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Simultaneous balancing, sequencing, and workstation planning for a mixed model manual assembly line using hybrid genetic algorithm

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ABSTRACT

Balancing and sequencing are two important challenging problems in designing mixed-model assembly lines. A large number of studies have addressed these two problems both independently and simultaneously. However, several important aspects such as assignment of common tasks between models to different workstations, and minimizing the number and length of workstations are not addressed in an integrated manner. In this paper, we proposed a mixed integer linear programming mathematical model by considering the above aspects simultaneously for a continuously moving conveyor. The objective function of the model is to minimize the length and number of workstations, costs of workstations and task duplications. Since the proposed model cannot be efficiently solved using commercially available packages, a multi-phased linear programming embedded genetic algorithm is developed. In the proposed algorithm, binary variables are determined using genetic search whereas continuous variables corresponding to the binary variables are determined by solving linear programming subproblem using simplex algorithm. Several numerical examples with different sizes are presented to illustrate features of the proposed model and computational efficiency of the proposed hybrid genetic algorithm. A comparative study of genetic algorithm and simulated annealing is also conducted.

1. Introduction

Assembly lines are types of manufacturing systems in which products are progressively assembled along a sequence of workstations. They are generally classified as single-model, mixed-model, and multi-product assembly lines. Single-model assembly line is the simplest of all, and as its name implies only one model of a given product is assembled. Whereas, in mixed-model situation, different models of a product are assembled one after the other without forming batches of identical models and without requiring setup between different models. In multi-product assembly lines, relatively different products are assembled in batches where one batch of a product is followed by a batch of another product with a significant setup time. Among these three assembly line types, mixed-model assembly line is widely studied and used in industry as it enables companies to produce different models of one product simultaneously to satisfy varying needs of customers in a responsive manner. Differences of models come from various factors such as size and color diversity, applied materials or even equipment. Therefore, varying assembly tasks, different task times and precedence relations are required to produce them (Becker & Scholl, 2006).

Several issues should be considered in designing a mixed-model assembly line. These include line balancing, layout design, and model sequencing (Boysen, Fliedner, & Scholl, 2009; Ho, 2005; Manavizadeh, Rabbani, Moshtaghi, & Jolai, 2012). The balancing and model sequencing are the main challenges for the planners of the mixed-model assembly line (McMullen & Frazier, 2000). The former requires assigning tasks to different workstations as evenly as possible while satisfying various constraints, such as the precedence relations among task and cycle time constraint (Simaria & Vilarinho, 2004). The sequencing problem, on the other hand, focuses on determining the sequence of the different models while meeting model mix requirements and minimizing line starvation and congestion (Scholl, Klein, & Domschke, 1998). These problems are generally considered hierarchically. The hierarchical manner focuses on balancing the assembly line first. Following that, the sequencing problem is solved (Mosadegh, Ghomi, & Zandieh, 2012). The challenge of balancing and sequencing can be more amplified in designing assembly lines with continuously moving conveyors. When the conveyor of the assembly line is moving continuously (opposed to intermittent synchronous motion), not only the number of workstation but also the length of workstations, the starting and finishing location of each task on the conveyor need to be determined. In this paper, we consider balancing and sequencing problems simultaneously assuming a continuously moving conveyor. The remainder of this paper is organized as follows: Section 2 provides a

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literature review. In Section 3, the proposed mixed integer linear programming model (*MILP*) is presented. A solution procedure based on genetic algorithm is developed in Section 4. Several numerical examples are conducted in Section 5 to illustrate the problem addressed in this paper and show the computational efficiency of the proposed algorithm. Finally, conclusions are given in Section 6.

2. Literature review

Mixed-model assembly line balancing and sequencing problems have been widely studied in literature. Comprehensive surveys of many of these studies can be found in Becker and Scholl (2006) and Boysen, Fliedner, and Scholl (2007). Vilarinho and Simaria (2006) employed ant colony algorithm to solve a balancing problem with parallel workstations and zoning constraints. Yagmahan (2011) solved mixed-model assembly line balancing problem by proposing a multi-objective ant colony optimization algorithm. A mixed integer linear programming model in the presence of parallel workstations, zoning constraints, and sequence-dependent set-up times between tasks was proposed in Akpinar and Baykasoglu (2014). The authors employed a multiple colony hybrid bees algorithm to solve the proposed model. Rabbani, Montazeri, Farrokhi-Asl, and Rafiei (2016) proposed a multi-objective model and evolutionary algorithms to solve balancing problem of a U-shaped mixed-model assembly line with the focus on minimizing the cycle time and the number of workstations, and maximizing the line efficiencies. Kucukkoc and Zhang (2016b) developed ant colony optimization algorithm to solve balancing problem in a mixed-model parallel two-sided line. Roshani, Roshani, Ghazi Nezami, and Ghazi Nezami (2017) proposed a mathematical model and simulated annealing algorithm to solve balancing problem of an assembly line with multi-manned workstations. The objectives of the proposed model were: minimizing the total number of workers on the line and minimizing the number of multi-manned workstations. Rabbani, Siadatian, Farrokhi-Asl, and Manavizadeh (2016) proposed a multi-objective model and algorithms to solve balancing in the mixed-model assembly line with parallel workstations in a dynamic situation.

