Exact and Suboptimal Reactive Strategies for Resource-Constrained Project Scheduling with Uncertain Resource Availabilities

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In order to cope with the uncertainty inherent in practical project management various strategies can be used. Proactive strategies try to accommodate disruptions in advance, whereas reactive strategies react after a disruption happened and try to revert to a feasible schedule. We give an extensive overview of reactive strategies, exact as well as heuristic, that can be used during project execution when the project is subject to disruptions due to unforeseen resource breakdowns. Furthermore, we present a heuristic that also takes future uncertainty into account when repairing the schedule.

1 Introduction

Traditional scheduling methods have only focused on deterministic environments in which all information is given in advance and is not subject to change. However, this will seldom be the case in practice. Delays may be caused by bad weather conditions, resource failures, absenteeism, activity duration increases, etc. Proactive strategies try to accommodate these disruptions in advance in order to minimize the negative impact of activity starting time delays. Unfortunately, totally eliminating their occurrence is economically unviable. One therefore also has to resort to good rescheduling techniques enabling the project manager to restore feasibility while incurring an instability penalty that is as small as possible.

The objective of the proactive-reactive project scheduling problem is to minimize schedule nervousness while meeting precedence, resource and due date constraints. This objective is measured by the sum of the weighted deviations between the original baseline schedule that is constructed before project execution starts and the expected actually realized schedule. The realized activity starting times are stochastic variables that depend on the baseline schedule (which we assume given), on the disturbances encountered during project execution and on the reactive strategy that is used to restore feasibility.

In case an infeasibility occurs due to a resource breakdown, schedule feasibility needs to be restored by postponing one or more of the offending activities in progress on the resource type causing the infeasibility during the period the disruption occurs. Our global objective is to minimize schedule instability. In case the encountered disruption is the last disruption until project completion, the optimal policy will be to create a feasible schedule for which the weighted deviation from the preschedule is as small as possible. This problem is studied in section 2. However, in practice we will usually continue facing resource breakdowns. Therefore, we want to find a schedule that is feasible, does not deviate too much from the original baseline schedule and is well protected against the occurrence of future disruptions. This problem is studied in section 3.

2 Reactive procedures

2.1 Exact approach

First of all, an exact approach has been developed that reduces the problem by creating a new scheduling problem for each preemption alternative. A preemption alternative is defined as a subset of the activities in progress during the time period the disruption occurs and that resolves the infeasibility when all of the activities contained in the alternative are preempted and postponed for at least one time period. The procedure iterates over all these preemption alternatives, creates a reduced problem instance for each alternative and then optimally solves the rescheduling problem corresponding to this reduced problem using an exact approach for solving the resource-constrained project scheduling problem with weighted earliness and tardiness costs that was developed by Vanhoucke et al. [1]. The best solution over all preemption alternatives is then the optimal solution for the rescheduling problem at hand.

2.2 Heuristic procedures

Inspired by the promising results of the use of priority lists in machine and project scheduling, we propose to use a simple reactive strategy relying on *list scheduling*. First of all, a *random* precedence feasible priority list is included for benchmarking purposes. However, we expect far better results from a *scheduled order list* that allows us to reschedule the activities in the order dictated by the baseline schedule (the lowest activity number being the tie-breaker). This priority list is then decoded into a feasible schedule using a *modified serial schedule generation scheme* that takes the known resource availabilities up to the current time period into account.

The *scheduled order list* approach is able to very quickly generate feasible solutions with a reasonable quality. However, solutions may be improved by superimposing a tabu search based improvement heuristic on the priority list rule. This procedure will try to improve the starting solution by iteratively executing the best precedence feasible interchange of two activities in the priority list that does not lead to a state included in the tabu list. The objective is to find a precedence feasible ordering of activities corresponding to a feasible schedule that deviates as little as possible from the baseline schedule S^0.

2.3 Hybrid procedure

In practice, a project manager will spend less time and effort on small disruptions than on disturbances having a major impact on project stability. Therefore, we present a new approach combining elements from both the exact and the heuristic solution procedures. Whenever an infeasibility occurs, a repaired schedule is quickly generated using the 'scheduled order' list-based heuristic. The weighted instability cost of this new, repaired schedule is then compared to the instability cost of the previous, but now infeasible schedule. In case the relative difference is larger than a preset cutoff percentage, we repair the schedule using the exact procedure. If not, the scheduled order schedule is retained.

3 Rescheduling for stability and robustness

The approaches we studied up to now were myopic strategies insofar that they try to optimize the global objective by locally minimizing the difference between the baseline schedule and the repaired schedule. However, it seems naive to assume that schedule uncertainty ceases to exist after the current disruption. Therefore, it is worthwhile to develop a rescheduling approach that does not only look backwards in time but also adequately tries to protect the schedule from disruptions that might still occur at some future point in time. A metaheuristic was developed that optimizes the bi-objective problem of weighted deviation minimization combined with robustness maximization. Because of the computational problems involved in analytically determining robustness we use a surrogate objective based on the expected activity duration increases due to breakdowns under various assumptions.

4 Computational Experiment

In order to test the relative performance of our reactive strategies we set up a computational experiment using the 480 30-activity test instances contained in the well-known PSPLIB set of project network instances [2]. For each instance a number of disruption scenarios and baseline schedules were considered. For more information regarding the construction of robust project baseline schedules when faced with resource breakdowns we would like to refer to [3] and [4]. Resource breakdowns were modeled using exponential interfailure and repair times.

It can be observed that scheduled order list scheduling performs quite well given the time necessary to execute the algorithm. However, even when only allowing for adjacent interchanges and 50 iterations, tabu search outperforms random as well as scheduled order list scheduling. These results can even be improved by allowing for general interchanges and more iterations. Surprisingly, when allowing for 200 iterations, the tabu search procedure even sometimes outperforms the exact approach. This is probably due to truncating the exact approach after a certain period of time.

As expected, the results of the hybrid procedure lie between those of optimal rescheduling and those of the scheduled order priority list. With only a small increase in required computation time, the procedure is able to yield significantly better results than the simple list scheduling heuristic. However, tabu search based improvement of the scheduled order heuristic still seems to be the most attractive option.

Reactive procedures incorporating robustness always perform worse than a pure instability-based strategy such as the tabu search procedure. This is no doubt due to the fact that we only penalize deviation from the starting schedule. Things change considerably, however, if we do not only consider instability performance but also penalize the number of rescheduling actions. The attractiveness of rescheduling for robustness depends on the ratio of the instability over the rescheduling costs.

References

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