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Resource-constrained assembly line balancing problems with multi-manned workstations

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ABSTRACT

This study proposes a mixed integer programming model for the resource constrained assembly line balancing problem with multi-manned workstations. Resources refer to machines or tools (such as jigs and hand tools) in the production line. The objective is to minimize the number of workstations, operators, and resources to obtain the optimal allocation of tasks, operators, machines, and resources. To improve the solving efficiency, this study develops a hybrid heuristic approach that combines the procedure of building feasible balancing solutions and the genetic algorithm. In the practical case of an automobile factory, the traditional planning method was compared with the proposed approach. Results in terms of solution quality, production efficiency, and allocation configuration are analyzed and discussed. The findings of this study can be used as reference for decision making in the allocation of tasks, workstations, and operators in the manufacturing industry.

1. Introduction

In the manufacturing industry, the assembly line balancing problem (ALBP) has developed over the years. If planned production-line configuration is optimized, then cost will be reduced and the workload of each workstation will be balanced. One-sided, two-sided, and multi-manned assembly lines are the common types of production lines. The difference among these types is the number of operators in each workstation. One-sided and two-sided ALBPs have been widely studied. However, multi-manned ALBPs have rarely been explored. Traditional ALBPs configure an operator in each workstation, which limits the productivity of the production line. Hence, Akagi, Osaki and Kikuchi [1] assigned more than one operator to each workstation and proposed the parallel assignment method. With this method, multiple operators can be allotted to a workstation and the work efficiency of the assembly line can be increased. If a workstation is assigned two operators, then it becomes a common two-sided assembly line. By assigning more than one operator, multiple work units can be completed simultaneously. Meanwhile, the preparation time can be shortened, space utilization rate increased, and material handling cost reduced, thereby improving the output efficiency of the production line. In addition, sharing hand tools or other resources among operators can reduce resource costs.

In Fig. 1, the encircled number represents the task number, the number above the circle indicates the processing time of tasks, the upper bound for the number of operators per workstation is 2, and the cycle time is 42 s. The allocation comparison between single-manned and multi-manned workstations for ALBPs is depicted in Fig. 2. As shown in the task assignment of single-manned workstations in Fig. 2(a), the number of operators is 5, and the number of workstations is 5. Meanwhile, for the multi-manned workstations shown in Fig. 2(b), the number of operators is 5, and the number of workstations is 3. The end time for each task is indicated at the top right of the task bar. A production line with multi-manned workstations can achieve the same result as that of a production line with single-manned workstations for the same production efficiency, but will require only 60% space utilization. Adopting multi-manned workstations can effectively reduce the number of workstations for a production line [2,3].

Multi-manned ALBP is widely used in the production and assembly of large products, such as large-scale home appliances or vehicles. This multi-manned ALB is based on the traditional one-sided ALB and increases the number of operators per workstation to form a production line where each workstation is assigned multiple operators. In turn, each operator can perform various tasks on the same product according to task precedence. This study proposes a mixed integer programming model for the resource constrained assembly line balancing problem (RCALBP) with multi-manned workstations. Resources refer to machines or tools (such as jigs and hand tools) in the production line. Production in the factory requires the use of specialized machinery and

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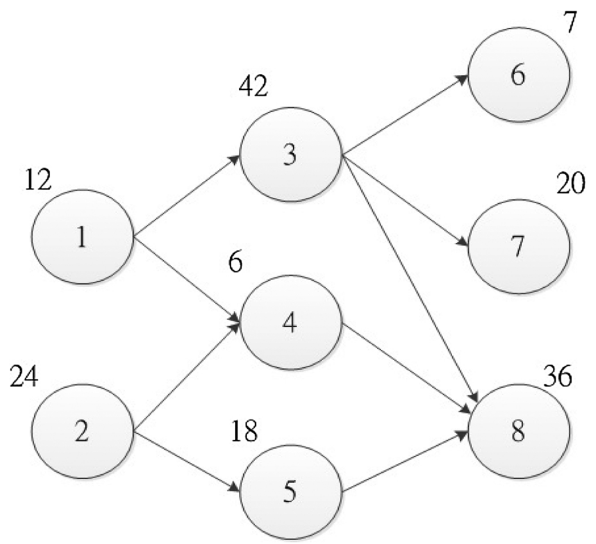

Fig. 1. The precedence diagram [2].

equipment, tools, and operators with specialized skills. However, these resources are limited. Existing research on ALBP neglects the issue of resource allocation. Moreover, only a few scholars have discussed the efficient allocation of limited machines and tools to workstations. Unlike traditional studies on ALBPs, this study considers multi-manned workstations; resource constraints; the minimization of the number of workstations, operators, and resources, the optimization of the allocation of tasks, operators, machines, and resources, and the determination of the start/end processing time of each task at different workstations.

