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Comprehensive design of Cellular manufacturing system: A Review

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Abstract - **Cellular Manufacturing (CM) is an approach to harness the benefits of high production rate of a flow shop while maintaining flexibility, and utilizing facilities, of a job-shop. CM necessitates that parts and machines are allocated into cells to produce the identified part families so that productivity and flexibility of the system can be improved. Most of the research work on cellular manufacturing is focused on binary part machine matrix, however in past few decades a spur has been observed in the literature considering the comprehensive data to design the cellular manufacturing system. In this work authors have critically examined the literature available on cellular manufacturing design based on operation sequences, production volume and machine availability and other important parameters. Various performance parameters have also been discussed which play important role in the cellular manufacturing design. Paper also discusses the key areas which need to be explored for efficient and economic implementation of cellular manufacturing on the shop floor level.**

Keywords - Cellular Manufacturing, Optimization, performance measures.

1. INTRODUCTION

Globalization and the development of global markets and technology are progressively accelerated forcing companies in today's competitive environment to change dramatically to satisfy the urgency and variability of consumer tastes and demands [Goyal et al., 2013a, 2013b, 2013c]. To cope with this trend, companies must develop/adopt novel approaches and practical strategies to deal with various production parameters such quantity (smaller batches), variety (larger diversity) and so on to optimize their production systems. Manufacturing systems are radically to cope up the situation [Goyal et al., 2012a, 2012b, 2012c, 2012d, 2011].

Cellular Manufacturing Systems (CMS) is a manufacturing paradigm based on Group Technology (GT). Although both terms CMS and GT are occasionally used interchangeably, GT is an area of study devoted to parts clustering and machine cells formation and considered as the starting point of cell design.

In a cellular manufacturing system (CMS), machines are grouped into a limited number of cells. Compared with conventional manufacturing systems (job shops, flow shops, etc.), the techniques of part family and machine cell formation of CMS is advantageous in reducing set up times, throughput times and material handling cost, as well as enhancing production efficiency (Wemmerlov and Hyer, 1989) because each machine is capable of handling different operations for different parts.

Major goal of cell formation is to produce small and independent cell. In BMPM, it is considered that each part is having equal production volume and operation sequences. In contrast, it does not provide actual intercellular movement because the exceptional part outside the block shows only 1 intercellular movement. Practically, it can be more than one inter-cell movement depending on the operation sequence and production volume (Harhalakis et al. 1990; Nair & Narendran, 1998). If production volume and operation sequence is considered for cellular design it is known as Comprehensive Part Machine Grouping (CPMG). Many research works have been done considering CPMG. Nair & Narendran, (1998) and Won & Lee, (2001) use matrix which account for the operation sequence. Wu, (1998), Wu & Salvendy, (1999)

Akturk & Balkose, (1996), Askin & Zhou, (1998) and Nair & Narendran, (1998) proposed the cell formation methodologies based on the similarity (or dissimilarity) coefficient reflecting the operation sequence and production volume the operation sequences and production volumes of parts.

2. LITERATURE REVIEW

Sarkar & Xu (1998) presented a concise review of methodology followed for cell design, based on the operation sequence. Basically, four types of method has been quoted while considering operation sequence i.e. mathematically programming, network analysis, material flow analysis and heuristic. Similarity/ dissimilarity coefficient based on operation sequence were also reviewed [Phanden et al., 2013, 2011a, 2011b, 2012a, 2012b, 2012c; Sharma et al., 2012]. Operation sequence was considered as most important key factor for the manufacturing system. It has also been investigated by them that research work is not well developed or reported properly and hence it is quite difficult to achieve the optimal solution to the operation sequence based cellular manufacturing because of its complexity of calculations.

Zhao & Wu (2000) provided a genetic algorithm for machine-part grouping with multiple objectives: minimizing total within cell load variation, cost of inter-cell and intra-cell part movement and number of exceptional elements. Production data e.g. part routing sequences, workload balance, production volumes were carefully considered. A method was suggested for part alternative routing. Some specific genetic operators were also developed which makes the solution of a problem quite easy. Approach suggested by them is fully compatible with medium scale tasks and complicated working conditions.

