as Das et al (2006) did that as the flexibility of the system decreases, the machines within CMS is more reliable and needs less preventive maintenance. Seifoddini and Djassemi (2001) investigate the significance difference between reliability level of system in cellular manufacturing and job shop manufacturing with paired t-test. They have used 15 part-types and 36 machines in a manufacturing system. Based on the considered reliability levels, results showed that as the reliability levels of machines reduced, the performance of manufacturing system in both job shop and cellular manufacturing system declines. Moreover, it was determined that the performance of cellular and job shop manufacturing performance is the same if the reliability of the system is 100%. Also, it was showed that the cellular manufacturing was more dependent on reliability of system than job shop manufacturing. This finding was verified later by Das et al (2007).

However, Das et al (2007) used the term preventive maintenance instead of reliability which is a broader term and mostly used as the performance of system in general. Das et al (2007) examine the machine reliability in the CMS based on his proposed model. They have used 12 process plans and seven machines for their numerical example. After having estimated machines availability in the system, Das et al (2007) identified the effective machine capacity. They have found that the failure of one machine in a CMS won't end up to the failure of whole system failure; however, it would affect the performance of the cell. Also, they have used €-constraint method to see what is the relationship between failure rates and availability of machine in a CMS with respect to costs and system reliability of them because it is important to obtain the machine utilization as an important indicator of a CMS configuration. They also have suggested that if it was the case that there are a few failed machines in a CMS either the planned parts should be directed to the alternative routes or waited for repair completion of failed machines. Their results were partially validated by Diallo et al (2001) when they were attempting to design a flexible CMS in presence of unreliable machines.

Nevertheless, Diallo et al (2001) used Marcov chain system to represent the dependency of a CMS to reliable machines. With a numerical example, they have showed the difference of considering reliability of machines and not considering the reliability of machines ends up to different cell configuration. Although their solutions were different from the ones obtained in previous works related to designing the configuration of a CMS, their solutions were more reliable and practical since they considered the non-availability and reliability of machines in their analysis. Das et al (2007), as mentioned before, considered preventive maintenance (PV) schedule in CMS configuration for examining its reliability. In their numerical analysis, they have considered four part-types and five machines which was less than what they had done a year before that with 12 part-types and seven machines. This point needs to be mentioned that their proposed model considered machine reliability at the design stage of cell. However, their multi-objective mathematical model was the same derivation as Das et al (2007) used which was in terms of minimizing cost and maximizing the reliability of integrated machines in a CMS configuration.

Ameli and Arkat (2008) pursued Das et al (2006), Das et al (2007) and Das et al (2007) works to develop an integrated model for a CMS that could reduce the cost and increase the reliability of intercellular movement. Their model was developed based on a binary integer programming model. They have found that by considering reliability in a CMS design, the machine part layout would be significantly different from the time that it is not considered. Also, their results showed that although the number of movement within a cell is increased, the reliability of the CMS increased in a way that the total cost in the system is decreased. This finding was already proved by Das et al (2006), Das et al (2007) and Sefoddini et al (2001) with different set of objectives.

Having used the literature problem for validating their model, Rafiee et al (2011) could represent their model by a numerical example to show the effect of reliability consideration on a CMS. Amongst previous works that used numerical example to investigate the reliability of a system, Rafiee et al (2011) solved a big-scale problem with 30 part-types and 17 machines. Their numerical sample could verify the applicability of the proposed model. Not only have they considered cost in their developed model, but also, they have separated the costs into different categories (procurement, reconfiguration, process routes setup, inter-cell, intra-cell…) so that they could get a better perception of which cost contributes more in designing a CMS. By doing so, they were even able to track the different level of reliability and its associated cost in a CMS configuration.

Proposing a Decision Support System (DSS) for CMS design, Xambre et al (2016) were pioneer to suggest a DSS system in terms of reliability of a CMS. Their model is more conceptual rather than following a unique mathematical equation and can be used by managers in order to get a better sense of how reliability can be applied into designing of CMS configuration. Their model includes: cell formation problem, decision maker intervention in CMS design, solution, and comparing the solutions. However, in order to use the model an adequate database from a CMS is required. And the correct conceptualization of database into the model helps in gaining more reliable results. Moreover, the decision makers can utilize the proposed conceptual map to analyze the reliability system associated with a CMS. However, no numerical sample has been introduced specifically regarding the reliability of a CMS; therefore, no exact output can be derived from the model unless motivating future researchers to validate this model by incorporating an example in terms of reliability of a CMS.

