Handling Uncertainties and Preparing for the Unexpected in Real-life Project Scheduling

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Abstract

Managing resources in different simultaneous, and often interrelated, projects is the principal goal for any solution to the Resource Portfolio Problem . To maximise the project gain, optimal allocation of limited resources is essential and is the principal goal of a typical resource constrained project scheduling problem (RCPSP). The early work reported here demonstrates the utility of RCPSP over traditional critical path method by scheduling one large real-life project. We employ the most relevant types of uncertainties in real-world scheduling problems and outline some important propositions or guidelines for practitioners. To do so, we consider a RCPSP in which resource availabilities and resource requests may vary from period to period for each of the activities, which may also have uncertain durations. After successfully solving using one existing meta-heuristic approach, some useful insights are available.

Keywords: Project Scheduling; Uncertainties; Resource Constraints

Introduction

The use of a project-based approach in organisations is increasing such that many organisations are involved in managing several projects and/or programs (groups of relevant projects) at the same time. The traditional approach to project management (PM) is to consider corporate projects as being independent. Yet, the relations between projects within the multiple-project environment have been recognized as a major issue for corporations (Payne, 1995). Therefore, research in this field has recently shifted towards project portfolio management (PPM). Although a number of studies have been developed to understand how PPM affects project performance, the core processes of any typical PPM approach are still not well formed. Padovani and Carvalho (2016) identified core processes in PPM, among which they considered resource allocation and management (RA&M) as an important activity to be included in the prioritization step. Considering these findings, the basic functions of PPM can be categorized in three domains (see Fig. 1): RA&M, time scheduling, and cost planning. As shown in Figure 1, the core functions of RA&M encompass selecting, prioritizing, optimising and sequencing of portfolio of projects, while considering optimal allocation of resources (Padovani & Carvalho, 2016). These optimizing and sequencing steps in RA&M resemble RCPSP, which is a rudimentary scheduling problem in a deterministic project framework.

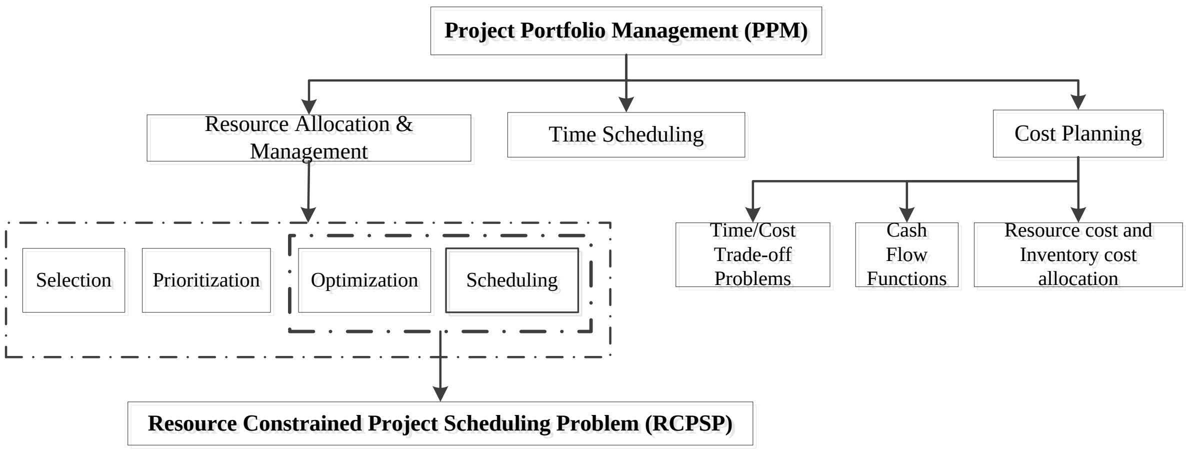


Fig. 1: RCPSP, as a branch of PPM (part of this figure taken from Padovani and Carvalho (2016))

