A new approach to minimize the makespan of various resource-constrained project scheduling problems

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1 Introduction

The resource-constrained project scheduling problem (RCPSP) is one of the most investigated scheduling problems in the project management literature. Resource-constrained project scheduling is the process of constructing a project schedule within the limited amount of resources available. It requires the examination of the possible unbalanced use of resources over time to resolve over-allocations (the so-called resource conflicts) when more resources are required than available. The critical path based scheduling methods will often schedule certain activities simultaneously, but when more resources such as machines or people are needed than there are available, these activities will have to be rescheduled concurrently or even sequentially to resolve the resource constraints. The resource-constrained project scheduling problem aims at resolving these resource conflicts such that the total project makespan is minimized.

This abstract presents a new solution approach to solve the resource-constrained project scheduling problem in the presence of multiple modes with mode identity constraints and two types of logical constraints. Apart from the traditional AND constraints with minimal time-lags, these precedences are extended to OR constraints. These logical constraints extend the set of relations between pairs of activities and make the RCPSP definition somewhat different from the traditional RCPSP research topics in literature. It is known that the RCPSP with AND constraints, and hence its extension to OR constraints, is NP-hard.

The new algorithm consists of a set of network transformation rules that remove the OR logical constraints and transforms them into AND constraints and extends the set of activities to maintain the original logic. A satisfiability (SAT) solver is used to guarantee the original precedence logic and is embedded in a meta-heuristic search to construct resource feasible schedules that respect both the limited renewable resource availability as well as the precedence logic. Computational results on a newly generated dataset that is publicly available show that the procedure is able to generate near-optimal solutions in reasonable time.

2 Problem description

In this abstract, a new solution approach will be proposed that will be able to solve various versions of the multi-mode resource-constrained project scheduling problem (section 2.1) and will take both AND and OR precedence relations (section 2.2) into account. The solution approach consists of a combined metaheuristic search and a SAT solver search (section 2.3), based on the principles used by [Coelho and Vanhoucke, 2011], to solve this new problem to near-optimality in reasonable time.

2.1 Multi-mode

Many research efforts have extended the RCPSP to the presence of multiple activity modes where each activity can be executed under a different duration and a corresponding renewable and nonrenewable resource use (the problem is further abbreviated as the MMRCPSP). Due to the complex nature of the problem, only a few exact algorithms have been presented in literature, and most algorithms presented in literature therefore consist of heuristic or meta-heuristic solution approaches. Moreover, a clear distinction can be made between algorithms incorporating both renewable and non-renewable resource constraints and algorithms limited to projects with only renewable resource constraints. In the paper written by [Van Peteghem and Vanhoucke, 2014], most algorithms have been benchmarked on existing and newly presented data instances. We will compare our solution approach on these data instances, extended with extra features such as mode identity constraints [Salewski et al., 1997] as well as the extended precedence relations that will be discussed in the next subsection.

2.2 AND/OR constraints

Scheduling activities with AND/OR constraints is not new in literature, and has been discussed in [Gillies and Liu, 1995], [Adelson-Velsky and Levner, 2002] and [Möhring et al., 2004]. They classify the traditional precedence relations to the class of AND constraints to model that an activity can only start when all predecessors have been finished. An OR constraint, however, is slightly different as it allows an activity to start as soon as any of its predecessors has been completed. Consequently, the OR precedence relations differ from the traditional AND constraints that they only require one predecessor to finish before the successor can start.

2.3 SAT approach

The solution approach to solve the existing and novel problems to near-optimality consists of the three-phased approach, including a set of network transformation rules, the use of a SAT solver and a metaheuristic search for resource feasible solutions, as briefly discussed along the following lines.

- Step 1. Network transformation: Including multi-modes and AND/OR relations into the RCPSP will be done by extending the network with various dummy nodes and dummy arcs that enable the algorithm to solve the problem using a traditional RCPSP solver. The specific details of the network conversions are not outlined in this document but will be shown in the presentation.
- Step 2. SAT Solver: In order to guarantee that the newly incorporated constraints will be satisfied, a satisfiability (SAT) problem solver will evaluate the logical conditions of the intermediate constructed schedules that act as a go/no go to further optimize the partial schedule in case all constraints are satisfied. A similar approach has been

proposed by [Coelho and Vanhoucke, 2011] to solve overallocations of non-renewable resources.

– Step 3. Metaheuristic search: A metaheuristic search procedure will evaluate thousands of solutions in reasonable time based on the traditional principles borrowed from genetic algorithms.

3 Computational design

During the presentation, the design for a new public dataset will be described and preliminary computational results for the computational experiments will be reported. These data instances will be generated by the network generators of [Demeulemeester et al., 2003, Vanhoucke et al., 2008] and will be used to test our solution approach.

Table 1 displays general and preliminary results for the new solution approach to solve the multi-mode RCPSP and shows its performance in comparison with the currently best performing algorithm from literature. To that purpose, we relied on the data instances of [Van Peteghem and Vanhoucke, 2014] that have been especially designed to solve MM-RCPSP instances and to benchmark the resulting solution in literature. In the table, the results for a 1,000, 5,000 and 50,000 schedules limit are shown for the instance set MM-LIB50, MMLIB100, and MMLIB+. For each set and stop criterion, the percentage of feasible instances, the deviation percentage from the lower bound, and the deviation percentage from the best solution known are displayed. The deviation percentages are calculated only for the feasible instances.

The results show that the procedure is competitive with the currently best performing algorithms since it stays at an average 2% from the best-known solutions. However, the newly presented solution approach can, unlike most algorithms presented in literature, be used to solve several extensions of the well-known MMRCPSP without any change in the algorithm. It should be noted that these results are only preliminary, and more detailed results will be presented on the workshop.

The infeasibility on some of the problem instances occur due to two reasons. Firstly, the number of activity modes might be too high for the current implementation of the RCPSP algorithm, and secondly, the number of backtracks limit during the SAT search was often reached. In the near future, an update of the data structure of the RCPSP solver is on the agenda in order to deal with a larger number of activity modes. Moreover, updating the SAT procedure to make a more specific search in order to find an activity mode assignments in a more efficient way also lie in our future research intentions.

Table 1. Preliminary results on a sample of the test data

Schedule Limit:		1,000	5,000	50,000
MMLIB50	feasibility	83%	83%	83%
	dev.LB	30%	21%	16%
	dev.Best	13%	5%	1%
MMLIB100	feasibility	83%	83%	82%
	dev.LB	40%	28%	19%
	dev.Best	19%	9%	2%
MMLIB+	feasibility	n.a.	50%	50%
	dev.LB	n.a.	67%	54%
	dev.Best	n.a.	10%	2%

4 Conclusions

In this abstract, the integration between resource-constrained project scheduling and a satisfiability (SAT) problem solver, as originally presented by [Coelho and Vanhoucke, 2011] has been extended to the presence of AND/OR constraints. Computational results tested on the datasets presented in [Van Peteghem and Vanhoucke, 2014] show promising results and show that the current state of the procedure can compete with some of the existing algorithms in literature. However, the newly presented solution approach can, unlike most algorithms presented in literature, be used to solve several extensions of the problem formulation without any change in the algorithm.

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