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Multi-objective dynamic cell formation problem: A stochastic programming approach

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ABSTRACT

This paper addresses dynamic cell formation problem (DCFP) which has been explored vastly for several years. Although a considerable body of literature in this filed, two remarkable aspects have been significantly ignored so far, as uncertainty and human-related issues. In order to compensate such a shortage, this paper develops a bi-objective stochastic model. The first objective function of the developed model seeks to minimize total cost of machine procurement, machine relocation, inter-cell moves, overtime utilization, worker hiring/laying-off, and worker moves between cells; while the second objective function maximizes labor utilization of the cellular manufacturing system. In the developed model, labor utilization, worker overtime cost, worker hiring/laying off, and worker cell assignment are considered to tackle some of the most notable human-related issues in DCFP. Considering the complexity of the proposed model, a hybrid Tabu Search–Genetic Algorithm (TS–GA) is proposed whose strength is validated to obtain optimal and near optimal solutions through conducted experimental results.
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1. Introduction

Cellular Manufacturing System (CMS) is an important application of Group Technology (GT). GT is a general philosophy that in the manufacturing context, attempts to group parts into part families, and allocate machines into machine cells based upon their similarities both in process and geometrical characteristics. Application of GT yields numerous advantages, not only reduce setup time, lot size, work-in-process (WIP), finished goods inventory, and throughput time, but also improve flexibility in manufacturing systems (Collet & Spicer, 1995; Fry, Breen, & Wilson, 1987; Levasseur, Helms, & Zink, 1995; Singh & Rajamaani, 1996; Süer & Sáiz, 1993). Designing a CMS consists of four major steps including (a) Cell Formation (CF): grouping parts with similar geometric or processing features into part families and grouping required machines into machine cells; (b) group layout: laying out machines within cells; (c) group scheduling: scheduling part families; and (d) resource allocation: assigning manufacturing resources, such as tools, manpower, and materials (Ghotboddini, Rabbani, & Rahimian, 2011).

Many researchers have developed different approaches and models yet to face with the Cell Formation Problem (CFP). Regarding this, Dynamic CFP (DCFP) has recently captivated academic societies, since it is inevitable to adapt system capabilities with market requirements in a static form. To do so, cell configurations are updated during different planning periods to respond dynamic product mix and demand volumes. Though a number of CFP models are found in the literature, two issues are mostly neglected in the presented models. One of the issues corresponds to human-related aspects of CFP, which are challenged in some papers, such as those of Süer (1996), Suresh and Slomp (2001), and Süer et al. (2013). The main attribute of these papers is that human-related issues have been considered in a separate manner with other requirements of CFP through a multi-step framework. In this regard, developing the second objective function of the proposed model, herein seeks to maximize worker utilization. Moreover, worker overtime cost, worker hiring/laying off cost, and worker assignment cost are taken into account within the developed model. On the other hand, indeterministic models have been rarely studied in comparison with the deterministic instances, among which readers are referred to product-mix uncertainty in Seifoddini (1990), fuzzy clustering methods in Lozano, Dobado, Larraneta, and Onieva (2002), fuzzy demands and machine capacities in Safaei, Saeidi-Mehrabad, Tavakkoli-Moghaddam, et al. (2008) and random demands in Süer, Huang, and Maddisetty (2010). In this paper, the proposed model along with the above features, adopts fuzzy stochastic programming to cope with the vagueness involved in part demands, machine capacities in regular time and overtime, and machine selling prices.

The remainder of the paper is structured as follows. Section 2 reviews literature body of DCFP briefly, while the developed model

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is discussed in Section 3. Since the proposed model is nonlinear, two transformations are utilized to linearize the model, which are explained in Section 3 as well. Section 4 presents the solution methodology to deal effectively with flexibility involved in the proposed model. Section 5 explores some numerical experiments in order to validate applicability of the proposed model. Finally, concluding remarks and future research directions are provided in Section 6.

2. Literature review

There are lots of methods for CFP in the literature but here we classify them into two major categories as design-oriented approaches, which group parts into families based on similar design features (Askin & Vakharia, 1991) and production-oriented approaches, which seek aggregation of parts requiring similar processes (Joines, Culbrethe, & King, 1996; Song & Hitomi, 1996). Regarding this, a number of review papers is found, among which the readers are referred to Balakrishnan and Cheng (2007) since the most comprehensive image of CFP has been delineated. In this following, research work with the assumptions close to those of this paper is reviewed.

Song and Hitomi (1996) proposed a mixed-integer model for designing a flexible CMS. Their model contained two integer programs. The first model defines production quantity for each product and, the second model lays out the cells in a finite planning horizon with dynamic demand. Later, Chen (1998) developed a mathematical programming model with the objective function of minimum inter-cell material moves, machine cost and reconfiguration cost in a DCMS. Regarding dynamic nature of production environment, Wicks (1995) proposed a multi-period part family and machine cell formation problem. The objective functions were, minimizing inter-cell material handling cost, minimizing investment in additional machines and minimizing cost of system reconfiguration over the planning horizon. Mungwatanna (2000) mentioned routing flexibility in DCFP. He proposed a non-linear mixed-integer model. Then the model was linearized and solved by Simulated Annealing (SA). Tavakkoli-Moghaddam, Aryanezhad, Safaei, and Azaron (2005) modified the Mungwatanna's model and compared performance of three meta-heuristics, Genetic Algorithm (GA), SA and Tabu Search (TS).

