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Multiobjective memetic algorithms for time and space assembly line balancing

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ABSTRACT

This paper presents three proposals of multiobjective memetic algorithms to solve a more realistic extension of a classical industrial problem: time and space assembly line balancing. These three proposals are, respectively, based on evolutionary computation, ant colony optimisation, and greedy randomised search procedure. Different variants of these memetic algorithms have been developed and compared in order to determine the most suitable intensification–diversification trade-off for the memetic search process. Once a preliminary study on nine well-known problem instances is accomplished with a very good performance, the proposed memetic algorithms are applied considering real-world data from a Nissan plant in Barcelona (Spain). Outstanding approximations to the pseudo-optimal non-dominated solution set were achieved for this industrial case study.

1. Introduction

Nowadays, assembly lines are crucial in the industrial production of high quantity standardized commodities and more recently even gained importance in low volume production of customised products (Boysen et al., 2008). An assembly line is made up of a number of workstations, arranged either in series or in parallel. Since the manufacturing of a production item is divided into a set of tasks, a usual and difficult problem is to determine how these tasks can be assigned to the stations fulfilling certain restrictions. Consequently, the aim is to get an optimal assignment of subsets of tasks to the stations of the plant. Moreover, each task requires an operation time for its execution.

A family of academic problems – referred to as simple assembly line balancing problems (SALBP) – was proposed to model this situation (Baybars, 1986; Scholl, 1999). Taking this family as a base, Bautista proposed a more realistic framework: the time and space assembly line balancing problem (TSALBP) (Bautista and Pereira, 2007). The new model considers an additional space constraint to become a simplified version of real-world problems. As described in Bautista and Pereira (2007), this space constraint emerged due to the study of the Nissan plant in Barcelona, Spain (a snapshot of an assembly line of this industrial plant is shown in Fig. 1). The new TSALBP framework is of a great importance in industrial engineering and operations research since it achieves a better modelling of the real conditions of the balancing of assembly lines. The proposal of more realistic ALB models, allowing us to properly cope with real-life scenarios, have become a hot topic in the area in the last few years (Boysen et al., 2008).

As many real-world problems, TSALBP formulations have a multi-criteria nature (Chankong and Haimes, 1983) because they contain three conflicting objectives to be minimised: the cycle time of the assembly line, the number of the stations, and the area of these stations. In this paper we deal with the TSALBP-1/3 variant which tries to jointly minimise two objectives, the number of stations and their area, for a given value of the remaining objective, the product cycle time. TSALBP-1/3 has an important set of hard constraints-like precedences or cycle time limits for each station that make the problem solving difficult. These characteristics initially demanded the use of constructive approaches like ant colony optimisation (ACO) (Dorigo and Stützle, 2004) or greedy randomised search procedures (GRASP) (Feo and Resende, 1995) as done in the proposals described in Chica et al. (2010a,b), respectively. Nevertheless, an advanced proposal based on the well-known NSGA-II multiobjective evolutionary algorithm (Deb et al., 2002) has been recently introduced in Chica et al. (2011a) using a specific representation scheme and customised genetic operators for the TSALBP. The latter *advanced TSALBP-NSGA-II* proposal has overcome the problem shortcomings requiring a constructive technique and has outperformed the existing algorithms, becoming the state-of-the-art method.

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Fig. 1. An assembly line of the Nissan Pathfinder car, located in the industrial plant of Barcelona (Spain).

Memetic algorithms (MAs) (Moscato, 1989; Ong et al., 2006, 2010) have been widely used in industrial and engineering applications like the fleet vehicle routing problem (Prins, 2009), the design of spread spectrum radar poly-phase codes (Pérez-Bellido et al., 2008), the design of logistic networks (Pishvaee et al., 2010), or the construction of three-dimensional models of real-world objects (Santamaría et al., 2009). However, the use of local search to improve the solutions obtained by a global search procedure for the TSALBP has not been extensively explored (Bautista and Pereira, 2007; Chica et al., 2010b). In this paper, we aim to make an advance in the solving of this complex and challenging real-world problem by considering the application of advanced MA designs to deal with it.

