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Two-sided assembly line balancing using teaching–learning based optimization algorithm

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ABSTRACT

Assembly line balancing plays a crucial role in modern manufacturing companies in terms of the growth in productivity and reduction in costs. The problem of assigning tasks to consecutive stations in such a way that one or more objectives are optimized subject to the required tasks, processing times and some specific constraints is called the assembly line balancing problem (ALBP). Depending on production tactics and distinguishing working conditions in practice, assembly line systems show a large diversity. Although, a growing number of researchers addressed ALBP over the past fifty years, real-world assembly systems which require practical extensions to be considered simultaneously have not been adequately handled. This study deals with an industrial assembly system belonging to the class of two-sided line with additional assignment restrictions which are often encountered in practice. Teaching–learning based optimization (TLBO), which is a recently developed nature-inspired search method, is employed to solve the line balancing problem. Computational results are compared with the current situation in terms of the line efficiency, and the solution structure with workload assigned to the stations is presented.

1. Introduction

Assembly lines are the mostly used technique in mass production, as they enable the assembly of complicated products by operators with restricted training and devoted robots and/or machines. Thus, production of standardized similar products is performed in cost efficient flow-line systems. A classic assembly line is composed of serial stages, in which workpieces (jobs) are flowed down the line and transferred from one workstation to the other through workforce or material handling equipment. At each stage, definite assembly operations are completed repeatedly in order to obtain finished products. The tasks are allocated to workstations considering some restrictions including precedence constraints, number of workstations, cycle time and incompatibility relations between tasks. The problem of assigning jobs to consecutive workstations that one or more goals are optimized based on the required tasks, processing times and some particular constraints are named the assembly line balancing problem (ALBP). The process of balancing is a crucial task in designing highly efficient and cost effective assembly lines. The establishment or re-arrangement of a line is quite an expensive investment so effective regulations of lines are essential at the beginning of process. Lines need to be balanced in the design stage; otherwise unbalanced lines cause inefficiency in production, increased cost, and a lot of casualties such as waste of labor or equipment.

Since the classical ALB problem was first described in 1955 by Salveson, many studies have been done with regard to assembly line design problems. Researchers have focused on improving qualified and fast solution approaches for solving the line balancing problem in assembly systems. In the first researches, the authors studied on mostly minimizing number of workstations and used mathematical modeling methods, e.g. integer programming and goal programming. Then, they head towards heuristic approaches to handle large size problems.

Based on the restrictions on operation directions, assembly lines can be classified as one-sided and two-sided assembly lines. Two-sided assembly lines are usually designed to produce high-volume large-sized standardized products, such as automobiles, trucks, buses and home appliances, in which some tasks must be performed at a specific side (left-side or right-side) of the product. Although a large number of methods for solving one-sided assembly line balancing problem have been studied in literature, little attention has been paid to balancing of two-sided assembly lines (Simaria & Vilarinho, 2009). In the last decade, the researchers started to study on two-sided assembly lines that are recognized

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to be of crucial importance in real life (Chutima & Chimklai, 2012; Kim, Song, & Kim, 2009; Lee, Kim, & Kim, 2001; Ozbakır & Tapkan, 2011; Ozcan, 2010; Ozcan & Toklu, 2009a, 2009b; Simaria & Vilarinho, 2009; Tapkan, Ozbakır, & Baykasoglu, 2012; Wu, Jin, Bao, & Hu, 2008). However, problems considered in these studies were generally test problems from the literature. Real-world assembly systems which require practical extensions to be considered simultaneously have not been adequately handled by the authors. The challenge lies in putting theory into practice, which involves simultaneously handling efficiency, practical assignment restrictions and competitiveness. This study deals with an industrial assembly system belonging to the class of two-sided line with additional assignment restrictions which are often encountered in practice. A novel optimization method, teaching–learning based optimization (TLBO) Algorithm, is employed for solving two-sided assembly line balancing problem. TLBO algorithm was proposed by Rao, Savsani, and Vakharia (2011) for the optimization of mechanical design problems, and then it has been applied to various engineering problems including some unconstrained and constrained non-linear programming problems by its developers and several other researchers (Amiri, 2012; Naik, Satapathy, & Parvathi, 2012; Rao & Kalyankar, 2011; Rao & Patel, 2012; Roy & Bhui, 2013; Satapathy & Naik, 2011; Singh, Panigrahi, & Abhyankar, 2013; Togan, 2012). Recently, the performance of the TLBO algorithm on some combinatorial optimization problems, namely flow shop and job shop scheduling problems is tested by Baykasoglu, Hamzadayi, and Yelkenci Kose (2014). The authors concluded that the performance of the TLBO algorithm is comparable with the best known solutions from the literature. Assembly line balancing is one of the most important problems in the field of production management and takes part in the NP-hard class of combinatorial optimization problems. This study is the first to apply the TLBO algorithm to the assembly line balancing problem.

