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On solving the assembly line worker assignment and balancing problem via beam search ☆

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ABSTRACT

Certain types of manufacturing processes can be modelled by assembly line balancing problems. In this work we deal with a specific assembly line balancing problem that is known as the assembly line worker assignment and balancing problem (ALWABP). This problem appears in settings where tasks must be assigned to workers, and workers to work stations. Task processing times are worker specific, and workers might even be incompatible with certain tasks. The ALWABP was introduced to model assembly lines typical for sheltered work centers for the Disabled.

In this paper we introduce an algorithm based on beam search for solving the ALWABP with the objective of minimizing the cycle time when given a fixed number of work stations, respectively, workers. This problem version is denoted as ALWABP-2. The experimental results show that our algorithm is currently a state-of-the-art method for the ALWABP-2. In comparison to results from the literature, our algorithm obtains better or equal results in all cases. Moreover, the algorithm is very robust for what concerns the application to problem instances of different characteristics.

1. Introduction

Assembly line balancing (ALB) [1] concerns the optimization of processes related to manufacturing products via assembly lines. The specific problem considered in this paper is a generalization of the so-called simple assembly line balancing problem (SALBP) [2], which is a well-studied scientific test case. In SALBP, an assembly line consists of a set of work stations arranged in a straight line, and by a transport system which moves the product to be manufactured along the line. The product is manufactured by performing a given set of tasks, each of which has a processing time. A solution to a SALBP instance is obtained by the assignment of all tasks to work stations subject to precedence constraints between the tasks. The fact that all work stations are equally sized and the assembly line moves in constant speed, implies a maximum of C time units (the cycle time) for processing all the tasks assigned to a work station. Among several possible goals for optimization, the following two are the ones that were most studied in the literature. Given a fixed cycle time C, the optimization goal consists in minimizing the number of necessary work stations. This problem version is called SALBP-1 in the literature. Given a fixed number m of work stations, the goal is to minimize the cycle time C. The literature knows this second problem version as SALBP-2.

In this paper we consider a generalization of SALBP-2: the so-called assembly line worker assignment and balancing problem with the objective of minimizing the cycle time (ALWABP-2). This problem was introduced in [3], motivated by the growing need and desire to incorporate the Disabled into the active workforce. The World Health Organization estimates that 10% of the global population, which amounts to around 610 million people worldwide, is disabled. Of these, 386 million people are within the active labor age range, but experience very high unemployment rates (fluctuating from 13% in the UK to 80% in many under-developed countries). This has led to various attempts of integrating these citizens into the working society. Indeed, under the concept of Corporate Social Responsibility (see, for example, [4]), an increasing number of companies are becoming concerned with this matter. In this context, the employment of disabled workers is seen as a way of including the interests of society in the company goals.

One of the strategies most commonly adopted for facilitating the integration of disabled workers into the labor market is the creation of sheltered work centers for Disabled (henceforth SWDs). This model of socio-labor integration tries to move away

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from the traditional stereotype that considers disabled people as unable to develop continuous professional work. Just as in any other firm, a SWD competes in real markets and must be flexible and efficient enough to adapt to market fluctuations and changes, the only difference being that the SWD is a Not-For-Profit organization. Thus, the potential benefits that may be obtained from increased efficiency are usually invested into the growth of the SWD. This results in more jobs for the Disabled and the gradual integration of people with higher levels of disability, which are in fact the primary aims of every SWD.

Miralles et al. [3] have shown the use of assembly lines to be beneficial for these centers. In particular, the traditional division of work into single tasks seems to be a useful tool for making certain worker disabilities invisible. Moreover, an appropriate task assignment can even become a good therapeutic method for the rehabilitation of certain disabilities. However, the employed balancing procedure should be able to cope with some specific constraints relative to time variability that arise in this environment. Moreover, it should be able to reconcile the following objectives (that should no longer be seen as contradictory but complementary): (1) to maximize the efficiency of the line by balancing the workload assigned to each available worker in each station; (2) to satisfy and respect the existent constraints in this environment due to human factors when assigning tasks to workers.

After analyzing several SWDs, the authors of [3] proposed the ALWABP-2. This problem was defined as a generalization of the classical SALBP-2, since the usual objective at SWDs is the minimization of the cycle time given a set of unique and differently abled workers to be integrated in the workforce. In other words, instead of simply considering the assignment of tasks to work stations, Miralles et al. introduced in addition a set of workers that execute the tasks and that have to be assigned to work stations. Moreover, each task may have a worker-dependent processing time, which allows to account for disabilities of different workers. The first mathematical model of this problem was proposed in [5]. Note that a technical description of the ALWABP-2 is given in Section 2 below.