Safaei, Saeidi-Mehrabad, Tavakkoli-Moghaddam, et al. (2008) issued batch inter/intra-cell material handling, while the operation sequence of the production was also determined. They solved the resulted model by a hybrid SA. Safaei, Saidi-Mehrabad, Jabal-Ameli (2008) reformulated the Mungwatanna's model considering fuzzy sets theory. In Aryanezhad, Deljoo, and Mirzapour Al-e-hashem (2009), the authors considered both dynamic cell formation and worker assignment problem developing a non-linear integer program for DCFP based on Mungwatanna's model (2000). They also linearized the developed model in order to reduce its complexity. Saxena and Jain (2011) proposed a multi-objective mixed-integer non-linear programming model to design a DCMS. They integrated many attributes in the developed model, such as breakdown effect, process batch size, transfer batch size for intra-cell moves, and transfer batch size for inter-cell moves. Balakrishnan and Cheng (2005) proposed a two-stage procedure based on the generalized machine assignment problem and dynamic programming. Their model was a flexible framework for modeling cellular manufacturing when product demand changed during the planning horizon. Kioon, Bulgak, and Bektas (2009) developed a mixed-integer non-linear model for DCMS which integrated production planning, dynamic system reconfiguration, and multiple routing. Since their non-linear problem was intractable, some linearization techniques were also proposed. Recent research works have usually considered cell formation as a single objective problem but today's business environment makes multi-objective optimization necessary. Multi-objective optimization offers new opportunity to determine problems with more accurate features and it makes the model become adaptable to the real world expectations. Wang, Tang, and Yung (2009) addressed the DCFP with multiple conflicting objective functions. In their developed solution approach, weights were considered for the developed three conflicting objective functions in order to form a single weighted sum of objective functions. The objective functions were minimizing machine relocation cost in the process of cell reconfiguration, maximizing utilization of machine capacity, and minimizing total number of intra-cell moves over the entire planning horizon. In order to solve the proposed model, a scatter search algorithm was developed and results were compared with the results of solver CPLEX. Safaei and Tavakkoli-Moghadam (2009) proposed an integrated mathematical model of the multi-period cell formation and production planning in a DCMS. Minimizing costs of machine, inter/intra-cell movement, reconfiguration, partial subcontracting, and inventory carrying was the objective function of their proposed model. Recently Ghotboddini et al. (2011) proposed a multi-objective mixed-integer model for DCMS. The model considered some real world critical conditions in lean production that had been neglected in the literature so far. Their model solved part-machine grouping simultaneously with labor assignment in order to minimize costs of reassignment of human resources, overtime cost of equipment and labor, and maximize utilization rate of human resource.

Although numerous research papers are found in the literature body of CFP, there are some aspects of this problem, which have been mostly neglected. Among them, worker assignment and system uncertainty are notable. Regarding worker-related issues of CFP, some research papers have been published so far (Cesani & Steudel, 2005; Slomp, Bokhorst, et al., 2005; Slomp, Chowdary, et al., 2005; Slomp & Suresh, 2005; Suresh & Slomp, 2001; Süer, 1996; Süer, Kamat, Mese, & Huang, 2013). Süer (1996) presented a two-phase hierarchical methodology for operator assignment and cell loading in labor-intensive manufacturing cells. Also, Slomp, Bokhorst, et al. (2005) addressed cell load balancing in trade-off with worker training costs using a developed integer program. Additionally, the labor load balancing was considered by Slomp and Suresh (2005) using a two-stage goal programming approach and by Slomp, Bokhorst, et al. (2005) and Slomp, Chowdary, et al. (2005) in designing virtual cells using a two-phase mathematical approach. The main common attribute of the worker-related papers is that the worker-related decisions are made in a different stage with the decisions of operations and production. As an instance, Suresh and Slomp (2001) addressed a multi-objective cellular design problem including labor group decisions using pattern recognition after part-machine grouping had been conducted. Their developed model partitioned workers into functionally specialized labor pools. Also, Süer et al. (2013) developed a two-stage methodology to optimize number of cells, crew size, cell loading, and cell scheduling. Some other samples considering worker assignment in DCMS include those of Egilmez, Erenay, and Süer (2014), Süer, Arikan, et al. (2009), Süer, Cosner, et al. (2009), and Süer, Vazquezb, and Cortes (2005). As mentioned earlier, all published research papers coped with the worker-related problem in a sequential manner, while this paper tackles the problem integrated with other aspects of DCFP.

Another aspect of CFP that has been mostly neglected is taking system uncertainty into account using probabilistic models. In this regard, two categories of stochastic and fuzzy models have been developed so far. Seifoddini (1990) minimized the expected inter-cell handling cost in the case of product-mix uncertainty, whereas Saidi-Mehrabad and Ghezavati (2009) adopted queuing theory

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