Until recently, research on RCPSP has mostly considered fixed resource capacities and deterministic activity durations. In real-world environments, however, it is impracticable to obtain only deterministic information. Consequently, uncertainty has become an inevitable aspect of project scheduling in recent decades, which also stems from the necessity of considering stochastic resource constrained project scheduling problems (SRCPSP). A SRCPSP is defined as a problem that involves scheduling project activities with uncertain durations, in order to achieve a predefined objective, such as to minimise expected project makespan, minimise project schedule instability, and/or minimize some other predefined objective, subject to precedence constraints and renewable resource constraints (Tseng & Ko, 2016). Moreover, in real world applications, resource requests and capacities can vary over time along with the activity processing times or durations. Though appealing, this sort of extension has never gained any attention in the scientific literature, apart from some earlier works of Hartmann (2012, 2015). In those papers, a priority rule is developed for the study on RCPSP with time-dependent resource capacities and requests (referred to as RCPSP/*t*).

This paper aims to investigate and show the effectiveness of RCPSP techniques over traditional methods by considering one real-life scheduling problem. In the later part, in lieu of assessing all possible types of uncertainties in real-world scheduling problems, we consider an important variant of RCPSPs in which resource availabilities are given for each period of the planning horizon, and resource demands are given for each period of an activity's duration, which itself is uncertain. Furthermore, resource capacities and demands are also considered to vary with time parameters. The resulting problem is referred to as RCPSP/t$\tilde{d}$ to represent the time-dependency of resource parameters and durational uncertainty. After successfully solving that RCPSP/t$\tilde{d}$ setting, some important guidelines or propositions are also outlined for the practitioners. Those propositions will help them to handle this kind of adverse situations by predicting the project completion time and other important scheduling parameters under dynamic situations.

Effectiveness of RCPSP methods for Project Scheduling

To illustrate the effectiveness of RCPSP methods, we consider one real-life scheduling problem, the Highway Bridge (HB) project, which consists of 44 activities with varying daily resource demands. Three types of renewable resources (e.g., workers, machine A and machine B) are considered with the maximum availability limit of each resource being 12, 8 and8 per day, respectively. Figure 2 shows the precedence relationships (network diagram) of the HB project. The duration of each project activity is indicated above the corresponding circle node. The amount of required resources is indicated below the circle node. The precedence constraints among activities are described using arrow lines. To schedule that project, this paper employs the evolutionary local search heuristic approach (ELSH) from Chakrabortty *et al.* (2017).

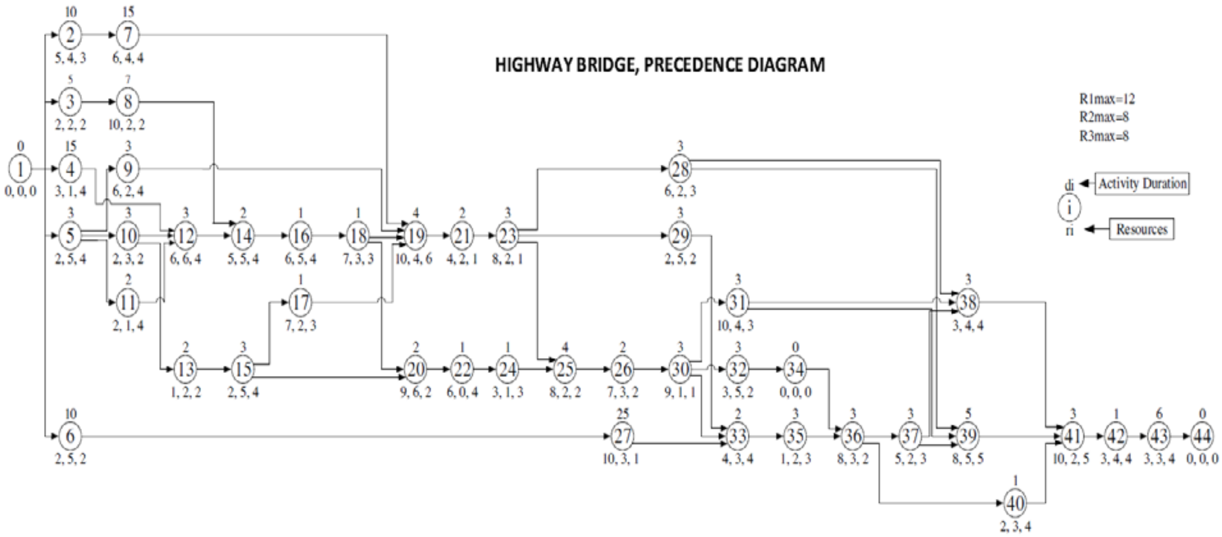


Fig. 2: Network diagram of the Highway Bridge project (Tran *et al.*, 2016)

