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Discrete Optimization

An experimental investigation of metaheuristics for the multi-mode resource-constrained project scheduling problem on new dataset instances

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ABSTRACT

In this paper, an overview is presented of the existing metaheuristic solution procedures to solve the multi-mode resource-constrained-project scheduling problem, in which multiple execution modes are available for each of the activities of the project. A fair comparison is made between the different metaheuristic algorithms on the existing benchmark datasets and on a newly generated dataset. Computational results are provided and recommendations for future research are formulated.

1. Introduction

Resource-constrained project scheduling has been a well-known and extensively studied research topic for the past decades. The optimization problem minimizes the makespan of the project, subject to precedence relations between the activities and resource constraints. When introducing different modes to each activity, with for every mode a different duration and different resource requirements, the problem is generalized to the Multi-Mode Resource-Constrained Project Scheduling Problem (MRCPSP).

In the MRCPSP, three different categories of resources can be distinguished (Slowinski, 1981): renewable resources, which are limited per time-unit (e.g. manpower, machines), nonrenewable resources, which are limited for the entire project (e.g. budget) and doubly constrained resources, which are limited both per time-unit and for the total project duration (e.g. cash-flow per time-unit). Since doubly constrained resources can be considered as a combination of renewable and nonrenewable resources, we do not consider them explicitly and do not take them into account in this study. In the remainder of this paper, we will refer to the MRCPSP/R if only renewable resources are considered while the general term MRCPSP is used for the multi-mode scheduling problem with both renewable and nonrenewable resources. Moreover, in this paper only discrete resources are considered. These resources can be allocated in discrete amounts to activities from a given finite set of possible allocations (Weglarz, Jozefowska, Mika, & Waligora, 2011).

As the MRCPSP is a generalization of the RCPSP, the MRCPSP is known to be NP-hard (Blazewicz, Lenstra, & Rinnooy Kan, 1983). Moreover, if there is more than one nonrenewable resource, the problem of finding a feasible solution for the MRCPSP is NP-complete (Kolisch, 1995). The problem is denoted as $m, 1T|cpm, disk, mu|C_{max}$ using the classification scheme of Demeulemeester and Herroelen (2002) and is denoted as $MPS|prec|C_{max}$ by Brucker, Drexl, Möhring, Neumann, and Pesch (1999).

In the MRCPSP, a set A of pairs of activities between which a precedence relationship exists, and a set N of n activities, where each activity $i \in N = \{1, \ldots, n\}$, can be performed in different execution modes, is given. The set $M_i = \{1, \ldots, |M_i|\}$ determines the possible execution modes for activity i, while m_i indicates the chosen mode for activity i. The duration of activity i, when executed in mode m_i, is d_{im_i}. Each mode m_i also requires $r^{\rho}_{im_ik}$ units for each resource in the set R^{ρ} of renewable resource types. For each renewable resource $k \in R^{\rho} = \{1, \ldots, |R^{\rho}|\}$, the availability a_k is constant throughout the project horizon. Activity i, executed in mode m_i, will also use $r_{im_i^{\nu}l}$ nonrenewable resource units of the total available nonrenewable resource a^{ν}_l, with $l \in R^{\nu}$ and R^{ν} the set of nonrenewable resources. The aim of the MRCPSP is to select exactly one

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mode for each activity in order to schedule the project with a minimal makespan, subject to the resource and precedence constraints.

Talbot (1982) presented the mathematical programming formulation of this problem, while the MRCPSP can be formulated conceptually as follows:

$$\text{minimize } f_n \quad (1)$$

$$\text{subject to } f_i + d_{jm_j} \leqslant f_j \quad \forall (i,j) \in A \quad (2)$$

$$\sum_{i \in S(t)} r^{\rho}_{im_ik} \leqslant a^{\rho}_k \quad \forall k \in R^{\rho}, \ \forall t \quad (3)$$

$$\sum_{i=1}^{n} r^{\nu}_{im_il} \leqslant a^{\nu}_l \quad \forall l \in R^{\nu}, \quad (4)$$

$$m_i \in M_i \quad \forall i \in N \quad (5)$$

$$f_0 = 0 \quad (6)$$

$$f_i \in \text{int}^+ \quad \forall i \in N \quad (7)$$

where $S(t)$ denotes the set of activities in progress in period $]t-1, t]$ and f_i the finish time of the ith activity. The objective of the MRCPSP is to find a mode and a start time for each activity such that the makespan is minimized and the schedule is feasible with respect to the precedence constraints and the renewable and nonrenewable resource constraints. If the schedule is not feasible with respect to one of the precedence or resource constraints, the solution is called infeasible.

