An analysis of critical alternatives in the RCPSP-AS

Tom Servranckx[1] and Mario Vanhoucke[1,2,3]

[1] Faculty of Economics and Business Administration, Ghent University, Belgium
tom.servranckx@ugent.be, mario.vanhoucke@ugent.be
[2] Technology and Operations Management Area, Vlerick Business School, Belgium
[3] UCL School of Management, University College London, UK

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1 Introduction

The most well-known problem in the field of project scheduling is the resource-constrained project scheduling problem (RCPSP) (Brucker *et al.* 1999). In the RCPSP, activities are scheduled as soon as possible given technological and renewable resource constraints with the objective of a minimal project makespan. It is assumed that the project structure is completely fixed and known prior to project scheduling, while the projects and the project environment are becoming increasingly complex. This raises the question whether a fixed project structure is realistic or preferred in a highly variable project environment. Therefore, several researchers have investigated scheduling problems in which there exist alternative ways to execute subsets of activities in the project, so-called alternative project structures (Kellenbrink and Helber 2015, Tao and Dong 2017, Tao and Dong 2018, Servranckx and Vanhoucke 2019a). Such problems typically consist of two subproblems: a selection and a scheduling subproblem. In the *selection subproblem*, a choice should be made between the different alternatives in the project structure. Subsequently, the activities corresponding to the selected alternatives should be scheduled in the *scheduling subproblem.* In this abstract, we will focus on the RCPSP with alternative project structures (RCPSP-AS) that extends the RCPSP by defining alternative ways to execute work packages (WPs) in the project (Servranckx and Vanhoucke 2019a).

The current studies in this research field present meta-heuristic solution approaches to solve both subproblems in a sequential or integrated way in order to rapidly generate high-quality schedules for case studies and/or analyse the impact of alternatives on the project scheduling objective. In general, these studies show that the existence of alternative execution modes for WPs improves the flexibility of project scheduling in highly complex and variable project environments. However, the added value of the inclusion of alternatives will be limited in case that the research efforts are limited to project scheduling alone. This is because the project scheduling process will reveal the best set of alternatives in the project structure, but will neglect the non-selected alternatives. In the complex and dynamic project environment, however, all alternatives (both the selected and non-selected alternatives in the best found solution) could be important during project rescheduling since the alternatives in the project structure provide innovative ways to deal with project disruptions. Servranckx and Vanhoucke (2019b) have proposed to construct a set of back-up schedules, so-called alternative schedules, that can be mutually switched in case that unexpected disruptions occur during project execution. As a result, the authors do not only determine the best set of alternatives in the baseline schedule, but also dynamically adjust this set of alternatives.

In this research, we will contribute to the field of research by proposing a technique to reduce the complexity of the selection subproblem of the RCPSP-AS. More precisely, we will analyse the frequency of selection of the alternatives during the project scheduling process in order to determine whether we can fix certain alternatives in the project structure with only a limited (negative) impact on the scheduling objective as a result. By fixing alternatives in the project structure, we reduce the number of possible combinations between alternatives and thus reduce the complexity in the selection subproblem. Our contributions are threefold: (1) We present a technique to analyse the impact of alternatives on the solution quality of project instances. (2) We analyse the impact of two criteria on the reduction of the number of alternatives in the project structure. (3) We validate the proposed technique on both artificial project instances and empirical case studies.

2 Problem description

In the RCPSP-AS, Servranckx and Vanhoucke (2019a) define alternative ways to execute a subset of interrelated activities in the project. Such a subset of activities is referred to as a WP, called an *alternative subgraph*, and an alternative way to execute a WP is called an *alternative branch*. For the sake of simplicity, we will refer to the former as work packages and the latter as alternatives in the remainder of this abstract. The objective of the RCPSP-AS is to select for each WP exactly one alternative such that the resulting precedence, resource and logical feasible schedule has a minimal project makespan. In the RCPSP-AS, two types of dependencies between alternatives are modelled. *Linked alternative branches* indicate that (part of) the activities in one alternative branch should be selected when another alternative branch is selected. *Nested alternative subgraphs* imply that the selection of one alternative branch from an alternative subgraph is triggered by the selection of the enclosed alternative branch. Servranckx and Vanhoucke (2019a) define two parameters to model the dependencies between alternatives: the degree of linked alternative branches (%linked) and the degree of nested alternative subgraphs (%nested).

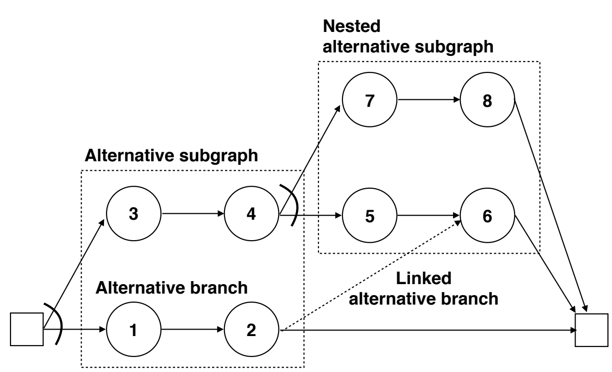

Fig. 1. Illustrative example of the RCPSP-AS

In figure 1, we show a simple example to illustrate the different concepts. We observe two alternative subgraphs with two alternative branches each, of which one alternative subgraph is nested. For the sake of simplicity, each alternative branch only consists of two activities in sequence. Each curved line ')' in figure 1 marks a choice between alternative branches in an alternative subgraph.

