Int. J. Production Economics 158 (2014) 314–333

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Mathematical model and agent based solution approach for the simultaneous balancing and sequencing of mixed-model parallel two-sided assembly lines

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ARTICLE INFO

Article history:
Received 27 January 2014
Accepted 12 August 2014
Available online 19 August 2014

Keywords:
Assembly line balancing
Mixed-model parallel two-sided assembly lines
Simultaneous line balancing and model sequencing
Agent based ant colony optimisation
Production lines
Meta-heuristics
Artificial intelligence

ABSTRACT

One of the key factors of a successfully implemented mixed-model line system is considering model sequencing problem as well as the line balancing problem. In the literature, there are many studies, which consider these two tightly interrelated problems individually. However, we integrate the model sequencing problem in the line balancing procedure to obtain a more efficient solution for the problem of *Simultaneous Balancing and Sequencing of Mixed-Model Parallel Two-Sided Assembly Lines*. A mathematical model is developed to present the problem and a novel agent based ant colony optimisation approach is proposed as the solution method. Different agents interact with each other to find a near optimal solution for the problem. Each ant selects a random behaviour from a predefined list of heuristics and builds a solution using this behaviour as a local search rule along with the pheromone value. Different cycle times are allowed for different two-sided lines located in parallel to each other and this yields a complex problem where different production cycles need to be considered to build a feasible solution. The performance of the proposed approach is tested through a set of test cases. Experimental results indicate that considering model sequencing problem with the line balancing problem together helps minimise line length and total number of required workstations. Also, it is found that the proposed approach outperforms other three heuristics tested.

1. Introduction

Production systems and product requirements have significantly evolved since the time of famous Model-T of Henry Ford. Assembly lines, which were initially developed for the cost efficient production of a single commodity, have changed to mixed-model lines to enable highly diversified and customised products to be manufactured. Different models of a product can be produced in an intermixed sequence on a mixed-model assembly line, so that a substantial reduction in set-up times and cost can be obtained with the utilisation of operators and workspace flexibly (Boysen et al., 2009).

Assembly lines are flow oriented production systems divided into sequentially arranged *(work)stations* connected by a mechanical transportation mechanism, such as a moving belt or conveyor. Each station is allowed a fixed time span, called *cycle time*, to perform assigned tasks on the product unit launched down the line. The set of tasks assigned to a station constitutes its *workload* (Otto et al., 2013; Sternatz, 2013). The wide spread use of mixed-model assembly lines can be attributed to the increased variety of customised product portfolio and compatibility of mixed-model lines with mass customisation in a Just-in-Time environment. So, accurately managed mixed-model assembly lines can help manufacturers balance workloads and minimise delay (Ding et al., 2006), because the assignment of tasks to workstations determines the productivity of the entire manufacturing system (Sternatz, 2013).

To obtain a successfully implemented mixed-model assembly line, both model sequencing and line balancing problems must be treated together, since these two problems are tightly interrelated to each other. The line balancing problem is the problem of assigning tasks to

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http://dx.doi.org/10.1016/j.ijpe.2014.08.010
0925-5273/

workstations by considering certain constraints (i.e. *precedence relationships*, *capacity constraints*, etc.) and is differentiated by sought objectives and considered constraints (Morrison et al., 2014). The model sequencing problem determines the production sequence of different product models assembled on the same line. The performance of an obtained line balance is affected by the sequence of produced models while the optimality of the model sequencing process depends on the results of line balancing (Kim et al., 2006). However, these two problems were dealt with separately by many researchers (i.e. Askin and Zhou (1997), Gokcen and Erel (1997), Vilarinho and Simaria (2002), McMullen and Tarasewich (2003), Haq et al. (2006), Ozcan and Toklu (2009); Hamta et al. (2013), Kucukkoc et al. (2013), and Manavizadeh et al. (2013a) for the line balancing problem; and Yano and Rachamadugu (1991), Bard et al. (1992), Kim et al. (1996), Zheng et al. (2011), Bautista and Cano (2011), and Xu and Li (2013) for the model sequencing problem) with different objectives ever since the mixed-model line balancing problem was first introduced by Thomopoulos (1967).

The rest of the paper is organised as follows. Following a comprehensive review of the literature in Section 2, Section 3 describes the MPTALB/S problem and presents the developed mathematical model. The solution procedure of the ABACO/S approach is depicted in Section 4. Sections 5 and 6 provide a numerical example and the results of computational experiments with comparisons. Finally, Section 7 gives conclusion and possible future research directions.

