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Multi-mode resource constrained project scheduling under resource disruptions

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A B S T R A C T

Over the last few decades, research on resource constrained project scheduling has focused on the development of mathematical programming based approaches for the generation of a nominal schedule under a deterministic environment. During the implementation phase, however, the nominal schedule may need to be revised when one or more resources are disrupted for a length of time. In this paper, we formulate two discrete time based models to deal with two different disruption scenarios for multi-mode resource constrained problems. We propose a reactive re-scheduling procedure for a single, as well as a series of disruptions, without having any disruption information in advance. To test the proposed approaches, sets of ten, twenty and thirty-activity multi-mode test instances from Project Scheduling Library (PSLIB) were used after introducing randomly generated disruption events. The experimental studies were also carried out to determine the effect of different factors related to the disruption recovery process.

1. Introduction

In Resource Constrained Project Scheduling Problems (RCPSPs), the objective is to minimize the makespan while satisfying the resource constraints and precedence relationships among the activities. The multi-mode resource constrained project scheduling problem (MM-RCPSP) is an extension of the conventional RCPSP, in which the duration of each task is a function of the level and type of resources committed to it, and the project interactions that result from the utilization of shared resources that are taken into consideration (Zapata et al. (2008). According to the classification scheme of Herroelen et al. (1999), this MM-RCPSP is denoted as $m, 1T\left|cpm, disc, mu\right|C_{\max}$ (i.e., m resource types which can be both renewable and nonrenewable| strict finish start precedence constraints with zero time-lag, activities that have multiple execution modes, the activity resource requirements are a discrete function of the activity duration| the objective is to minimize the makespan). The resources used by project activities are generally of two types, namely: (1) renewable resources with availability restrictions that may vary from one period to the next (e.g. the number of workers per shift), (2) non-renewable resources with availability restrictions over the whole project horizon (e.g. raw material). As of the literature, the renewable resources are mainly considered for single mode RCPSP, however both renewable and non-renewable resources are considered simultaneously for MM-RCPSP. Other specific resource categories that have been considered for RCPSP are: partially (Nonobe and Ibaraki, 2002) renewable resources (Böttcher et al., 1999), dedicated resources (Bianco et al., 1998), spatial resources (Hans et al., 2007), cumulative resources (Neumann et al., 2003), reusable resources (Shewchuk and Chang, 1995), synchronizing resources (Schwindt and Trautmann, 2003), multi-skill resources (Néron, 2002), heterogeneous resources (Tiwari et al., 2009), and allocatable resources (Schwindt and Trautmann, 2003). The variants of traditional RCPSP include: Generalized RCPSP, RCPSP with generalized precedence constraints, RCPSP with time varying resource constraints, and Dynamic RCPSP (Węglarz et al., 2011).

RCPSP has gained widespread attention for the last few years due to its practical importance and computational challenge. While some of the earlier endeavor was on refining the basic model, the majority of research has been aimed at developing better solution methods (Zhu et al., 2006). Blazewicz et al. (1983) have shown that RCPSP is an NP-hard problem. Moreover, when the process allows the choice of modes (in MM-RCPSP), further complexity is added by enlarging the search space (Kyriakidis et al., 2012). In solving MM-RCPSP, mixed integer linear programming (MILP) modeling is a popular choice. For finding optimal solutions for RCPSP (and also MM-RCPSP), copious algorithms and methods can be found in the literature. Among them, the branch and bound algorithm

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(Hartmann and Drexl, 1998; Sprecher and Drexl, 1998), branch and cut based algorithm (Zhu et al., 2006), tree based branch and bound algorithm (Hartmann and Drexl, 1998), self developed heuristics (Ballestín et al., 2008) and, linear programming based algorithm (Kopanos et al., 2014) are the most common approaches. According to Herroelen (2005), computational results indicate that many of the 60-activity and most of the 90- and 120-activity instances from the Project Scheduling Library-PSLIB (Kolisch and Sprecher, 1997) are still a good way off the solution capabilities of the exact methods.

Industrial resource constrained problems have been considered as a significant challenge in highly regulated industries, such as pharmaceuticals and agrochemicals, where a large number of candidate new products must undergo a set of tests for certification (Choi et al., 2004). In spite of that, in the recent past, different industrial resource constrained problems have been applied/addressed for process systems engineering, such as the application of RCPSP in semi-continuous food industries (Kopanos et al., 2011), multistage batch processing (Méndez and Cerdá, 2003), automated wet-etch station (AWS) scheduling (Novas and Henning, 2012), and for varied set up times (Nadjafi and Shadrokh, 2008). A detailed discussion on earlier applications of planning and scheduling in the process industry can be found in Kallrath (2002). However, chemical process industries are dynamic in nature, and therefore different types of unexpected events occur quite frequently. The most frequent rescheduling factors in the chemical process industry are: machine failure, rush job arrival, job cancelation, due date change, inadequacy of raw materials, price changes, and overestimation (or underestimation) of processing time, set-up times, and equipment release. In particular, Adhitya et al. (2007) proposed a heuristic for rescheduling crude oil operations to manage abnormal supply chain events. Their proposed model gives some provision to refinery personnel to choose a suitable feasible schedule from amongst many identified feasible schedules. Apart from that, Janak et al. (2006) also proposed a reactive schedule for a large-scale industrial batch plant in which the authors ignored full rescheduling in the current production horizon. Instead, they utilized an efficient mixed integer linear programming (MILP) mathematical framework to determine which tasks would not be affected by the unforeseen event, either directly or indirectly, such events were carried out as scheduled. However, reactive scheduling in case of RCPSPs is still insufficient. Keeping this in mind, this paper deals with reactive rescheduling techniques for real time based generalized MM-RCPSPs. The applicability of this research is highly diversified, as this paper conveys the dynamic features of machine or resource inadequacy/unavailability for a general MM-RCPSP case. This way of tackling such resource uncertainties can easily be applied for any real-time based chemical process industry.