Literature shows that the simple ALBP (SALBP) is well known as NP-hard [4,5]. Thus, multi-manned RCALBP, which is the generalized format of the SALBP, is strongly NP-hard [2,3]. It incorporates all of the difficulties and complexities of SALBP and is more complex than SALBP because of the addition variables and limitations such as selecting the sequence of the workers in each multi-manned workstation [6]. Therefore, an optimal solution based on the definition and solution of a mathematical programming model can be obtained only for small-sized instances of the multi-manned ALBP [7]. For this reason, it is necessary to use a heuristic-based algorithm to solve the medium- and the large-sized instances of the considered problem [7]. This study proposes a hybrid heuristic approach that combines the procedure of building feasible balancing solutions and genetic algorithm (GA) to map out an optimal line balancing plan for multi-manned workstations under resource constraints and optimize the space required for shop operations.

This paper is organized as follows. Section 2 reviews the related literature. Section 3 develops the mathematical model formulation for multi-manned RCALBP. Section 4 proposes a hybrid heuristic approach. Section 5 provides the computational results. Finally, the conclusion is presented in Section 6.

2. Literature review

Kim, Kim and Kim [8] divided ALBPs into five types, namely, Types 1–5, according to their objective functions. Type-1 problems involve a minimal number of workstations with known cycle time, total number of tasks, and task precedence. Yu and Yin [9] proposed the adaptive GA to resolve ALBPs (minimal number of workstations and workload balance). In the algorithm, a dynamic adjustment mechanism was designed, with crossover and mutation rates that automatically adapt to the specific fitness value. Compared with the traditional heuristic algorithms, their algorithm has effective convergence and efficient computation speed. For ALBPs with resource constraints, Kao, Yeh, Wang and Hung [10] presented the shortest route algorithm to minimize the total number of workstations and amount of resources required for production. Tapkan, Ozbakir and Baykasoglu [11] addressed two-sided ALBPs of a single type of products. To solve the minimal number of workstations within a given period of time, the authors developed a mixed integer nonlinear programming model. With regard to the complexity of such ALBPs, they introduced two algorithms, namely, the bees algorithm and artificial bee colony algorithm, with which the best or approximate best solution can be obtained as proven in literature. Noorul Haq, Rengarajan and Jayaprakash [12] proposed a hybrid GA for mixed-model ALBPs and solved the minimal number of workstations with the given cycle time. The modified ranked positional method was applied to obtain an initial solution. The search range was reduced, and the computational efficiency was enhanced.

In Type-2 problems, the minimum cycle time with the given conditions (such as the total number of workstations and tasks, and task precedence) is resolved to enhance output efficiency. For two-sided ALBPs with mated-stations arranged on both sides of the conveyor belt, Kim, Song and Kim [13] presented a mixed-integer programming model and a GA to solve the minimal cycle time with the given number of workstations. Premature convergence was avoided with increased population diversity and search efficiency by adopting the strategy of localized evolution and steady-state reproduction. The proposed algorithm's superiority was confirmed by comparing it with the existing GA.

Type-3 problems with the given number of workstations aim to balance the workload of various workstations by optimizing task assignment. Kim, Kim and Cho [14] proposed a new heuristic method combined with the modified GA for ALBPs to achieve equal task assignment among workstations where applicable and minimize workload differences. Results under this method are better than those of GA and others, but the cycle time is shorter. Mozdgir, Mahdavi, Badeleh and Solimanpur [15] developed a differential evolution algorithm to smooth the workload among workstations and optimized the algorithm parameters by using the Taguchi method.

In Type-4 problems, maximizing work relatedness requires finding an assignment of tasks such that interrelated tasks are allotted to the same workstation where possible [8]. Generally, a small number of direct link segments between the tasks in the precedence diagram denote high work relatedness. Kim, Kim and Kim [8] provided a measure for Type-4 problems, namely, the index of work relatedness (IWR), to quantitatively assess the relatedness. The greater the IWR, the higher the work relatedness.

In Type-5 problems, the two objectives, namely, maximizing workload smoothness and maximizing work relatedness, are considered simultaneously [8]. For this type of ALBPs, Kim, Kim and Kim [8] aimed to explore the Pareto optimality by combining a new decoding and repair method with a GA. Lee, Kim and Kim [16] considered the maximum work relatedness and slackness as judgement factors in decision making on two-sided ALBPs and proposed a new heuristic method for task assignment to solve the multi-objective programming problems. Nearchou [17] introduced a novel method based on particle swarm optimization (PSO) for the SALBP. Two criteria are simultaneously considered for optimization: maximize the production rate (equivalently, minimize the cycle time) and maximize the workload smoothing (i.e., to evenly allocate the workload to the workstations).

Azizoğlu and İmat [18] considered a SALBP with fixed number of workstations and prespecified cycle time. The objective is to minimize the sum of the squared deviations of the workstation loads around the cycle time, hence maintain workload smoothing. They developed several optimality properties and bounding mechanisms, and use them in their proposed algorithm. Moreira, Pastor, Costa and Miralles [19] proposed the use of Miltenburg's regularity criterion and cycle time as metrics for integration of workers and productivity, respectively. Results obtained through an extensive set of computational experiments indicate that a good planning can obtain trade-off solutions that perform well in both objectives. Oksuz, Buyukozkan and Satoglu [20] aimed the maximization of the line efficiency for the U-shaped assembly line worker assignment and balancing problem by considering