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RESEARCH ARTICLE

METHODS FOR SOLVING CELL FORMATION, STATIC LAYOUT AND DYNAMIC LAYOUT CELLULAR MANUFACTURING SYSTEM PROBLEMS: A REVIEW

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ABSTRACT

Cellular Manufacturing (CM) has been emerged as a strong approach for improving operations in batch and job shop environments. In cellular manufacturing, Cell formation, static layouts, dynamic layouts are the prime areas for achieving the optimal cellular layout for any problems. In this paper it is decided to review the recent research work in this particular area and to project the effective ways of solving the cellular layout problems by comparing with the standard performance measures.

INTRODUCTION

Cellular manufacturing (CM) is an approach for organizing machines and peopleinto groups to produce a variety of parts in part families. As discussed by many researchers, benefits of CM include reduced setup times, reduced material flow and in-process inventory, better system management, and improved production efficiency and product quality. Typically, a cell is a small group of machines (as a rule of thumb not more than five). Cellular Manufacturing offers an opportunity to combine the efficiency of product flow layouts with the flexibility of functional layouts. In cellular manufacturing, products with similar process requirements are placed into families and manufactured in a cell consisting of functionally dissimilar machines dedicated to the production of one or more part families.8 By grouping similar products into families, the volume increases justifying the dedication of equipment. But since this volume is justified by process and product similarity, cellular manufacturing warrants much more flexibility than a pure product-flow layout. An example would be a machining center with inspection and monitoring devices, tool and Part Storage, a robot for part handling, and the associated control hardware. The idea of Ground Technology can also be used to build larger groups, such as for instance, a department, possibly composed of several automated cells or several manned machines of various types. Pure item flow lines are possible, if volumes are very large.

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If volumes are very small, and parts are very different, a functional layout (job shop) is usually appropriate. In the intermediate case of medium-variety, medium-volume environments, group configuration is most appropriate. GT can produce considerable improvements where it is appropriate and the basic idea can be utilized in all manufacturing environments. To the manufacturing engineer GT can be viewed as a role model to obtain the advantages of flow line systems in environments previously ruled by job shop layouts. The idea is to form groups and to aim at a product-type layout within each group (for a family of parts). The benefits of cellular manufacturing include faster throughput times, improved product quality, lower work-in-process (WIP) levels and reduced set-up times. These gains are achieved because the batch sizes can be significantly reduced. As set-up times decrease through the use common tools or the collaboration of cell workers during set-up times, batch size can be reduced. The shorter the set-up time the smaller the batch size, and as a goal a batch size of one is feasible when set-up time is zero. Within a cell, small batch sizes do not travel very far as machines are collocated, resulting in less work-in-progress, shorter lead times and much less complexity in production scheduling and shop floor control.

Methods to solve cellular layout problems

Meta-heuristics Method: AM eta heuristic is also a heuristic, but a more powerful one, since a mechanism to avoid be trapped in a local minimum is present in any good

Metaheuristic. Moreover, the Metaheuristic is able to employ heuristics methods by guiding them over the search space in order to exploit its best capabilities to achieve better solutions.

Genetic Algorithm

In this review article (Hao *et al*., 2010), critical assessment of various Metaheuristic techniques which utilized in cell formation problem solving is made through extensive literature review. Various existing models for cell formation are argued consequently and directions for future work are presented. Also the Cellular Manufacturing System and Process Planning is done under a dynamic environment. So it is proposed to create a multi-objective model having a dynamic environment where there is fluctuating in demand happens over a period of time. This problem is solved using meta-heuristics approaches. For solving this a meta-heuristics approaches is proposed by the author to get the optimal results.

This paper is proposed by K. Yasuda , L. Hu and Y. Yin (Yasuda *et al*., 2005) is said to have an efficient method to solve the multi-objective cell formation problem (CFP) partially adopting Falkenauer's grouping genetic algorithm (GGA), by minimizing of both the cell load variation and intercellular flows considering the machines' capacities, part volumes and part processing times on the machines Genetic Algorithm is used to solve the multi-objective cell formation problem partially adopting Falkenauer's (1998) grouping genetic algorithm (GGA), which is an extension of general GAs. Here they review the research on the cell formation problem with genetic algorithms, and the improvements obtained with GGA are presented along with a mathematical model for the multi-objective cell formation problem is proposed.

