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A vibration damping optimization algorithm for solving a new multi-objective dynamic cell formation problem with workers training

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ABSTRACT

This paper presents a comprehensive multi-objective mixed integer mathematical programming model which considers cell formation and production planning problems simultaneously. This comprehensive model includes dynamic system reconfiguration, multi period production planning, operation sequence, alternative process plans for part types, machine and worker flexibility, duplicate machines, machine capacity, available time of workers and worker assignment. The aim of the proposed model is to minimize inter and intra-cell movement costs, machine and reconfiguration costs, setup costs, production planning costs (holding, backorder and subcontracting costs) and workers hiring, firing, training and salary costs, as well as minimizing summation of machines idle times as a second objective. Due to NP-hardness of the problem, a recent and efficient meta-heuristic algorithm namely multi-objective vibration damping optimization (MOVDO) is designed for finding Pareto-optimal frontier. In order to check the efficiency of the developed algorithm, it is compared with two salient multi-objective genetic algorithms named NSGAII and NRGA. Finally, by generating some test problems in small and large scales and using some multi-objective comparison metrics, the algorithms are compared and analyzed statistically.

1. Introduction

Generally, in real world environment, many problems have the same solving method. Therefore, by grouping these similar problems a same method can be used to solve a set of problems. As result, time and cost of the systems are saved. Group Technology (GT) which works based on this grouping concept can be defined as a production philosophy for identifying similar parts and grouping them together in order to access their similarity benefits in design and manufacturing (Selim, Askin, & Vakharia, 1998). Cellular Manufacturing (CM) is one application of GT and has been appeared as a promising alternative manufacturing system. Cellular Manufacturing System (CMS) is one of the efficient systems for manufacturing process with high production volume and variety that predispose growth and progress in global markets.

CM includes creation and operation of manufacturing cells. Parts are grouping into part families and machines into cells. In this process, a number of machines that usually have different performance are grouping into a manufacturing cell which is called machine cell. This cell is responsible for completing operation related to similar parts which are in a group and are known as a part family. Machine assignment into groups consists processing of all existent part in a part family by a group of machines. Major advantages of CMS are simplifying and reducing material handling, reducing work in process inventory, decreasing setup time, increasing flexibility, better production control and lead time reduction. Identifying similar parts (part families) and machine cells in designing a cellular manufacturing system is generally noted as cell formation. Cell formation problem is the most significant step in implementing group technology. Hence, different methods are proposed by researchers to solve cell formation problem. Because of increasing the variety of consuming goods and reduction in product life cycles, manufacturing organizations often face with fluctuation in product demand and product mix which results in a dynamic or turbulent production environment (Rheault, Drolet, & Abdulnour, 1995). In dynamic environment a planning horizon can be divided into smaller periods where each period has different product mix and demand requirements. Consequently, the formed cells in a current period may not be optimal and efficient for the subsequent period. To overcome the disadvantages of traditional CMS, the concept of Dynamic Cellular Manufacturing System (DCMS) has been introduced (Rheault et al., 1995). DCMS refers to manufacturing cell reconfiguration which includes part family and machine group formation in each period. Reconfiguration includes exchange current machines among cells which is called machine relocation and consists adding new machines to cell including machines duplication and removing current machines from cells. In this case, the decision maker in order to make an appropriate decision to keep balance between production and

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outsourcing costs should select through available choices like adding a new machine, machines relocation among current cells, subcontracting for some parts and workers hiring or firing strategy. Outsourcing requirement such as inventory, backorder and subcontracting can have an important effect on cell formation over the planning horizon by relocating, adding and removing machines continuously. A comprehensive review of the DCMS literature can be acquired in Safaei, Saidi-Mehrabad, and Jabal-Ameli (2008) and Balakrishnan and Cheng (2007).

Good and useful discussion of cellular manufacturing systems can be found in Suresh and Meredith (1985), Singh (1993), Joines, King, and Culbreth (1995), Reisman, Kumar, Motwani, and Cheng (1997), Selim et al. (1998), Kia et al. (2012) and Houshyar et al. (2014). Defersha and Chen (2008) proposed a comprehensive mathematical model for designing DCMS based on tools requirements for parts and tools availability on machine. This model minimizes machine operational cost, reconfiguration cost, inter-cell transportation cost, tool consumption cost, parts outsourcing cost and inter-cell workload balancing. They used a new parallel genetic algorithm method to solve the model. Rezaeian, Javadian, Tavakkoli-Moghaddam, and Jolai (2011) presented a nonlinear programming model in a dynamic environment. Furthermore, they proposed a novel hybrid approach based on the genetic algorithm and artificial neural network to solve the presented model. Majazi-Delfard (2013) presented a nonlinear integer programming model for a dynamic CF problem in CMS based on the number and average length of inter/intra cell movements. Because of the presented model is NP-hard, a simulated annealing embedded in branch and cut was performed to solve the problem.