Agarwal *et al.* (2011) reviewed that there are number of approaches for part family and machine cell formation. The main concern is to calculate grouping efficiency to determine the quality of grouping. They also investigated the pros and cons of grouping efficiency, mainly focuses on the efficiency developed by P. Chandrasekharan & Rajagopalan, (1986). It was detected that number of groups formed will always affect almost all type of grouping efficiency. With contrast to this they proposed, two new efficiency measure considering number of groups formed, exceptional elements and voids. It has been proved with example taken from literature that the proposed efficiency has much better characteristic of discriminating good groups from bad ones. Comparison analysis of two proposed efficiency has also been done.

Kusiak & Cho (1992) developed two similarity measures and heuristic approach. One is applicable for cellular manufacturing with alternative process plan without bottleneck and second is generalization of first which target on bottlenecks part or machine. Algorithm used in second approach is clustering identification algorithm applied to similarity matrix. Second algorithm tested with 20 problems taken from literature which provide solutions of good quality.

Goncalves & Resende (2004) reported a new approach for cellular design. They combined Genetic Algorithm with local search heuristic. Genetic Algorithm used an elitist selection strategy, parameterized uniform crossover. To guarantee the maximum utilization of machines in the cell a local search heuristic combined with genetic algorithm. Main objective of this algorithm is maximizing machine utilization and reducing inter-cell movement. Proposed approach applied on 35 problem of GT taken from literature and it shows remarkable results.

Selvam & Balasubramanian (1985) discussed the Algorithmic Grouping of parts by using operation sequence. Basic of this grouping is that, the components having same operation sequence are grouped together. Thus, more than one component can be machined in the same line instead of developing separate line for each component. The objective of grouping, that the sum of material handling cost and machine idle time is minimized. The algorithm use similarity coefficient approach and also demonstrate the usefulness of heuristic algorithm for covering technique. Guidelines for detailed plan layout were also provided by the algorithm.

Nair & Narendran (1998) reported that the cell manufacturing based on machine incidence matrix whose main objective is to minimize the inter-cell movement. If other factor like, operation sequence and production volume incorporated into the machine cell design the quality of solution will be enhanced. They considered sequence data for cellular manufacturing and defines a similarity approach applicable to it. A non hierarchical clustering algorithm, CASE (Clustering Algorithm with sequence data) has also been proposed which based on the value of similarity between different machines. Some machines shows high similarity i.e. almost same components are processed by them while other have zero similarity. Each machine with zero similarity chosen as a seed for clustering. On the basis of clustering other machine can be rearranged to these seeds.

Wu (1998) reviewed that most of the research, carried out for machines duplication were not properly identified to an optimal solution. In general, shared machines are identified and then duplication is done on the basis of shared machine. In contrast to this, he stated firstly the capacity requirement of machine should be calculated on the basis of part produced and then machine duplication proceeds. For this he proposed a new method considering a network model for cell design. If machine type has one or more than one machine it was represented by simple node and complex node respectively. Model is capable of describing multiple machines of the same type, simultaneously cell formation problem and allocation of similar machine are solved here.

Won & Lee (2001) analyzed that most of the studies were done using binary machine incidence. A new approach was suggested with an objective of minimizing the inter-cell flow considering operation sequence and production volume. Two types of Production data-based part machine incidences matrices (PMIM) were developed. In type PMIM-1 it actually calculates the movement from machine to another for each individual part. If an intermediate operation is considered outside the cell then it involves two inter-cell movements and if it is first or last operation only one inter-cell flow will be considered including production volume. It is just a modification of Boctor's formulation.PMIM-2 is a revised version of PMIM-1 to just reflect the inter-cell movement by bottlenecks parts.

Through, the computational result achieved in this paper it was concluded that this PMIM's approach can easily replace the binary machine incidence with better result.

Iqbal (2010) reported that in cellular design the parts have to travel within the cell and outside the cell for required processing steps. The costing due to the movement of parts to and from machines contributes in majority to the total production cost. A non linear mathematical model was generated with an objective of minimizing and balancing total inter-cell and intra-cell moves costs. Using Arena production simulation of the job shop can accurately model into cellular manufacturing system which further, results in cost saving.