Xiaodan Wu *et al*. (Xiaodan *et al*., 2007) proposed a new approach to concurrently make the CF, GL and GS decisions. A conceptual framework and mathematical model, which integrates these decisions, are proposed. A hierarchical genetic algorithm (HGA) is developed to solve the integrated cell design problem. A conceptual framework and mathematical model, which integrates these Cell formation, Group layout and Group scheduling decisions, are proposed. They proposed a heuristic mutation method to speed up the convergence process. However, we need to conduct more pilot tests to find out where is the proper place heuristic knowledge can come into playing in the most effective manner. S. P. Singh and R. R. K. Sharma (Singh and Sharma, 2006) reviewed mainly the research work done in facility layout using heuristic and meta-heuristics approaches such as Genetic Algorithm, Simulated Annealing and Tabu Search. Elaborate discussions and suggestions prescribed by various other researchers are reviewed in this research article.

A new Meta heuristic called a Memetic algorithm (MA) is introduced to solve the machine cell formation problem in group technology by A. Muruganandam *et al*. (Muruganandam *et al*., 2005). The objective functions considered in this work are (a) minimization of total number of moves and (b) minimization of cell load variation and the constraints considered are minimum number of machines in each cell as two and each machine should be assigned in one cell only. The results of Memetic algorithm is compared with the Genetic Algorithm and Tabu Search for small size problems and found that Memetic Algorithm is getting better results than GA and Tabu Search Methods. This paper presents the problem of machine assignment in cellular manufacturing layout. The author Anbumalar *et al*. (Anbumalar and Prabakaran, 2006) focused on the intra-cell machine assignment with the objective of minimizing the intra-cell movement by assigning the machines in the optimum position within a 3x3 grid. Genetic Algorithm (GA) is proposed to solve the problem. To examine the performance of the proposed GA, data sets taken from the literature are used and the results are compared with that of from other approaches. This paper proposes a classification scheme which, incorporating the idea of the source of the "value-added" and the degree of product component delivered, offers an effective method of classifying service for the management of technology. The proposed GA provides a near optimal layout.

Simulated Annealing

A cell formation (CF) problem in dynamic condition is considered by R. Tavakkoli-Moghaddam *et al*. (Tavakkoli-Moghaddam *et al*., 2005) and solved using some traditional Metaheuristic methods such as genetic algorithm (GA), simulated annealing (SA) and Tabu search (TS). Most of previous researches were done under the static condition. In this research, a nonlinear integer model of CF is first given and then solved by GA, SA and TS. The SA algorithm found and reported the better near-optimal solutions inshorter average computational times than GA and TS in most of the test problems.

The mathematical model is formulated for a Cellular manufacturing system to solve inter-cell and intra-cell problems. Here the demand fluctuates along a time period. So considering this dynamic environment and to improve the efficiency and effectiveness of the layout T.Y. Wang *et al*. (Wang *et al*., 2001) used Simulated Annealing algorithm. Thus the Simulated Annealing algorithm is a local search algorithm capable of obtaining satisfactory solutions to difficult problems efficiently. The paper proposed by Vakharia *et al*. (Vakharia and Chang, 1997) addresses the cell formation problem in group technology (GT) by developing two heuristic methods for generating solutions to the problem. These methods are based on two powerful combinatorial search methods simulated annealing and Tabu search. The performance of the heuristics is examined using randomly generated, published and industry data. The results indicate that the simulated annealing based heuristic is the preferred technique in the context of the problem addressed in this paper