3 Solution approach

Due to the complexity of the RCPSP-AS, the search for a (near-)optimal solution is hard. Furthermore, a single best-found solution corresponds with a single set of selected alternatives, while significant information can be embedded in other alternative schedules. In this study, we therefore consider a set of (high-quality) solutions to analyse the impact of the selected certain alternatives on the solution quality. More precisely, we use the Tabu Search (TS) developed by Servranckx and Vanhoucke (2019a) to generate the set of high-quality solutions within a limited computational time.

In our research, we define two important criteria to analyse the set of generated solutions:

1. **SOLUTION QUALITY (Q)**: Since we should balance between a general approach (i.e. focus on all schedules generated in the TS) or a restrictive approach (i.e. focus on the best solutions generated in the TS), we will analyse a subset of schedules in the population. More precisely, we will select the best solutions with respect to the project makespan (i.e. scheduling objective) observed throughout the search process. A small subset will result in a high solution quality, while a larger subset will increasingly consist of schedules with a lower solution quality.
2. **CRITICALITY (C)**: In order to determine when an alternative can be fixed in the project structure, we measure for each schedule in our selected set of schedules, how many times each alternative is selected. The higher the frequency of occurrence, the more likely it is that this alternative must be chosen, and that it can therefore be fixed. When the frequency of an alternative exceeds a specified threshold, we fix it and do not consider the other alternatives. A higher (lower) threshold makes it harder (easier) to fix alternatives and thus corresponds with a higher (lower) criticality.

In our research, we will consider three thresholds (LOW, MED and $HIGH$) for both criteria. Using these two criteria, we can compare the frequency of selection of an alternative in the subset (Q) with the required frequency (C). This results in two possible outcomes. On the one hand, the frequency of one alternative for a WP in the subset Q is higher than the threshold C and thus this alternative can be fixed in the project structure. On the other hand, the frequency of all alternatives for a WP in the subset Q is lower than the threshold C. In this case, the selection of an alternative for this WP remains part of the selection subproblem. We prefer a higher number of fixed alternatives as this implies that a larger part of the selection subproblem can be considered solved. Therefore, the number of fixed alternatives is an important metric throughout the analysis of the artificial data instances and empirical case studies in the next section.

4 Computational results

In order to analyse the impact of the proposed technique on the complexity of the selection subproblem (i.e. the degree of alternatives that can be fixed in the project structure for different settings of Q and C), we will analyse a set of 3,600 artificial project instances presented in Servranckx and Vanhoucke (2019a). Furthermore, we will also validate these results based on three case studies. In general, we can conclude that the number of fixed alternatives indeed increases as the solution quality increases and the criticality decreases. As expected, this behaviour is observed in both the artificial dataset and the three case studies. However, we observe that the relative number of fixed alternatives is lower in the artificial projects compared to the case studies since the artificial dataset consists of projects with more or less similar alternatives. Furthermore, the experiments on the artificial dataset show us that the number of fixed alternatives increases in case that more dependencies exist between the alternatives in the project structure (i.e. %linked and %nested increase). Some preliminary results are summarised in table 1. In figure 2, the im-

		%nested					%linked				
		0	0.25	0.5	0.75	1	0	0.25	0.5	0.75	1
Solution quality	LOW	0.38	0.39	0.39	0.41	0.42	0.34	0.36	0.37	0.39	.42
	MED	0.40	0.40	0.42	0.43	0.44	0.35	0.38	0.40	0.43	0.46
	HIGH	0.41	0.41	0.45	0.46	0.48	0.38	0.41	0.44	0.47	0.51
Criticality	LOW	0.43	0.43	0.45	0.48	0.51	0.41	0.42	0.44	0.46	0.53
	MED	0.29	0.31	0.32	0.34	0.35	0.28	0.29	0.33	0.33	0.36
	HIGH	0.21	0.21	0.23	0.24	0.26	0.19	0.20	0.22	0.24	0.27

Table 1. Relative number of fixed alternatives for different settings of %nested and %linked

pact of both criteria on the number of fixed alternatives is illustrated for one of the three case studies. A darker color in the 3D-graph corresponds with a larger relative number of fixed alternatives. Similar results are obtained for the other case studies as well.

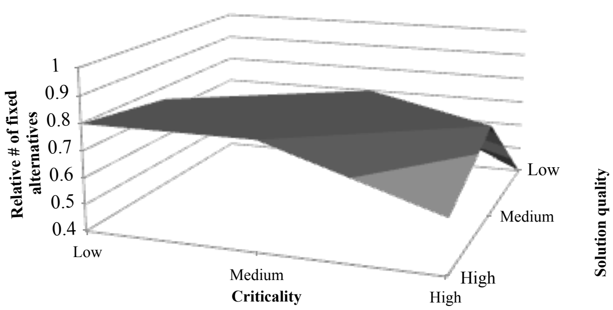

Fig. 2. Number of fixed alternatives for different settings of Q and C - Empirical data

In conclusion, we show that the elimination of certain alternatives allows us to identify key alternatives in the project structure. As a result, it can help project managers to focus their efforts during project rescheduling on important alternatives, while neglecting certain fixed alternatives.

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