Adil *et al*. (2001) discussed that a cellular design depends upon two basic requirement i.e. cell compactness and cell independence. In general the main objective of cellular manufacturing design is maximization of cell independence. For fulfilling this objective, a threshold value is prescribed for cell compactness. The inter-cell and intra-cell move cost viewed as cell compactness and cell independence respectively. Trade off between inter-cell and intra-cell is also established. For minimizing the total cost incurred by inter-cell and intra-cell moves, a non linear mathematical model and simulated annealing method. Developed method shows well results as compared with other procedures.

Murugan & Selladurai (2011) recommended an Art Modified Single Linkage Clustering approach (ART-MOD-SLC) for the cellular manufacturing problem. An ART network is unified with Modified single linkage clustering. In this approach, firstly cell formation is done with the help of ART1 approach and further re-correction is done with Modified Single Linkage Clustering. The proposed approach validity has been tested using four different solution approach to cellular design i.e. ROC2, DCA, SLC, MOD-SLC. Performance of all four techniques is poorer than the ART-MOD-SLC techniques. Performance measure used for evaluation of proposed approach is GE, PE, MU and GC. In most of the literature work ART-MOD-SLC approach is used for real manufacturing data.

James *et al.* (2007) presented a hybrid grouping genetic algorithm (HGGA) for the generation of machine cell and their concerned part family. Hybrid genetic algorithm comprises of local search and standard genetic algorithm to solve the problem of machine cell design. With lesser iteration the HGGA finds better results as compared to traditional genetic algorithm. From literature, 35 problems have been tested for both HGGA and genetic algorithm including the parameters like, maximum number of groups, number of iterations, and size of population and stopping criterion. With adding of local search in genetic algorithm improves the quality of solution as well decrease the variability of solution.

Chattopadhyay *et al.* (2013) reviewed the impact of two important soft computing technique i.e. artificial neural network (ANN) and genetic algorithm (GA) for cellularmanufacturing system. In depth, research ha been carried out to judge the trends of approaches and improvement in cell formation problems. An analytical comparison has also been done between ART and GA approaches for evaluating research trends and continuous improvement in cell formation using different objectives. It was also reported, over past years crossover, mutation and population size used in genetic algorithm have also been improved.

Paydar & Mohammad (2013) presented a linear fractional programming model with a target of maximizing the grouping efficacy, while the number of cells in cellular manufacturing is undetermined. The validation and performance of the model has been checked by considering 2 problems from literature. They also proposed an algorithm which was a combination of genetic algorithm(GA) and variable neighborhood search (VNS). It is a Hybrid meta-heuristic algorithm in which GA is based on the concept of Darwin theory i.e. survival of the fittest. VNS relate one or more than one neighborhood system and alter it to reach of a local search. 35 problems from literature were considered for evaluating the performance of the proposed algorithm and it showed better result than other algorithm.

Banerjee & Das (2012) discussed that for cell formation problems there is an appreciable growth approaches in both classical and soft computing techniques likes mathematical modeling, genetic algorithm, ant colony method etc. Main motive of their study was to scrutinize the application and performance of prey predator genetic algorithm. The algorithm depends upon the local search for creating a harmony between prey and predator. They provide optimized solution with lesser number of iterations as compared to GA. It efficiently works for large scale real sized problems. A grouping efficacy was also proposed with two linear objective i.e. exceptional elements and machine utilization.

Yasuda & Yin (2005) designed a cellular manufacturing system using Falkenauer's grouping genetic algorithm (GGA). It is multi-objective cell formation problem considering two objectives i.e. minimization of inter-cell movements and cell load variation. Cell size constraint was not predetermined which is usually consider in literature. Many design factors has been considered like processing sequences, production volume, machine investment, alternative processing routes so that realistic results can be obtained for cell formation problem.

Ponnambalam S.G. *et al.* (2007) reported that usually binary machine part matrix is used for the cell formation problem. In this paper for the realistic solution to the cell formation work load data has been used with genetic algorithm. Performance of proposed approach compared with K-mean clustering and modified ART1 algorithm with a performance measure i.e. Modified Grouping Efficiency (MGE).