2. Literature review

In the literature, few researches dealt with the two problems at the same time. A summary of the literature on simultaneous balancing and sequencing of mixed-model lines is given in Table 1. The solution approaches in those researches can be divided into two groups: (i) hierarchical solution approaches, and (ii) simultaneous solution approaches. Hierarchical approaches, which solve one problem first and then the other under the constraint of the first solution, were employed by Thomopoulos (1967), Darel and Nadivi (1981), Merengo et al. (1999), and Rekiek et al. (2000); (Kim et al., 2006).

Regarding the simultaneous solution approaches, few studies have been carried out. Kim et al. (2006) proposed an endosymbiotic evolutionary algorithm for the integration of balancing and sequencing in mixed-model U-lines and demonstrated that hierarchical approaches cannot explore the solution space effectively. Kara et al. (2007b) addressed simultaneous balancing and sequencing problem in mixed-model U-shaped lines as contrary stations utilised on both back and front of the line are seriously affected by the model sequences on the line. That is why a task may require different processing time for different models and this issue may yield an unbalanced workload in contrary stations. They also proposed a simulated annealing approach to solve the problem with multiple conflicting objectives. Then, Ozcan et al. (2011) and Hamzadayi and Yildiz (2012) proposed different genetic algorithm based approaches for balancing and sequencing of U-shaped lines simultaneously; by considering stochastic times, and parallel workstations – zoning constraints, respectively.

Ozcan et al. (2010a) introduced balancing and sequencing of parallel mixed-model assembly lines and developed a simulated annealing based solution approach to the problem. Mosadegh et al. (2012) developed a mixed-integer linear programming model and a simulated annealing algorithm to provide exact and heuristic solutions of the problem with station-dependent assembly times in traditional mixed-model lines.

On the other hand, there is plenty of research on balancing of mixed-model lines in the context of different types of line configurations. Battaïa and Dolgui (2013) presented a taxonomy of those line balancing problems and their solution approaches. However, studies on the combination of mixed-model lines with different layouts or configurations (i.e. two-sided lines, parallel lines, U-shaped lines, etc.) are rather new as well as scarce. Two-sided lines are usually established to produce large-sized items, and both sides of the line are used to

Table 1
Summary of the literature on simultaneous balancing and sequencing of mixed-model lines.

Research	Problem	Method/approach	Performance measure(s)										
			NS	C	LE	WLS	RI	WIP	PUR	TUW	CoS	BC	LBT
Merengo et al. (1999)	B/S manual MALs	3-Phase methodology & simulation	•				•	•	•				
Kim et al. (2000a)	B/S MAL	Co-evolutionary algorithm								•			
Kim et al. (2000b)	B/S U-shaped MALs	Co-evolutionary algorithm			•								
Karabati and Sayin (2003)	B/S MAL	New mathematical model + heuristic		•									
Kim et al. (2006)	B/S U-shaped MAL	Endosymbiotic evolutionary algorithm				•							
Kara et al. (2007a)	B/S JIT U-shaped MAL	Simulated annealing	•			•							
Kara et al. (2007b)	B/S JIT U-shaped MAL	Simulated annealing				•			•		•		
Battini et al. (2009)	B/S MALs with finite buffer capacity	Branch and bound based step-by-step procedure			•							•	
Boysen et al. (2009)	MMS, car sequencing, level scheduling	Survey											
Hwang and Katayama (2010)	B/S straight and U-shaped MALs	Multi-objective evolutionary algorithm	•			•							
Ozcan et al. (2010a)	B/S parallel MALs	Simulated annealing			•	•							
Ozcan et al. (2011)	B/S stochastic U-shaped MAL	Genetic algorithm		•									
Mosadegh et al. (2012)	B/S MALs	Evolutionary strategies algorithm								•			•
Hamzadayi and Yildiz (2012)	B/S U-shaped MALs	Genetic algorithm based approach	•			•							
Kucukkoc and Zhang (2014b)	B/S of mixed-model parallel two-sided assembly lines	Agent based ACO enhanced with ten heuristics & model sequencing agent	•		•								

B/S: balancing and sequencing, MAL: mixed-model assembly line, MMS: mixed-model sequencing, JIT: just in time, NS: number of stations, C: cycle time, LE: line efficiency (minimising idle time), WLS: workload smoothness (=absolute deviations of workloads across workstations), RI: rate of incomplete jobs, WIP: work in process, PUR: part usage rate, TUW: total utility work, CoS: cost of setups, BC: buffer capacity, LBT: last best time.