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An interactive fuzzy programming approach for bi-objective straight and U-shaped assembly line balancing problem

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ABSTRACT

The consideration of this paper is given to address the straight and U-shaped assembly line balancing problem. Although many attempts in the literature have been made to develop deterministic version of the assembly line model, the attention is not considerably given to those in uncertain environment. In this paper, a novel bi-objective fuzzy mixed-integer linear programming model (BOFMILP) is developed so that triangular fuzzy numbers (TFNs) are employed in order to represent uncertainty and vagueness associated with the task processing times in the real production systems. In this proposed model, two conflicting objectives (minimizing the number of stations as well as cycle time) are considered simultaneously with respect to set of constraints. For this purpose, an appropriate strategy in which new two-phase interactive fuzzy programming approach is proposed as a solution method to find an efficient compromise solution. Finally, validity of the proposed model as well as its solution approach are evaluated though numerical examples. In addition, a comparison study is conducted over some test problems in order to assess the performance of the proposed solution approach. The results demonstrate that our proposed interactive fuzzy approach not only can be applied in ALBPs but also is capable to handle any practical MOLP models. Moreover, in light of these results, the proposed model may constitute a framework aiming to assist the decision maker (DM) to deal with uncertainty in assembly line problem.

1. Introduction

The growing global competitive market compels manufacturing organizations to engage themselves in all productivity improvement plans aiming to promote efficiency and effectiveness. In this direction, constructing an efficient assembly line is being considered as one of the most important issues in developing an assembly line [1]. Generally, assembly line balancing problem (ALBP) is considered as an assignment of the required tasks to the set of workstations to produce a product using either batch or mass production method with respect to the precedence relations among tasks and some other constraints. Thus, the main issue in ALBPs lies on design of appropriate order and sequence of the tasks [2]. ALBPs are generally classified into two main categories including simple ALBP (SALBP) and generalized ALBP (GALBP). GALBPs have some extra features such as cost goals, station parallelization, mixed-model production, etc. in comparison with SALBPs [3].

All versions of SALBPs with respect to their objectives are presented in Table 1 [4].

SALBP-F is considered as a feasibility problem for a given combination of cycle time and the number of stations. SALBP-I and SALBP-II models have a dual relationship while the first tries to minimize the number of stations with respect to a given cycle time, the second, tries to minimize the cycle time with regard to a given number of stations. Additionally, SALB-E model aims to simultaneously minimize the number of stations as well as the cycle time so that the efficiency has to be maximized.

The assembly line can be also organized into other classifications depending on its layout as well as variety of products. In this direction, in layout of production line perspective, it can be classified into two groups: straight and U-shaped assembly lines, while with regard to number of different products it might be categorized into the single model (one product) and mixed model (multi-product) assembly lines.

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Table 1
Versions of SALBP [4].

		Cycle time	
		Given	Minimize
The number of stations	Given	SALBP-F	SALBP-II
	Minimize	SALBP-I	SALBP-E

The straight assembly line has been considered as the most important part of traditional mass production until introducing U-shaped assembly line as a result of continuous improvement and cost reduction proposed in just-in-time (JIT) system [5]. There are several advantages associated with U-shaped assembly line in comparison with the straight one, such as flexibility increase, productivity increase, quality improvement, and lower WIP inventory.

The main feature which makes the U-shaped assembly line different from a straight one is that in the former, the entrance and exit are located in the same position.

The two main problems investigated in this paper consist of the simple assembly line balancing problem (SALB) and U-shaped version of SALB (SULB) such that SALB and SULB refer to straight and single model assembly lines, and U-shaped and single model assembly lines problems, respectively.

The remainder of this paper proceeds as follows: Section 2 is devoted to report the relevant literature in this area. In Section 3, proposed fuzzy MOLP models for the SALB and SULB are developed. A novel interactive fuzzy approach as a solution procedure for solving the problem is provided in Section 4. In Section 5, the validity of the proposed model and the solution method are evaluated through illustrative examples. Finally, conclusion remarks and proposal for future works are presented in Section 6.

2. Literature review

The SALB problem was first formulated by Salveson [6]. After that, considerable researches have been spent to address this problem and they have been reviewed in [4,7–11]. Thus, among ample of works dedicated to this context, some of the most recent ones are provided as follows.

