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# Applying hybrid Monte Carlo Tree Search methods to Risk-Aware Project Scheduling Problem

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ABSTRACT

In this paper we investigate an application of hybrid Monte Carlo Tree Search (MCTS) based algorithms to solving dynamic decision making problems.

We employ UCT (the most popular MCTS approach) in combination with well-known Resource Constrained Project Scheduling Problem (RCPSP) and Stochastic Resource Constrained Project Scheduling Problem (SRCPSP) solvers to devise strategies for a generic and highly dynamic version of RCPSP, which we call Risk-Aware Project Scheduling Problem (RAPSP). We compare these strategies' performance with results of both pure MCTS approach and non-MCTS solvers for projects of varied characteristics. We reach a conclusion that proposed hybrid simulation-heuristic methods are promising approaches to dynamic decision making problems, RAPSP in particular. Consequently, we argue that more research effort should be directed to applications of MCTS algorithm outside the domain of game-playing, with which it is commonly associated.

At the same time, to the best of our knowledge, this paper is the first attempt at defining generalized SRCPSP model encompassing arbitrary risks and risk response / mitigation strategies as an optimization problem and applying Computational Intelligence methods to build fully-automated decision making systems. We strongly believe it to be a research direction worth further investigation, combining project scheduling, risk management and metaheuristic optimization techniques into a well-defined platform allowing direct comparisons of different strategies.



## 1. Introduction

Monte Carlo Tree Search (MCTS) is a family of simulation-based methods and UCT (Upper Confidence bounds applied to Trees) [24] is its most widely used variant. It is most popular and successful in the area of game playing, especially Go [38] – still the most demanding and difficult game to master for AI of all traditional games.

MCTS can, however, be useful in the wide research area of decision-making and decision-support [14]. It can, in particular, be applied to any Markov Decision Process (MDP), for which generative model exists [21]. It should be especially useful in stochastic problems with very large or infinite state spaces, for which many traditional algorithms and reinforcement learning approaches prove inapplicable. Still, MCTS applications outside game domain remain fairly limited – an insightful overview of those can be found, e.g., in [5].

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So far, there have been few attempts at applying MCTS to scheduling problems [10,30], and its employment in project scheduling is a new idea, not yet significantly explored. A single recently published paper [2] successfully uses MCTS as one part of a sophisticated approach to solving Multi-mode Resource-Constrained Multi-Project Scheduling Problem (MRCMPSP) - a complex, yet fully deterministic optimization problem with an optimization goal of minimizing the sum of project completion times. We were not inspired by this research in any way, as it has been published only after we have finished most of our experiments. Additionally, it deals with a fully deterministic problem, while we concentrate mainly on the dynamic aspects of project scheduling.

In this paper, we continue our research [20,26,28,39,40,43–45] into verifying MCTS applicability and efficiency in dynamic decision making problems, especially as a part of hybrid algorithms combining it with problem-specific heuristic approaches. To this end we apply MCTS to a highly dynamic stochastic version of the project scheduling task – Risk-Aware Project Scheduling Problem (RAPSP).

While the Resource-Constrained Project Scheduling Problem (RCPSP) and its myriad deterministic and stochastic variations have been studied for years, RAPSP is innovative in that it incorporates not only scheduling risk (present in all stochastic models), but also external risks, as well as risk mitigation / response strategies. The proposed representation is flexible enough to allow modeling of aspects considered by many other project scheduling problems, including multiple activity execution modes, stochastic resources availability, external events influence and restarting activities. At the same time, the dynamism and non-determinism of RAPSP makes it a useful testbed for both advanced scheduling strategies and general-use metaheuristic approaches.

Risk management, on its own and as part of the, so called, *dynamic scheduling*, has been an active topic of interest for many years and multiple methodologies of varying complexity have been proposed for dealing with both scheduling risk and external project risks. While the simpler of them, such as PERT [35] or critical chain management [11], would concentrate on better duration estimations and time buffers introduction, others would make use of techniques such as Monte Carlo simulations [16], sensitivity analysis [37] or decision trees [17]. More sophisticated frameworks, such as Event Chain Methodology [18], sometimes advocate using a combination of multiple of the above-mentioned approaches.

Still, to the best of our knowledge, research presented herein is unique for two reasons. Firstly, we define an optimization problem incorporating both activities scheduling and a very flexible external risks model; secondly, in order to solve it we develop several fully autonomous decision-making agents based on Computational Intelligence methods. Combined with the fact that we also introduce a procedure for creating RAPSP instances of varying characteristics based on popular RCPSP library (PSPLIB [33]), this opens new research perspectives, by creating a platform for effective comparison of varied risk-aware project scheduling strategies.

We propose five solvers for RAPSP, in total. Heuristic Solver is based on the standard method applicable to RCPSP: priority rule in combination with a schedule generation scheme. GRASP solver is a modified version of the GRASP method applied to SRCPSP in [3]. BasicUCT is an attempt at solving RAPSP with plain UCT method, while Proactive UCT is a hybrid approach combining UCT with any of the first two methods, thus arriving at two solvers: ProUCT-HS and ProUCT-GRASP.

We analyze the relative performance of all the strategies for projects of varied sizes and characteristics, prove that UCT may be an important part of the dynamic scheduling toolkit and further verify that hybrid MCTS-based algorithms can be successfully applied to varied complex decision problems.

Compared to our previous publications on RAPSP [44,45], as part of the research presented in this paper we introduce a new strategy (ProUCT-GRASP), design improvements to the Proactive UCT algorithm (most notably reactive heuristic) and further tune all solvers' control parameters. We also redesign our set of project test instances to offer more challenge and avoid pitfall of being partially solved by trivial strategies (e.g. one of the risk responses being universally more beneficial than others). Last but not least, we perform more in-depth testing and experimentation, drawing more conclusions about the pros and cons of each of the methods. This publication is also the first one in which our research is presented in full detail.

The remainder of this paper is divided into 7 main sections. The first of them is concerned with the MCTS and UCT algorithms themselves and their general characteristic. The next one (Section 3) contains short overview of Resource-Constrained Project Scheduling Problem and selected methods for solving it. Section 4, defining Risk-Aware Project Scheduling Problem, is followed by the one describing the five strategies that we propose and analyze. After that, in Sections 6 and 7, we present the experimental setup and results, respectively. Finally, Section 8 sums up the research and the conclusions we have drawn.

## 2. Monte Carlo Tree Search and UCT

Monte Carlo Tree Search (MCTS) is an iterative method, in which an in-memory representation of the problem is gradually built in the form of a repeatedly visited and expanded tree, starting with only root node in the first iteration. Each iteration consists of 4 phases, as presented in Fig. 1.

**Selection** Step 1, selection, is a traversal of the in-memory tree built so far. Various path selection policies can be employed to optimize exploration (testing new possibilities) to exploitation (repeating the best choices so far) ratio, yet one have become predominant: UCT (Upper Confidence bounds applied to Trees) [24]. It is also employed in our research and defines a relatively straightforward algorithm for selecting next action (tree arc) in each state (tree node). In each node all actions are first sampled once (one per each iteration in which the node is visited). Further choices