Using a multi-objective programming models has been attracted a few attention among accomplished researches in this concept as yet in spite of very desirable efficiency in cell formation problem model especially in case of studying contradictory objectives simultaneously. Bajestani, Rabbani, Rahimi-Vahed, and Khoshkhou (2009) developed a bi-objective DCMS model with objectives like minimizing general cost (machine constant cost, inter-cell transportation cost and machine relocation cost) and total work variables. They applied MOSS algorithm to solve the proposed model and compared results with SPEA-II and NSGA-II algorithms. Ghotboddini, Rabbani, and Rahimian (2011) presented a new multi-objective mixed integer model for DCMS. Their model solved the part and machine grouping simultaneously with labor assignment to minimize the cost of various terms like reassignment cost of human resources, over time cost of equipments and labors and maximize utilization rate of human resources. Daei Niaki, Mehdizadeh, and Tavakkoli-Moghaddam (2011) developed a comprehensive multi-objective mixed integer mathematical programming model which considers cell formation problem, production planning and worker assignment, simultaneously. They considered dynamic system reconfiguration, multi period production planning, operation sequence, alternative process plans for part types, machine and worker flexibility, duplicate machines, machine capacity, available time of workers and worker assignment. However, they didn't present any approach to solve the model in large scale instance.

Because of the effect of production planning goals on reconfiguration and cell formation in dynamic condition, integrating these concepts is an important problem which has been studied in some limited researches. Chen and Cao (2004) proposed an integrated model for a production planning (PP) in a CMS that minimizes the inter-cell material handling cost, fixed charge cost of setting up manufacturing cells, cost of holding the finished items over the planning horizon, cost of setting up the system to process different parts in different time periods and machine operating cost. They developed a heuristic method to solve the presented problem. Solimanpur, Vrat, and Shankar (2004) proffered a fuzzy goal programming approach to solve a multi-objective mathematical model of cell formation problem and production planning in a virtual dynamic cellular manufacturing system with considering worker flexibility. Kioon, Bulgak, and Bektas (2009) proposed a production planning and dynamic cell formation integrated model with aims such as minimizing inter and intra cell material handling cost, inventory and production costs, reconfiguration costs and machine operation and overhead costs. Safaei and Tavakkoli-Moghaddam (2009) studied effect of parts subcontracting on reconfiguration with adding machine constant costs and backorder costs to objective function of model in Kioon et al. (2009). Sakhaii and et al. (2015) developed a new integrated mixed-integer linear programming model to solve a dynamic cellular manufacturing system with unreliable machines and a production planning problem simultaneously. There model incorporated with dynamic cell formation, intercell layout, machine reliability, operator assignment, alternative process routings and production planning concepts. They, to cope with the parts processing time uncertainty, a robust optimization approach immunized against even worst-case adopted.

On the other hand, considering worker requirements is such a critical parameter in implementation of cell formation phase which increases the designing efficiency of cellular manufacturing systems and make the proposed model more practical. Bidanda, Ariyawongrat, Needy, Norman, and Tharmmaphornphilas (2005) presented a generic review and evaluation on a wide range of worker related issues in cellular manufacturing system. The first paper which was allocated to operator related issues of dynamic cell formation is the one of Aryanezhad, Deljoo, and Mirzapour Al-e-Hashem (2009). They presented a new mathematical model to deal with the dynamic cell formation and worker assignment problems, simultaneously. Since the presented model was nonlinear integer, the authors linearized the presented model. The objective function of this model includes two components of which both related to system costs consisting of machine, operating, inter-cell material handling, machine relocation, worker hiring, firing, training, and salary costs. Mahdavi, Aalaei, Paydar, and Solimanpur (2010) presented a mixed integer mathematical model for designing dynamic cellular manufacturing systems with considering production planning and worker assignment. The advantages of their proposed model was considering multi-period production planning, dynamic system reconfiguration, machine duplication, machine capacity, available time of workers and worker assignment. Papaioannou and Wilson (2010) studied a literature review of cell formation problem concentrating formulation proposed in the last decades. They reviewed a number of solution approaches that have been employed for CF such as mathematical programming heuristic and meta-heuristic methodologies and artificial intelligence strategies. Rafiei and Ghodsi (2013) considered a dynamic cell formation problem with the consideration of human related issues and developed a bi-objective model. The first objective seeks to minimize related the costs of the problem such as machine procurement and relocation costs, machine variable cost, inter and intra cellular movement costs, overtime costs and operator shifting cost between cells, and the second objective seeks to maximize operator utilization. Because of NP-hardness of dynamic CF problem, a hybrid ACO-GA meta-heuristic developed. Bagheri and Bashiri (2014) considered a CF problem with intercell layout and operator assignment problems in a dynamic CMS, simultaneously. They proposed a new mathematical model based on three mentioned sub-problems. The objective of the model is to minimize inter and intra cell movements, machine relocation costs, and operator related issues. Due to commensurable statements in objective function, the preferred solution is obtained by the LP-metric approach. The generated example solved by branch and bound technique. A real case study is illustrated in an automobile producer company.