General and Critical Comments (Pros and Cons)

Previously, researchers performed designing of the CMS without taking the reliability of machines into account. But started from early 2000, researchers attempted to have a more real picture from designing of CMS by considering the reliability of systems, the reliability of machines associated with each cell, preventive maintenance plans for cellular manufacturing and its breakdown.

As mentioned in previous sections, there was a trend of using simulation environment in terms of reliability of CMS configuration such as Patchong and Willaeys (2001) and Das et al (2006) which also used by Renna (2017) currently. Although they have utilized the same method to develop their model, the type of simulation they have applied was different and as a result, their conclusion was different as well. For example, Patchong and Willaeys (2001) used ARENA simulation which was popular tool for discrete simulation that time. But if we want to compare it with Das et al (2006) work and Renna (2017), we can infer that the current works are more reliable and accurate since the type of simulation used have become more authentic. However, Patchong and Willaeys (2001) work was credited by successful implementation in industry and its best benefit was that it could be applied easily and could be tracked by performance diagnosis. Das et al (2006) proposed heuristic algorithm that could be applied to small-scale problems regarding the reliability of a CMS. It might be applied to a large-scale one but it will be more time-consuming and inaccurate since the obtained solutions are not conveyed. That is why more experimentations regarding their heuristic algorithm should be performed to investigate its applicability in large-scale problems.

Renna (2017), as the newest work done in CMS area using simulation with consideration of its reliability, concludes that the preventive maintenance policy should be applied to the system to increase the reliability of CMS. Their results can be used as an authentic support system for future use. If we were to conduct their research, we would investigate on more complicated CMSs because it would increase the credibility of the study. Also, we would assess the product quality reliability using preventive maintenance.

We believe that Seifoddini and Djassemi (2001) could provide a novel in their work related to reliability of cellular manufacturing because they could do a comparison between job shop and cellular manufacturing reliability at different quality index that has never been performed before. Also, this procedure should be continued in the future in future studies because not only is it important to find various methods in investigating the reliability of a CMS, but also the researchers should find the reliability correlation between different types of manufacturing configuration. Diallo et al (2001) attempted to use non-availability of machines as a reliability factor of cellular manufacturing which was a new view in the terms of reliability of a CMS. They have used Marcov chain system to investigate the reliability of machines in a CMS that until then no one used this approach before. However, we believe that since they have applied Marcov chain system in their analysis, they should have proposed a performance criterion to reduce the computation time of their algorithm.

Das et al (2006) and Das et al (2007) followed the same pattern in developing a reliable CMS and their results as well. However, Das et al (2006) in 2006 pursued the methodology of providing multiple conveyed solutions and select the best one with respect to cost and reliability trade-off. The only advantage in their work compare to what they did in the next year was that their proposed approach provides routing flexibility in the case of machine breakdown. Das et al (2007) in 2007 tried to investigate the reliable cells and machines in a CMS by proposing preventive maintenance plans. But since their numerical example was tested for limited available data, it can be implemented fully in industrial world. Therefore, we believe that if they were to collect data regarding industrial settings and apply it into the real world, their solutions could be more authentic in terms of reliability and maintenance of cellular manufacturing system.

The same as Patchong and Willaeys (2001) and Diallo et al (2001), Ameli and Arkat (2008) also suffer from the long-lasting computation which is going to raise an issue in the case of having a large-scale CMS problem. Thus, my suggestion is that researchers should provide algorithms in terms of reliability of a CMS that can deal with real world problems in the future. Also, they should provide a multi-objective algorithm that the objective is to maximize the reliability of machines in the system as well as minimizing cost of preventive maintenance. Nevertheless, they had huge contribution on providing a meaningful algorithm that was able to increase the reliability of the system by having increase in intercellular movement of machines which had not been considered in previous studies.

Rafiee et al (2011) could be considered as the only researchers that have built up their model based on dynamic situation. This modeling process can significantly be improved by developing system dynamics models not only in manufacturing fields but in modeling complex systems which needs considering multiple variables. Recently, this approach has been used and developed in investigating economic-optimal solutions by Rabiei Hosseinabad and Moraga and Rabiei Hosseinabad (2017) which gave other researchers the opportunity to analyze the cellular manufacturing reliability in terms of various cost settings. This helps them to find the best economic-optimal solutions with respect to the movement of machines within the cell and lot sizing of products which suggest most reliable layout of machines. we believe this study can be improved in two directions: first, the assessment of exact solution methodologies such as heuristic models and in second phase to continue to pursue the dynamic cellular manufacturing since it is a new topic that needs to be taken care of in terms of reliability of a CMS. Xambre et al (2016) hasn't introduced any numerical example for their model to investigate the validation of the model. Examples should mainly address to the development of new algorithm directed at CMS' design with regards to reliability. The authors should have also addressed to the impact of Decision Support System (DSS) in cellular manufacturing system reliability.