1.1. Problem classification and previous work

In recent years a big effort has been made towards modelling real world assembly line systems through different extensions of the SALBP, aiming to narrow the considerable gap between research and practice. The recent classification proposed by Boysen et al. in [6] structures the vast field of assembly line balancing by means of a notation consisting of three elements $[\alpha|\beta|\gamma]$, where:

- α concerns the precedence graph characteristics;
- β concerns the station and line characteristics;
- and γ concerns the optimization objectives.

Various possible values are defined for each of these three elements, covering all assembly line balancing problems that have appeared in the literature. In [6], Boysen et al. classified the ALWABP-2 as $[pa,link,cum|equip|c]$. Note that the fundamental difference of the ALWABP-2 with respect to other equipment selection problems is the fact that resources are limited: there are unique workers and each one must be assigned to exactly one workstation. In contrast, in most automated lines—and in general in the so-called *assembly system design problems*—there are different kinds of resources (normally robots), and each resource is available as many times as required [7–17]. Moreover, in contrast to the ALWABP-2 none of these references has the objective of minimizing the cycle time ($\gamma = c$). Instead, they all aim to minimize the cost ($\gamma = Co$) or the utilized resources ($\gamma = m$), an objective that would seem contradictory in SWDs, where the philosophy is to integrate as many disabled workers as possible (which means to utilize all the available resources in order to achieve as much production efficiency as possible).

Concerning previous work on the ALWABP-2, Miralles et al. [5] presented a branch and bound algorithm for solving the ALWABP-2 to optimality. They tested their algorithm on a range of benchmark instances. Unfortunately, only small instances (in terms of the number of tasks) could be solved. Additionally, the authors of [5] developed a simple constructive one-pass heuristic for obtaining approximate solutions to larger problem instances. The currently best performing algorithm for the ALWABP-2 is a hybrid algorithm proposed by Chaves et al. in [18], where the authors hybridized a clustering search approach proposed in [19] with iterated local search.

1.2. Contribution of this work

In this work we present an algorithm based on beam search for solving the ALWABP-2. Beam search is a classical tree search method that was introduced in the context of scheduling [20]. The central idea behind beam search is the parallel and non-independent construction of a limited number of solutions with the help of a greedy function and a lower bound to evaluate partial solutions. Our choice of beam search was motivated by the fact that the crucial algorithmic component of one of the current state-of-the-art methods for the SALBP-1 is strongly based on beam search [21]. By the application to a wide range of benchmark instances we show that our algorithm is currently a state-of-the-art method for the ALWABP-2.

1.3. Paper outline

In Section 2 we present a technical definition of the ALWABP-2. In Section 3 we outline the proposed algorithm. Finally, in Section 4 we present the computational results, and in Section 5 we offer conclusions and an outlook on future work.

2. The ALWABP-2

A technical description of the ALWABP-2 can be given as follows. An instance (T, S, W, G) of the ALWABP-2 consists of four components. $T=\{1,\ldots,n\}$ is a set of n tasks that must be processed by workers assigned to work stations. $S=\{1,\ldots,m\}$ is an ordered line of m work stations, where 1 is the index of the first work station and m is the index of the last one. $W=\{1,\ldots,m\}$ is a set of m workers. Each worker must be assigned to exactly one work station such that each work station is occupied by only one worker. Each task $i \in T$ has a worker-specific processing time. More specifically, for each tuple (i,h) where $i \in T$ and $h \in W$ a processing time $t_{ih} > 0$ is given. If $t_{ih} = \infty$, worker h is incompatible with task i. Finally, given is a precedence graph $G=(T, A)$, which is a directed graph without cycles whose nodes are the tasks. An arc $l_{i,j} \in A$ indicates that task i must be processed before task j. Given a task $j \in T$, we denote by $P_j \subset T$ the set of tasks that must be processed before j.

A solution is obtained by assigning workers to work stations and tasks to workers such that the precedence constraints between the tasks are satisfied. The objective function is to minimize the so-called cycle time. This problem can be expressed in the following way as an integer programming (IP) problem (see also [5]).