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Cell Formation in a Batch Oriented Production System Using a Local Search Heuristic with a Genetic Algorithm: An Application of Cellular Manufacturing System

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Abstract

Cellular manufacturing is a production strategy which is capable of solving certain problems in a batch manufacturing system. A batch manufacturing system produces some intermediate varieties of products with intermediate volumes. Production equipment in batch manufacturing must be capable of performing a variety of tasks. One of the fundamental problems in cellular manufacturing system is the formation of part families and machine cells that is the cell formation. For cell formation the part families are identified that require similar processing on a set of machines. In turn, these machines are grouped into cells. Each cell is capable of satisfying all the requirements of the part family assigned to it. In this paper an approach is used to form the part families and machine cell in a batch oriented production system. This approach combines a local search heuristic with a genetic algorithm. The genetic algorithm is used to generate the sets of machine cells. The local search heuristic is applied to the sets of machines cells generated by the genetic algorithm. The objective of the heuristic is to construct a set of machine/part groups and improve it, if possible. The result obtained by this approach is compared with the existing initial machine part matrix. Grouping efficacy of the existing initial machine part matrix is 24.56%. After this approach, the grouping efficacy of the final machine part matrix is 54.25%. The result with a grouping efficacy is higher than the existing initial machine part matrix. The grouping efficacy has improved by 29.69%. So this approach can useful in cell formation in any batch oriented production system.

Keywords: *Cell Formation, Batch Production System, Cellular Manufacturing System, Genetic Algorithm, Local Search Heuristic.*

1. Introduction

The group technology (GT) concept in manufacturing was first introduced by Flanders in 1925. In 1959, Mitrofonov published a book on scientific principles of GT and Burbidge in 1960 proposed a systematic planning approach for GT called production flow analysis. From then onwards there has been a lot of methods, models and algorithms developed for finding the solution for the primary problem of design of manufacturing cells. In the last three decades of research in cell formation, researchers have mainly used zero-one machine component incidence matrix as the input data for the problem.

1.2 Different Approach for Cell Formation Problem

1.2.1 Graphical Approach

Graphical method is first approach used by the researcher to solve the cell formation problem in GT. Rajagopalan & Batra (1975) used graph theory to solve the grouping problem. They developed a machine graph with as many vertices as the number of machines. Kumar et al. (1986) solved a graph decomposition problem to determine machine cells and part families for a fixed number of groups and with bounds on cell size. Their algorithm for grouping in flexible manufacturing systems is also applicable in the context of GT. Vannelli and Kumar (1986) developed graph theoretic models to determine machines to be duplicated so that a perfect block diagonal structure can be obtained. Later Kumar and Vannelli (1987) developed a similar procedure for determining parts to be subcontracted in order to obtain a perfect block diagonal structure.

1.2.2 Array-Based Clustering Techniques

Array-based clustering methods perform a series of column and row permutations to form product and machine cells simultaneously. Existing cluster analysis methods are reviewed and a new approach using a rank order clustering algorithm is described which is particularly relevant to the problem of machine-component group formation by King (1980).A comprehensive comparison of three array-based clustering techniques is given by Chu and Tsai (1990). The quality of the solution given by these methods depends on the initial configuration of the zero-one matrix. An efficient nonhierarchical clustering algorithm, based on initial seeds obtained from the assignment method, for finding part-families and machine cells for group technology (GT) is presented by Gupta & Seifoddini (1990) which aim was to minimize the inter-cell movements and blanks (machine idling). Another efficient nonhierarchical clustering algorithm, based on initial seeds obtained from the assignment method, for finding part-families and machine cells for group technology (GT) is presented by Srinivasan & Narendran (1991) which aim is to minimize the exceptional elements (inter-cell movements) and blanks (machine idling). Later a clustering approach of the non-hierarchical type was proposed by Nair & Narendran TT (1998) which clusters machines and components on the basis of sequence data. The algorithm gives encouraging results which provide better optimum solution than the previous approaches.