Discussion and Conclusion

In this literature review, potential research areas regarding lean manufacturing and cellular manufacturing were identified. A chronological comparison of major areas in cellular manufacturing indicates the high concentration of research in this area. In future, more researchers will be interested and conduct fruitful research. Although, there is no perfect method or design of CM, it should always be tried to be improved as part of TPM. Implementation of CM might not be suitable for all the industries. Proper assessments of the manufacturing industry, its product mixes, capacity, throughput, lead time etc. are vital to the success for CM implementation. Small and medium sized industries can adopt this practice more easily than the large ones.

Only four themes are considered for CM and GT in this review. There obviously exist different other themes as well. Due to time and resource constraints, all themes were not explored. Sometimes, the themes overlap with one another and becomes difficult to differentiate. From what is understood with this review is that a GT or cellular manufacturing must be designed well, formed with caution, implemented with success and be sustainable with reliability.

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Appendices

Results.

Pro. no.	Problem size	B & B			EM-like					GA					EM & GA comparison		
	NP × NM × MC	f^{bound}	f^{best}	Run time (S)	Z^{mean}	Z^{best}	G^{mean}	G^{best}	Run time (S)	Z^{mean}	Z^{best}	G^{mean}	G^{best}	Run time (S)	Ga^{mean}	Ga^{best}	R
Small size																	
1	6 × 6 × 2	49.5	49.5	745	49.5	49.5	0	0	6.59	78.16	50.5	57.90	2.02	4.26	0.37	0.02	−0.55
2	9 × 7 × 2	73.5	73.5	26,712	73.5	73.5	0	0	6.66	122.24	86.5	66.31	17.69	3.92	0.40	0.15	−0.69
3	12 × 10 × 3	33.25	212	226,551	82.5	82.5	−0.61	−0.61	15.28	229.84	170	8.42	−19.81	6.37 0.64	0.51	−1.40	
4	12 × 12 × 3	50.01	386	10,800	209.76	194	−0.46	−0.50	14.72	317.76	255.5	−17.68	−33.81	6.57	0.34	0.24	−1.24
	5	12 × 12 × 4	28.73	316	10,800	140.65 93	−0.55	−0.71	15.32	231.35	169	−26.79	−46.52	9.74	0.39	0.45	−0.57
Average		**46.00**	**207.4**		**111.18**	**98.50**			**11.71**	**195.87**	**146.30**	**17.63**	**−16.07**	**6.17**	**42.77**	**27.50**	**−0.89**
Medium size																	
6	15 × 12 × 4	-	-	>>3 h	149.51	140.5	-	-	17.73	292.80	240	-	-	9.95	0.49	0.41	−0.78
7	20 × 15 × 5	-	-	>>3 h	340.88	264	-	-	24.37	530.44	424	-	-	10.45	0.36	0.38	−1.33
8	25 × 20 × 5	-	-	>>3 h	722.66	531	-	-	36.22	1069.93	818	-	-	15.53	0.32	0.35	−1.33
9	25 × 20 × 6	-	-	>>3 h	581.48	462	-	-	44.54	890.06	748.5	-	-	15.39	0.35	0.38	−1.89
10	30 × 20 × 6	-	-	>>3 h	683.02	440.5	-	-	24.55	1124.74	876.5	-	-	17.11	0.39	0.50	−0.43
Average					**495.51**	**367.60**			**29.48**	**781.59**	**621.4**			**13.69**	**0.38**	40.46	−1.15
Large size																	
11	35 × 25 × 6	-	-	>>3 h	1086.10	884	-	-	30.35	1557.47	1304.5	-	-	26.95	0.30	0.32	−0.13
12	35 × 30 × 7	-	-	>>3 h	1616.81	1355.5	-	-	34.24	2141.26	1770.5	-	-	36.02	0.24	0.23	0.05
13	35 × 35 × 8	-	-	>>3 h	1802.76	1589	-	-	47.14	2299.74	1907.5	-	-	48.45	0.22	0.17	0.03
14	40 × 30 × 6	-	-	>>3 h	1629.18	1416.5	-	-	39.07	2203.75	1956.5	-	-	38.99	0.26	0.28	−0.00
15	40 × 35 × 8	-	-	>>3 h	2227.80	1870.5	-	-	45.59	2840.39	2421.5	-	-	51.17	0.22	0.23	0.11
16	43 × 40 × 10	-	-	>>3 h	2378.74	1911	-	-	58.75	3256.36	2698	-	-	68.01	0.30	0.29	0.17
17	45 × 43 × 10	-	-	>>3 h	2532.63	2191.5	-	-	65.52	3682.78	3048	-	-	76.91	0.31	0.28	0.15
18	45 × 45 × 9	-	-	>>3 h	4617.94	3996	-	-	69.64	7415.00	6290	-	-	84.53	0.38	0.36	0.18
19	46 × 45 × 11	-	-	>>3 h	2608.01	2267	-	-	74.10	3822.30	3034	-	-	89.25	0.32	0.25	0.17
20	50 × 25 × 5	-	-	>>3 h	2259.17	1582	-	-	39.95	3004.69	2455.5	-	-	34.06	0.25	0.36	−0.17
21	60 × 35 × 7	-	-	>>3 h	3882.33	3321	-	-	62.19	4876.09	4185	-	-	69.64	0.20	0.21	0.11
22	60 × 38 × 6	-	-	>>3 h	4862.53	4130.5	-	-	80.35	5216.7	3956.5	-	-	72.87	0.07	−0.04	−0.10
23	65 × 40 × 8	-	-	>>3 h	4484.98	3453	-	-	68.37	6028.69	5222.5	-	-	97.01	0.26	0.34	0.30
24	70 × 45 × 8	-	-	>>3 h	6201.26	5284.5	-	-	98.06	7491.12	6192	-	-	128.04	0.17	0.15	0.23
25	80 × 40 × 8	-	-	>>3 h	6057.11	5295	-	-	97.76	7545.13	6376	-	-	127.35	0.20	0.17	0.23
Average					**3098.92**	**2703.13**			**60.74**	**4225.43**	**3521.2**			**81.61**	**0.24**	**0.24**	0.11
Comprehensive average					**2051.23**	**1715.10**			**44.68**	**2730.75**	**2266.26**			**33.82**	**0.31**	**0.28**	**−0.34**

