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Technical Paper

Modeling and solving mixed-model assembly line balancing problem with setups. Part II: A multiple colony hybrid bees algorithm

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ABSTRACT

This paper is the second one of the two papers entitled "Modeling and Solving Mixed-Model Assembly Line Balancing Problem with Setups", which deals with the mixed-model assembly line balancing problem of type I (MMALBP-I) with some particular features of the real world problems such as parallel workstations, zoning constraints and sequence dependent setup times between tasks. Due to the complex nature of the problem, we tackled the problem with bees algorithm (BA), which is a relatively new member of swarm intelligence based meta-heuristics and tries to simulate the group behavior of real honey bees. However, the basic BA simulates the group behavior of real honey bees in a single colony; we aim at developing a new BA, which simulates the group behavior of honey bees in a single colony and between multiple colonies. The multiple colony type of BA is more realistic than the single colony type because of the multiple colony structure of the real honey bees; each colony represents the honey bees living in a different hive and is generated with a different heuristic rule. The performance of the proposed multiple colony algorithm is tested on 36 representatives MMALBP-I extended by adding low, medium and high variability of setup times. The results are compared with single colony algorithms in terms of solution quality and computational times. Computational results indicate that the proposed multiple colony algorithm has superior performance. Part II of the paper also presents optimal solutions of some problems provided by MILP model developed in Part I.

1. Introduction

This paper is the second one of the two papers entitled "Modeling and Solving Mixed-Model Assembly Line Balancing Problem with Setups". We aimed at formally describing the problem and developing an effective approach in order to tackle the problem in these papers.

Mixed-model assembly lines (MMAL) produce several models having similar characteristics on a single assembly line. The models assembled in a MMAL usually have differences in the set of tasks associated with each model, the processing times of tasks, set of precedence relations which specify the permissible orderings of tasks for each model, and amount of production. Under these conditions, the MMALBP-I has to assign tasks to workstations with the aim of minimizing the number workstations for a predefined cycle time and given M models, while the precedence relations of each model are satisfied. The MMALBP-I is NP-hard (Bukchin and Rabinowitch [1]), complex, and CPU time-consuming (Battaïa and Dolgui [2]). Hence, designing effective meta-heuristic approaches for MMALBP-I has been became much more attractive for scientist, since exhaustive search methods could not solve MMALBP-I within polynomially bounded computation times. Within this context, the reader can refer to Battaïa and Dolgui [3] for a recent survey on solution approaches of assembly line balancing problems.

Design issues of the meta-heuristic approaches are generally depending on nature just because offering much broader wealth of inspiration. Social insects seem to be more interesting than the other sources of inspiration in nature, since their communication systems provides developing efficient solution procedures for combinatorial optimization (Özbakır et al. [4]). In fact, their behavior is attractive not only individually but also in a population from the optimization point of view, such that, some meta-heuristics approaches based on the simulation of this group behavior. This class of meta-heuristic approaches is named as population-based or swarm-based optimization algorithms and includes Ant Colony Optimization (ACO) (Dorigo et al. [5]), Particle Swarm Optimization (PSO) (Kennedy and Eberhart [6]), Bee Colony Optimization (BCO) (Karaboga [7]) and bees algorithm (BA) (Pham et al. [8]). Additionally, Genetic Algorithm (GA) (Holland [9]) must be mentioned when

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population-based optimization algorithms are discussed, however, GA simulates the genetic evolutional process not the group behaviors of social insects. In this study, we are interested in BA for solving type I mixed-model assembly line balancing problem with setups (MMALBPS-I) because of the multi population structure of the honey bees; each population represents the honey bees living in a different hive.

The basic version of the BA is a combination of random search and neighborhood search, which may have different structures according to the features of the problem on hand. Most of the existing literature about the applications of BA to combinatorial optimization tries to evolve only a single population, with an exception of Akbari and Ziarati's work as they developed a cooperative bee swarm optimization algorithm for functional optimization [10]. Furthermore, the implementations of BA for the assembly line balancing problems (ALBPs) could be classified into improvement type of search algorithms because of the employed neighborhood structures (shift and swap movements), however, the constructive type of search algorithms like ACO are much more effective if the problem has an inherently network structure (Baykasoglu et al. [11]) as ALBPs. The existing literature (McMullen and Tarasewich; Simaria and Vilarinho; Vilarinho and Simaria; Yagmahan) addressing the solution of mixed-model ALBPs using ACO also introduced the encouraging performance of ACO [12–15].