1.2.3 Mathematical Programming Methods

Mathematical programming methods treat the clustering problem as a mathematical programming optimization problem. At first Choobineh (1988) used a cluster algorithm to form the part families and an integer programming model. Then Gunasingh & Lashkari (1989) formulated an integer programming problem to group machines and products for cellular manufacturing systems. A mathematical model and solution procedure for the group technology configuration is proposed by Askin & Chiu (1990) for the grouping of individual machines into cells and the routing of components to machines within cells. A nonlinear mathematical programming model is developed by Adil, Rajamani, & Strong (1997) for cell formation that identifies part families and machine groups simultaneously which objective is the minimization of the weighted sum of the voids and the exceptional elements. Another mathematical programming model for the cell formation problem with multiple identical machines, which minimizes the intercellular flow, is presented by Xambre & Vilarinho (2003). After that, Tsai & Lee (2006) developed a multi-functional MP model that incorporates the merits of related CF models based on the systematic study of MP models. A comprehensive mathematical model for the design of CMS based on tooling requirements of the parts and tooling available on the machines was proposed by Defersha & Chen (2006). Mahdavi et al. (2007) formulated a new mathematical model for cell formation in cellular manufacturing system (CMS) based on cell utilization concept which objective is to minimize the exceptional elements (EE) and number of voids in cells to achieve the higher performance of cell utilization.

1.2.4 Genetic Algorithm Based Technique

Zulawinski, Punch & Goodman (1995) developed a grouping genetic algorithm for Bin balancing which is better suited for grouping problems than the classical representations. After their approach, genetic algorithms become more popular to the researchers for finding the optimum solution for the cell formation problem. Cheng et al. (1998) formulated the cell formation problem as a travelling salesman problem (TSP) and a solution methodology based on genetic algorithms (GAs) is proposed to solve the TSP-cell formation problem. Onwubolu and Mutingi (2001) developed a genetic algorithm (GA) meta-heuristic based cell formation procedure having the objective function of minimizing the intercellular movement and cell load variation. Zolfagharia and Liang (2003) proposed a new genetic algorithm (GA) for solving a general machine/part grouping (GMPG) problem where processing times, lot sizes and machine capacities are all explicitly considered. An approach has taken by Goncalves and Resende (2004) for solving the manufacturing cell formation problem in the term of group efficacy where they also used a local search heuristic genetic algorithm. Another genetic algorithm approach was done by Chiang & Lee (2004) for cell formation and inter-cell layout to minimize the actual inter-cell flow cost, instead of the typical measure that optimizes the number of inter-cell movements. Yasuda, Hu and Yin (2005) proposed an efficient method to solve the multi-objective cell formation problem (CFP) partially adopting Falkenauer's grouping genetic algorithm (GGA). James, Brown & Keeling (2007) presented a hybrid grouping genetic algorithm for the cell formation problem that combines a local search with a standard grouping genetic algorithm to form machine-part cells. Pillai et al. (2008) suggested a new approach for forming part families and machine cells, which can handle all the change in demands and product mix without any relocation. Tariq, Hussain and Ghafoor (2009) developed an approach that combines a local search heuristic (LSH) with genetic algorithm (GA). The results show that new approach not only converges to the best solution very quickly but also produces solutions that are as accurate as any results reported so far in literature.