In this prescribed paper Su and Hsu (Su and Hsu, 1998) introduced modified SA with the merits of a genetic algorithm (GA), call parallel SA (PSA), and propose a PSA-based procedure to solve the MPCF problem. More specifically, this study aims to minimize (1) total cost which includes intercellular and intracellular part transportation cost and machine investment cost, (2) intracellular machine loading unbalance and (3) intercellular machine loading unbalance under many realistic considerations. This paper proposes a solution to solve the part-family and machine-cell formation problem considering the within-cell layout problem. The cellular manufacturing system is formulated as a multiple departures single destination multiple travelling salesman problem (MDmTSP) and a solution methodology based on simulated annealing is Mohammad Mahdi Paydar *et al*. (Mohammad Mahdi Paydar *et al*., 2010) proposed to solve the formulated model. Numerical examples show that the proposed method is efficient and effective in finding optimal solutions. The proposed method is compared to three other algorithms in the literature (CASE by Nair and Narendran (1998), genetic algorithm by Boulif and Atif (2006) and CLASS by Mahdavi and Mahadevan (2008b)). Computational experience showed supremacy of the solutions obtained by the proposed method as compared with CASE, GA and CLASS methods.

Scatter Search

The research work proposed by R. Tavakkoli-Moghaddam (Tavakkoli-Moghaddam *et al*., 2010) presents a new mathematical model for a multi-criteria group scheduling problem in a cellular manufacture system (CMS). The main objective is to minimize the makespan, intracellular movement, tardiness, and sequence-dependent setup costs, simultaneously. Due the complexity to solve this problem, we develop a meta-heuristic algorithm based on scatter search (SS). Considering this problem is more general than the conventional flow shop group scheduling problem they have proposed a scatter search (SS) algorithm to solve the foregoing problem that minimizes the make span, intracellular moving, tardiness, and sequence-dependent setup cost. The proposed SS and the Lingo 8.0 software have been used to solve the problem and the obtained results indicate that our proposed Scatter Search algorithm is able to reduce the computational time as compared to the B&B algorithm.

In this prescribed paper by Solimanpur *et al*. (Solimanpur *et al*., 2004), we introduce modified SA with the merits of a genetic algorithm (GA), call parallel SA (PSA), and propose a PSA-based procedure to solve the MPCF problem. More specifically, this study aims to minimize (1) total cost which includes intercellular and intracellular part transportation cost and machine investment cost, (2) intracellular machine loading unbalance and (3) intercellular machine loading unbalance under many realistic considerations.

Ant-colony optimization

An Ant colony optimization algorithm is used for the proposed inter-cell layout problem and a mathematical formulation for material flow between the cells is presented by S.P. Singh *et al*. (Singh *et al*., ?). An ant colony algorithm is developed to solve the formulated problem. Here the flow of materials is across different cells of the layout. The performance of the proposed algorithm is compared with other heuristics developed for facility layout problem as well as many other ant algorithms recently developed for Quadratic Assignment Problem (QAP). The attempted experiments reveal that the proposed an algorithm is effective and efficient for the inter-cell layout problem.

Heuristic approach

The work done by Schaller (Jeffrey Schaller, 2007) is to frame a model for the cell formation problem for dynamic cellular manufacturing systems. The model allows for demand variability from period to period. Five heuristic procedures were presented for generating solutions to the model. These procedures were tested on 16 problems. Four of the procedures were Tabu search based procedures and performed better than the CB procedure in terms of the cost of the solutions generated. The TSH2 procedure performed the best or was very close to the best on the test problems and was recommended for generating solutions to the model. The first approach considered only the average demand over the planning horizon to generate a solution. This procedure performed poorly when compared to the TSH2 procedure. The second procedure considered demand variability over the planning horizon but did not allow for reassigning a part from one cell to another.

The paper deals with the multi-objective machine cell formation problem done by Chang Ouk Kim *et al*. (Chang *et al*., 2004) to minimize inter-cell part movements. Here the multi-objective cell formation problem that simultaneously minimizes both inter-cell part movements and maximum workload imbalance between machines, with the consideration of alternative part routes and the machine sequences of part routes. In the first phase, representative part routes with part route families are determined using the concept of potential function. In the second phases, there maining part routes are allocated to part route families with an n stage look ahead heuristic algorithm. Throughout the computational experiments, we verified that the two-phase heuristic algorithm is effective in minimizing inter-cell part movements and maximum machine workload imbalance.

