Journal of Manufacturing Systems 33 (2014) 177–187

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

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

Modeling and solving mixed-model assembly line balancing problem with setups. Part I: A mixed integer linear programming model

Şener Akpinar*, Adil Baykasoğlu*

Dokuz Eylul University, Faculty of Engineering, Department of Industrial Engineering, Izmir, Turkey

ARTICLE INFO

Article history:
Received 19 June 2013
Received in revised form
15 November 2013
Accepted 27 November 2013
Available online 27 December 2013

Keywords:
Mixed-model assembly line balancing
Mixed-integer linear programming
Sequence dependent setup times
Intra-station sequencing
Zoning constraints
Parallel workstations

ABSTRACT

This paper is the first one of the two papers entitled "modeling and solving mixed-model assembly line balancing problem with setups", which has the aim of developing the mathematical programming formulation of the problem and solving it with a hybrid meta-heuristic approach. In this current part, a mixed-integer linear mathematical programming (MILP) model for mixed-model assembly line balancing problem with setups is developed. The proposed MILP model considers some particular features of the real world problems such as parallel workstations, zoning constraints, and sequence dependent setup times between tasks, which is an actual framework in assembly line balancing problems. The main endeavor of Part-I is to formulate the sequence dependent setup times between tasks in type-I mixed-model assembly line balancing problem. The proposed model considers the setups between the tasks of the same model and the setups because of the model switches in any workstation. The capability of our MILP is tested through a set of computational experiments. Part-II tackles the problem with a multiple colony hybrid bees algorithm. A set of computational experiments is also carried out for the proposed approach in Part-II.

1. Introduction

In 1913, Henry Ford changed the type of manufacturing system by introducing a moving belt in a factory for the first time. Before the moving belt, workers were able to build one piece of an item at a time instead of an item at a time. This changed type of manufacturing system named as assembly line and reduced the cost of production. Over the years a new problem type, design of efficient assembly lines, increased in importance. Assembly line balancing problem (ALBP) is a well-known assembly design problem, which consist of partitioning the assembly work among the workstations so as to optimize some objective.

Assembly lines were firstly created to produce one single homogeneous product in high volumes. The balancing problem of this type of lines named as simple assembly balancing problem (SALBP), which was first mathematically formulated by Salveson [1]. Single-model assembly lines are the least suited production system for high variety demand scenarios. Current consumer-centric market conditions require high flexibility in manufacturing systems. Hence, assembly lines must be designed so as to satisfy high-mix/low volume manufacturing strategies. Due to high cost to build and maintain an assembly line, the manufacturers produce one model with different features or several models on a single assembly line. This changed type of assembly lines lead to arise the mixed-model assembly line balancing problem, which was handled by Thomopoulos for the first time in the literature [2].

The relevant literature about the solution procedures of the mixed-model assembly lines was initiated by the approaches of Thomopoulos [3] and can be divided into three groups: mathematical programming, heuristics and meta-heuristics, and hybrid approaches. For more detailed information, the reader can refer to Battaïa and Dolgui for a recent survey [4]. Heuristic and meta-heuristic approaches were widely used in order to cope with the problem. The field of hybrid approaches has become very popular among researchers because of the insufficient performance of heuristics and pure meta-heuristics while exploring the solution space effectively as problems get larger and more complex as in the real life. On the other hand, mathematical programming approaches are used to formally describe the problem. In this paper we proposed a new mathematical programming model for type-I mixed-model assembly line balancing with sequence dependent setup times between tasks (MMALBPS-I). To the best of our knowledge, this is the second attempt to model type-I mixed-model assembly line balancing problem while considering the sequence dependent setup times in the literature. The first attempt belongs to Nazarian et al. [5] and a comparison between these two models will be given in Section 3.

Akpinar et al. summarized the published papers related to type-I mixed-model assembly line balancing problem (MMALBP-I)

* Corresponding authors. Tel.: +90 232 301 76 32; fax: +90 232 301 76 08.
E-mail addresses: sener.akpinar@deu.edu.tr (Ş. Akpinar), adil.baykasoglu@deu.edu.tr (A. Baykasoğlu).

0278-6125/$ – see front matter © 2013 The Society of Manufacturing Engineers. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jmsy.2013.11.004

between the years 1997 and 2011 by taking into account the line configuration, the methodology, and the employed data to test the performance of the proposed approach [6]. From their summary, it is observed that few papers dealt with mathematically modeling of the MMALBP-I and none of these studies handled the sequence dependent setup times between tasks except Nazarian et al.'s study [5].

Askin and Zhou proposed a non-linear integer mathematical model for MMALBP-I [7]. Their model allows using parallel workstations if required. By the way, the authors relaxed the splitting restriction for the first time. Gokcen and Erel modeled the MMALBP-I as a binary goal program [8]. They considered several conflicting goals and their model provides flexibility to the decision maker. Their model also allow to the use of zoning constraints. Moreover, Gokcen and Erel developed a binary integer programming model for the MMALBP-I [9]. The authors stated that their model may be used as a validation tool for the heuristic procedures for the MMALBP-I. On the hand, Erel and Gokcen proposed a shortest-route formulation of the MMALBP-I [10].