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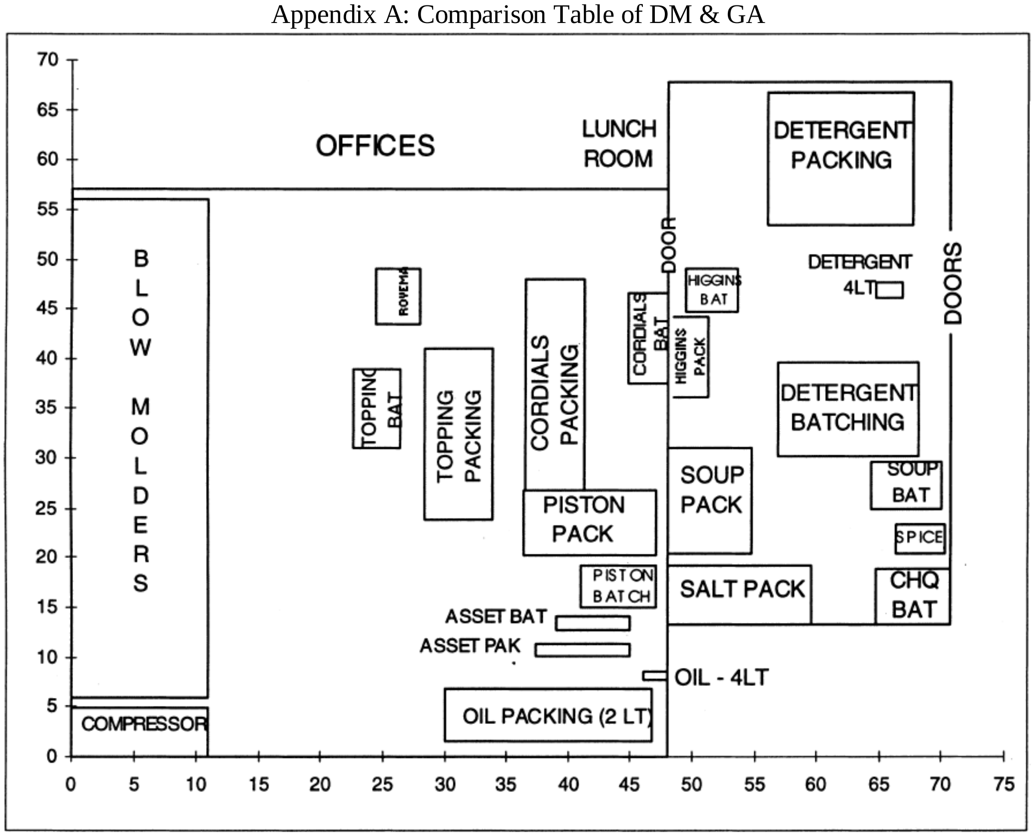
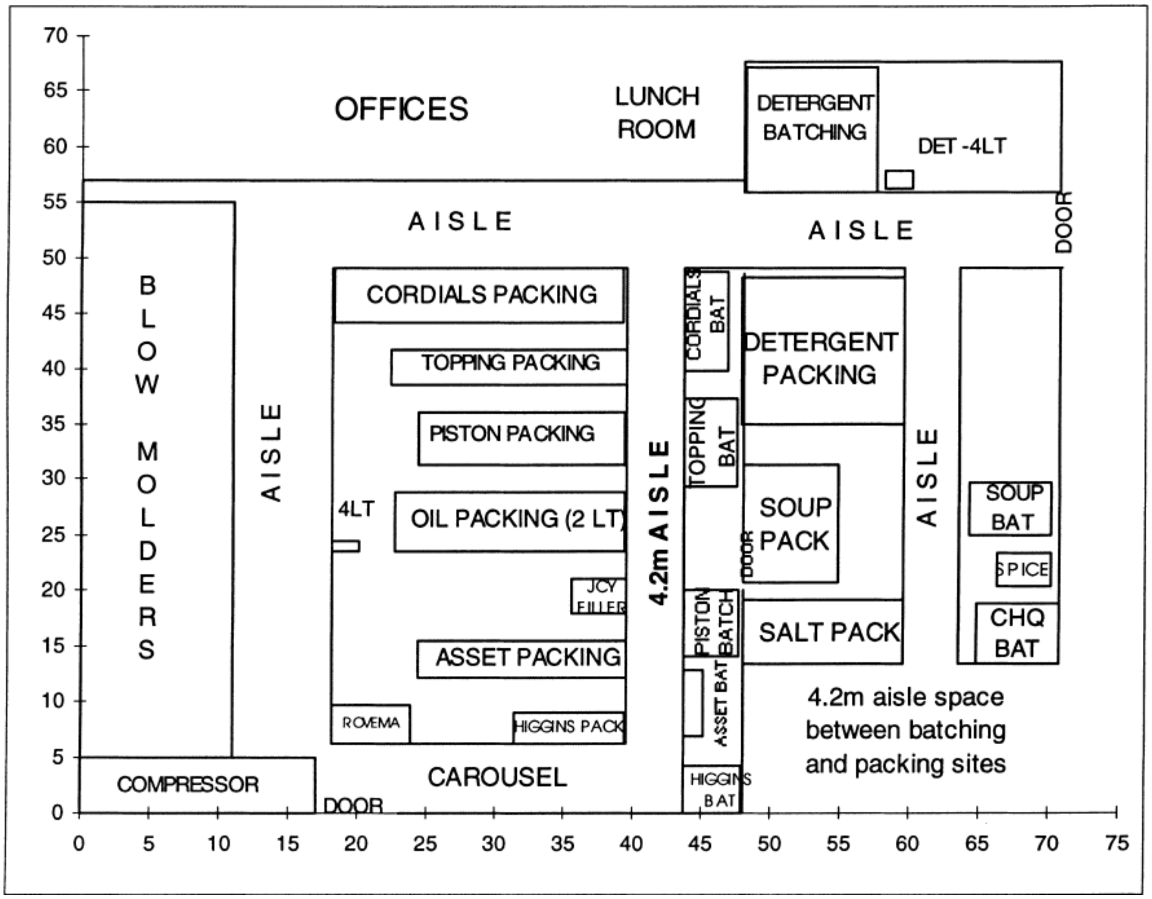
Appendix A: Comparison Table of DM & GA



Appendix B. Food Product Industry Layout by Bazargan-Lari (1999)



Appendix C. Food Process Industry Layout by Mohammadi & Forghani (2016)