To design a cellular manufacturing system numerous mathematical models and various algorithms have been extensively investigated in the literature by Chen Guang Liu *et al*. (ChenGuang *et al*., 2010). They propose a mathematical model that incorporates multiple key real-life production factors simultaneously, namely, production volume, batch size, alternative process routings and perfect coefficient of each routing, cell size, unit cost of intercellular and intracellular movements, and path coefficient of material flows. For solving this NP-hard model, we develop a heuristic algorithm with three stages. The computational results for several problems showed that the approach provides feasible solutions in quality and speed. The results which are got by this algorithms is providing only local optimum so a larger search by various other methods for finding the optimal solution is needed.

The proposed DCMS model integrates concurrently the important manufacturing attributes in existing models in a single model such as machine breakdown effect in terms of machine repair cost effect and production time loss cost effect to incorporate reliability modeling. Further, the objective of the proposed model by Lokesh Kumar Saxena *et al*. (Lokesh Kumar Saxena and Promod Kumar Jain, 2011) is to minimize the sum of various costs such as intracellular movement costs; intercellular movement costs and machine procurement costs; setup cost; cutting tool consumption costs. Multi- period dynamic cell formation mathematical models are generally more complex and difficult to solve than single-period models due to the nature of combinatorial optimization. They proposed a generalized mathematical model to generate manufacturing cells over multiple time periods.

Alan R. McKendall Jr *et al*. (Alan *et al*., 2010) proposed that the departments may have unequal-areas and free orientations, andthe layout for each period is generated on the continuous plant floor. Because of the complexity of the problem, only small-size problems can be solved in reasonable time using exact techniques. Therefore, a construction and improvement type heuristic were developed to solve the problem in reasonable computational time. The construction heuristic (i.e., BSH) finds solutions quickly. TS/BSH heuristic performed well, especially for the large size problems, for a DFLP data set and a SFLP data set both taken from the literature.

In this paper Raja *et al*. (Raja and Anbumalar, 2014) put forth an efficient approach in Cellular Manufacturing for implementing the principles of Group Technology in a manufacturing environment. Here a new heuristic approach based on modified flow matrix is proposed to group similar parts and corresponding different machines in same cells and additionally considering the sequence of machines, exceptional elements and voids. A new performance measure modified group technology efficacy is proposed for evaluating the performance of the proposed methodology. Two well-known benchmark problems from the literature are considered and results are compared with the existing methods. The results clearly demonstrated that our proposed approach outperforms the previously proposed methods.

Fuzzy Method

In this paper, fuzzy dynamic facility layout problem withunequal area constraints and closeness rating values were considered by Hamed Samarghandi (Hamed Samarghandi *et al*., 2012). Dynamic facility layout problem is a NP-hard problem. Therefore, the fuzzy version of this problem is also NP-hard. In order to find good-quality solutions for this problem in a reasonable time, a fuzzy Tabu search, a fuzzy variable neighborhood search, a fuzzy genetic algorithm, and a fuzzy particle swarm optimization were developed. Two different approaches were considered with the developed algorithms.

This paper given by Reza Kia (Reza Kia *et al*., 2011) presents a novel integer non-linear programming model for the layout design of dynamic cellular manufacturing systems (DCMS) under an uncertain environment. A new fuzzy linear programming approach is taken and a mathematical model is developed to solve the linearized model and is solved by the Lingo software to verify the performance of the proposed model and developed fuzzy approach.

Non-Linear Integer Programming

In this paper a nonlinear integer model of cell formation under dynamic conditions by M. Saidi-Mehrabad *et al*. (Saidi-Mehrabad and Safaei, 2007). They have proposed a new cell formation model with assumptions obtained from dynamic production, alternative process plans and a sequence of operations. The proposed model are the parts families and machine groups simultaneously determining the optimum number of cells in each period, the best processing route for each part in each period and inter-cell relocation of machines between two consecutive periods as required. The proposed neural approach has advantages because additional algorithms are not used for improvement of the solutions obtained. The mathematical model of cell formation problem is presented by Iraj Mahdavi *et al*. (Iraj Mahdavi *et al*., 2010) based on dynamic cellular manufacturing system with worker assignment. The objective is to minimize the sum of the penalty of deviation of production volume from the desirable value of the part demand (holding and backorder cost), inter-cell material handling, machine and reconfiguration, hiring, firing and salary worker costs. The nonlinear formulation of the proposed model was linearized using some auxiliary variables. The performance of the model is illustrated by two numerical examples. CPU time required to reach the optimal solution of the attempted examples show that obtaining an optimal solution in a reasonable time is computationally intractable. Therefore, it is necessary to develop a heuristic or Metaheuristic approach to solve the proposed model for large-sized problems.

