Computers & Operations Research 54 (2015) 64–73

Contents lists available at ScienceDirect

Computers & Operations Research

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

Model and heuristics for the Assembly Line Worker Integration and Balancing Problem

Mayron César O. Moreira [a,*], Cristóbal Miralles [b], Alysson M. Costa [c]

[a] Instituto de Ciências Matemáticas e de Computação, Universidade de São Paulo, Brazil
[b] ROGLE - Departamento Organización de Empresas, Universitat Politècnica de València, Spain
[c] Department of Mathematics and Statistics, University of Melbourne, Australia

ARTICLE INFO

Available online 6 September 2014

Keywords:
Assembly line balancing
Disabled workers
Mathematical modeling

ABSTRACT

We propose the Assembly Line Worker Integration and Balancing Problem (ALWIBP), a new assembly line balancing problem arising in lines with conventional and disabled workers. The goal of this problem is to maintain high productivity levels by minimizing the number of workstations needed to reach a given output, while integrating in the assembly line a number of disabled workers. Being able to efficiently manage a heterogeneous workforce is especially important in the current social context where companies are urged to integrate workers with different profiles. In this paper we present mathematical models and heuristic methodologies that can help assembly line managers to cope with this additional complexity. We demonstrate by means of a robust benchmark how this integration can be done with losses of productivity that are much lower than expected.

1. Introduction

According to the International Labour Organization (ILO), people with disabilities represent an estimated 10% of the world's population, including approximately 500 million of working age; being apparent that in the unemployment rates of the disabled are much higher than the average.

Employment is the main path for social inclusion and participation in modern societies. Having a job is not only the basis for the survival and stability for many individuals, but also a key way of accessing many rights as citizens. Therefore the welfare and the social inclusion of the disabled depend very much on the degree of labor integration they are able to achieve. Different active policies to fight against discrimination have been set during the last few decades, following models that are more/less inclusive depending on the local culture. Across specific national legislations, a general common formula is to reserve a share of workplaces in ordinary companies for people with disabilities. This share normally increases with the size of the company and, depending on the country legislation, usually goes from 2% to 5% of the jobs.

Unfortunately, it is also a common phenomenon in many countries that this share is not always respected, indicating that the solution should come not only by legal imposition, but mainly by overcoming the prejudices about the capabilities of the disabled, and by the genuine commitment of ordinary companies to include integration programs in their strategies. The aim of this paper is to contribute in making this commitment easier: (1) by providing the production managers with practical approaches that ease the integration of disabled workers in the production lines; (2) by demonstrating that, through the approaches proposed, the productivity of production systems suffers little (and often none) decrease.

Once stated the great importance of integrating Disabled into the workforce of ordinary companies, we should make a brief introduction on some previous work inspired on the specific scenario of the so-called "Sheltered Work Centers for Disabled" (henceforth SWDs). SWDs are a special work formula legislated in many countries (with different variants) whose only difference from an ordinary company is that most of its workers must be disabled, and therefore they receive some institutional help in order to be able to compete in real markets. This labor integration formula has been successful in decreasing the former high unemployment rates of countries like Spain, and one of the strategies used by SWDs to facilitate the labor integration has been the adoption of assembly lines. In this sense, Miralles et al. [9] were the first to evidence how the integration of disabled workers in the productive systems can be done without losing, even gaining, productive efficiency through the use of assembly lines. This pioneer reference defined the so-called Assembly Line Worker Assignment and Balancing Problem (ALWABP) and demonstrated how the division of worker into single

* Corresponding author.
E-mail addresses: mayron@icmc.usp.br (M.C.O. Moreira), cmiralles@omp.upv.es (C. Miralles), alysson.costa@unimelb.edu.au (A.M. Costa).

http://dx.doi.org/10.1016/j.cor.2014.08.021
0305-0548/© 2014 Elsevier Ltd. All rights reserved.

tasks becomes a powerful tool for making certain workers disabilities invisible.

1.1. Contribution and outline of this work

ALWABP was inspired in the SWDs reality, where the very high diversity of most of the workers and their limitations are the main characteristics. This scenario is quite different to that one of an ordinary company, where the aim is to efficiently integrate in the workforce just some workers, often to cope with the 2–5% of disabled workers legislation requirements. In this case the problem supposes much less diversity in the input data, and can also be stated with very different approaches with respect to the ALWABP, regarding the objective function, the hypothesis and model defined, and the kind of appropriate solution procedures.

The aim of this paper is to introduce and analyze this new problem that has been named "Assembly Line Worker Integration and Balancing Problem" (ALWIBP). Our study aims to answer specific requirements that normally arise in assembly lines of ordinary companies, where only few disabled workers have to be integrated, providing the production managers with practical tools that ease the integration of disabled workers in the most efficient manner. We propose new mathematical models for the problem as well as a constructive heuristic based on the similarities between the proposed problem and the so-called Simple Assembly Line Balancing Problem (SALBP).