Traditionally practitioners most often consider critical path method (CPM) to predict project completion time, which ignores resources availability and constraints, which violates practicability. As can be observed for the HB project, the completion time can be 69 days (as shown in Figure 3), if a project manager neglect resource considerations. Second scenario could be while a project manager considers resource constraints using resource-levelling techniques but does not apply RCPSP principles. In that case, his planned project completion time will be 126 days, as shown in Figure 4. Meanwhile, as can be observed from Figure 5, after applying RCPSP concepts or optimising resource-levelling problem, the project completion time drops to 117 days. Hence, application of RCPSP principles with an optimised way of resource allocation or levelling is very useful for the practitioners in predicting more accurate project completion times. In a nutshell, without precise knowledge on RCPSP, a project manager can plan or predict project completion time. However, on most cases their prediction is either too restrictive or too lenient.

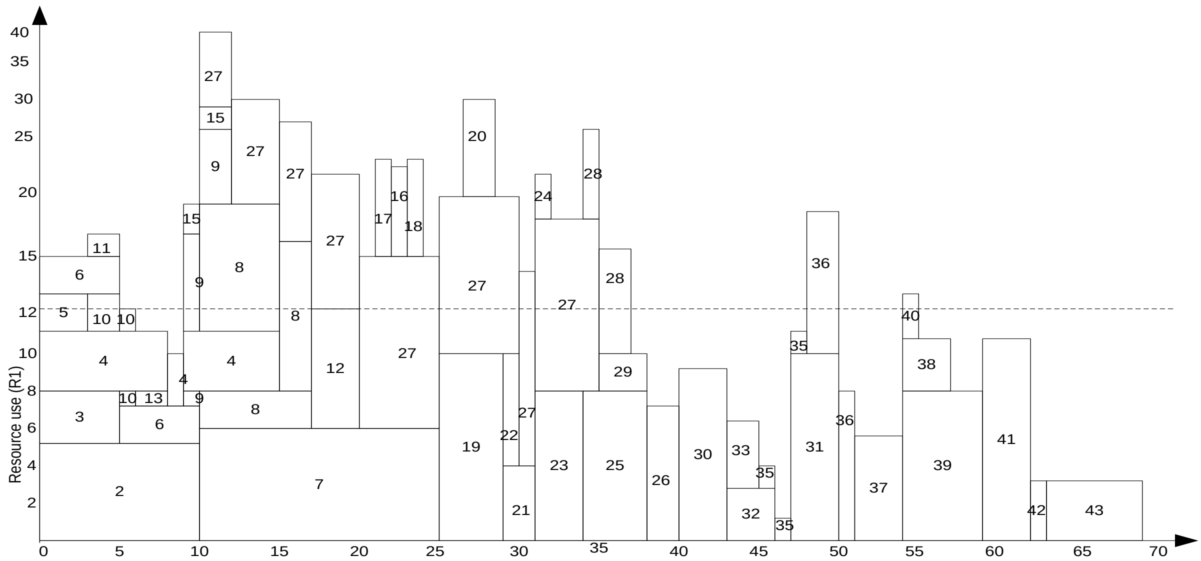


Fig. 3: Planned resource histogram for resource R1 (ignoring resource constraints)

