Metaheuristic Techniques on Cell Formation in Cellular Manufacturing System

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***Abstract*—Cellular manufacturing system is a submission of group technology wherein are different machines or processes have been combined into cells, each of which is devoted to the fabrication of a part, product family, or limited group of families. Cell formation is necessary for implementation of cellular manufacturing. Many of methods exist for cell formation problem solving. Some of these methods are applying in traditional cell design, in fixed routines and others are applying in dynamic cells environment. In this review article, 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.**

***Index Terms*—*Metaheuristics*, Cell formation, Cellular manufacturing system**

I. Introduction

Majorities of the cell formation models that have employed in existing methods that include alternative operations and multiple routes utilize mathematical programming and have limitation in solving large-scale problems. Obtaining an exact solution for such a hard problem in a reasonable time is computationally intractable. Thus, it is necessary to use meta-heuristic methods to solve these dynamic environment models for real sized problems attaining an exact solution for such a hard problem in a reasonable and intractable computationally time [55].

Because cell formation problems are NP-hard, therefore it is difficult to obtain solutions that satisfy all constraints [40]. For that reason, it is desired to apply of efficient computing techniques. Meta-heuristic techniques are more convenient for this type of problems and able to produce good results [60].

Meta-heuristics is a promising method to computing which parallels the outstanding ability of the human mind to reason and learn in an environment of uncertainty and ambiguity [51]. Meta-heuristics are innovative methods for construction computationally complicated systems. Complex real world problems require refined systems that integrate knowledge, techniques, and models from a variety of sources. Meta-heuristic techniques are consist of Genetic Algorithm (GA), Simulated Annealing (SA), Artificial Neural Networks (ANN), Fuzzy Set theory(FS), Water Flow- A like algorithm (WFA), Particle Swarm Optimization(PSO), Bee Swarm Intelligence (BSI), Ant Colony Systems (ACO), Tabu Search (TS), Branch and Bound (B&B), Mean Field Annealing (MFA), Bacteria Foraging Optimization (BFO) etc together or separately as shown in Fig. 1. From 1990, the applications of meta-heuristic techniques to group technology problems have been inspiring with confidence [60]. The literatures in relation to applying most important metaheuristic techniques in cell formation are discussed as follows.

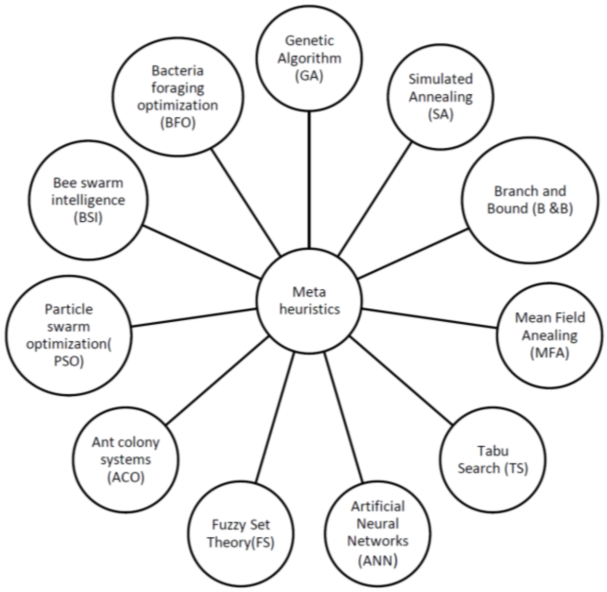

Figure 1. Taxonomic frame for meta-heuristic techniques.

II. Metaheuristic Methods Implemented to Traditional Cell Formation

Design of cellular manufacturing systems (CMSs) is a complex, multi-criteria and multi-step process. Ballakur

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and Steudel [6] showed that this problem, even under restrictive conditions, is NP-complete. Table I and II shows metaheuristic methods implemented to traditional cell formation. As shown in these tables, these techniques are modern for last decades and some of researchers for improving performance of meta-heuristic techniques combined them with each other. In addition, As shown in Table I and II, The greater part of the metaheuristic techniques uses binary representation for input data without considering real life production factors such as operation sequences and operations time. Such an approach leads to inefficient flow of materials resulting in become worse of system operations. A considering operation sequence in part–machine grouping stage is desirable for several reasons [39]:

a) It is aimed directly at streamlining material flows and formation of flow lines. Flow line cells, with their streamlined workflows, enable a fuller realization of the benefits of cellular manufacturing (CM), with less backtracking and material handling, easier use of conveyors within the cell, easier operation overlapping, and less lead-time and work-in-process (WIP) inventory, compared with job shop-like cells.
b) Ignoring operation sequences tends to distort the real extent of material-handling efforts within and outside the cells.
c) Identifying similar operation sequences facilitates implementation of just-in time (JIT), business process reengineering, etc., serving to streamline materials flows in general.
d) The flow of material is influenced by sequence of operation. In contrast of intermediate operation of a part performed outside, its cell involves two inter-cell transfers, the first or last operation requires only one transfer. From the point of view of material handling, multiple operations in an external cell do not matter, if they are consecutive.

