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Type-E parallel two-sided assembly line balancing problem: Mathematical model and ant colony optimisation based approach with optimised parameters

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ABSTRACT

There are many factors which affect the performance of a complex production system. Efficiency of an assembly line is one of the most important of these factors since assembly lines are generally constructed as the last stage of an entire production system. Parallel two-sided assembly line system is a new research domain in academia though these lines have been utilised to produce large sized products such as automobiles, trucks, and buses in industry for many years. Parallel two-sided assembly lines carry practical advantages of both parallel assembly lines and two-sided assembly lines.

The main purpose of this paper is to introduce *type-E parallel two-sided assembly line balancing problem* for the first time in the literature and to propose a new ant colony optimisation based approach for solving the problem. Different from the existing studies on parallel assembly line balancing problems in the literature, this paper aims to minimise two conflicting objectives, namely *cycle time* and *number of workstations* at the same time and proposes a mathematical model for the formal description of the problem. To the best of our knowledge, this is the first study which addresses both conflicting objectives on a parallel two-sided assembly line configuration. The developed ant colony optimisation algorithm is illustrated with an example to explain its procedures. An experimental design is also conducted to calibrate the parameters of the proposed algorithm using response surface methodology. Results obtained from the performed computational study indicate that minimising cycle time as well as number of workstations help increase system efficiency. It is also observed that the proposed algorithm finds promising results for the studied cases of *type-E parallel two-sided assembly line balancing problem* when the results are compared with those obtained from other three well-known heuristics.

1. Introduction

Assembly lines are widely used flow-oriented production systems designed to produce high-quality and low-cost standardised homogeneous products, and have been a matter of concern of researchers for decades. An assembly line consists of serially linked workstations (with a conveyor belt or material handling system), in which a group of tasks is performed according to given precedence relationships within a limited duration (cycle time) (Avikal, Jain, Mishra, & Yadav, 2013; Kara, Ozguven, Yalcin, & Atasagun, 2011; Scholl & Boysen, 2009). Assembly line balancing problem is to assign tasks to an ordered sequence of workstations optimally by satisfying specific constraints (*i.e.* capacity constraints, assignment constraints, precedence constraints, etc.) (Kucukkoc, Karaoglan, & Yaman, 2013; Tuncel & Topaloglu, 2013). Each task must be assigned to exactly one workstation. The sum of processing times of all tasks assigned to a workstation constitutes its workload time and cannot exceed the cycle time designated for this workstation (Khorasanian, Hejazi, & Moslehi, 2013).

The studies related to assembly line balancing problems can be classified into two general groups according to the implementation of the lines: 'traditional assembly lines' and 'parallel assembly lines'. While traditional lines do not address line parallelisation; in parallel assembly lines, two or more lines are located in parallel

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to each other to maximise the sharing of resources and tools. Although the literature on traditional lines is rather extensive, the number of studies on Parallel Assembly Line Balancing Problem (PALBP) is quite limited. Table 1 summarises the main contributions regarding parallel assembly line balancing problems and lists out the proposed approaches till now.

The parallel line configuration idea was first addressed by Suer and Dagli (1994). They proposed a heuristic procedure which aims at determining the number of lines and workstations by considering assigning different models of a product to the lines. However, the precedence constraints were not considered and it was assumed that the entire job could be divided into any number of operations. Afterwards, Suer (1998) proposed alternative line configuration strategies for a single product.

However, the real PALBP, balancing of two or more assembly lines with a common set of resources, was introduced by Gökçen, Agpak, and Benzer (2006). Gökçen et al. (2006) formulated the PALBP mathematically and proposed two heuristic approaches. Development of other heuristic/meta-heuristic approaches followed Gökçen et al. (2006) and Benzer, Gokcen, Cetinyokus, and Cercioglu (2007) proposed a new shortest path approach based model for PALBP and illustrated the performance of the model on a numerical example. Baykasoglu, Ozbakir, Gorkemli, and Gorkemli (2009) proposed a novel Ant Colony Optimisation (ACO) based algorithm for PALBP and compared their test results with three other existing approaches from the literature. Cercioglu, Ozcan, Gokcen, and Toklu (2009) proposed a simulated annealing approach to solve PALBP and compared their results with the results of existing heuristic algorithm proposed by Gökçen et al. (2006). Ozcan, Cercioglu, Gokcen, and Toklu (2009) developed first multi-objective tabu search algorithm for PALBP and tested the performance of the algorithm on a set of well-known problems in the literature. Scholl and Boysen (2009) modelled the PALBP mathematically and proposed an exact solution procedure. Kara, Gokcen, and Atasagun (2010) suggested a fuzzy goal programming model that could be used for balancing parallel assembly lines. Ozcan, Cercioglu, Gokcen, and Toklu (2010) addressed parallel mixed-model assembly line balancing and sequencing problem with a simulated annealing approach with the aim of maximising the line efficiency by considering workload smoothness among workstations. Ozbakir, Baykasoglu, Gorkemli, and Gorkemli (2011) developed a novel multiple-colony ant algorithm for balancing bi-objective parallel assembly lines. This was one of the first attempts to solve the problem with swarm intelligence based meta-heuristics. Please refer to Lusa (2008) and Zhang and Kucukkoc (2013) for a more detailed survey on multiple and parallel assembly line balancing problems.

