Computers and Operations Research 82 (2017) 102–113

Contents lists available at ScienceDirect

Computers and Operations Research

journal homepage: www.elsevier.com/locate/cor

Balancing stochastic two-sided assembly line with multiple constraints using hybrid teaching-learning-based optimization algorithm

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ARTICLE INFO

Article history:
Received 5 November 2014
Revised 20 April 2016
Accepted 26 January 2017
Available online 28 January 2017

Keywords:
Stochastic two-sided assembly line balancing
Teaching-learning-based Optimization
Variable neighborhood search
Multiple constraints

ABSTRACT

Two-sided assembly lines are usually found in the factories which produce large-sized products. In most literatures, the task times are assumed to be deterministic while these tasks may have varying operation times in real application, causing the reduction of performance or even the infeasibility of the schedule. Moreover, the ignorance of some specific constraints including positional constraints, zoning constraints and synchronism constraints will result in the invalidation of the schedule. To solve this stochastic two-sided assembly line balancing problem with multiple constraints, we propose a hybrid teaching-learning-based optimization (HTLBO) approach which combines both a novel teaching-learning-based optimization algorithm for global search and a variable neighborhood search with seven neighborhood operators for local search. Especially, a new priority-based decoding approach is developed to ensure that the selected tasks satisfy most of the constraints identified by multiple thresholds of the priority value and to reduce the idle times related to sequence-dependence among tasks. Experimental results on benchmark problems demonstrate both remarkable efficiency and universality of the developed decoding approach, and the comparison among 11 algorithms shows the effectiveness of the proposed HTLBO.

1. Introduction

Two-sided assembly lines are usually designed to produce large-sized high-volume products. In this two-sided line, some tasks may be preferred to be operated on exactly one side of this line (called L-type or R-type tasks), while others can be operated on either side of the line (E-type tasks). And, in a typical two-sided assembly line shown in Fig. 1, tasks are operated in parallel on both sides. A pair of facing stations (E.g. station 1 and station 2) on this line is called a mated-station (e.g. mated-station 1), and one of them calls the other a companion. Two-sided assembly lines can provide many advantages over the well-known one-sided assembly lines. They are: (1) the length of assembly line can be shortened, (2) throughput and setup time can be reduced, (3) the cost of fixtures and tools can be decreased and (4) the material handling can be lessened (Bartholdi JJ, 1993).

Compared with the one-sided assembly line balancing, the distinguishing feature of the two-sided is the restriction on the operation directions. Due to the combination of the direction constraint and precedence constraint, idle times between two successive tasks are always unavoidable. For example, supposed that task k is an immediate predecessor of task l in Fig. 1, task l cannot be started until task k is completed, resulting in the sequence-dependent waiting time in station 1.

On the other hand, multiple constraints existing in real application, which did not receive enough attention due to its complexity, should be taken into account. For example, synchronism constraints arise when two operators on both sides of the same mated-station need to collaborate (Simaria and Vilarinho, 2009). Zoning constraints may occur when some tasks are forced or not allowed to be assigned to the same station or mated-station (Baykasoglu and Dereli, 2008). If tasks must be operated on the same station or mated-station, positive zoning constraints often show up. If tasks are prohibited on the same station or mated-station, negative zoning constraints are the consequence. Positional constraints arise when certain tasks need to be allocated to a predetermined station due to heavy or immovable facilities in that station (Kim et al., 2000).

In most literatures concerning two-sided assembly line balancing (TALB) problems, the operation times of tasks are assumed to be deterministic. But in real application, the tasks may have varying operation times due to machine breakdown, lack of employee training, loss of motivation, non-qualified operators, complex tasks, and unfavorable environment (Özcan, 2010; Chiang et al., 2015). If the stochastic attribute of operation times is ignored, the perform-

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http://dx.doi.org/10.1016/j.cor.2017.01.015
0305-0548/

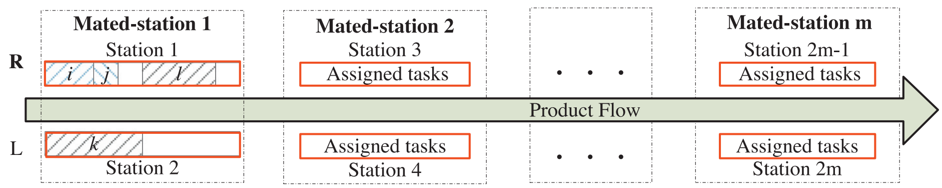

Fig. 1. A two-sided assembly line.

ing schedule may become less productive. Even worse, the schedule sometimes becomes infeasible and leads to the interruption of production.