Considering operations time is needed for calculating cells load variation and consequently considering cells load variation in part machine-grouping stage is desirable for several reasons:

a) The flow of materials inside each cell will be smooth aided by minimizing cell load variation tends to the minimization of work in process (WIP) inventories and increased productivity [40].
b) Higher within-cell machine utilization comes out due to the minimization of cell load variation [40].
c) In one-piece flow production system, products are produced one unit at a time and only the number of products required by the customer is produced. Therefore, when a machine problem occurs, the whole production system will be disrupted. Based on the same maintenance plan, the probability of breakdown for each machine is almost equal. For the sake of reducing the risk of stopping a production line before the required number of pieces has been made, the cell load should be equalized [32].
d) Workload balancing contributes to a smooth running of the system and better performance in terms of throughput; make span, flow time, and tardiness [29].
e) Balancing workload reduces work-in-process inventory, improves material flow through the system, and prevents heavy utilization of some cells and lower utilization of others [8].

III. Metaheuristic Methods Implemented to Dynamic Cell Formation

As depicted in Table I and II, most metaheuristic algorithms in the literatures employ only a part-machine incidence matrix that consists of a pre-determined single and fixed route. Furthermore, most of these models assume that demand is same for all parts. Therefore, when the demand among part is unequal (which is most likely) the machine cells and part families formed using this assumption may be useless [54].

TABLE I. Metaheuristics Methods Implemented to Traditional Cell Formation not Considering Operation Sequences and Times

Application	Metaheuristic models
Traditional cell formation non-considering operation times and sequences	ART-1 [37] TCNN [56] ART-1 [22] Modified ART-1 [68] SOM [26] ART+MOD+SLC [38] CNN [27] NN+GA [42] FNN [45] Fuzzy MIN-MAX NN [20] CNN [43] Hopfield Model+Potts Mean Field [33] SA [67] HGA [16] GA [35] GA [41] HGA [58] GA+Integer Programming [52] GA [13] Adaptive GA [36] CGA [24] GA+NN [42] GA+QAP [31] HGA [61] HGA+PSO [47] GA [69] GA+Local Search [59] Heuristic GA [65] GA+SPEA-II [30] B&B [1] SA [62] PSO [2] PSO [21] BSI [46] TS [25] WFA [64] TS [7] ACO+TS [5] ACO [48]

Because of growing variety of consumer goods and decrease in product life cycles, manufacturing organizations often face variations in product demand and product mix leading to a dynamic or unstable production environment [49]. As commonly discussed in literatures, traditional CMS has many operational rewards over other manufacturing systems such as job shop and flow shop, but there are also some drawbacks such as reducing shop flexibility and machine utilization [49]. In dynamic environment, the formed cells in a current period may not be optimal and efficient for the next period. To rise above drawbacks of traditional CMS, the concept of dynamic cellular manufacturing system (DCMS) is introduced [49].

TABLE II. METAHEURISTICS METHODS IMPLEMENTED TO TRADITIONAL CELL FORMATION CONSIDERING OPERATION SEQUENCES AND TIMES

Application	Metaheuristic models
Traditional cell formation Considering operation sequences and times	PSO [3] TS [12] ACO [57] ART [44] GA [38] GA+B&B [10] GA [34] GA [15] Hierarchical GA [66]

TABLE III. METAHEURISTICS METHODS IMPLEMENTED TO DYNAMIC CELL FORMATION

Application	Meta heuristic models
Dynamic cell formation	ACO (Machine assignment + Inter-cell travels) [23] MFA-SA (machine assignment + inter/intra-cell travels) [53] SA+B&B (Machine assignment + Inter-cell travels) [14] TS (Inter-cell travels) [9] HSA (Inter-cell travels) [63] TS+B&B (Machine assignment + Inter-cell travels) [50] GA (Inter-cell travels) [28] GA+SA (Tooling assignment + Machine assignment) [17] GA+LP (Lot sizing +Product quality) [18] GA (Machine assignment+ Inter-cells travels) [19] GA (Machine assignment+ Inter-cell travels) [11] QFHN+TS (Machine assignment) [4]