Mixed-Integer Programming Model

This paper develops a mixed-integer programming model to design the cellular manufacturing systems (CMSs) under dynamic environment. In dynamic environment, the product mix and part demand change under a multi-period planning horizon. The objective is to minimize the sum of the machine constant and variable costs, inter- and intra-cell material handling, and reconfiguration costs. An efficient hybrid meta-heuristic based on mean field annealing (MFA) and simulated annealing (SA) so-called MFA–SA is used to solve the proposed model by N. Safaei *et al*. (Safaei *et al*., 2008). The main difference between the classical SA and the proposed MFA–SA is generating a high quality initial solution by MFA for SA. The obtained results show that MFA can provide a good initial solution in a negligible time where the average Gap between the quality of the initial solution found by MFA and the best solution found by branch and bound (B&B) method is nearly 22%. The performance of MFA–SA is evaluated and compared to the performance of a classical SA by 23 small/medium-sized problem and 10 large-sized problems, with respect to the some of defined measures. It is observed that quality of the results obtained by MFA–SA is better than SA with respect to the all defined measures.

In this paper, a novel mathematical and integrated model of the multi-period cell formation and production planning (PP) in dynamic cellular manufacturing system (DCMS) has been introduced focusing on the operational aspects of the cell formation by Nima Safaei *et al*. (Nima Safaei and Reza Tavakkoli-Moghaddam, 2009). This model is extended based on a basis DCMS model proposed in the literature (Safaei *et al*., 2008).

Our proposed model minimizes the constant and variable costs of machine, inter and intra- cell material handling costs by assuming the operation sequence, machine relocation costs, and PP costs including inventory, backorder, and partial subcontracting costs. The obtained results show that the outsourcing requirements, obtaining an exact solution for such a hard problem in a reasonable time is computationally intractable. Thus, it is necessary to use a heuristic or meta-heuristic approach to solve the proposed model for real-sized problems. Most of the related studies use a multi-stage heuristic approach.

Particle Swarm Optimization

Rafiee *et al*. (Rafiee *et al*., 2011) presents a comprehensive mathematical model for integrated cell formation and inventory lot sizing problem. The proposed model seeks to minimize cell formation costs as well as the costs associated with production, while dynamic conditions, alternative routings, machine capacity limitation, operations sequences, cell size constraints, process deterioration, and machine breakdowns are also taken into account. The developed model is NP-complete and not solvable in an acceptable amount of time by means of any exact solution procedure and commercial optimization software's. Therefore, a modified PSO meta-heuristic is developed to cope with computational complexity of the developed model. Finally, a numerical sample validates the feasibility and applicability of the developed model and the developed meta-heuristic.

FariborzJolai *et al*. (Fariborz Jolai *et al*., 2011) proposed a new mathematical model is proposed for inter- and intra-cell layout problem in cellular manufacturing system. A binary particle swarm optimization algorithm with a new heuristic approach for satisfying the constraints of model is implemented to solve the proposed model. A heuristic approach to relaxing the constraints of the problem and use VNS algorithm for improving the quality of the solutions.

Hybrid Algorithms

This paper present a comprehensive model for designing a cellular manufacturing system using Hybrid Genetic Algorithm is proposed by Aaron Luntala Nsakanda *et al*. (Aaron Luntala Nsakanda *et al*., 2006). The model bridges several known problems in that it integrates the cell formation problem, the machine allocation problem, and the part routing problem. A computational study is conducted to evaluate the viability of our approach for solving large scale problems. This paper has proposed for the single process plans and multiple routes, multiple process plans and single routing or single process plan and single part route and can be used in a variety of decision contexts.

Conclusion

In the future the review made in this study can be further developed for meta-heuristic methods for real time problems and incorporate real time production factors for Cell Formation Problem, Static Layout and Dynamic Layout Cellular Manufacturing Systems to enhance the production.

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