We will design new multiobjective memetic methods for tackling the real-world TSALBP-1/3 variant. Such methods are based both on the state-of-the-art multiobjective algorithm, the *advanced TSALBP-NSGA-II*, and on the other existing multiobjective algorithms for the TSALBP. The new memetic proposals will incorporate a successful multi-criteria local search (LS) scheme used in a previous GRASP approach.

We aim at comparing different MA variants to show that there is no general method that is able to achieve the best results for all the problem instances (as stated in the *No Free Lunch* theorem Wolpert and Macready, 1997). Thus, we will develop 15 different MA designs to be compared to each other and to the basic global search methods in a complete experimentation with nine well-known problem instances.

Finally, an industrial case study will be considered to investigate the appropriateness of our MA proposals for solving real-world problems. This case study includes real-world data from the Nissan Pathfinder engine manufacturing process obtained from the assembly line of Barcelona. Up-to-date multiobjective performance indicators and statistical tests are used to analyse the behaviour of the algorithms.

The paper is structured as follows. In Section 2, the TSALBP-1/3 formulation is explained. The proposed multiobjective memetic algorithms to solve the problem are described in Section 3. Then, the experimental setup, the analysis of results, and the Nissan case study are presented in Section 4. Finally, some concluding remarks are discussed in Section 5.

2. Time and space assembly line balancing

The manufacturing of a production item is divided into a set V of n tasks. Each task j requires a positive operation time t_j for its execution. This time is determined as a function of the manufacturing technologies and the resources employed. A subset of tasks S_k ($S_k \subseteq V$) is assigned to each station k ($k=1,2,\ldots,m$), referred to as the workload of this station. Each task j can only be assigned to a single station k.

Every task j has a set of immediate "preceding tasks" P_j which must be accomplished before starting that task. These constraints are represented by an acyclic precedence graph, whose vertices correspond to the tasks and where a directed arc $\langle i,j \rangle$ indicates that task i must be finished before starting task j on the production line. Thus, task j cannot be assigned to a station that is ordered before the one where task i was assigned.

Each station k presents a station workload time $t(S_k)$ that is equal to the sum of the tasks' lengths assigned to it. The workload time of the station cannot exceed the cycle time c, common to all the stations of the assembly line. In general, the SALBP (Baybars, 1986; Scholl, 1999) focuses on grouping these tasks into workstations by an efficient and coherent method. In short, the goal is to achieve a grouping of tasks that minimises the inefficiency of the line or its total downtime satisfying all the constraints imposed on the tasks and stations.

Nevertheless, this formulation is too simple to deal with real-life ALB problems. Different extensions to this formulation have been proposed (Scholl, 1999), showing the great interest of the scientific community (Boysen et al., 2008). In particular, there is a significant and real need of introducing space constraints in the assembly lines' design. This is because of three main reasons found in real manufacturing scenarios:

(1) The length of the workstation is limited. Workers start their work as close as possible to the initial point of the workstation, and must fulfil their tasks while following the product. They need to carry the tools and materials to be assembled in the unit. In this case, there are constraints for the maximum allowable movement of the workers. These constraints directly limit the length of the workstation and the available space.
(2) The required tools and components to be assembled should be distributed along the sides of the line. In addition, in the automotive industry, some operations can only be executed on one side of the line. This fact restricts the physical space where tools and materials can be placed. If several tasks requiring large areas are put together the workstation would be unfeasible.
(3) Another usual source of spatial constraints comes from the products evolution. Focusing again on the automotive industry, when a car model is replaced with a newer one, it is usual to keep the production plant unchanged. However, the new space requirements for the assembly line may create more spatial constraints.

Based on these new realistic spatial features, a new real-like problem comes up. In order to model it, Bautista extended the SALBP into the TSALBP by means of the following formulation (Bautista and Pereira, 2007): the area constraint must be considered by associating a required area to each task. The areas of tasks are devoted to store auxiliary elements for manufacturing purposes like tools, shelves, containers, or hardware brackets. The needed area for each task is defined by the logistics and methods departments based on the characteristics of the involved auxiliary elements. We should keep in mind that the inclusion of space constraints in the problem formulation can decrease the efficiency with respect to a formulation which does not consider spatial constraints. However, these efficiency values only represent a theoretical nature because if spatial constraints are not included, the assembly line cannot be arranged.