Table III shows metaheuristic methods implemented to dynamic cell formation. As shown in this table, only few of research works using metaheuristics to tackle dynamic cell formation problems and Even though some of these research works considered dynamic cell formation as their objective but mostly did not consider operation sequences in their defined objectives or objective models have not been comprehensive and just considered a few aspects of cell design such as machine assignment cost and inter/intra-cell travels cost. Therefore, to move toward a more satisfactory algorithm result, other manufacturing information, such as set time requirements, tooling and crew requirements, machine capacity, alternative routings, machine costs, inter/intra-cell transfers, inter/intra-cell and intra cell layout, and cell load variation need to be included. Comparatively few research works have concerned about utilizing alternative operations, alternative routings, part demand fluctuation, or machine redundancy in cell formation according Tables III.

IV. CONCLUSIONS

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

In addition, the existing incorporated dynamic cells design and process planning models are constructed based on some assumptions. Therefore, it is useful relaxing these assumptions for make more realistic model that can simulate real environment and will produce solutions that are more feasible for using in factories with different issues.

Meta-heuristics algorithms may use one of four different constraint-handling strategies:

a) discarding infeasible solutions (death penalty)
b) reducing the fitness of infeasible solutions by using a penalty function
c) transforming infeasible solutions to be feasible (repair)
d) crafting heuristic operators to always produce feasible solutions

The death penalty and using penalty function are constraint-handling methods that most part of previous research works have used it. However, the drawback of these methods is often producing non-feasible solutions and then those destroy the populations for creating next generation and consequently distort the convergence performance of algorithm. Therefore, results of most part of meta-heuristic methods that have been applied to cell formation and process planning have violated constraints of models and have been non-feasible solutions for using in factory. In addition, these non-exact solutions distort population of solution points for next generation. Therefore, it is critical need to develop meta-heuristic technique by using crafting and transforming heuristic operators to produce feasible solutions always that will satisfy all of constraints and will produces exact feasible solutions in real life environments.

Large part of existing designed Manufacturing cells are formed with the objective of minimizing inter-cell moves. In addition to inter-cell material handling cost, other costs, such as machine cost, tooling cost, worker cost, operating cost, etc., should be considered in the objective function in order to obtain more valid solutions. Costs in the design objectives may be conflicting; hence, tradeoffs may need to be made during the design process. Therefore, it is needed define comprehensive multi objectives model suitable for cell formation and practical process planning to minimizing costs simultaneously such as machines, inter/intra-cell travels, backorder, inventory, subcontracting, worker costs and minimizing cells load variation that have crucial effects on full utilization of cellular manufacturing systems in dynamic environment.

In addition, it is felt there are open avenue to develop comprehensive multi objectives model in cell formation and process planning considering real life production factor like workload balancing among cells, machine assignment, worker assignment, tooling assignment, inter/intra-cell material handling, revisit of the parts to a particular machine, setup, effect of the trade-off between machine adjacency constraints, and product quality based on operation sequences, operation times, and outsourcing concurrently in dynamic environment, where demand of parts is fluctuated over entire periods horizon, is open avenue for research in cell formation.

Moreover, it is felt in order to solve aforementioned multi objectives model in real size integrated cell design and process planning problems efficiently and to overcome previous methods limitations it is required to have attempt for applying new meta heuristic technique for find exact feasible solution that satisfy all constraints in reasonable time.

LIST OF ABBREVIATIONS

ACO: Ant Colony Optimization
ART: Adaptive Resonance Theory
B&B: Branch and Bound
BFO: Bacteria Foraging Optimization
BSI: Bee Swarm Intelligence
CGA: Constructive Genetic Algorithm
CNN: Competitive Neural Network
HGA: Hybrid Genetic Algorithm
HSA: Hybrid Simulated Annealing
IAC: Interactive Activation and Competition
LP: Linear Programming
MFA: Mean Field Annealing
PSO: Particle Swarm Optimization
QAP: Quadratic Assignment Problems
QFHN: Quantized and Fluctuated Hop field Neural Network
SA: Simulated Annealing
SOFM: Self Organizing Feature Maps
SPEA-II: Strength Pareto Evolutionary Algorithm-II
TCNN: Transiently Chaotic Neural Network
TS: Tabu Search
WFA: Water Flow-like Algorithm

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