Ağpak and Zolfaghari [12] presented a mixed integer programming model for the parallel two-sided ALBP. Gupta [13] optimized a multi model assembly line. Moreira et al. [14] proposed a new assembly line balancing problem namely assembly line worker integration and balancing problem (ALWIBP). Roshani and Giglio [15] presented a mathematical programming formulation for cost-oriented multi-manned ALBP. Triki et al. [16] presented an ALBP in a real-world automotive cables manufacturer company. Choudhary and Agrawal [17] improved the performance measures of mixed model assembly line. Pereira [18] introduces new lower bounds for the simple ALBP and analyzed their performance.

Compared with SALB literature, SULB has been relatively less taken into account in the literature. The first dynamic programming formulation for the SULB problem was proposed by Miltenburg and Wijngaard [19]. They also presented a modified heuristic approach to solve the problem. The integer programming (IP) formulation for SULB problem was first developed by Urban [20]. The first multi-criteria approach to SULB models was presented by Gökçen and Ağpak [21]. In their research, a goal programming approach is presented so that it was a combination of IP formulation of Urban [20] and goal programming model proposed in Deckro and Rangachari [22].

Fattahi and Turkay [23] presented a revised formulation for SULB model and tested their revision formulation on same benchmark problems. Fattahi et al. [24] presented a novel integer programming formulation for SULB and enhanced the efficiency of the LP relaxation of their new formulation.

2.1. Fuzzy models of ALBP

In many cases of the real world, we have to make decision with respect to vague or uncertain conditions. This uncertainty and vagueness can be resulted from either goals values or imprecision in problem's data. In assembly line problem, the uncertainty associated with real data is resulted from both human and machine factors which can be estimated only using uncertain values [25]. In this regard, Fuzzy Set Theory is considered as one of the most promising approaches to deal with uncertainty [26]. In other words, fuzzy objectives can be employed to satisfy the aspiration level of imprecise goals. Also, fuzzy numbers can appropriately reflect the vagueness corresponding to real data.

In comparison with crisp ALBP, studying the ALBP in uncertain environment has received less attention in the literature so that there are few studies addressing the assembly line problem in uncertain environment [4,10].

Tsujimura et al. [27] and Gen et al. [28] were the first who developed a genetic algorithm as a solution approach to address fuzzy SALB (*f*-SALB) problem with considering fuzzy task processing times. Other works provide solution approach for both *f*-SALB and *f*-SULB problems such as [25,29–36]. Also, some researchers applied stochastic approach to deal with uncertainty in the modeling process. In this line some most recent studies in this context are presented in [37–39].

Having employed fuzzy programming, La Scalia [40] conducted the first and the last study in which the *f*-SALB problem was formulated and solved following an exact solution procedure where task processing times were considered as fuzzy numbers. Zhang and Cheng's [41] is the only work dealt with the *f*-SULB problem considering fuzzy parameters.

Applying fuzzy goal programming (FGP) method, Toklu and özcan [42] developed a FGP approach to consider the SULB problem. Use of binary FGP (BFGP) approach Kara et al. [43] proposed a mathematical formulation as well as a solution approach to deal with both the multi-objective SALB and SULB problems. Hazır and Dolgui [44] employed a robust formulation for U-type assembly line balancing with interval data.

As mentioned above, due to the importance of SALB problem, many works have been dedicated to this area of research. However, despite a significant advantage of SULB to increase the efficiency of assembly line compared to SALB, the SULB received less effort in the literature so far. This issue reveals a considerable gap exists in the literature where the presented study attempts to fill that. Additionally, due to importance of fuzzy approach in modeling the real world problems and lack of a comprehensive model for the SALB and SULB problems wherein fuzzy parameters and fuzzy goals are considered at the same time, this paper intended to response the need of comprehensive model for *f*-SALB and *f*-SULB in which fuzzy parameters as well as fuzzy goals are taken into account simultaneously.

One of the methods employed for modeling the fuzzy goals is to apply fuzzy interactive approach that because of its capability to directly communicate with DM has been received considerable attention by recent researchers. In fact, this method enables the DM with the least possible information of the problem domain to achieve preferred compromise solution so that this issue led the presented study to utilize the fuzzy interactive approach in the modeling process.

To the best of our knowledge, there is no work in the literature dedicated to model multi-objective SALB and SULB problems regarding fuzzy interactive approach. Therefore, this paper constitutes a first framework to deal with assembly line balancing