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A particle swarm optimization based hyper-heuristic algorithm for the classic resource constrained project scheduling problem

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ABSTRACT

In this paper, we propose a particle swarm optimization (PSO) based hyper-heuristic algorithm for solving the resource constrained project scheduling problem (RCPSP). To the best of our knowledge, this is the first attempt to develop a PSO hyper-heuristic and apply to the classic RCPSP. The hyper-heuristic works as an upper-level algorithm that controls several low-level heuristics which operate to the solution space. The solution representation is based on random keys. Active schedules are constructed by the serial scheduling generation scheme using the priorities of the activities which are modified by the low-level heuristics of the algorithm. Also, the double justification operator, i.e. a forward–backward improvement procedure, is applied to all solutions. The proposed approach was tested on a set of standard problem instances of the well-known library PSPLIB and compared with other approaches from the literature. The promising computational results validate the effectiveness of the proposed approach.

1. Introduction

The resource constrained project scheduling problem (RCPSP) has been recognized by researchers and practitioners as one of the most important and challenging problems in operational research. Many other problems in production planning, grid computing, network packet switching, and facility location involve the scheduling concept given that these problems commonly accompany the cost objective related to certain constraints. The objective of the RCPSP is to minimize the total project makespan by scheduling the activities of a project such that both the precedence relations between the activities and limited resource availabilities are satisfied.

Traditionally, the RCPSP is a problem that appears growing interest by the researchers. Exact methods, such as branch and bound algorithms [22,10,49] have been proposed in the literature for solving the problem to optimality. However, treating instances with large number of activities requires considerable computation time since it has been proven that the RCPSP is an NP-hard problem in the strong sense as a generalization of the job shop scheduling problem [8]. Thus, heuristic and meta-heuristic approaches have been proposed to find near-optimum solutions in reasonable computational time and overcome the combinatorial explosion phenomenon.

Simple heuristics based on priority rules were proposed by Kolisch [42]. Many of these priority rules are borrowed from machine scheduling, and particularly from job shop scheduling. A review and computational analysis of priority rules can be found in Klein [39]. Bouleimen and Lecocq [9] proposed simulated annealing, Nonobe and Ibaraki [51] and Klein [40]

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developed tabu search, and Palpant et al. [53] and Lova et al. [46] presented variable neighborhood search and hybrid metaheuristics, respectively.

As for the population based approaches, genetic algorithms [31,3,34,32,61,47,28,54], scatter search [21], and ant systems [48] have also been proposed. Kochetov and Stolyar [41] developed an evolutionary algorithm which combines genetic algorithm, path relinking, and tabu search. Recently, Chen et al. [17] proposed a hybrid ant colony and scatter search algorithm, and Wang and Fang [62] developed a hybrid estimation of distribution algorithm to solve the RCPSP.

New approaches such as neurogenetic algorithms [1], artificial immune algorithms [50], bee algorithms [69], and shuffled frog leaping algorithms [26] are applied recently to the RCPSP.

It is clear from the literature that the research interest in RCPSP and its extensions is great and constant over the years, confirming that these problems are a popular research field for applying the latest optimization techniques.

Despite the success of heuristics and metaheuristics in solving real world problems, they are not easily applicable to new problems, or even new instances of similar problems. This drawback arises from the range of parameter choices involved when using these approaches since there are no commonly accepted directions on parameter tuning. As a result, developing such a problem-specific method is expensive to develop and maintain. The core idea of hyper-heuristics is to develop algorithms that are more generally applicable than many of the classic search approaches. A hyper-heuristic, attempts to find a good performing sequence of heuristics in a given problem instance rather than trying to solve the problem directly. Therefore, the goal is to develop generic methods, which should produce solutions of acceptable quality, based on a set of easy-to-implement low-level heuristics. A hyper-heuristic is employed as a higher level methodology, and given a particular problem instance or class of instances, manages a number of low-level heuristics producing combinations of algorithmic applications to find a near-optimal solution.

Over the last few years there is a growing literature in the field of hyper-heuristics. Storer et al. [56], Dowsland et al. [25], and Anagnostopoulos and Koulinas [5] proposed simulated annealing hyper-heuristics, Burke et al. [12] developed tabu search and Qu and Burke [55] proposed variable neighborhood search. Additionally, population based hyper-heuristics have been developed. Dorndorf and Pesch [24], Hart and Ross [30], Han and Kendall [29], and Anagnostopoulos and Koulinas [6] proposed genetic algorithm based hyper-heuristics. Gascón-Moreno et al. [27] proposed an evolutionary hyper-heuristic. Burke et al. [13] proposed ant colony based algorithm, Anagnostopoulos and Koulinas [7] introduced a GRASP-based hyper-heuristic algorithm, and Koulinas and Anagnostopoulos [45] proposed a threshold accepting hyper-heuristic. Recently, Crawford et al. [19], Alinia Ahandani et al. [4], and Ahmed et al. [2] proposed hyper-heuristic approaches based on particle swarm optimization.

Numerous applications have also been developed. In particular, hyper-heuristic algorithms have been proposed for treating well-known scheduling problems such as the flow shop scheduling problem [52], and the job shop scheduling problem [24,56,29,64]. Recent reviews of hyper-heuristics and their applications could be found in [16,14].

Recently, hyper-heuristics have been applied for handling project scheduling problems. Anagnostopoulos and Koulinas [5] proposed a simulated annealing hyper-heuristic for the resource leveling problem, Anagnostopoulos and Koulinas [6] developed a genetic hyper-heuristic algorithm for the RCPSP, Anagnostopoulos and Koulinas [7] introduced a GRASP hyper-heuristic for RCPSP, and Koulinas and Anagnostopoulos [45] proposed a threshold accepting hyper-heuristic for both resource allocation and leveling. These approaches are developed within a widely used commercial project management software to enhance its efficiency and proved to be of acceptable efficiency.

Hyper-heuristics have been recently classified by Burke et al. [15] and a new definition of the term "hyper-heuristic" has been proposed. A hyper-heuristic algorithm is defined as "a search method or learning mechanism for selecting or generating heuristics to solve computational search problems". From this definition, two categories of hyper-heuristics are distinguished: heuristic selection and heuristic generation. Heuristic selection refers to methods for choosing or selecting existing heuristics and heuristic generation refers to methods for generating new heuristics from components of existing heuristics. An extensive analysis of this newly proposed classification can be found in Burke et al. [15].

In this paper, we propose a particle swarm optimization based hyper-heuristic algorithm (PSO-HH) to handle the resource constrained project scheduling problem. The proposed algorithm manages solution methods rather than solutions, and employs simple low-level heuristics. The procedure has been developed using Visual Basic 2010 programming language.

2. Formulation of the problem

A project is represented by an acyclic activity-on-node (AoN) network topology. The network consists of n activities (nodes) and precedence relations (arcs) between activities, and R renewable resources. We denote d_i and f_i the non-preemptable duration and the finish time of an activity i. Nodes 1 and n are dummy activities representing the start and finish of the project with no ingoing and outgoing arcs, respectively. The RCPSP is defined as follows:

$$\min f_n \tag{1}$$

subject to

$$f_i \leqslant f_j - d_j \quad \text{for all precedence relations } (i,j) \tag{2}$$

$$f_1 = 0, \quad d_1 = 0, \quad d_n = 0 \tag{3}$$

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