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Modeling and solving multi-objective mixed-model assembly line balancing and worker assignment problem

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ABSTRACT

This paper deals with mixed-model assembly line balancing and worker assignment problem (MMALBWAP). Mixed-model assembly lines allow the simultaneous assemble of a set of products on a single assembly line and have achieved great attention during last decades. The worker assignment problem deals with assigning workers to workstations considering their abilities and operating costs. The proposed model in this paper considers two incoherent objectives. The first objective aims to minimize the total cycle time. From one side different models of product have different operating task times and on the other hand different worker skills make more varieties in operating times, therefore minimizing cycle time in these problems seems so important. Simultaneous with cycle time the operating costs related to workers is the second objective of interest to be minimized. In order to solve this multi-objective problem a goal programming approach is utilized and because of high complexity of the problem, an evolutionary algorithm named imperialist competitive algorithm (ICA) is developed. In order to evaluate the efficiency of proposed algorithm, the experimental results obtained are compared with a genetic algorithm.

1. Introduction

Mixed-model assembly lines (MMAL) allow the simultaneous assembly of a set of products on a single assembly line. Different models of products could be parts of a base product or constitute a special package of products, so inherently their assembly process is somehow similar and assembly models mostly differ in performance times. Recent markets show great tends to product variety and in some cases differentiation and special packages of products are of necessity Single-model assembly lines are appropriate to carry out a single homogeneous product and are least suited while dealing with high variety demand (Simaria & Vilarinho, 2004). Current consumer-centric market conditions require high flexibility in manufacturing systems. Hence, assembly lines must be designed so as to satisfy high/low-mix volume manufacturing strategies (Akpinar & Baykasoglu, 2014). Since developing an assembly line for any single model claims significant costs, manufacturers try to assemble a set of products on a mixed-model assembly line (Akpinar & Bayhan, 2011). Generally, in the literature of mixed-model assembly line balancing two types of problems are faced, MMALBP-1 and MMALBP-2. The MMALBP-1 (MMALBP-2) consist in assigning tasks to workstations such that the number of workstations (cycle time) is minimized for a given cycle time (number of workstations) given M models, the set of tasks associated with each model, the performance times of tasks and the set of precedence relations which specify the permissible orderings of the tasks for each model (Gokcen & Erel, 1998). With attention to different performance times that is the result of assembling various models and different worker capabilities, MMALBP-2 seems more applicable for our problem. On the other hand due to different operating costs, minimization of the total operating costs is simultaneously considered.

The rest of paper is organized as follows: Section 2 provides a literature review of the problem and the problem description and formulation is dealt with in Section 3. The solution method and proposed algorithm will be discussed in Section 4. Section 5 represents the experimental results and Section 6 includes the conclusions and future works discussion.

2. Literature survey

The assembly line balancing problem (ALBP) is widely discussed in the literature. The comprehensive reviews have been proposed by Ghosh and Gagnon (1989), Scholl and Becker (2006), Baybars

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(1986), Gokcen and Erel (1998) and Becker and Scholl (2006). Due to their increasing importance, the mixed-model assembly lines have attained more attention in modern industry during two last decades and therefore many researchers have addressed the MMALBP in their researches (Dar-El & Cother, 1975; Erel & Gokcen, 1998, 1999; Gokcen & Erel, 1998; McMullen & Frazier, 1997; Merengo, Nava, & Pozetti, 1999; Thomopoulos, 1967, 1970; Vilarinho & Simaria, 2002) and as a result many exact solution methods, heuristics and meta-heuristics have been proposed. The new researches have discussed new constraints and conditions and developed new solution methods. Simaria and Vilarinho (2004) have used a two-stage genetic algorithm for MMALBP-2 and the parallel workstations have been considered in their research. Akpinar and Baykasoglu (2014) have proposed a mixed integer linear programming model and considered the sequence-dependent set up times, besides parallel workstations and zoning constraints have been discussed. A multi-objective ant colony optimization approach has been used by Yagmahan (2011) that aims to handle three objectives, minimizing the number of workstations (that is equivalent to maximizing the balance delay), maximizing the smoothness index between stations and maximizing smoothness index within stations. Akpinar and Bayhan (2011) have proposed a hybrid genetic algorithm for maximizing the production rate (minimizing the cycle time) and later Akpinar, Bayhan, and Baykasoglu (2013) have hybridized ant colony and genetic algorithm for solving MMALBP-2 considering sequence dependent set up times. Multi-objective two-sided mixed-model assembly line balancing problem has been considered by Chutima and Chimklai (2012) that presents a particle swarm optimization algorithm with negative knowledge (PSONK) to solve the problem. Instead of modeling the positions of particles in an absolute manner as in traditional PSO, PSONK employs the knowledge of the relative positions of different particles in generating new solutions. Manavizadeh, Sadat Hosseini, Rabbani, and Jolai (2013) have employed a simulated annealing algorithm for a mixed model assembly U-line balancing type-I problem in a Just-In-Time (JIT) production system. They assumed that there are two types of operators: permanent and temporary that are classified into four skill levels and so the human efficiency is incorporated to the problem. Simultaneous balancing and sequencing of mixed-model parallel two-sided assembly lines is discussed in Kucukkoc and Zhang (2014) and an agent based ant colony optimization approach is proposed as the solution method.

