



Development of a comprehensive model and BFO algorithm for a dynamic cellular manufacturing system



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ABSTRACT

A comprehensive multiobjective model of the cellular manufacturing system (CMS) operating in a dynamic environment is developed. The proposed algorithm takes into consideration various important cell design issues, such as machine assignment, intercell/intracell material handling, worker assignment, outsourcing and workload balancing based on operational time and operation sequence of the parts. Workload balancing among cells tends to increase CMS processing costs, and hence the use of multiobjective optimization methods is required for CMS solutions that are optimal and feasible. A multiobjective matrix-based bacteria foraging optimization algorithm with traced constraint handling (MOMBATCH) is developed for this purpose. The performance of the proposed algorithm is compared with that of the non-dominated sorting genetic algorithm II method that is frequently reported in the literature and the off-the-shelf program CPLEX. The results show that MOMBATCH solves problems more efficiently in terms of finding optimal solutions while maintaining the Pareto frontier diversity.

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1. Background

The cellular manufacturing system (CMS) is a manufacturing philosophy where similar parts are grouped together on the basis of their manufacturing design and/or attributes. The basic problem in cellular manufacturing lies in grouping the machines into machine cells and the parts into part families in the process of 'cell formation'. Because of a growing variety of consumer goods and a decrease in product life cycles, manufacturing organizations often face variations in product demand and product mix, leading to a dynamic or unstable production environment [1]. To overcome the drawbacks of the traditional CMS, the concept of a dynamic CMS (DCMS) has been introduced [1]. It is well recognized that machine assignment, intercell/intracell material handling, assignment of workers to cells, outsourcing and workload balancing based on operation sequences and times have critical impacts on cell design. In horizon planning, factors associated with outsourcing, such as inventory, backorder and subcontracting, can significantly affect the cell configuration owing to the frequent relocation/addition or removal of machines. This is because outsourcing creates a situation in which a large portion of the total demand of the horizon may be satisfied in only a few selected periods, whereas there is no production in other periods. In general, outsourcing can lead to a vacillation or convulsive behaviour in cell reconfiguration in the DCMS [2].

It is important to take into consideration the total cell load variation because the workload among cells is balanced and flow of materials inside each cell is smooth when cell load variation is minimized. This consequently reduces the level of work in process (WIP) and leads to better performance in terms of throughput, makespan, reduced backtracking and material handling,

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and minimizes the risk of production line stoppage [3–6]. Yasuda et al. [7] showed that the above-mentioned objectives may be in direct contradiction; the model proposed in this work is therefore multiobjective. Intercell movement cost is zero if all the machines are grouped into one cell, and the total cell load variation is zero if only one machine is assigned to each cell [8].

Manufacturing cells are formed with the objective of minimizing intercell movements. In addition to intercell material handling cost, other costs, such as machine cost, tooling cost, worker cost and operating cost, should be considered in the objective function to obtain more valid solutions. Costs in the design objectives may be conflicting; hence, trade-offs may need to be made during the design process. Further, any cell configuration should satisfy operational goals (constraints), such as desired machine utilization, production volume, number of manufacturing cells and cell sizes.

Consideration of the operation sequence in the part-machine grouping stage is desirable for several reasons: streamlining material flows, less backtracking, shorter lead time and less WIP inventory.

Generally, incorporation of the theories of CMS design and process planning is an elementary necessity for modelling and simulation of real production environments. In fact, variations in product mix and volume and the introduction of new products are the key aspects that validate the incorporation of the CMS and process planning. In general, outsourcing can lead to a vacillation or convulsive behaviour in cell reconfiguration in the DCMS. Because of the dynamic environment of process-planning problems, the incorporation of the CMS and process planning makes the problem very complex and computationally hard.

The assignment of workers to cells becomes a critical aspect for complete operations of CMSs because workers play a large role in doing tasks on machines

In conclusion, it is necessary to define a comprehensive multiobjective model suitable for cell formation and practical process planning to minimize costs simultaneously that includes machines, intercell/intracell movement, backorders, inventory, subcontracting, worker costs and minimization of cell load variation, which have crucial effects on full utilization of CMSs in a dynamic environment. Therefore, we feel there is an avenue open to develop a comprehensive multiobjective model in cell formation and process planning considering real-life production factors such as workload balancing among cells, machine assignment, worker assignment and intercell/intracell material handling based on operation sequences, operation times and outsourcing concurrently in a dynamic environment.

In addition, because cell formation problems are non-deterministic polynomial-time hard, it is difficult to obtain solutions that satisfy all the constraints of an algorithm model [6]; hence, the need to apply efficient computing techniques. Metaheuristic techniques that are able to produce good results are more appropriate for this type of problem [9]. Nevertheless, metaheuristic methods have the tendency to violate model constraints of cell formation and process planning, leading to the generation of infeasible solutions for the factory. In addition, these non-exact solutions distort the population of solution points carried over to the next generation. Therefore, there is a critical need to develop metaheuristic techniques that satisfy all model constraints and that produce exact feasible solutions in real-life environments [2,10–13].

Al Kattan [14], Lee and Chen [15], Lee et al. [16], Chu and Hayya [17], Alhourani and Seifoddini [18], Logendran [19], Akturk [20], Ahkioon et al. [21] and Defersha and Chen [22] presented different methods such as heuristics, fuzzy *c*-means, King's algorithm, similarity coefficient, and genetic algorithms to optimize workload balance and minimize the set-up, inventory-holding, overtime and tardiness costs in designing multiple CMSs by considering parameters including cycle demand, batch size, pallet size, routing sequences, processing times, machine capacities and workload status of machines. But none of them considered a comprehensive model for the cell formation problem in a DCMS.

Recently, the bacteria foraging optimization (BFO) algorithm, invented by Passino [23], has been applied successfully to various real-world problems. The BFO technique has been shown to be very effective in solving optimization problems, including very complicated versions of non-deterministic polynomial-time hard problems, without a significant increase in computational cost. The algorithm has inspired researchers to attempt wide-scope scaling and dynamic environment benchmarking of the BFO algorithm and to compare the performance of the BFO algorithm with that of other global optimum searching algorithms in other optimization fields, such as cell formation in a CMS. The ultimate objective of such studies is the actual application of the BFO algorithm in factory management. Tang et al. [24] presented the first applications of this emerging novel optimization algorithm in the development of a mixed-integer programming model to design CMSs and production planning under a dynamic environment. The proposed model is as follows: taking into account the batch intercell/intracell material handling by assuming the sequence of operations; allowing for alternative process plans for part types; considering machine copying and with emphasis on the effect of the trade-off between production and outsourcing costs. The aim is to minimize the sum of the machine constant and variable costs, intercell and intracell material handling costs, reconstruction costs, partial subcontracting costs and inventory-carrying costs. In addition, a newly developed BFO-based optimization algorithm is compared with the branch and bound algorithm. The results are in favour of better performance of the proposed algorithm.

The algorithm proposed by Tang et al. did not take into consideration other important cell design issues, such as worker assignment and workload balancing based on operational time and operation sequence of the parts. Consideration of minimization of cell load variation in the proposed model causes the flow of materials inside each cell to be smooth and leads to the minimization of WIP inventories, increased productivity, higher within-cell machine utilization, reduction of the risk of stopping a production line based on the same maintenance plan and the probability of breakdown for each machine before the required number of pieces has been made, and moreover, smooth running of the system and better performance in terms of throughput, makespan, flow time and tardiness.

Consideration of worker assignment in the proposed model means choosing the workers with relatively low cost and then optimizing their tasks on machines for completion of operations of CMSs.

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