In the present paper, we have proposed a multiple colony hybrid bees algorithm for MMALBPS-I. Our proposed approach is based on the multiple colonies (similar to (Ozbakir et al. [16])); each colony is formed according to different heuristic information, with the purpose of improving the diversification of the algorithm. Diversification generally refers to the ability to visit many and different regions of the search space (Lozano and García-Martínez [17]). Moreover, we used a new neighborhood structure which ensures the algorithm to be a constructive type. This neighborhood structure also enables the proposed approach to utilize the positive feedback mechanism as ACO does. Due to the multiple colonies, the proposed algorithm needs a communication strategy to be realized by the new neighborhood structure for sharing the information. Information sharing is an essential issue from the optimization point of view. However, we should mention here that there is not much information about the information sharing mechanisms between different colonies in real honey bees. We have adopted a mechanism which is similar to the one that used by Ozbakir et al. [16].

The remainder of this paper is organized as follows. In Section 2, the description of the bees algorithm is given. Definition of MMALBPS-I and the literature review about the sequence dependent setup times between tasks in assembly line balancing problems are given in Section 3. The proposed multiple colony hybrid bees algorithm is defined in Section 4. Comparative computational study is given in Section 5. Finally, the discussions and conclusions are presented in Section 6.

2. Bees algorithm

Swarm intelligence is a developing research area in the field of both combinatorial and functional optimization, as a matter of fact, many researchers attempted to develop various search algorithms by modeling different swarms such as birds, fishes, ants, and honey bees. The BA which is based on the behaviors of honey bees is actually one of the most inspirational areas for the researchers for developing efficient search algorithms. The basic BA in its simplest form (see Fig. 1) is initially proposed by Pham et al. [8].

As mentioned in by Pham et al. the basic BA requires a number of parameters to be set: the number of scout bees (n), the number of patches selected out of n visited points (m), the number of best patches out of m selected patches (e), the number of bees recruited for e best patches (nep), the number of bees recruited for the other ($m-e$) selected patches (nsp), the size of patches (ngh) and the stopping criterion [8]. BA initializes itself in Step 1 by placing n scout bees randomly in the search space. Fitness evaluation of the points visited by the scout bees are done in Step 2. In Step 4, the fittest bees are chosen as "elite bees", thus those sites are chosen for neighborhood search. After that, in Steps 5 and 6, the algorithm executes neighborhood searches in the sites of the selected bees in terms of more bees for the e best bees. In Step 7, for each site only the fittest bee is selected to survive in the next bee population. In Step 8, the remaining bees in the population are assigned randomly around the search space scouting for new potential solutions. These steps are repeated until a stopping criterion is met. From the observations of the main steps of the basic BA, bee system has two essential components, food sources and foragers, as mentioned in (Baykasoğlu et al. [18]).

In this paper, we only deal with the application of bee swarm intelligence to the assembly line balancing problems. The literature about the applications of bee swarm intelligence to assembly lines is scarce. To the best of our knowledge, there are only two papers which dealt with ALBPs. Tapkan et al. used BA for solving Two-sided Assembly Line Balancing Problem (TSALBP) [19], and Tapkan et al. solved constrained TSALBP via BA [20]. In both studies, the authors considered the problem by employing positional, zoning and synchronous task constraints. Tapkan et al. utilized fuzzy approaches so as to maximize work slackness index and line efficiency, and to minimize the total balance delay [19]. Ozbakır and Tapkan also dealt with TSALBP with zoning constraint with the aim of minimizing the number of stations for a given cycle time [21]. Both of the papers were adopted BA to TSALBP by generating random solutions according to different heuristic rules by using shift and swap movements as neighborhood generators.

Baykasoğlu et al. surveyed the application areas and algorithms on behavioral characteristics of the honey bees and the authors presented a classification [18], while, Ozbakır and Tapkan gave a brief literature review about the "foraging behavior" based optimization algorithms [21]. Moreover, another survey of the algorithms based on the intelligence in bee swarms and applications has been presented by Karaboga and Akay [22]. For more detailed information about the applications of bee swarm intelligence, the readers can refer to one of these three papers, especially to [18] or [22].

3. Literature survey and problem definition

High-mix/low-volume manufacturing strategies substitute for low-mix/high-volume manufacturing strategies because of the consumer-centric market conditions, which brings about the higher product variability. Under these circumstances, single model assembly lines are not able to respond this higher product variability anymore, thus, manufacturers prefer producing one model with different features or several models on a single assembly line. This type of assembly lines are named as mixed-model assembly lines and handled by Thomopoulos for the first time in the literature [23].

Mixed-model assembly lines have mainly two types of balancing problems like traditional single-model assembly lines: design of a new assembly line for which the demand can be easily forecasted (Type-I) and redesign of an existing assembly line (Type-II) when changes in the assembly process or in the product range occurs. In this paper we deal with MMALBP-I, which has some particular features of the real-world assembly line balancing problems such as parallel workstations, zoning constraints, and sequence dependent setup times between tasks.

The assembly line balancing literature usually assumes that the setups are negligible because of their low times in comparison