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Designing cellular manufacturing systems considering S-shaped layout

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ABSTRACT

In this paper, we present a new layout framework, called S-shaped layout, for the layout of cellular manufacturing systems. Based on the proposed S-shaped layout, we formulate an integrated bi-objective cell formation and layout problem, considering parameters such as part demands, operation sequences, machine dimensions and aisle widths. The first objective is to minimize the total inter- and intra-cell material handling costs. Also, the second objective is to maximize the total similarity between machines. A normalized weighted sum method is suggested to unify these objectives. As the problem is NP-hard, an efficient hybrid solution method combining simulated annealing and dynamic programming is developed to solve large-sized problems in a reasonable computational time. Finally, by solving numerical examples from the literature the suggested approach is compared with two recently developed approaches.

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1. Introduction

In the last two decades, Cellular Manufacturing system (CMS) has emerged as an innovative and successful strategy in manufacturing systems producing a medium-volume and medium-variety productions. It derives from group technology concept and joins together the advantages of both flexible and mass production approaches. The main advantages of production using CMS are: reduction in setup times, work-in-process inventories, lead times, tool requirements and material handling costs. It could also cause remarkable improvement in product quality, productivity and production control (Mungwattana, 2000; Solimanpur, Vrat, & Shankar, 2004; Wemmerlöv & Hyer, 1986). One of the crucial steps in the CMS design process is the cell formation (CF) problem, which has been extensively studied in the literature. It involves grouping parts with similar design features or processing requirements into part families and grouping machines into machine cells on the basis of operations required by the part families. The material flow between manufacturing cells as a result of exceptional elements (EEs) is a major obstacle in achieving the benefits of CMS (Arıkan & Güngör, 2009). An EE is a part that needs to be processed in more than one cell. So, in the CF problem, one common objective is to minimize the number of EEs. Other common objectives include minimization of inter-cell movement costs, minimization of number of inter-cell material flows, maximization of grouping efficiency, and maximization of grouping efficacy.

Facilities layout is a key factor in manufacturing systems and has a direct impact on the operational performance, as measured by manufacturing lead time, throughput rate and work-in-process (Benjaafar, 2002). Tompkins, White, Bozer, and Tanchoco (2003) estimated that 20–50% of manufacturing costs is related to the handling of parts. They also stated that an efficient facility layout may reduce them for 10–30%. Although minimizing the number of EEs or optimizing other common objectives mentioned above may reduce the flows between the cells, they do not necessarily lead to a minimum material handling cost. Because, the parameters related to the facility layout problem are ignored in the calculation of these objectives. This brings the attention towards the need for incorporating the facility layout problem into the CMS design process. In a CMS, the material handling cost usually consists of two cost components, inter- and intra-cell material handling costs. The inter-cell material handling arises from the movements of parts between the cells, and the intra-cell material handling cost arises from the movements of parts within the cells. Therefore, the inter-cell layout involves the placement of the cells on the shop floor, and the intra-cell layout involves the arrangement of machines within the cells.

Most approaches in the area of facility layout and CF problems, usually consider one of the inter- and intra-cell layouts in the CMS design problem. For simplicity, these approaches aim at minimizing the number of inter-cell movements or intra-cell movements or both, instead of minimizing the material handling cost. Moreover, those approaches that aim at minimizing the material

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handling cost usually apply unrealistic assumptions such as fixed cell locations and equal-sized machines in the layout problem. Consequently, the resulting layout may be inefficient. To overcome these drawbacks, this paper presents a new layout framework, called S-shaped layout, for designing CMS layout. Based on this S-shaped layout, we formulate an integrated bi-objective CF and layout problem, considering parameters such as part demands, operation sequences, machine dimensions and aisle widths. The first objective is to minimize the total inter- and intra-cell material handling costs, and the second one is to maximize the total similarity between machines. A normalized weighted sum method is proposed to unify these objectives. Due to computational complexity of the problem, a hybrid solution method combining Simulated Annealing (SA) and Dynamic Programming (DP) is developed to solve large-sized problems in a reasonable computational time. Finally, by solving numerical examples from the literature the suggested approach is compared with two recently developed approaches.

The remainder of this paper is organized as follows: Section 2 reviews relevant literature, Section 3 presents the description of the problem and Section 4 presents the hybrid method. Computational experiments and comparisons are carried out in Section 5. Finally, conclusions and directions for future research are given in Section 6.

2. Literature review

In recent years, there have been some studies that have applied simultaneous or sequential approaches to solve the CF and layout problems. As both of these problems are NP-hard (Garey & Johnson, 1979; Papaioannou & Wilson, 2010), using heuristic and meta-heuristic algorithms is very popular among researchers.