1.2.5 Others Different Approaches

Waghodekar & Sahu (1984) presented a heuristic approach based on the similarity coefficient of the product type for the problem of machine-component cell formation in group technology. Then Seifoddini & Wolfe (1986) developed a Similarity Coefficient Method (SCM) method to form the machine cells in group technology applications which is more flexibility into the machine-component grouping process and more easily lends itself to the computer application. Askin and Subramaniam (1987) proposed a heuristic approach to the economic determination of machine groups and their corresponding component families for group technology. After that, Srinivasan, Narendran & Mahadevan (1990) presented an assignment model to solve the grouping problem where a similarity coefficient matrix is used as the input to the assignment problem. A non-heuristic network approach is developed by Vohra et al. (1990) to form manufacturing cells with minimum intercellular interactions. At first Kumar & Chandrasekharan (1990) proposed the concept of grouping efficacy which objective is to maximize the group efficiency by reducing the number of voids in the cell and inter-cell movements for the cell formation in group technology. Later Boctor (1991) suggested a new linear zero-one formulation to avoid the disadvantages of other alternative formulations to solve the cell formation problems which having better computational feasibility and efficiency. A network flow methodology was developed by Lee & Garcia-Diaz (1993) to measure the functional similarity between machines and then to group the machines into cells in such a way that all the parts in each family can be processed in a machine cell. Heragu & Kakuturi (1997) solved a real-world machine grouping and layout problem in which the objective is not only to identify machine cells and corresponding part families but also to determine a near-optimal layout of machines within each cell and the cells themselves. Sarker (2001) presented a critical review of existing grouping measures, introduces a new measure called ‘doubly weighted grouping efficiency measure. After that, Kim, Baek & Baek(2004) deal with the multi-objective machine cell formation problem to determine the part route families and machine cells. A new Branch-and-Bound (B&B) enhancement is then proposed by Boulif and Atif (2006) to improve the GA's performance which is used to solve the cell formation problem by using the binary coding system.

1.3 Comparison among Our Approach and Other Different Approaches

Array-based clustering methods perform a series of column and row permutations to form product/part and machine cells simultaneously. The main problem in array-based clustering methods is that the quality of the solution given by these methods depends on the initial configuration of the zero-one matrix. But in case of our approach, the quality of solution does not depend on the initial configuration of the zero-one matrix. Hierarchical methods have the disadvantages of not forming part and machine cells simultaneously. Our approach overcomes these disadvantages. One limitation of graphical method is that the machine cells and part families are not formed simultaneously. But our method overcomes these limitations. Mathematical programming methods can solve the machine part grouping problem simultaneously by considering the within-cell layout. But this technique is slightly complex and time consuming.

All the above techniques for cell formation problems are slightly complex and time consumable. None of the approaches presented above guarantees optimal solutions. So that the modern researchers have the tendency to continue their research activities in the field of group technology for machine part cell formation problem by using genetic algorithm. The objective of this paper is to present a procedure for obtaining product-machine groupings when the manufacturing system is represented by a binary product-machine incidence matrix. The approach combines a genetic algorithm with a local search heuristic. The genetic algorithm is responsible for generating sets of machines cells. The local search heuristic is applied on the set of machines cells with the objective of constructing sets of machine/product groups and improving their quality.

2. Research Methodology

For conducting thesis Data were collected from “OTOBI Limited”Savar factory which is a leading furniture manufacturing company in Bangladesh. In this paper a genetic algorithm approach is used to create the chromosome. The chromosome contains the information for the machine cell. According to the chromosome the number of machine cell has been selected and the machines have been inserted to the cells. After that the initial machine cell has been formed. The local search heuristic has been applied then to form the part families. Then the machine part matrix has been formed and the corresponding grouping efficacy has been calculated. Then with the help of part families the local search heuristic has been applied again to obtain the new machine cell. Then again the machine part matrix has been formed with the part families and the new machine cell and the corresponding grouping efficacy has been calculated. This process has been continued until the optimum solution has been found.

3. Measure of Performance

Grouping efficacy $$\mu = \frac{N_1 - N_1^{OUT}}{N_1 - N_0^{IN}} \qquad (1)$$

Where,

N_1 = total number of 1’s in the matrix; N_1^{OUT} = total number of 1’s outside the diagonal blocks;

N_0^{IN} = total number of 0’s or blank space inside the diagonal blocks.

4. Machine part cell formation

In this paper we attempt to solve the machine part cell formation problem using zero one matrix, to minimize the inter-cellular movements and maximize the utilization of machines within a cell. Table 4.1 represents a 15×19 matrix (zero values are replaced by spaces in order to make the table more readable).