Goncalves & Jose (2006) discussed grouping genetic algorithm (GGA) for cellular manufacturing system. They consider the group machine encoding rather than machine encoding. For the effective implementation of genetic algorithm repair heuristic for crossover and mutation operator was also consider. Minimization of inter-cell movement and cell load variation were used as the objective function for the CFP.

Sudhakara & Mahapatra (2009) discussed the limitation of zero-one part machine incidence matrix (PMIM) i.e.it does not consider operation time, operation sequence and lot size of parts which are important factor for the designing of cell problem. To overcome this limitation a clustering methodology based on adaptive resonance theory (ART) has been proposed for the generalized cell formation. Two design factors have been considered i.e. operation sequence and operation time. Ratio–ordinal combined efficiency (ROCE) was also proposed as a new performance measure for the calculating the efficiency of proposed algorithm.

Khaksar *et al.* (2013) presented a model for designing multi-floor layout of cellular manufacturing systems (CMS) using integer linear programming. It includes many design features like alternative process routings, operation sequence, processing time, production volume of parts, duplicate machines, machine capacity, machine purchasing, lot splitting, material flow between machines, intra-cell layout, inter-cell layout, multi-floor layout, and flexible configuration. A genetic algorithm approach has been used with multiple objective is minimize the total costs of intra-cell, inter-cell, new machines purchasing and machine processing.

Darla *et al.* (2014) considered cellular manufacturing design by developing a mathematical model. The objectives function were minimization of inter-cellular movement and cell load variation which was optimized using Genetic Algorithm. These two objectives further leads to minimization of exceptional elements which in turn leads to minimization of transportation cost between cells and also manufacturing cost.

Solimanpur Maghsud *et al.* (2004) presented a mathematical model to solve multi-objective cell formation problem with multiple alternative process plans for parts. The objectives function were considered are as follows: maximize the total similarity between the parts, minimize the total processing cost, minimize the total processing time, and minimize the total investment needed for the procurement of machines. The mathematical model was comprehensive as it considers machine requirements, processing costs, processing times, sequence of operations, multiple process plans, production volumes, capacity of machines, etc. the proposed method solve the multi-objective using genetic algorithm which provides a novelty of considering different fitness function instead of single fitness function.

Sengupta Sourav *et al.* (2011) reviewed the literature of cellular manufacturing system and concluded that production factor like production time is usually not considered for the cellular design. They proposed a new hybrid neural network approach, Fuzzy ART K-Means Clustering Technique (FAKMCT), to solve the cell formation problem while considering operation time. The proposed algorithm was compared with algorithms like K-means clustering and modified ART1. Machine grouping efficiency (MGE) was considered as a performance measure for the proposed algorithm.

From the literature review, it is evident that although there has been considerable research on cellular manufacturing, cell formation but insufficient attention has been devoted to the development of a comprehensive method or technique for designing and building cell formation, which are critical in designing an efficient cellular manufacturing system close to actual practice in industries.

3. MATHEMATICAL FORMULATION FOR COMPREHENSIVE MACHINE PART GROUPING

In this section a mathematical model is presented to solve the multiple objective cell formation problem with ordinal and ratio data. The objectives considered in this model are to: (1) minimize the cell load variation and, (2) minimize the intercellular movement for the acquisition of machines. The problem is formulated as:

3.1 Assumptions

- The operating times for all part type operations on different machine types are known.
- The product mix and demand for each part type in each period is known.
- The capabilities and capacity of each machine type are known and constant over time.
- Each machine type can perform one operation. Likewise, each operation can be done on one machine type only.
- No inventories are considered.

- Set up times are not considered.
- Machine breakdowns are not considered.
- Machines are available at the start of the period (zero installation time).

3.2 Indices

$g = \text{cell index } 1,2,3....\text{G}$

$i = \text{part index } 1,2,3....\text{I}$

$k = \text{machine index } 1,2,3....\text{K}$

$r = \text{operation sequence of parts } 1,2,3...\text{R}_i$

$w_{ki} \rightarrow$ workload on machine k induced by part i.

$t_{ki} \rightarrow$ processing time (seconds /part) of part i on machine k.

$T_k \rightarrow$ available time on machine k in a given period of time.