The assembly line worker assignment and balancing problem (ALWABP) has been discussed during few last years. Miralles, Garcia-Sabater, Andres, and Cardos (2008) have studied the assembly line worker assignment and balancing problem and its application to sheltered work centers using branch and bound procedures. Blum and Miralles (2011) studied the same problem aiming the minimization of the cycle time and used a beam search algorithm. Zhang, Xu, and Gen (2013) proposed a multi-objective evolutionary algorithm for minimizing the cycle time and operating costs for single-model assembly lines that are discussed in this paper, Vila and Pereira (2014) use a branch and bound algorithm and a heuristic algorithm based on beam search and a branch-and-bound algorithm is employed by Borba and Ritt (2014) that for a fixed number of workers aims to maximize the production rate of an assembly line. Mutlu, Polat, and Supciller (2013) have studied the ALWABP of type-2 using an iterative genetic algorithm and developed three search approaches in order to obtain search diversity named: modified bisection search, genetic algorithm and iterated local search.

The papers above represented for worker assignment problem deal with single lines while our paper studies a mixed-model one that is more complicated, besides a new approach for worker assignment problem that is more practical to real world problems is proposed. All the researches in the literature of ALWABP assume that there are a number of workstations and so operators to assign to these workstations that have different capabilities. Substantially, the operation times for each task differ between this operators as well as operating costs. In the case of mixed-model assembly and especially where dealing with large size problems, defining all these related values is so hard and almost inapplicable. In order to overcome this problem, the worker capabilities are restricted to a number of worker skill levels where each skill level includes a number of workers (here unlimited) that differentiation of their capability is disregarded, so their performance times and costs for each task are the same.

3. Problem description and formulation

3.1. Multi-objective modeling

In this paper, the MMALWABP is discussed that aims is to minimize the total cycle time and operating costs, simultaneously.

Here we introduce the general assumptions of the problem, next parameters and variables will be introduced and then we propose an integer linear programming for the problem. The general assumptions of the problem are as follows.

- A number of M product models will be assembled on an assembly line.
- Assembly tasks for different models are almost similar, so we can suppose a total precedence diagram for all of the models. Now, if some models do not use some tasks in their assembly process, the relevant task time will be 0.
- Operating times related to a task may be different for different models.
- There are operators with different skill levels to carry out the assembly tasks. Each skill level includes a number of operators (here this number is equal to the number of workstations) that differences between their skill is low and ignored.
- The operating time for a task differs dependent on the operators from different skill levels to do this task.
- The operating cost of a task differs dependent on the skill of the operator and the task condition.
- Each operator works only on a single station, on each station only one operator carries out the assembly tasks and the tasks are undividable.
- Assembly models will be assembles with the same rate and consecutively.

Considering the above mentioned assumptions, the parameters and indices of the model will be as:

S: number of workstations (predefined) $s = 1, 2, \ldots, S$
M: number of product models to be assembled $m = 1, 2, \ldots, M$
N: number of tasks $i, j = 1, 2, \ldots, N$
W: number of skill levels $w = 1, 2, \ldots, W$
d_{jw}: operating cost related to an operator with skill level w performing the task j
t_{jmw}: operating time of the task j of model m performed by an operator from skill level w
pre_j: A set of direct predecessors for task j in the general precedence diagram
There are two types of decision variables in this model. First type is for assigning tasks and second type is for assigning operators to different workstations.