Table 4.1: Initial machine part incident matrix

Part	**Machine**																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1						1		1		1					1			
2	1						1		1		1					1			
3	1				1		1		1				1						
4	1				1		1		1				1						
5		1						1		1		1						1	
6		1						1		1							1		1
7		1						1		1				1					
8		1				1		1		1		1						1	
9	1						1		1		1							1	
10	1						1		1		1							1	
11		1						1	1									1	
12	1						1			1								1	
13		1				1		1		1					1			1	
14		1	1																
15		1		1															

Here on the table ”1” represents that the part has an operation on the machine and “blank space” represents that the part has no operation on the machine. The objective of this is to produce a matrix such as the one in table 6.1.

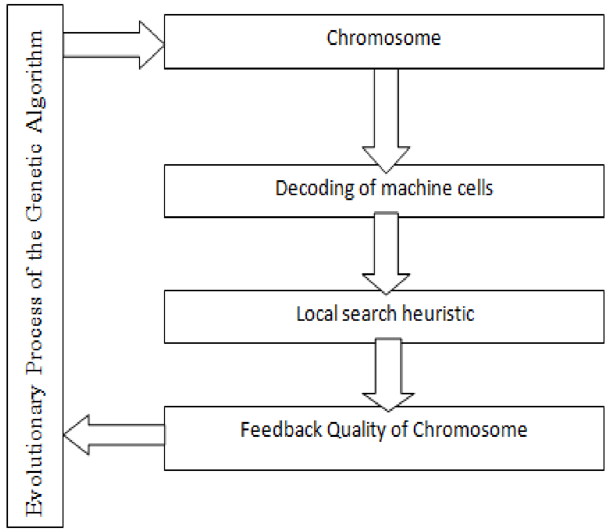

Fig. 5.1 Sequence of steps applied to each chromosome generated by the genetic algorithm.

In this paper combines a genetic algorithm with a local search heuristic. The genetic algorithm is used to generate sets of machine cells. The evolutionary process, embedded 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 generated by the genetic algorithm. The objective of the heuristic is to construct 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. Fig. 5.1 shows the sequence of steps applied to each chromosome generated by the genetic algorithm.

5. Result analysis

5.1 Chromosome & Decoding of Machine Cell

Now for our approach suppose we start with the initial set of chromosome given by the genetic algorithm created randomly which is shown below.
Chromosome = 1421123324221142545 12345
For the left string, digit length indicates total machine number, each digit position indicates the corresponding machine number and each digit represents the machine cell it goes. For the right string, digit length indicates total number of machine cell and each digit represents the corresponding machine cell.
Here number of cells = 5
Machine cell 1 = {1, 4, 5, 13, 14}
Machine cell 2 = {3, 6, 9, 11, 12, 16}
Machine cell 3 = {7, 8}
Machine cell 4 = {2, 10, 15, 18}
Machine cell 5 = {17, 19}
The initial machine cell obtained is given below.
M1INITIAL = {(1, 4, 5, 13, 14), (3, 6, 9, 11, 12, 16), (7, 8), (2, 10, 15, 18), (17, 19)}

5.3 Fitness Function

The fitness function is defined over the genetic representation and measures the quality of the represented solution. The fitness function is always problem dependent. It is assigned to the chromosome according to the problem. Fitness function is used as an objective function which is the basis of genetic algorithm approach to get the optimum result. The optimum result is gained by evaluating the chromosome according to the fitness value of it using different operation of Gas.