The remainder of this paper is organized as follows. A brief introduction to basic characteristics of two-sided assembly lines is given in the next section. In Section 3, we described an industrial assembly system, which can be characterized as a two-sided assembly line. In order to improve the line balance implemented by the company for a given cycle time, the assembly line balancing problem is solved by using a population based optimization algorithm, TLBO, which simulates the teaching–learning process within a classroom environment. Computational results are compared with current state in terms of the line efficiency, and the solution structure with workload assigned to the stations was presented in Section 4. Finally, the summary and concluding remarks are presented in Section 5.

2. Two-sided assembly lines

Depending on production tactics and different conditions in practice, assembly line systems show a large diversity; therefore they can be classified in various ways. One of those is to categorize ALs based on the restrictions on operation directions. If only one side (left or right) is used in an assembly line, then it is called as one-sided assembly line. Most of the studies in the literature dealt with balancing of one-sided assembly lines. A two-sided assembly line is a type of production line in which different assembly tasks are performed in parallel at both sides of the line as shown in Fig. 1. In this case, some of the assembly operations should be performed at strictly one side of the line (right or left side) and the others can be assigned to either side of the line. Thereby, tasks are classified into three types according to the restrictions on the operation directions: L (left), R (right) and E (either)-type tasks.

Two-sided assembly lines are usually designed to produce large-sized high-volume products such as automobiles, buses, trucks, and some home appliances. These lines have some advantages over one-sided assembly lines: (i) shorter line length (ii) reduced throughput time, worker movements, and setup time (iii) lower cost of tools and fixtures (iv) less material handling (Bartholdi, 1993).

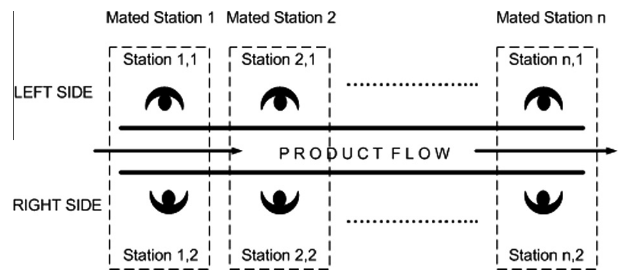

Fig. 1. Configuration of a two-sided assembly line.

Besides the cycle time and precedence restrictions, the following constraints may appear in a two-sided assembly line balancing problem (TALBP) in practice:

(a). Synchronization constraints

The essential difference between the assignment of tasks in one-sided lines and in two-sided lines is mainly related with the sequence in which the tasks are performed. In one-sided lines, the sequence of the tasks within a workstation is not important considering providing precedence relations. But in two-sided lines, sequencing is a critical job for an efficient assignment of tasks. If a task has synchronization constraint, it has to be assigned to a workstation at the opposite side of the line where its mated-task was started in parallel. Otherwise, tasks performed opposite sides of the line can conflict with each other through precedence constraints which might cause idle time if a workstation needs to wait for a predecessor task to be completed at the opposite side of the line (Gunasekaran & Sandhu, 2010).

(b). Task zoning constraints

Some zoning restrictions constrain the assignment of various operations to a specific station which is named *positive zoning constraints* and others forbid the assignment of operations to the same station which is named *negative zoning constraints*. Positive zoning constraints are mostly related with the usage of common equipment or tooling. Hence, some of the operations are needed to assign to the same workstation. Negative zoning constraints are usually related with the technological issues. It may not be possible to perform some tasks in the same workstation because of safety reasons or any other causes.

(c). Workstation related constraints

Some operations need particular equipment or material that is only available at a certain workstation so these tasks should be assigned to that workstation.

(d). Position related constraints

In producing of the large and heavy workpieces, they have a fixed position and cannot be turned. In this case, we come up position related constraints which are commonly faced in real-world problems (Tuncel & Topaloglu, 2013). Then, tasks are grouped according to the position in which they are performed.