The papers reviewed above are mainly concerned with line balancing. Numerous studies were also conducted to solve sequencing problem. A comprehensive review of many of these studies was conducted by Boysen et al. (2009). Ishigaki and Miyashita (2016) used simulated annealing algorithm to solve sequencing problem. Makarouni, Siskos, and Psarras (2016) developed an integer programming model with the objective to maximize the just-in-time use of resources by minimizing the differences between actual and planned production dates. A greedy randomized adaptive search procedure (GRASP) was developed in Bautista, Alfaro-Pozo, and Batalla-García (2016) for a sequencing problem with the focus on minimizing work overload and unused assembly time. Bautista, Cano, and Alfaro-Pozo (2017) proposed a hybrid metaheuristic by combining dynamic programming and linear programming. The objective of their study was to minimize the total work overload. Guo and Ryan (2017) proposed a stochastic mixed-integer model to minimize the total earliness and lateness when the finished products have due dates.

Many research articles that attempt to solve balancing and sequencing problems in a hierarchical manner have also been published. For example, Sawik (2002) proposed a monolithic and a hierarchical approach to solve balancing and sequencing problems of a flexible assembly line. The author developed mixed integer programming models to minimize the completion time of products. Hwang and Katayama (2010) solved balancing and sequencing problems in a hierarchical manner to minimize the number of workstations and the variance of their workload. Faccio, Gamberi, and Bortolini (2016) solved two problems of the paced mixed-model assembly line hierarchically with using a supplementary flexible operators, so-called jolly operators. Objectives of their study were to minimize the number of jolly operators and work-overloads. Fish School Search algorithm (FSSA) was proposed in Monteiro Filho (2017) to solve balancing and sequencing problems hierarchically. The results were compared with Particle Swarm Optimization algorithm (PSO). PSO outperformed FSSA in solving balancing problem. However, FSSA gave more efficient results in solving the sequencing problem.

The articles reviewed so far address either balancing or sequencing problem or both problems hierarchically. There are also a considerable number of studies carried out to solve these problems simultaneously. Kim, Kim, and Kim (2000) solved balancing and sequencing problems simultaneously by employing a genetic algorithm. Their study aimed to minimize the total utility work, which is the total amount of work that is not completed within the given length of a workstation. Bock, Rosenberg, and van Brackel (2006) proposed a new mathematical model and a simulated annealing based solution procedure. The objective is to minimize the total cost related to wages for the operators, overtime, wages for the floaters (operators assigned temporarily to a workstation), and for off-line repair if a work overload does not allow the correct production of a specific product. Saif, Guan, Liu, Wang, and Zhang (2014) utilized a multi-objective artificial bee colony algorithm to minimize the total flow time of models, decreasing the workload deviations of stations from the average workloads, and reducing the number of incomplete units by balancing the workload on each station. Manavizadeh, Rabbani, and Radmehr (2015) proposed a multi-objective model and a heuristic algorithm to simultaneously solve the balancing and sequencing problems in the U-shaped assembly line. Kucukkoc and Zhang (2016a) developed a hybrid algorithm, which was a combination of genetic algorithm and ant colony optimization algorithm to solve balancing and sequencing problems in a parallel two-sided assembly line. Overall, the studies mentioned above have made notable contributions towards developing models for solving balancing and sequencing problems in mixed-model assembly lines. Nonetheless, they did not consider several important aspects such as assigning common tasks between various models of a product to different workstations, which is called task duplication. Ignoring this aspect without considering the related costs can reduce the number of feasible and efficient configurations (Bukchin & Rabinowitch, 2006). In addition, the above studies did not attempt to minimize the number and the length of workstations in an integrated manner. In this paper, we developed a mathematical model that incorporates many of the above aspects of assembly lines by assuming a continuously moving conveyor. A multi-phased linear programming embedded genetic algorithm is also developed to effectively solve the proposed model.

3. Mathematical model

3.1. Problem definition

Assume a mixed-model assembly line intended to manufacture a total of M different models of a product. The demand D_m for each model in a given time period is also assumed to be known and hence the model launching interval (L_r cycle time) is determined. In this scenario, the demand can be broken into f cycles in order to use a cyclic production strategy where f is the greatest common divisor of demand values. The vector $d = d_1,...,d_m$, where $d_m = \frac{D_m}{f}$, represents the model mix called Minimum Part Set (*MPS*) to be manufactured in each production cycle (Hyun, Kim, & Kim, 1998; Mosadegh, Ghomi, et al., 2012). A total of f repetitions of the production of the *MPS* is required to satisfy the demands for the models. Fig. 1 illustrates a typical assembly line producing two models (A and C) with $d_1 = d_A = 1$ and $d_2 = d_C = 2$. Given the precedence relationship of the tasks for each model, the demand vector $d = d_1,...,d_m$, the launching interval L_r, and the conveyor speed, the problem is to determine (1) the sequence of model launching, (2) the assignment of tasks to the various station and (3) the starting and finish location of the tasks on the conveyor. The objective is to minimize weighted sum of the number of workstations, the length of the assembly