To our best knowledge, only two papers deal with the stochastic two-sided assembly line balancing (STALB) problem (Özcan, 2010; Chiang et al., 2015), and no paper focuses on the multiple constraints in stochastic two-sided assembly line. Therefore, this paper concentrates on the STALB with multiple constraints (STALB-MC), and we mainly represent three contributions to this problem as follows. (1) The mathematical model for stochastic two-sided assembly with multiple constraints is presented and a set of new benchmark problems are tested. (2) A new universal priority-based decoding approach is developed to tackle stochastic operation times and multiple constraints, in order to reduce idle times related to sequence-dependence of the tasks and increase the possibility of obtaining feasible solutions. (3) A hybrid teaching-learning-based optimization (TLBO) is utilized to seek for optimal solutions. The TLBO has shown distinguished performance in addressing optimization problems of constrained benchmark functions, constrained mechanical design, and continuous non-linear numerical optimization (Rao et al., 2011; Niknam et al., 2012; Rao et al., 2012 and Rao and Patel, 2013). The main features of the proposed TLBO algorithm include the heuristic initialization, the crossover operator to enhance global search and the variable neighborhood search for a strong local search. Several other algorithms, including a genetic algorithm, a tabu search algorithm, a bee colony intelligence and etc., are extended to solve the STALB problem and we also carry out a comparative evaluation of these meta-heuristics.

This paper is organized as follows: Section 2 presents the literature review on STALB problems; Section 3 deduces the formulation of the STALB problems; Section 4 details implementing the HTLBO for STALB problems, especially the methodology to cope with multiple constraints; Section 5 discusses the experiment results and compares the proposed algorithm with other established ones; Section 6 provides the conclusions and proposes future research.

2. Literature review

Bartholdi (1993) was the first to address and solve the two-sided assembly line balancing (TALB) problem. After that, more approaches are developed, which can be divided into two groups: exact algorithms and heuristic/meta-heuristics algorithms. For exact algorithms, Hu et al., (2008) provided the lower bound of the station number and presented a station-oriented enumerative algorithm to find optimal solutions for small-size problems. Wu et al. (2008) proposed the branch-and-bound algorithms to solve both small-size and certain large-size problems optimally. Hu et al., (2010) developed dominance rules and reduction rules in the branch-and-bound algorithms to solve large-size TALB problems, and most of them were optimal solutions. To speed up the computational process, heuristic/meta-heuristic algorithms are gradually adopted. Kim et al., (2000) proposed a meta-heuristic named genetic algorithm to deal with TALB with positional constraints. Lee et al., (2001) came up with a heuristic-based assignment procedure to maximize the relatedness and work slackness. Özcan and Toklu (2009a) developed a tabu search algorithm, in which two objectives of minimizing the number of stations and the smoothness index were achieved concurrently. Chutima and Chimklai (2012) used the particle swarm optimization algorithm and Özcan and Toklu (2009b) utilized the simulated annealing algorithm to solve the mixed-model TALB problem.

To deal with multiple constraints in TALB problem, Kim et al., (2000) addressed positional constraints. Baykasoglu and Dereli (2008), Özbakir and Tapkan (2011) considered zoning constraints. Simaria and Vilarinho (2009) considered the zoning and synchronism constraints. Then Tapkan et al., (2012a) proposed bee algorithm to deal with the positional constraints, the zoning constraints and the synchronism constraint. Yuan et al., (2015), Li et al., (2014), Wang et al., (2014), and Purnomo et al. (2013) used late acceptance hill-climbing algorithm, teaching-learning-based optimization algorithm, hybrid imperialist competitive algorithm, and genetic algorithm respectively to handle the above three constraints. And Tuncel and Aydin (2014) also utilized teaching-learning-based optimization algorithm to handle the constraints in real application. With respect to the decoding method for TALBP problem with multiple constraints, there are only a few researches including Yuan et al., (2015) and Li et al., (2014). And all of them ignore the positional constraint in the decoding scheme. Moreover, these researches allocate the tasks in positive zoning constraint as a whole, although they only need to be in the same station or mated-station in real application.

To cope with the uncertain factors in real application of the two-sided assembly lines, Özcan (2010) built a chance-constrained mixed integer programming model to approach the TALB problem with stochastic operation times. Chiang et al., (2015) improved this model by considering the probability that both sides of the mated-station are finished within the cycle time. Özbakir and Tapkan (2010) considered the fuzzy multi-objective two-sided assembly lines and the bee algorithm was proposed to handle the imprecise objectives. Tapkan et al., (2012b) tackled the fuzzy multi-objective two-sided assembly line balancing problem with all the three additional constraints via bee algorithm.

As we can see, multiple constraints and stochastic operation times are two main aspects in two-sided assembly lines. However, no study has been performed to consider these two factors concurrently. Moreover, no research focuses on the decoding methodology of STALB problem with multiple constraints. This study thus concentrates on STALB problem with multiple constraints with new recent algorithm, and develops a new priority-based decoding approach to deal with multiple constraints specially.

3. Stochastic two-sided assembly line balancing

3.1. Problem assumptions

Basic assumptions of the STALB problem with multiple constraints in this study are given as follows:

(1) The operation times of tasks are stochastic and distributed with normal distribution independently.