Chapter 7
A Hybrid Particle Swarm Algorithm for Resource-Constrained Project Scheduling

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ABSTRACT

The authors present and analyze a particle swarm optimization (PSO) approach for the resource-constrained project scheduling problem (RCPSP). It incorporates well-known procedures such as the serial schedule generation scheme and it is hybridized with forward-backward improvement. The authors investigate the application of PSO in comparison to state-of-the-art methods from the literature. They conduct extensive computational experiments using a benchmark set of problem instances. The reported results demonstrate that the proposed hybrid particle swarm optimization approach is competitive. They significantly improve previous results of PSO for the RCPSP and provide new overall best average results for the medium size data set. Furthermore, the authors provide insights into the importance of crucial components for achieving high-quality results.

1 INTRODUCTION

The problem considered in this chapter is the non-preemptive single mode resource-constrained project scheduling problem (RCPSP). It consists in scheduling a set of activities with deterministic processing times, resource requirements, and precedence relations between activities. The aim is to find a schedule with minimum makespan (total project duration) respecting both precedence relations and resource limits. The RCPSP is a classical problem in project scheduling. It is related to and subsumes many other scheduling problems (e.g., the job shop scheduling problem as a special case.
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The RCPSP is encountered in diverse application areas, including production, service industry, software development, and civil engineering. For a recent survey of variants and extensions of the RCPSP we refer to Hartmann and Briskorn (2010).

Various exact methods for the RCPSP have been proposed – e.g., implicit enumeration with branch and bound, zero-one programming, and dynamic programming (for a survey see Kolisch & Padman (2001)). The currently best known exact method is described by Schutt et al. (2009); it is based on the constrained programming approach.

Since the RCPSP is NP-hard (Blazewicz et al., 1983), exact methods may be time consuming and inefficient for solving large problems and real-world applications. Hence, the majority of state-of-the-art algorithms are based on metaheuristics. Kolisch & Hartmann (2006) present a comprehensive experimental evaluation of heuristic approaches for the RCPSP. In their tests the best performing heuristics are population-based metaheuristics that use the activity-list representation and the serial schedule generation scheme. In addition, the forward-backward improvement method is noted as an effective component of most state-of-the-art algorithms.

Evolutionary computation (EC) algorithms manipulate a population of solutions rather than a single solution. A prominent subclass of these algorithms is based on ideas recently derived from swarm intelligence. To the best of our knowledge almost no research has been devoted on using and investigating the paradigm of swarm intelligence, in particular particle swarm optimization (PSO), for the RCPSP with comprehensive computational experiments following the test design used by Kolisch & Hartmann (2006). Zhang et al. (2005) propose a PSO approach for the RCPSP and compare the effectiveness of different solution representations; computational results are provided only for small problem instances.

The aim of this chapter is to develop and investigate a robust evolutionary computation algorithm which combines concepts from swarm intelligence and well-known procedures for the RCPSP that is competitive to state-of-the-art algorithms. Via computational experiments we analyze the importance of algorithm components that are crucial for achieving high-quality results. The remainder of this chapter is organized as follows: We provide a formal description of the RCPSP and a review of related literature in Section 2. In Section 3 we present a general framework for EC algorithms and describe the incorporation of swarm intelligence features and procedures for the RCPSP. The computational experiments will be subject of Section 4. Finally we draw conclusions in Section 5.

2 BACKGROUND

In this section we formally introduce the RCPSP and briefly review the related literature.

2.1 Formal Problem Description

A project consists of a set \( J \) of \( N \) activities, \( J = \{1, \ldots, N\} \) and a set \( R \) of \( K \) renewable resources, \( R = \{1, \ldots, K\} \). In general the dummy start activity \( 1 \) and the dummy termination activity \( N \) are added to the project and act as source and sink of the project, respectively. The duration or processing time of activity \( j \in J \) is \( d_j \) with \( d_1 = d_N = 0 \). Each activity has to be processed without interruption. Precedence constraints force activity \( j \) not to be started before all its immediate predecessors in the set \( P_j \subseteq J \) have been finished. The structure of a project can be represented by an activity-on-node network \( G = (V, A) \), where \( V \) is the set of activities \( J \) and \( A \) is the set of precedence relationships (Valls & Ballestin, 2004). While being processed, activity \( j \) requires \( r_{j,k} \) units of resource \( k \in R \) in every time unit of its duration (with \( r_{1,k} = r_{N,k} = 0, k = 1, \ldots, K \)). For each renewable resource \( k \) there is a limited capacity of \( R_k \) at any point in time. The values \( d_j, R_k \) and \( r_{j,k} \) (duration of activities, avail-
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