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A bi-objective model in sustainable dynamic cell formation problem with skill-based worker assignment

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ABSTRACT

The most recent revolution in industry (Industrial Revolution 4.0) requires increased flexibility, agility and efficiency in the use of production equipment. The Dynamic Cellular Manufacturing System (DCMS) is one of the best production systems to meet such requirements. In addition, the increasing importance of environmental and social issues, along with recent laws, is forcing manufacturers and managers to take account of sustainability when designing and configuring manufacturing systems. This paper proposes a new bi-objective mathematical model of the Dynamic Cell Formation Problem (DCFP), in which the worker's assignment, environmental and social criteria are considered. The first objective in this model is to minimize both production and labor costs while the total production waste (e.g., energy, chemical material, raw material, CO_2 emissions, etc.) is minimized as second objective. Social criteria in this model, are represented as constraint. Due to the NP-hardness of this problem, we propose a new resolution approach called NSGA II-MOSA, that merges an efficient hybrid meta-heuristic based on the Non-dominated Sorting Genetic Algorithm (NSGA-II), with Multi-Objective Simulated Annealing (MOSA). Finally, randomly-generated test problems demonstrate the performance of our algorithm.

1. Introduction

In order to remain competitive, manufacturers and producers have been forced to increase the productivity and flexibility of their manufacturing systems. Depending on the specification of production in an Industrial Revolution 4.0 environment [1], a production system must have a high degree of flexibility and agility to deal with product changes. The Dynamic Cellular Manufacturing System (DCMS) is one of the well-known production systems that meets this requirement. The Cellular Manufacturing System (CMS) based on Group Technology attempts to classify parts and machines in order to create cells and part-families; this is called a Cell Formation Problem (CFP). This classification is done according to the similarities in the geometry and operation process of each part, as well as a reduction of Work-In-Process (WIP) inventory, flow time and space utilization, while improving production planning and control. Most of the existing cell formation methods (static cell formation) have been developed for only one extended time period. But, under dynamic conditions, the components of product mixes change, the variety of products increases and the duration of product life cycles decreases. As a consequence, the configuration of the cells in CMS needs to be reorganized in order to maintain a high level of performance. Optimal cells in one period may therefore not be optimal in other periods because their configuration of part families and machine grouping may need either substitution of machines between cells or a change of the number of cells. These reasons motivate researchers to focus on the configuration of Dynamic CMS (DCMS).

In previous investigations the economic aspect has traditionally been considered while the pressures of communities, government and non-governmental organizations force managers and manufacturers to consider environmental and social criteria as well. In 1987 the United Nations World Commission on Environment and Development (WCED) [2] coined the famous definition of sustainable development as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". In this definition, the trade-off between present and future depends on how we choose to balance economic, social and environmental criteria. For these reasons, sustainability has recently attracted researchs. Despite the potential impact of sustainability on most decision-making, only few areas on tactical and operational decision levels have been addressed, such as aggregate production planning, location allocation and routing problems in supply chains. To the best of our knowledge there have been no studies on layout and cell formation.

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In order to fill this gap, this research proposes a bi-objective mathematical model of DCFP, in which the environmental aspect is represented as the objective, and the social issues are represented as the constraints. A trade-off is thus made between some related costs as economic criteria, and production waste as environmental criteria, without compromising social needs. A restriction on the maximum daily noise exposure level is also considered for worker assignment as a social issue. As a resolution approach, a new efficient algorithm called NSGA II-MOSA is designed, which is a hybrid of the Non-dominated Sorting Genetic Algorithm (NSGA II) and Multi-Objective Simulated Annealing (MOSA).

The remainder of this paper is organized as follows. Next section reviews the literature related to DCFP. Section 3 motivates this research. Section 4 describes the assumptions and problem formulation, and Section 5 the hybrid NSGA II-MOSA algorithm. The experimental result and a comparison between the proposed hybrid NSGA II-MOSA hybrid and a traditional application of NSGA II and MOSA are shown in Section 6. Finally, Section 7 ends on conclusions and future research directions.

