Hybridizing a multi-objective simulated annealing algorithm with a multi-objective evolutionary algorithm to solve a multi-objective project scheduling problem

Virginia Yannibelli [a,b,∗], Analía Amandi [a,b]

[a] ISISTAN Research Institute, Fac. Cs. Exactas, UNCPBA, Campus Universitario, Paraje Arroyo Seco, Tandil 7000, Buenos Aires, Argentina
[b] CONICET, Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina

ABSTRACT

In this paper, a multi-objective project scheduling problem is addressed. This problem considers two conflicting, priority optimization objectives for project managers. One of these objectives is to minimize the project makespan. The other objective is to assign the most effective set of human resources to each project activity. To solve the problem, a multi-objective hybrid search and optimization algorithm is proposed. This algorithm is composed by a multi-objective simulated annealing algorithm and a multi-objective evolutionary algorithm. The multi-objective simulated annealing algorithm is integrated into the multi-objective evolutionary algorithm to improve the performance of the evolutionary-based search. To achieve this, the behavior of the multi-objective simulated annealing algorithm is self-adaptive to either an exploitation process or an exploration process depending on the state of the evolutionary-based search. The multi-objective hybrid algorithm generates a number of near non-dominated solutions so as to provide solutions with different trade-offs between the optimization objectives to project managers. The performance of the multi-objective hybrid algorithm is evaluated on nine different instance sets, and is compared with that of the only multi-objective algorithm previously proposed in the literature for solving the addressed problem. The performance comparison shows that the multi-objective hybrid algorithm significantly outperforms the previous multi-objective algorithm.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

A multi-objective project scheduling problem involves defining feasible start times and feasible human resource assignments for project activities so that the different optimization objectives, defined as part of the problem, are reached. Moreover, to define human resource assignments, it is necessary to have knowledge about the effectiveness of the available human resources in relation to different project activities. This is because the development and the results of an activity depend on the effectiveness of the resources assigned to it (Heerkens, 2002; Wysocki, 2003).

In the literature, many different kinds of multi-objective project scheduling problems have been formally described and addressed until now. However, to the best of the authors' knowledge, only few multi-objective project scheduling problems have considered

human resources with different levels of effectiveness (Bellenguez & Néron, 2005; Gutjahr, Katzensteiner, Reiter, Stummer, & Denk, 2008; Hanne & Nickel, 2005; Yannibelli & Amandi, 2012a), a central aspect in real multi-objective project scheduling contexts. These problems state different assumptions about the effectiveness of the human resources.

The multi-objective project scheduling problems described in Bellenguez and Néron (2005), Gutjahr et al. (2008), Hanne and Nickel (2005) assume that each human resource only has one or several skills, and an effectiveness level in relation to each skill. Then, the effectiveness of a human resource in a given activity is determined only on the basis of the effectiveness level of the resource in relation to one of the skills required for that activity. Thus, only the skills of a human resource are considered as determining factors of their effectiveness. However, other contextual factors that also determine the effectiveness of a human resource in a given activity are not considered in the mentioned problems. Such factors involve the attributes of the activity to which the resource is assigned, the other resources with whom the resource in question must work, as well as the experiences and attributes of the resource (Barrick, Stewart, Neubert, & Mount, 1998; Heerkens, 2002; Wysocki, 2003).

∗ Corresponding author at: ISISTAN Research Institute, Fac. Cs. Exactas, UNCPBA, Campus Universitario, Paraje Arroyo Seco, Tandil 7000, Buenos Aires, Argentina. Tel.: +54 (0249) 4439682x28; fax: +54 (0249) 4439681x52.

E-mail addresses: vyannibe@exa.unicen.edu.ar (V. Yannibelli), amandi@exa.unicen.edu.ar (A. Amandi).

Unlike the above-mentioned problems, the multi-objective project scheduling problem introduced in Yannibelli and Amandi (2012a) considers that the effectiveness of a human resource depends on various factors inherent to its work context (i.e., the activity to which the resource is assigned, the skill to which the resource is assigned within the activity, the set of human resources that has been assigned to the activity, and the attributes of the resource). This is a really significant aspect of the multi-objective project scheduling problem introduced in Yannibelli and Amandi (2012a). This is because, in real multi-objective project scheduling problems, the human resources usually have different effectiveness levels in relation to different work contexts (Barrick et al., 1998; Heerkens, 2002; Wysocki, 2003) and, therefore, the effectiveness of a human resource needs to be considered in relation to its work context. To the best of the authors' knowledge, the influence of the work context on the effectiveness of the human resources has not been considered in other multi-objective project scheduling problems. Because of this, it is considered that the multi-objective project scheduling problem introduced in Yannibelli and Amandi (2012a) is really valuable in comparison with other multi-objective project scheduling problems.

In this paper, the multi-objective project scheduling problem introduced in Yannibelli and Amandi (2012a) is addressed. This problem considers two conflicting, priority optimization objectives for project managers. One of the objectives entails minimizing the project makespan, whereas the other objective involves assigning the most effective set of human resources to each project activity. As was previously mentioned, the addressed problem considers that the effectiveness of a human resource depends on various factors inherent to its work context.