$N_i \rightarrow$ production requirement of part i in a given period of time.

$e_{ik} \rightarrow$ transpose of W_{ki} matrix where time replaced by 1.

$x_{kg} \rightarrow$ shows membership of k^{th} machine in g cell.

$y_{ig} \rightarrow$ shows membership of i^{th} part in g cell.

$M \rightarrow$ average cell load matrix.

$T_k \rightarrow$ capacity of each machine of type k.

$$w_{ki} = \frac{t_{ki} \times N_i}{T_k}$$

3.3 Parameters

$$m_{ig} = \frac{\text{Total load of cell } g \text{ induced by part } i}{\text{Number of machines in cell } g} = \frac{\sum_{k=1}^{K} x_{kg} \times w_{ki}}{\sum_{k=1}^{K} x_{kg}}$$

3.4 Decision variable

$$x_{kg} = \begin{cases} 1 \; if \text{ machine } k \text{ is in cell } g \\ 0 \text{ otherwise} \end{cases}$$

$$y_{ig} = \begin{cases} 1 \; if \sum_{k=1}^{K} e_{ik} \times x_{kg} > 0 \\ 0 \text{ otherwise} \end{cases}$$

$$e_{ik} = \begin{cases} 1 \; if \; t_{ki} > 0 \\ 0 \text{ otherwise} \end{cases}$$

$$x_{ir} = \begin{cases} 0 \; if \text{ operations } r, r+1 \text{ are performed in the same cell} \\ 1 \text{ otherwise} \end{cases}$$

3.5 Objective function

$$Minimize \; O_1 = \sum_{k=1}^{K} \sum_{g=1}^{G} x_{kg} \sum_{i=1}^{I} (w_{ki} - m_{ig})^2 \qquad (1)$$

$$Minimize\ O_2 = \sum_{i=1}^{I} N_i \left[\sum_{i=1}^{I} \sum_{r=1}^{R_i - 1} (x_{ir}) \right] \qquad (2)$$

$$Minimize\ O_3 = \sum_{g=1}^{G} \sum_{k=1}^{K} \left[\frac{\sum_{i=1}^{I} \sum_{p=1}^{P_i} N_i\, a_{ik}^p t_{ik}^p x_{ig}^p}{T_k} \right] \times A_k \ (3)$$

$$Minimize\ O_4 = \sum_{i=1}^{I} \sum_{g=1}^{G} \sum_{p=1}^{P_i} \sum_{k=1}^{K} N_i c_{ik}^p x_{ig}^p \qquad (4)$$

Subject to:

$$\sum_{g=1}^{G} x_{kg} = 1 \text{ for } k = 1, 2.....K \qquad (3)$$

$$\sum_{g=1}^{G} y_{ig} = 1 \text{ for } i = 1, 2.....\mathrm{I} \qquad (4)$$

$$\sum_{k=1}^{K} x_{kg} \geq 2 \text{ for } g = 1, 2.....G \qquad (5)$$

$$\sum_{k=1}^{K} y_{ig} \geq 2 \text{ for } g = 1, 2.....G \qquad (6)$$

$$\sum_{k=1}^{K} x_{kg} = 1 \qquad (7)$$

The objective functions (1) and (2) represent the cell load variation and intercellular movements. Constraints (3) and (4) ensure that each machine and part can only be assigned to only one cell. Constraints (5) and (6) assure that each cell should be accompanied by at least two machines and parts and the (7) constraint ensures that no cell is empty.

5. CONCLUSIONS AND FUTURE SCOPE

Although lot of research work, has been witnessed in CMS, but most of the articles present Binary Cell formation without considering ordinal and ratio level data.

- In the literature, study of alternative operation sequences is quite sparse.
- The multiple objective optimizations have been done mostly by classical techniques or weighted objective and the Pareto frontiers have not been obtained.
- The repair heuristic are not developed instead penalizing the infeasible solution is used leading to inefficient evolutionary algorithms.

A comprehensive methodology can be developed incorporating all major objectives and practical issues. The design comprehensive methodology will consider all the major problems and practical concerns since exclusion of major problems or practical concern has caused wide gap between academic research and practices in industry.

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