Assembly lines can alternatively be classified as one-sided assembly lines and two-sided assembly lines. While only one side of the line is used in a one sided assembly line, both left and right sides are used parallel in two-sided assembly lines. Two-sided assembly lines, introduced by Bartholdi (1993) for the first time, are usually designed to produce high-volume large-sized products such as trucks and buses. To solve the two-sided assembly line balancing problem some exact solution approaches were developed by Wu, Jin, Bao, and Hu (2008), Hu, Wu, Bao, and Jin (2010); and some heuristic/meta-heuristic approaches were proposed by Kim, Kim, and Kim (2000), Lee, Kim, and Kim (2001), Hu, Wu, and Jin (2008), Kim, Song, and Kim (2009), Ozcan and Toklu (2009, 2010), Yegul, Agpak, and Yavuz (2010), Ozcan (2010), Ozbakir and Tapkan (2010, 2011), Taha, El-Kharbotly, Sadek, and Afia (2011), Chutima and Chimklai (2012), Rabbani, Moghaddam, and Manavizadeh (2012), Purnomo, Wee, and Rau (2013), Khorasanian et al. (2013), and Tuncel and Aydin (2014). Among proposed meta-heuristics, studies belong to Baykasoglu and Dereli (2008), and Simaria and Vilarinho (2009) represented implementation of different ACO algorithms to balance two-sided lines with success.

Although the combination of the aforementioned types of production lines (parallel lines and two-sided lines) are frequently used in producing large sized items in industry, Parallel Two-sided Assembly Line Balancing Problem (PTALBP) was introduced by Ozcan, Gokcen, and Toklu (2010) very recently and there is only one published research concerning this problem so far. The reason for this situation could be the complexity of the PTALBP, as there is more than one line to be balanced and different conditions (*i.e.* precedence relationships, cycle times, task processing times, etc.) exist on each of the lines. Also, disregarding (or ignoring) the advantages of multi-line stations, which can be established between two adjacent lines, could contribute to the lack of studies on PTALBP. However, Ozcan, Gokcen et al. (2010) described the concept of parallel two-sided assembly lines and showed the advantage of utilising

Table 1
Summary of the literature on parallel assembly line balancing problems, adapted from Kucukkoc and Zhang (2014c).

Research	Method/approach	PM: K	PM: C	PM: O	Additional aims/features
Suer and Dagli (1994)	Heuristic procedure	●			Dynamic number of lines
Suer (1998)	3-phase heuristic with IP and MILP model	●			Dynamic number of lines
Gökçen et al. (2006)	Heuristic procedures and a mathematical programming model	●			
Benzer et al. (2007)	A network model	●			
Lusa (2008)	Survey				
Baykasoglu et al. (2009)	Ant colony optimisation	●			
Cercioglu et al. (2009)	Simulated annealing based approach	●			
Ozcan et al. (2009)	Tabu search algorithm	●			Workload balance between workstations
Scholl and Boysen (2009)	Binary linear programme and SALOME based exact solution procedure	●		●	Product-line assignment
Kara et al. (2010)	Two goal programming approaches	●	●		Three conflicting goals, task loads of workstations
Ozcan, Cercioglu et al. (2010)	Simulated annealing algorithm	●			Mixed-models and model sequencing, workload variance between workstations
Ozcan, Gokcen et al. (2010)	Tabu search algorithm	●			Parallel two-sided lines
Kucukkoc and Zhang (2014c)	Framework of a possible solution approach	●			Line length, mixed-model parallel two-sided lines, model sequencing
Kucukkoc and Zhang (2014b)	Agent based ant colony optimisation algorithm	●			Line length, mixed-model parallel two-sided lines, model sequencing

PM: Performance measure, K: Number of stations, C: Cycle time, O: Number of operators, IP: Integer programming, MILP: Mixed-integer linear programming.