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A Lagrangian relaxation approach to the mixed-product assembly line sequencing problem: A case study of a door-lock company in Taiwan

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ABSTRACT

In mixed-product assembly line sequencing, the production resources required for the assembly lines should be scheduled to minimize the overall cost and meet customer demand. In this paper, we study an assembly line sequencing problem for the door-lock industry in Taiwan and develop an integer programming formulation with realistic constraints. The complex solution space makes the resulting program difficult to solve using commercial optimization packages. Therefore, a heuristic based on the Lagrangian relaxation principle is developed to solve this problem efficiently. We evaluate the efficiency of the developed Lagrangian relaxation heuristic by comparing its solutions with those obtained using a commercial optimization package: the computational results show that the developed heuristic solves the real-world problem faster than the optimization package by almost 15 times in CPU time at a comparable solution quality.

1. Introduction

The increasingly competitive nature of the door-lock production industry has motivated manufacturers to improve customer service and lower costs. A well-designed assembly line system is a crucial factor for success in this industry because assembly line costs are a primary part of the overall manufacturing costs. Furthermore, providing a diversified range of products is one of the key success factors for most manufacturing industries; therefore, a mixed-product assembly line that can be flexibly reconfigured for different product models has become popular in recent years. However, requiring a mixed-product assembly system to be both flexible and effective poses new challenges.

In this paper, the door-lock mixed-product assembly line sequencing problem is investigated and an effective solution approach is designed. We interview one of the largest ironware manufacturing companies in Asia, company F, and solve its assembly line sequencing problem for a real-world case. To ensure productivity and efficiency in the sequencing of assembly lines, company F must consider practical factors, such as the daily fulfillment of orders, inventory cost, delay penalty and warehouse capacity, in the design of its production line system. However, these considerations complicate the problem significantly and make the resulting production planning problem a challenging optimization task. In this paper, we formulate the mixed-product assembly line sequencing problem as an integer program and examine the features of this program. A solution approach based on Lagrangian relaxation (LR) is devised based on the mathematical features of the

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program and is empirically applied to realistic cases. The numerical results demonstrate both the efficacy and efficiency of the developed solution heuristic.

The remainder of this paper is organized as follows. In Section 2, we review previous research on the mixed-product assembly line sequencing problem and LR approaches that have been used in previous studies. In Section 3, we present the mathematical formulation that is used to devise the solution heuristic. In Section 4, we present a heuristic based on the LR principle and detail the design of the heuristic. Numerical analyses for different scenarios using real-world data from company F are presented in Section 5. In Section 6, we summarize the paper and identify future research directions.

2. Literature review

Mixed-product assembly lines have been widely studied in the literature. Rekiek et al. [1] outlined three core steps in designing mixed-product assembly lines: detailing the logical layout, selecting the product mix and production sequence and constructing the physical layout of the line. The authors introduced the concept of balance for ordering for the first two steps and designed grouping and ordering genetic algorithms (GA) to solve the problem. Tseng et al. [2] studied the integrated assembly and disassembly sequence planning problem. A mathematical program was developed that accounted for the tradeoff between avoiding delayed orders and inventory reduction and was solved by a GA. Lovgren and Racer [3] investigated the mixed-model sequencing (MMS) problem with conflict objectives (i.e., the customers' due date restrictions versus the production goals). The MMS problem with conflict objective functions was formulated as a multi-objective optimization program. Three basic types of heuristics were discussed and evaluated: greedy methods, a 2-optimal method and a border swap method.

The production line design problem presents new challenges. As increasing customer satisfaction is critical in today's market, manufacturers have offered a variety of products to meet the variations in customer demand in recent years. Nazarian et al. [4] discussed that in designing a multi-product production line, it is important to incorporate the times of product-change-dependent inter-task, line changeover, and flexible machine usage. Boysen et al. [5] considered both finished and intermediate inventory costs to be key factors in the mixed-product assembly line sequencing problem. Bukchin and Masin [6] investigated an assembly system design problem that included the concept of teams. Each team had workers with different specializations and every team member had to work cooperatively to complete the production process. The empirical results demonstrated that teamwork can potentially improve overall performance and reduce production costs. The aforementioned issues have seldom been considered in earlier studies.

To cope with demand fluctuations from end customers, many manufacturers have started to hire part-time workers to make production lines agile and flexible. Giard and Jeunet [7] explored the mixed-model assembly lines sequencing problem and developed an integer program. The authors optimized the number of sequence-dependent configurations and the number of temporary workers. A commercial optimization package was used to solve the resulting program. Except for the issue of part-time workers, other worker-related issues have been addressed in the literature. For instance, Zhao and Ohno [8] presented a mixed integer programming model that accounted for the walking times of each worker to minimize the total conveyor stoppage time. Celano et al. [9] considered human resource management in manual mixed model assembly U-lines. Various human resource management policies were introduced to minimize the total conveyor stoppage time. Ding and He [10] incorporated multiple sequencing concerns (i.e., worker- and pattern-related issues) and cost-based penalty weights into a mathematical formulation for a multiple product automobile assembly line sequencing problem. A constructive-swapping re-sequencing heuristic was developed to solve the resulting program. The mixed model sequencing problem for assembly lines with serial workstations was studied by Bautista and Cano [11]. The authors considered interruption rules for workload minimization in their formulation and developed a dynamic programming solution approach. Lin and Chu [12] studied the mixed-product assembly line sequencing problem. Although insights could be gained from their empirical studies, a commercial optimization package was used to solve the problem, significantly reducing the practical value of their work. As we demonstrate later in this study, commercial optimization packages cannot be used to solve this type of problem efficiently, especially for problems of realistic sizes.

It is well recognized that the various types of assembly line problems that have been reported in the aforementioned literature are difficult to solve. The LR technique has been widely used to effectively solve this complex problem. To solve multi-item lot-sizing problems with joint piecewise linear resource costs and dynamic demand, Rizk et al. [13] developed an LR heuristic and devised a subgradient method to determine an upper bound on the solution. Matta [14] presented LR-based relaxation and decomposition procedures for a single-line multiproduct scheduling problem. A lower bound on the solution was obtained by solving a shortest path problem using Lagrangian decomposition and a *N*-multiple knapsack problem.

Sural et al. [15] presented LR-based heuristics for lot sizing of a setup time problem with the objective of minimizing the total inventory holding cost. To generate effective upper bounds, the authors devised objective functions that maximized the production time over a fixed period and implemented a branch-and-bound-based method to tighten the upper bound.

Two important streams of research have received significant attention in recent years: mixed-model sequencing and mixed-product sequencing problems. Although these problems appear to be similar to each other, there is only one product with multiple models in each production line in a mixed-model sequencing problem and multiple products with only one model in each production line in a mixed-product sequencing problem. To solve the mixed-model flow line sequencing

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