Several exact, heuristic and metaheuristic solution methods for the MRCPSP have been proposed in the literature in recent years. Exact solution procedures have been proposed by Slowinski (1980), Talbot (1982), Patterson, Slowinski, Talbot, and Weglarz (1989), Speranza and Vercellis (1993), Sprecher (1994), Sprecher, Hartmann, and Drexl (1997), Sprecher and Drexl (1998), Hartmann and Drexl (1998) and Zhu, Bard, and Tu (2006). Except from the last, all procedures are applications of branch-and-bound algorithms, for which an overview is made by Hartmann and Drexl (1998). However, none of these exact procedures can be used for solving large-sized realistic projects, since they are unable to find an optimal solution in a reasonable computation time. Therefore, different single-pass heuristic and metaheuristic procedures were presented.

For the MRCPSP/R (with renewable resource only), heuristic procedures were proposed by Elmaghraby (1977); Boctor (1993, 1996a); Knotts, Dror, and Hartman (2000); Artigues and Roubellat (2000) and Lova, Tormos, and Barber (2006). Heuristic solution procedures for the general MRCPSP (with renewable and nonrenewable resources) were presented by Talbot (1982); Drexl and Grünewald (1993); Özdamar and Ulusoy (1994) and Kolisch and Drexl (1997).

The increasing interest in operations research for metaheuristics during the recent years has also resulted in the development of several metaheuristic solution procedures for the MRCPSP. A wide variety of metaheuristic strategies, solution representations and schedule generation schemes were used to develop the most efficient algorithms. Since the methods are tested on different benchmark datasets using different stop criteria, a fair comparison between each of these procedures is difficult. Moreover, the current benchmark datasets show several shortcomings, which could lead to biased results. For an extensive overview of the available exact, heuristic and metaheuristic approaches to the MRCPSP, the reader is referred to the overview paper of Weglarz et al. (2011).

The objective of this paper is threefold: first, an overview of the available metaheuristics is given and a classification is made based on the characteristics of each method. Second, a new dataset will be proposed in order to deal with the shortcomings of the current benchmark datasets. Finally, an extended computational comparison is performed to compare the metaheuristics and to evaluate the impact of the network and resource parameters of the project on the efficiency of the procedures.

The remainder of this paper is organized as follows: in Section 2, an overview is given of all the metaheuristics solution procedures for the MRCPSP. In Section 3, the shortcomings of the current benchmark datasets are mentioned and a new benchmark dataset is proposed. In Section 4, the computational experiments are reported as well as the results of the different metaheuristics on the current and new benchmark datasets. In the last section, overall conclusions and suggestions for future research are presented.

2. Metaheuristics for the MRCPSP

This section gives an overview of the current available metaheuristics from literature. In Section 2.1, we briefly explain the preprocessing process as proposed by Sprecher et al. (1997). In Section 2.2, an overview of the different classification criteria, as mentioned in Kolisch and Hartmann (1999), is given and the available algorithms are classified according to these criteria. Finally, in Section 2.3, an overview is given of the methodology used to code each of the metaheuristics in order to make a fair comparison for these procedures.

2.1. Preprocessing

Sprecher et al. (1997) developed a preprocessing procedure, which can be applied before the solution procedure is started, to reduce the search space in which the solution procedure will operate. This reduction procedure excludes those modes which are inefficient or non-executable and those resources which are redundant. As defined by Sprecher et al. (1997), a mode is called *inefficient* if there is another mode of the same activity with the same or smaller duration and no more requirements for all resources. A mode is called *non-executable* if its execution would violate the renewable or nonrenewable resource constraints in any schedule. A nonrenewable resource is called *redundant* if the sum of the maximal requests for that nonrenewable resource does not exceed its availability. Excluding these modes or nonrenewable resources does not affect the set of feasible or optimal schedules and reduces the search space of the problem.

2.2. Classification criteria

In order to make a classification of the available metaheuristics, the procedures are categorized based on four classification criteria: the metaheuristic strategy, the schedule representation, the mode representation and the schedule generation scheme. In what follows, each of these criteria is briefly discussed.

Metaheuristic strategy. Several metaheuristic strategies to solve a scheduling problem are available. For an overview of these metaheuristic strategies we refer to Glover and Kochenberger (2003) and Talbi (2009). For the MRCPSP the following eight strategies were used in literature: genetic algorithm (GA), scatter search (SS), simulated annealing (SA), particle swarm optimization (PSO), ant colony optimization (ACO), differential evolution algorithm (DEA), the multi-agent learning algorithm (MAL) and the estimation of distribution algorithm (EOD).

Schedule representation. Kolisch and Hartmann (1999) distinguished five different schedule representations in the RCPSP literature, from which the activity-list (AL) representation and the random key (RK) representation are the most widespread. In both representations, a priority structure between the activities is embedded. In the AL representation, the position of an