Vilarinho and Simaria combined the concepts of parallel workstations assignment and zoning constraints in their mathematical programming model [11]. Their model aims at minimizing the number of workstations as a primary goal, and balancing the workloads between and within workstations as a secondary goal.

The literature about the mixed-model assembly line balancing problem (MMALBP) use a restriction ensures that assigning common tasks of different models to the same workstation. This restriction has been relaxed by Bukchin et al. [12], and Bukchin and Rabinowitch [13] and they allow the assignment of a common task for multiple products to different workstations. The same relaxation was also used by Kara et al. [14]. They proposed a new binary mathematical programming model based on the Bukchin and Rabinowitch's [13] model and have also developed two goal programming approaches, one with precise and the other with fuzzy goals. Hop dealt also with fuzzy concept and handled the MMALBP with fuzzy processing times and formulated the problem as a fuzzy binary linear programming model, which was transformed to a mixed zero-one program [15].

Simaria and Vilarinho dealt with the MMALBP-I with a different line configuration, two-sided assembly line and developed a mathematical programming model covers the parallel workstations assignment and zoning constraints [16]. The phenomenon of two-sided assembly lines was also handled by Özcan and Toklu [17]. They also proposed a mathematical programming model for the two-sided MMALBP-I. On the other hand, Sparling and Miltenburg [18], and Kazemi et al. [19] handled the U-line MMALBP-I. They all developed mathematical programming models for the problem.

In this paper, we deal with the MMALBP-I with some particular features of the real world problems such as parallel workstations and zoning constraints. Furthermore, we extend the problem by adding sequence dependent setup times between tasks, which is a new concept for assembly line balancing problem. We developed a mixed integer linear programming (MILP) model for formally describing the extended problem.

The rest of the paper is organized as follows. In Section 2, an overview on the concept of sequence-dependent setup times in assembly line balancing are given. The proposed MILP model is given in Section 3. An illustrative example is solved in Section 4. Computational experiments are given in Section 5. Finally, the discussions and conclusions are presented in Section 6.

2. An overview on the sequence-dependent setup times

The concept of the sequence-dependent setup times had been considered negligible until the importance of setup times were investigated for the scheduling problems [20]. Furthermore, setup times were generally considered in low production systems like job shops [21]. On the other hand, most of the studies about assembly lines also assumed that setup times are negligible, because of their low proportion in comparison with task processing times. The phenomenon of sequence dependent setup times has been a challenging field in ALBPs, since Andrés et al. (see the corrigendum to this paper provided by Pastor et al. [23]) dealt with the sequence dependent setup times for the first time for the SALBP [22].

For the assembly line balancing applications setups were considered independently as they executed just before or after the tasks. Thus, their times were added to the task times [22]. In such situations, it is not required to determine intra-stations schedules; however, they have considerable effect on the workload of a workstation in case of sequence dependent setup times between tasks. In other words, different intra-station schedules mean different workloads for a workstation. Since the aim of assembly line studies is achieving effectively balanced lines, determining optimum intra-station schedules become much more important. That is to say, determining the optimum task performing sequences provides the maximum line efficiency, which is one of the most important performance criteria of the assembly lines. Besides, if the cycle time is low, considering sequence dependent setup times between tasks becomes more important, because setup times may represent a high percentage of cycle time.

The existing literature about the assembly line balancing problems with sequence dependent setup times has extensively dealt with single model lines. Andrés et al. extended the simple version of the ALBPs by considering the sequence dependent setup times between tasks for the first time and they referred it to be general assembly line balancing problem with setups (GALBPS) [22]. The authors developed the mathematical programming model of the problem. Due to the high combinatorial nature of the problem they provided some heuristics and a GRASP algorithm to tackle the innovative problem. Moreover, Martino and Pastor developed heuristic procedures based on priority rules in order to solve the same problem; however the performance of their procedures were not effective in high-size tests [24]. A similar problem was introduced by Scholl et al. and they formulated several versions of a mixed-integer program for the problem [25]. As a result of their experiments, the authors stated that it is not effective enough modeling and solving the problem with MIP standard software. Scholl et al. modified the problem by introducing the phenomena of backward and forward setups and the triangle inequality for the setup times [26]. They formulated the modified problem as a mixed-binary linear model and developed effective solution procedures for the problem. Yolmeh and Kianfar dealt also with single model lines with sequence dependent setup times between tasks [27]. They proposed a hybrid genetic algorithm for solving the problem. Hamta et al. enriched the SALBP by adding some realistic relevant aspects such as sequence dependent setup times [28]. They developed a mathematical model for the problem and the problem was tackled by a combination of particle swarm optimization (PSO) algorithm with variable neighborhood search (VNS). Seyed-Alagheband et al. addressed type-II SALBP, which was enriched by considering sequence-dependent setup times between tasks (GALBPS-II) [29]. They proposed a mathematical model based on Andrés et al.'s [22] model and the authors developed a novel simulated annealing (SA) algorithm to tackle the problem. Ozcan and Toklu handled the two-sided assembly line balancing problem with setups (TALBPS) [30]. The authors proposed a mixed integer program in order to solve and model the problem. The proposed model minimizes the number of mated-stations as a primary objective and minimizes the number of stations as a secondary objective. A heuristic approach was also presented.

This paper concerns the type-I mixed-model assembly line balancing problem with sequences dependent setup times between