To solve the addressed problem, a multi-objective hybrid algorithm is proposed. This is a search and optimization algorithm composed by two search and optimization algorithms: a multi-objective simulated annealing algorithm and a multi-objective evolutionary algorithm. The multi-objective simulated annealing algorithm is integrated into the framework of the multi-objective evolutionary algorithm. This is meant to improve the performance of the evolutionary-based search (Coello Coello, Lamont, & Veldhuizen, 2007; Corchado, Abraham, & Carvalho, 2010; Corchado, Graña, & Wozniak, 2012; Deb, 2009; Ishibuchi, Yoshida, & Murata, 2003). Specifically, the multi-objective simulated annealing algorithm serves two purposes. At the early stages of the evolutionary-based search, when this search is diverse, the simulated annealing algorithm behaves like an exploitation process to fine-tune the solutions reached by the evolutionary-based search. At later stages of the evolutionary-based search, when this search starts to converge, the simulated annealing algorithm behaves like an exploration process to diversify the solutions reached by the evolutionary-based search and thus to allow this search progresses. To achieve the two mentioned purposes, the behavior of the multi-objective simulated annealing algorithm is self-adaptive based on observations from the state of the evolutionary-based search.

The multi-objective hybrid algorithm generates an approximation to the true Pareto set as a solution to the problem. Thus, the algorithm can provide a number of solutions (i.e., project schedules) with different trade-offs between the optimization objectives to project managers.

A multi-objective hybrid algorithm is proposed because of the following reasons. The problem addressed here can be seen as a multi-objective case of the RCPSP (Resource Constrained Project Scheduling Problem) (Blazewicz, Lenstra, & Rinnooy Kan, 1983) and, therefore, the problem is an *NP-Hard* problem. In this sense, the hybridization of multi-objective evolutionary algorithms with other search and optimization techniques (e.g., simulated annealing) has been proven to be more effective than the classical multi-objective evolutionary algorithms in the resolution of a wide variety of multi-objective *NP-Hard* problems and, in particular, in the resolution of different kinds of multi-objective scheduling problems (Coello Coello et al., 2007; Corchado et al., 2012; Deb, 2009; Ishibuchi et al., 2003, 2010). Thus, it is considered that a multi-objective hybrid algorithm could outperform the multi-objective evolutionary algorithm presented in Yannibelli and Amandi (2012a) for solving the addressed problem. The multi-objective evolutionary algorithm presented in Yannibelli and Amandi (2012a) is the only multi-objective algorithm previously proposed in the literature for solving the addressed problem.

The remainder of the paper is organized as follows. In Section 2, a brief review of published works that consider the effectiveness of human resources in the context of multi-objective project scheduling problems is given. In Section 3, the addressed multi-objective project scheduling problem is described. In Section 4, the multi-objective hybrid algorithm designed to solve the problem is described. In Section 5, the computational experiments developed to evaluate the performance of the multi-objective hybrid algorithm are presented, and their results are analyzed. Finally, in Section 6, the conclusions of the present work are presented.

2. Related works

In the literature, various multi-objective project scheduling problems have considered the effectiveness of human resources. These multi-objective project scheduling problems state different assumptions about the effectiveness of human resources. In this regard, only few multi-objective project scheduling problems have considered human resources with different levels of effectiveness (Bellenguez & Néron, 2005; Gutjahr et al., 2008; Hanne & Nickel, 2005; Yannibelli & Amandi, 2012a), a central aspect in real multi-objective project scheduling problems. In this section, the attention is focused on analyzing the way in which the effectiveness of human resources is considered in multi-objective project scheduling problems reported in the literature.

Li and Womer (2009), Drezet and Billaut (2008) and Bellenguez (2008) address multi-skill project scheduling problems considering different optimization objectives. In these problems, each project activity requires specific skills and a given number of human resources (employees) for each required skill. Each available employee masters one or several skills, and all the employees that master a given skill have the same effectiveness level in relation to the skill (homogeneous levels of effectiveness in relation to each skill).

Bellenguez and Néron (2005) consider a multi-skill project scheduling problem with hierarchical levels of skills. In this problem, given a skill, for each employee that masters the skill, an effectiveness level is defined in relation to the skill. Thus, the employees that master a given skill have different levels of effectiveness in relation to the skill. Then, each project activity requires one or several skills, a minimum effectiveness level for each skill, and a number of resources for each pair skill-level. This work considers that all sets of employees that can be assigned to a given activity have the same effectiveness on the development of the activity. Specifically, with respect to effectiveness, such sets are merely treated as unary resources with homogeneous levels of effectiveness.

Hanne and Nickel (2005) address a multi-skill project scheduling problem considering different optimization objectives. In this problem, most activities require only one employee with a particular skill, and each available employee masters different skills. In addition, the employees that master a given skill have different levels of effectiveness in relation to the skill. Then, the effectiveness of an employee in a given activity is defined by considering only the effectiveness level of the employee in relation to the skill required for the activity.