2. Literature review

This section gives an overview of the most prominent research on DCMS. Due to the large number of investigations in this area, we focus mainly on recent studies. First, Rheault et al. [3] introduced the concept of a dynamic environment in CFP. Schaller et al. [4] integrated CFP with inventory aspects, then showed the performance of their model on multiple heuristics and evaluated several alternative lower bounding methods. Chen and Cao [5] proposed a mathematical model for multi-period Cellular Manufacturing Systems (Dynamic CMS) minimizing the total cost, which includes: inter-cell material handling, inventory holding and the setting up of cells. They also developed a Tabu Search (TS) method to obtain good solutions and show the efficiency of their model. Next, these authors [6] generated a robust system configuration by integrating cell formation and part allocation. They also proposed a two-stage TS to find the optimal or near optimal solutions. Tavakkoli-Moghaddam et al. [7] presented a nonlinear integer model of DCMS with machine capacity limitation, machine replication, inter-cell movements and production in batches. They used constant and variable costs as well as reconfiguration and inter-cell movement costs to formulate their objective function. Some of these authors [8] applied a Memetic Algorithm (MA) to solve their DCMS model. Defersha and Chen [9] formulated a comprehensive model containing dynamic cell configuration, alternative routings, lot splitting, sequence of operations and workload balancing. They also considered machine adjacency and cell size capacity as constraints. Moreover, Defersha and Chen [10] also proposed a two-phase GA-based heuristic to solve DCFP with alternative routings. Safaei et al. [11,12] presented a DCMS mathematical model with uncertain circumstances, assuming fuzzy demand and fuzzy machine availability. They solved their mixed-integer programming model by developing fuzzy programming-based aspects to determine optimal cell configuration with maximum satisfaction of the fuzzy objective and constraints. Safaei et al. [13] proposed a mixed-integer programming model in DCMS with batch inter/intra-cell material handling, sequence of operations, alternative process plans and machine replication. In this study, the authors minimized machine variable/constant costs, inter/intra-cell movements and reconfiguration costs as objective function. Defesha and Chen [14] integrated DCMS with production lot sizing in their minimization model with both production and quality-related (operation, set up, inventory, etc.) costs. They solved this model with a linear programming-embedded GA. Defersha and Chen [15] developed a parallel GA approach for DCFP. Ahkioon et al. [16] formulated a mixed integer mathematical model in DCMS by considering routing flexibility. In other words, they made a trade-off between increased flexibility and the imposed additional cost of part routings. Aryanezhad et al. [17] proposed a model to combine Simultaneous Dynamic Cell formation with a Worker assignment Problem (SDCWP). The objective function in their model has two components: (i) production costs such as inter-cell material handling and machine costs in the planning horizon, and (ii) human issues consisting of hiring, training, salary and firing costs. Egilmez et al. [18] addressed three stochastic skill-based manpower allocation models which allocate each worker to a manufacturing cell according to their performance. They also proposed a four-phased hierarchical robust optimization method to optimize manpower assignment and system production rates. Saidi-Mehrabad et al. [19] proposed a mathematical model to integrate production planning and worker assignment. This model minimizes the costs of maintenance and overheads, system reconfiguration, backorder and inventory holding, training, and salaries. Safaei and Tavakkoli-Moghaddam [20] developed a mathematical model to integrate multi-period cell formation and subcontracting of production planning in DCMS. Their study makes a trade-off between production and outsourcing costs on the re-configuration of CMS. Bajestani et al. [21] formulated a multi-objective mathematical modeling in DCMS and minimized the sum of various costs and total cell load variation simultaneously. They obtained the Pareto-optimal frontier with a new multi-objective scatter search method. Wang et al. [22] presented a non-linear mixed integer problem in DCMS with three conflicting objectives (machine relocation cost, utilization rate of machine capacity, and total number of inter-cell movements over the entire planning horizon). Deljoo et al. [23] improved their previous model by correcting some essential errors which had reduced the model's efficiency.

Mahdavi et al. [24] proposed an integer non-linear program of DCMS, considering worker aspects such as worker assignment, alternative workers, available time of workers, hiring and firing costs, and workers' salaries. Furthermore, they utilized holding and backordering costs in their model as an inventory aspect to make it more realistic. Javadian et al. [25] presented a multi-objective problem of cellular manufacturing systems in a dynamic and deterministic production environment to simultaneously minimize total cell load variation and the sum of miscellaneous costs (machine costs, inter/intra-cellular material handling, backorder, inventory holding and subcontracting). NSGA-II was applied to obtain optimal the Pareto-frontier. Rafiee et al. [26] integrated DCMS and an inventory lot sizing problem into a comprehensive mathematical model that includes several design factors: machine procurement, cell reconfiguration, preventive and corrective maintenance, intra/inter-cell material handling, subcontracting, inventory and defective parts replacement costs, etc. Saxena and Jain [27] provided a mixed-integer nonlinear programming model to merge machine breakdown effects and DCMS by incorporating reliability modeling. Kia et al. [28] proposed a mixed-integer non-linear programming model for DCMS by integrating three major decisions into the design of a CMS (cell formation, group layout) and developed an efficient SA method to solve their model. The objective function minimizes the total costs of intra/inter-cell movement, machine relocation, machine procurement, machine overheads and machine processing. Moreover, Kia et al. [29] addressed a mixed integer model for multi-floor layout design in DCMS. They developed a GA to solve their model. Rafiei and Ghodsi [30] presented a bi-objective model in DCMS and focused on human-related aspects. Their proposed model seeks (i) to minimize various costs including machine procurement relocation, machine variables, inter/intra-cell movement, and overtime and worker shifting as a first objective; and (ii) to maximize worker utilization as second