5.4 Local Search Heuristic

The heuristic consists of an improvement procedure that is repeatedly applied. Each iteration ***K*** of the procedure starts with a given initial set of machine cells $M_K^{INITIAL}$ and produces a set of part families P_K^{FINAL} and a set of machine cells M_K^{FINAL}. Two block-diagonal matrices can be obtained by combining $M_K^{INITIAL}$ with P_K^{FINAL} and M_K^{FINAL} with P_K^{FINAL}. From these two matrices, the one with the highest grouping efficacy is chosen as the resulting block-diagonal matrix of the iteration ***K***. The procedure stops if $M_K^{INITIAL} = M_K^{FINAL}$ or if the grouping efficacy of the block-diagonal matrix resulting from iteration ***K*** is not greater than the grouping efficacy of the block-diagonal matrix resulting from the previous iteration ***K***-1, (for ***K***>2). Otherwise, the procedure sets $M_K^{INITIAL} = M_K^{FINAL}$ and continues to iteration ***K***+1.
Each iteration ***K*** of the local search heuristic consists of following two steps:
Step 1: Assignment of parts to the initial set of machine cells $M_K^{INITIAL}$. (Note that the initial the set of machine cells of iteration 1, $M_1^{INITIAL}$; is supplied by the genetic algorithm). Parts are assigned to machine cells one at a time (in any order). A part is assigned to the cell that maximizes an approximation of the grouping efficacy, that is, a part is assigned to the machine cell C*, given by

$$C^* = \text{argmx} = \frac{N_1 - N_1^{OUT}}{N_1 - N_0^{IN}} \qquad (2)$$

Where,
argmax = argument that maximizes expression,
$N_1 =$ total number of 1's in the matrix;
N_1^{OUT} = total number of 1's outside the diagonal blocks if the part is assigned to cell C;
N_0^{IN} = total number of 0's or blank space inside the diagonal blocks if the part is assigned to cell C.
In this step, the heuristic generates a set of part families P_K^{FINAL}. Let μ_K^1 be the efficacy of the block-diagonal matrix defined by $M_K^{INITIAL}$ and P_K^{FINAL}.
Step 2: Assignment of machines to the set of part families P_K^{FINAL} obtained in step (1). Machines are assigned to part families, one at a time (in any order). A machine is assigned to the part family that maximizes an approximation of the grouping efficacy, that is, a machine is assigned to the part family F*, given by,

$$F^* = \text{argmax} = \frac{N_1 - N_1^{OUT}}{N_1 - N_0^{IN}} \qquad (3)$$

Where,
argmax argument that maximizes expression,
$N_1 =$ total number of 1's in the matrix;
N_1^{OUT} = total number of 1's outside the diagonal blocks if the part is assigned to cell F;
N_0^{IN} = total number of 0's or blank space inside the diagonal blocks if the part is assigned to cell F.

In this step, the local search heuristic generates a new set of machine cells $M_K^{INITIAL}$: Let μ_K^2 be the efficacy of the block-diagonal matrix defined by M_K^{FINAL} and P_K^{FINAL}.

The block-diagonal matrix resulting from the iteration has a grouping efficacy given by $\mu_K = \max(\mu_1^K, \mu_2^K)$. If $M_K^{FINAL} = M_K^{INITIAL}$ or $\mu_K \leq \mu_{K-}(k \geq 2)$; then the iterative process stops and the block-diagonal matrix of iteration ***k*** -1.is the result. Otherwise, the procedure sets $M_{K+1}^{INITIAL} = M_K^{INITIAL}$ and continues to step (1) of iteration ***k*** +1.
From the calculations the final machine cell and the corresponding part families are

M_2^{FINAL}= {(5.6, 13,14,15), (1,7,9,11,16), (2,8,10,12,18)}
P_2^{FINAL}= {(3,4),(1,2,9,10),(14,15),(5,6,7,8,11,12,13)}
The resulting machine part matrix combining $M_2^{FINAL}$and P_2^{FINAL} is given table 6.1.

Table 6.1: Final machine part matrix

Part	Machine																		
	5	6	13	14	15	1	7	9	11	16	3	4	17	19	2	8	10	12	18
3	1		1			1	1	1											
4	1		1			1	1	1											
1						1	1	1	1	1									
2						1	1	1	1	1									
9						1	1	1	1										1
10						1	1	1	1										1
14											1				1				
15												1			1				
5															1	1	1	1	1
6													1	1	1	1	1		
7				1											1	1	1		
8		1													1	1	1	1	1
11								1							1	1		1	1
12						1	1										1	1	1
13		1			1										1	1	1		1

The grouping efficacy is :Objective function = Fitness function = $\mu_2^2 = \mu_{Final} = \dfrac{70-19}{70+22} = 55.43\%$