During the implementation phase, a project may face significant predicaments due to resource unavailability, unproven technology, unreasonable commitment and unrealistic or an unclear goal set up (Zhu et al., 2005). Due to these factors, a project may be delayed in completion, so any such noteworthy deviation in a project schedule is considered as a disruption. Because of disruption, the traditional deterministic project scheduling models must be revised and resolved to match with the changed environment (Deblaere et al., 2011). That means, an initial optimal solution is only optimal during the execution of the schedule if there is no disruption. Vieira et al. (2003) have classified the existing rescheduling strategies into three primary types: (1) repairing a schedule that has been disrupted, often known as reactive strategy (Deblaere et al., 2011); (2) creating a schedule that is robust with respect to disruptions, known as proactive scheduling (Herroelen and Leus, 2004); and (3) studying how rescheduling policies affect the performance of dynamic manufacturing systems. In the case of proactive (robust) scheduling, a degree of anticipation of variability during project execution is incorporated into the nominal schedule. Hence even if there is no variation in the project run, this strategy always have some extra allowance and therefore gives suboptimal results. The use of a nominal schedule in combination with reactive scheduling procedures is sometime referred to as proactive-reactive scheduling, which is an iterative strategy. Reactive scheduling, on the other hand, is generally of two types: schedule repair, often known as the right shift rule because it moves forward all the affected activities (Sadeh et al., 1993) and full rescheduling (Artigues and Roubellat, 2000) which differs considerably from the nominal schedule. However, determining the best rescheduling solution still remains an open research issue, and consequently is the most difficult part of the rescheduling process (Vieira et al., 2003).

The literature on handling disruption in MM-RCPSP is however scarce. To the best of our knowledge, there are only two earlier works on handling disruptions for MM-RCPSPs. Zhu et al. (2005) have formulated an MILP model for a general class of reactive scheduling problem, and solved it with a hybrid mixed integer programming or constraint programming procedure. For recovering disruptions, they considered three different recovery options, namely rescheduling, mode alternation and resource alternation. Deblaere et al. (2011) considered activity duration variability and resource disruption explicitly, and evaluated some dedicated exact reactive scheduling procedures, as well as a Tabu search heuristic for repairing a disrupted schedule, under the assumption that no activity can be started before its baseline starting time. However, developing a proper mathematical programming model for multi-mode RCPSP, considering resource disruptions, is still a challenging research topic.

When dealing with RCPSPs and their analysis, the two practical scenarios of preempt-repeat and preempt-resume are generally considered by researchers (Lambrechts et al., 2010). In the case of the preempt-repeat environment, interrupted activities must be started from scratch, because they assume that incomplete jobs cannot be continued for completion and are so counted as wastage. On the contrary, in a preempt-resume environment, only the residual portion of any affected/interrupted activity will need to be restarted during its recovery schedule.

In this paper, we consider multi-mode resource constrained project scheduling under disruption. First, the problems with disruption of multiple renewable resources is discussed for two different practical scenarios, known as 'preempt-repeat' and 'preempt-resume', and the mathematical programming models, based on discrete time, for recovering from the disruptions are developed. A solution approach is proposed, which can generate a revised schedule after a disruption event takes place, where the disruption information is not known in advance. It is expected that the parameters of disruption follow a stochastic process. We deal with these stochastic parameters within a deterministic environment. The proposed solution approach is capable of dealing with a single, as well as a series of disruption events, for multiple resources and for multiple modes, on a real-time basis. To judge the performance of our proposed approach, we have generated a set of test problems and compared the solutions with their upper and lower bounds. In generating the test problems, we have selected sets of ten, twenty and thirty-activity benchmark instances from PSLIB and introduced randomly generated disruption scenarios into them. Experimental studies have also been conducted to analyze the effects of different factors relating to the disruption recovery process, such as changes in activity duration, changes in precedence relationship, and addition of new activity.

The structure of the paper is as follows: in Section 2, we define basic MM-RCPSPs and discuss the associative disruption recovery strategies. The terminologies, disruption recovery models, and their MILP formulations are described in Section 3. In Section 4,