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An efficient hybrid algorithm for resource-constrained project scheduling

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ABSTRACT

We propose an efficient hybrid algorithm, known as ACOSS, for solving resource-constrained project scheduling problems (RCPSP) in real-time. The ACOSS algorithm combines a local search strategy, ant colony optimization (ACO), and a scatter search (SS) in an iterative process. In this process, ACO first searches the solution space and generates activity lists to provide the initial population for the SS algorithm. Then, the SS algorithm builds a reference set from the pheromone trails of the ACO, and improves these to obtain better solutions. Thereafter, the ACO uses the improved solutions to update the pheromone set. Finally in this iteration, the ACO searches the solution set using the new pheromone trails after the SS has terminated. In ACOSS, ACO and the SS share the solution space for efficient exchange of the solution set. The ACOSS algorithm is compared with state-of-the-art algorithms using a set of standard problems available in the literature. The experimental results validate the efficiency of the proposed algorithm.

1. Introduction

The classical resource-constrained project scheduling problem (RCPSP) continues to be an active area of research. In recent years, this study attracted increasing interest from researchers and practitioners searching for better solution methods [45,5] . This problem involves finding a feasible schedule minimizing the makespan, that is, the total duration, of a project consisting of a set of activities with known deterministic durations. In addition, this problem is subject to precedence constraints between activities and accumulative constraints related to resource availability and resource consumption by the activities.

Previous studies have proposed several exact approaches. The most competitive exact algorithms seem to be those of Brucker et al. [4] and Mingozzi et al. [33] , amongst others. However, with respect to the NP-hardness characteristic of the RCPSP [3], these studies can only solve small scale problem instances with up to 60 activities in a satisfactory manner. Therefore, heuristic solution procedures remain the only feasible way of handling practical larger resource-constrained project scheduling problems [45]. Many researchers have proposed various heuristics and meta-heuristics to solve the underlying RCPSP in real-time. Several previous studies [25,27,26,21] provided detailed descriptions of different heuristic methodologies employed to solve the RCPSP. These methodologies may be classified into several categories: (1) priority-rule-based X-pass methods [23,7], (2) classical meta-heuristics [9,19,20,22,31,32,34,38,39,47,45,1,51,52], (3) local-search-oriented approaches [15,48], and (4) population-based approaches [46].

In population-based approaches, ant colony optimization (ACO) has been successfully applied to several NP-hard combinatorial optimization problems [12,14], and in particular, can be used to solve large scale problems [29,43,16]. Therefore, we believe that ACO is a promising method for solving the RCPSP. However, to the best of our knowledge, there are very few studies on the application of ACO to the RCPSP. Merkle et al. [32] presented the first application of ant systems for the RCPSP.

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Tseng and Chen [44] presented a hybrid meta-heuristic named ANGEL for the RCPSP. To exploit the potential of ACO meta-heuristics for solving the RCPSP, we propose a hybridized algorithm known as ACOSS, that combines ant colony optimization, a scatter search and a local search method.

The scatter search (SS), first introduced by Glover [17], is an evolutionary method that has been successfully applied to combinatorial and non-linear optimization problems. In contrast to other evolutionary methods such as genetic algorithms, the SS is founded on the premise that systematic designs and methods for creating new solutions afford significant benefits beyond those derived from recourse to randomization. The SS strategies for search diversification and intensification have proved to be effective in a variety of optimization problems [8]. However, there are few applications of the SS to the RCPSP. Debels et al. [10] presented a hybrid scatter search/electromagnetism meta-heuristic for the RCPSP. Yamashita et al. [50] implemented several variants of the SS for the resource availability cost problem (RACP) and the experimental results showed that the SS is capable of providing high-quality solutions for the RACP in a reasonable computational time. Subsequently, Yamashita et al. [49] developed a SS for the resource availability cost problem with scenarios (RACPS). Ranjbar et al. [38] used a SS algorithm to tackle the discrete time/resource trade-off project scheduling problem, the computational results of which verified the efficiency of the algorithm. Additionally, Mobini et al. [34] proposed an enhanced scatter search (ESS) to solve the RCPSP. In this study, we also make use of a SS hybridized with ACO for large scale RCPSPs.

The remainder of this paper is organized as follows. Section 2 provides a description of the RCPSP. ACOSS is presented in Section 3. Computational results are reported in Section 4, while Section 5 presents our conclusions.

2. The resource-constrained project scheduling problem

This study focuses on the classical resource-constrained project scheduling problem (RCPSP), which can be described as follows [45]. A project consists of a set of activities $V = 0, 1, \ldots, n, n+1$ and K renewable resource types. We denote the duration of an activity j in V as d_j. The availability of each resource type $k \in K$ in each time period is R_k and each activity j requires r_{jk} units of resource k during each period of its duration. The dummy activities 0 and $n + 1$ represent the beginning and the end of the project, where $d_0 = d_{n+1} = 0$ and $r_{0k} = r_{n+1k} = 0$. Parameters d_j, r_{jk}, and R_k are assumed to be non-negative integer values. The activities are interrelated by two types of constraints: (1) precedence constraints prevent activity j from being started before all its predecessor activities P_j have been completed, and (2) the sum of the resource requirements for resource k in any time period cannot exceed R_k. The optimized objective of the RCPSP is to find precedence and resource feasible completion times for all activities such that the makespan of the project is minimized [26]. Fig. 1 shows an example of a project comprising $n = 6$ activities that need to be scheduled subject to $K = 1$ renewable resource type with a capacity of 6 units. Fig. 2 shows a feasible schedule with an optimal makespan of 15 periods.

Let the completion time of activity j be denoted as F_j, then the completion times of schedule S are denoted as $F_1, F_2, \ldots, F_n$. The conceptual model of the RCPSP can be described as follows [6]:

$$\min \; F_{n+1} \tag{1}$$

$$\text{s.t.} \quad F_h \leqslant F_j - d_j, \quad j = 1, \ldots, n+1; \; h \in P_j \tag{2}$$

$$\sum_{j \in A(t)} r_{j,k} \leqslant R_k, \quad k \in K; \; t \geqslant 0 \tag{3}$$

$$F_j \geqslant 0, \quad J = 1, \ldots, n+1 \tag{4}$$

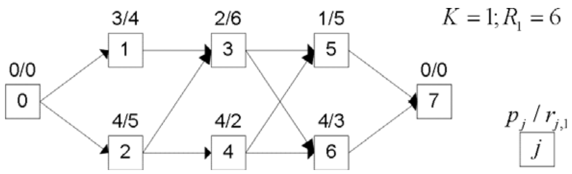

Fig. 1. Project example.

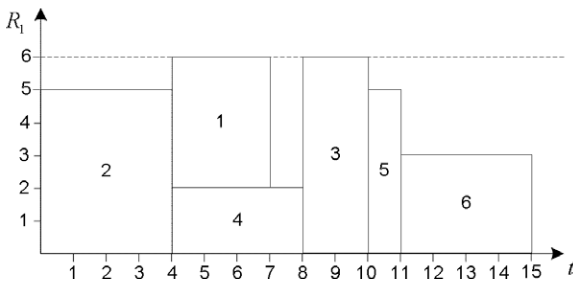

Fig. 2. Feasible schedule.