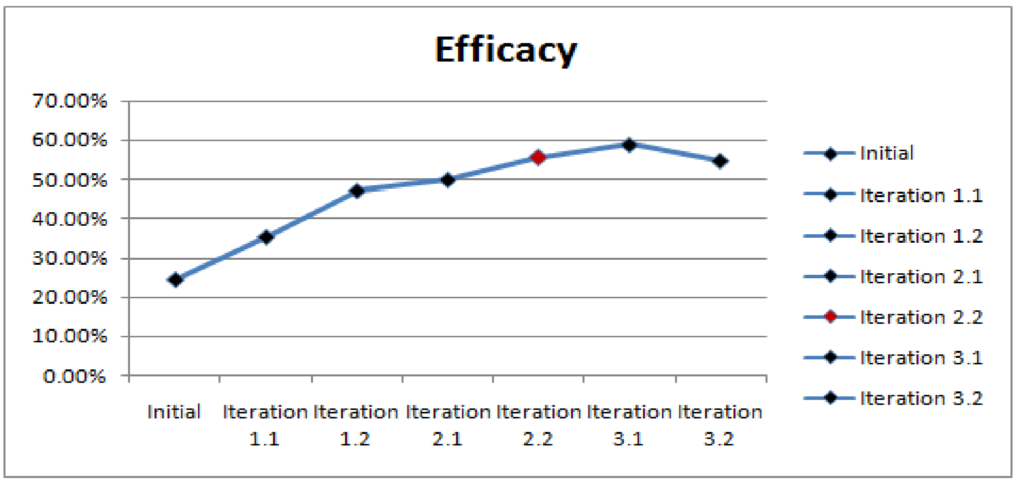

Fig. 6.1: Grouping efficacy at different iterations

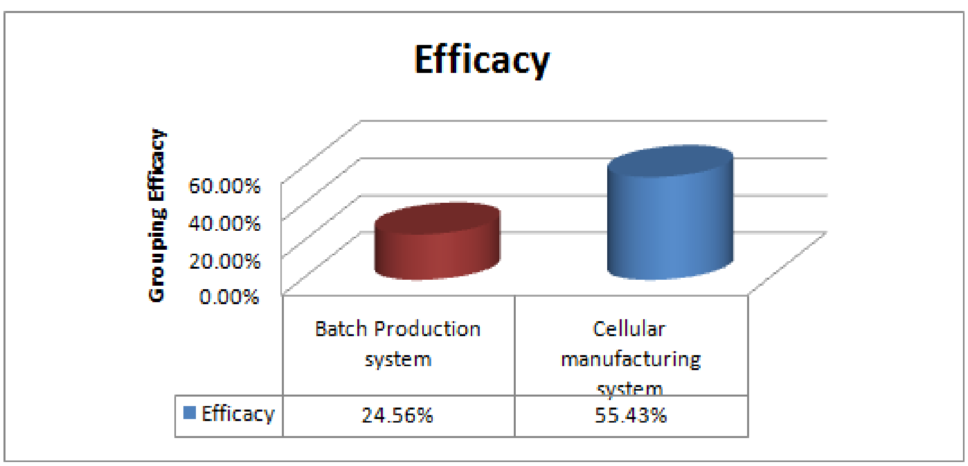

Fig. 6.2: Grouping efficacy comparison

6. Conclusions

The grouping efficacy is evaluated in terms of intercellular movements and utilization of machines in a cell. The aim of this paper was machine part cell formation in a batch oriented production system. The cell formation has been done for an existing problem. For this cell formation, an approach is used which is a combination of a genetic algorithm and a local search heuristic. The measure of performance to evaluate the performance of machine part cell, the grouping efficacy has been chosen. The grouping efficacy for the existing machine part cell is 24.56%. The grouping efficacy of the final machine part cell using our method is 55.43%. The grouping efficacy has been improved about 30.87%. This is an indication of more utilization of the machines. The resulting grouping efficacy obtained is 55.43%.

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