In the context of sequential approaches, Heragu and Kakuturi (1997) attempted to integrate the machine grouping problem with the layout problem. The machine cells were first formed by a heuristic algorithm, and then a hybrid SA algorithm was employed to construct near-optimal inter- and intra-cell layouts. Chan, Lau, Chan, and Choy (2006) proposed a two-stage solution approach based on Genetic Algorithm (GA) for solving the CF problem as well as the cell layout problem. The first stage was to identify machine cells and part families. Also, the second stage was to obtain the layout sequence of machine cells (linear inter-cell layout) such that the total inter-cell material handling cost is minimized. In their approach, the Quadratic Assignment Problem (QAP) was used to represent the inter-cell layout. Leung, Quintana, and Chen (2008) first attempted to find the number of each machine type by knowing part demands, the processing times and machine capacities. Then, they applied various space filling curves to create initial layouts (it was assumed that each machine occupies almost the same area, i.e., one unit block of floor). In the next step, each of these initial layouts was improved by the CRAFT software. Finally, the layout design with the lowest cost was selected. Krishnan, Mirzaei, Venkatasamy, and Pillai (2012) developed a method based on the flow between machines to obtain machine cells. A modified grouping efficiency measure was used to determine the efficiency of grouping. They employed a GA-based machine placement procedure for the placement of machines in a facility layout matrix (grid) as a QAP. Chang, Wu, and Wu (2013) formulated a two-stage mathematical programming model to integrate the CF and layout problems. They employed a Tabu Search (TS) algorithm to solve the problem. In their approach, the CF and inter-cell layout problems were simultaneously solved in the first stage. Then, the intra-cell machine sequence was determined on the basis of the solution obtained in the first stage. In their research, the linear single- and double-row layouts were considered as two alternatives for the inter-cell layout. Javadi, Jolai, Slomp, Rabbani, and Tavakkoli-Moghaddam (2014) presented a mathematical model for the inter- and intra-cell layout problems in a dynamic environment. The objective was to minimize the total costs of rearrangement as well as the total inter- and intra-cell material flows. They assumed that the CF phase has been already done and the locations for placing machines and cells are known in advance. A hybrid algorithm combining electromagnetism-like algorithm and GA was used to solve the problem. Ghosh, Doloi, and Dan (2015) used the QAP to represent the cell layout problem, and developed an Immune GA to solve it.

In connection with simultaneous approaches, Aktürk and Turkcan (2000) proposed a solution methodology to simultaneously solve the CF and intra-cell layout problems. A holistic approach was used to maximize the profit of not only the overall system but also individual cells. Lee and Chiang (2001) addressed the joint problem of CF and its layout assignment to minimize the inter-cell material flow cost. It was assumed that the cell locations are approximately equally spaced, and the machine cells are located along a bi-directional linear layout. They proposed a new graphic approach based on a multi-terminal cut tree network model to form machine cells. A partition procedure was developed to separate the cut tree into a number of sub-graphs (cells) and assigns the location sequence of each cell by comparing the cut capacities. Chiang and Lee (2004) employed a SA algorithm combined with DP for solving the same problem presented in (Lee & Chiang, 2001). In their approach, the configuration of a solution is comprised of a string of integer values, where each value is associated with a machine. The DP algorithm is applied to partition each string into several segments (cells) such that the total inter-cell flow cost is minimized. Yin, Yasuda, and Hu (2005) incorporated part demands, sequence data and alternative process routings into a nonlinear mathematical model. They aimed to minimize a weighted sum of both inter-cell and intra-cell movements in which the weights are based on the actual unit costs of inter- and intra-cell movements. A heuristic methodology was also developed for solving such a nonlinear problem. Wu, Chu, Wang, and Yan (2007) developed a GA for solving an integrated CF and layout problem considering sequence data, work load, machine capacities, part demands, batch sizes, and layout type. Mahdavi, Shirazi, and Paydar (2008) presented a heuristic approach based on a modified flow matrix for solving an integrated CF and intra-cell layout problem. The objective was to minimize the number of inter- and intra-cell movements as well as EEs and voids. Paydar, Mahdavi, Sharafuddin, and Solimanpur (2010) formulated the integrated CF and intra-cell layout problem as a multiple departures single destination multiple traveling salesman problem, and proposed a SA algorithm to solve it. Jolai, Taghipour, and Javadi (2011) proposed a mathematical model for the inter- and intra-cell layout problem in CMS. They assumed that both machines and cells are assigned to pre-specified locations. A binary particle swarm optimization algorithm was implemented to minimize the total material handling cost. Jolai, Tavakkoli-Moghaddam, Golmohammadi, and Javadi (2012) presented a modified version of the proposed model by Wu et al. (2007) considering parameters such as forward and backward transportation, different batch sizes for parts and sequence data. They developed an Electromagnetism-like algorithm with a heuristic local search to minimize the total material handling cost and the number of EEs. Mohammadi and Forghani (2014) developed a GA for solving an integrated CF and layout problem. To increase the accuracy of the inter- and intra-cell layouts, they calculated the material handling cost on the basis of the actual location of machines on the shop floor and regarding machine dimensions and aisle widths. In their approach, machines assigned to a same cell are arranged along a line. Also, the machine cells are placed on the shop floor from bottom to top as a

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