The remainder of this paper is structured as follows: in Section 2, we state a formal codification of the new problem and some extensions, analyzing their practical implications and reviewing references of the literature with useful related approaches. Section 3 then presents the corresponding IP models for the proposed versions of the ALWIBP while Section 4 describes a fast heuristic that has been developed to solve the problem. A experimental study in order to analyze the effectiveness of the proposed models and algorithms is conducted in Section 5. General conclusions end this paper.

2. The Assembly Line Worker Integration and Balancing Problem

2.1. Introduction: SALBP vs ALWABP

The SALBP was initially reviewed by Baybars [1] and consists of an assembly line balancing problem with several well-known simplifying hypotheses. This classical single-model problem which aims at finding the best feasible assignment of tasks to stations so that certain precedence constraints are fulfilled, has been the reference problem in the literature in its two basic versions: when the cycle time C is given, and the objective is to optimize the number of necessary workstations, the problem is called SALBP-1. Whereas when there is a given number m of workstations, and the goal is to minimize the cycle time C the literature knows this second version as SALBP-2 [17].

A trend in Assembly Line research in the last decade has been to narrow the gap between the theoretical proposals and the industrial reality, which faces multiple specific configurations such as multi-manned workstations [6,7], two sided assembly lines [8,14], or operator allocation in job sharing and operator revisiting lines [20], among many others. As part of this trend, Miralles et al. [9] properly defined the ALWABP, a generalization of the SALBP where, in addition to the assignment of tasks to stations, a set of heterogeneous workers also has to be assigned to stations. In this scenario each task has a worker-dependent processing time, which allows taking into account the limitations and specific production rates of each worker. Moreover, when the time to execute a task for certain worker is very high, this assignment is considered infeasible in the input data matrix.

Since Miralles et al. [9], many other references have contributed to give ALWABP visibility throughout academia, proposing different methods to solve the problem. The same authors have later developed a branch-and-bound algorithm for the problem, obtaining the exact solution of small-sized instances [10]. Because of the problem complexity and the need to solve larger instances, the literature has since then shifted its efforts to heuristic methods. The current state-of-the-art methods for solving the ALWABP are the iterated beam search (IBS) metaheuristic of Blum and Miralles [2], the biased random-key genetic algorithm of Moreira et al. [11], the iterative genetic algorithm of Mutlu et al. [12], the heuristic and the branch-and-bound algorithms of Borba and Ritt [3] and the branch-and-bound algorithm of Vilà and Pereira [19].

2.2. ALWIBP

The ALWABP problem was inspired in the SWDs reality with most workers presenting a high diversity of operation times; whereas the ALWIBP scenario introduced in Section 1 intends to simulate the more inclusive situation in which disabled workers relative (in a small number) are integrated in a conventional assembly line. It has to be noted that the main (and only studied) problem focusing on disabled integration in assembly lines has been the ALWABP-2 [10,11] e.g., since the typical objective at SWD is to be as efficient as possible with the (diverse) available workforce.

In the scenario associated with the ALWIBP, it makes sense to deal with the type 1 problem, since a reasonable aim of a production manager can be to integrate the given disabled workers (in some cases some 2 or 5% of workers, or even more whether some compensation is needed due to low shares in other factory sections) while minimizing the number of additional workstations needed for doing so. This problem is named ALWIBP-1, by analogy with the SALBP case.

In addition to this basic objective, once inside the solution subspace with minimal number of workstations, the manager may aim to find those assignments in which the idle time in stations with disabled workers is minimum, in order to increase their participation in the production process. We call this extension ALWIBP-1$S_{\min}$. If, according to Boysen et al. [4] classification, ALWABP-2 was stated as $[pa, link, cum|equip|c]$, in this case we can define ALWIBP-1 as $[pa, link, cum|equip|m]$, while the ALWIBP-1$S_{\min}$ can be stated as $[pa, link, cum|equip|m, SLL^{stat}]$ using the same codification scheme.

In the following, we propose integer linear models for the basic ALWIBP-1 situation and also for the extension proposed.

3. Mathematical models

In this section, we present a mathematical model for the ALWIBP-1 defined earlier, and further extend it to cope with ALWIBP1-$S_{\min}$ extra objective with the use of the following notation:

N	set of tasks to be assigned;
S	set of workstations;
W	set of disabled workers, $\lvert W\rvert \le \lvert S\rvert$;
t_i	execution time of task i when assigned to a "conventional" worker;
t_{wi}	execution time of task i when assigned to disabled worker $w \in W$;
$I_w \subseteq N$	set of unfeasible tasks for worker $w \in W$;
F_i	set of immediate successors of task i;
F_i^*	set of all successors of task i.