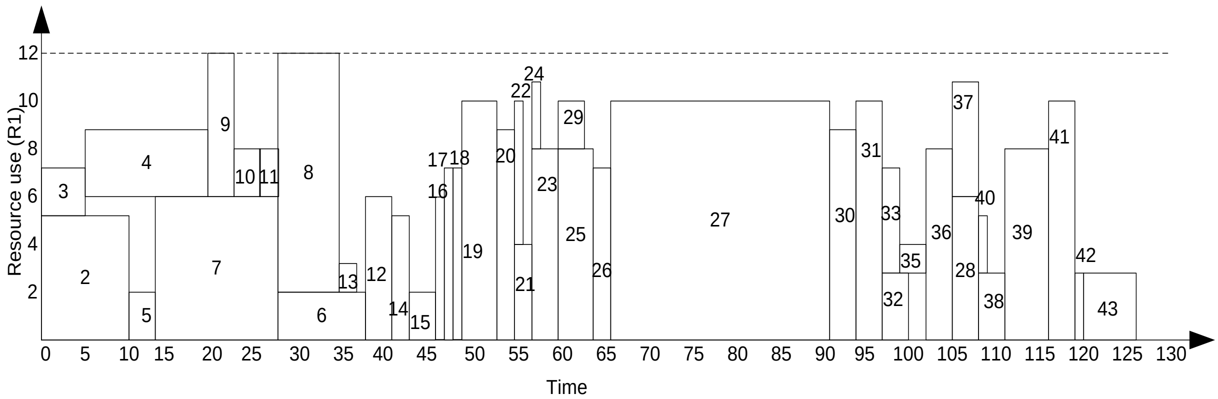


Fig. 4: Resource histogram for resource R1 (considering resource constraints: applying basic resource levelling)

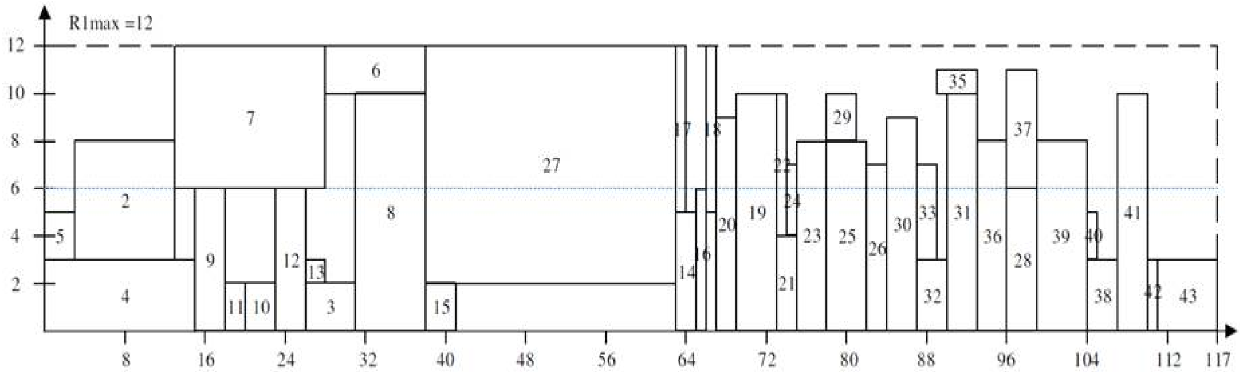


Fig. 5: Optimised resource histogram for resource R1 (using a RCPSP method)

RCPSP/t$\tilde{d}$

In this section, we present a model that extends the standard RCPSP by applying uncertainties and risk involves after considering three additional concepts: 1) time-dependent resource availability, 2) time-dependent resource request, and 3) uncertain activity duration (i.e., RCPSP/t$\tilde{d}$). We assume that each activity j requires r_{jkt} units of resource k in the t^{th} period of its uncertain processing time, $t = 1, \ldots, \tilde{d}_j$. Each resource capacity R_k is replaced by a list $R_{k1}, \ldots, R_{kT}$, with $T = \sum_j \tilde{d}_j$ being the sum of all realized durations. We consider the objective is to minimise the completion time of the project, such that the time-dependent resource constraints are fulfilled.

For better demonstration of this RCPSP/t$\tilde{d}$ setting, consider the following example. Figure 6 shows a deterministic RCPSP with 6 activities (0 and 8 are dummy activities) and where every single resource has a capacity of 6 units, with the activity numbers inside the nodes and the activity durations and resource requirements next to them. Figure 7 represents a sample example of RCPSP/t$\tilde{d}$ for the same project while activity durations are uncertain, and the resource requirements and demands are time-dependent. As with Figure 6, the activity numbers are inside the nodes and the activity durations and the list of time-dependent resource requirements are next to them. For instance, for activity 1, 3/{1,0,1} means only 1 resource is needed in day 1 and 3 (0 for day 2). Also, as with standard RCPSPs, the resource demands for any activity j should be extended up to its uncertain processing time $\tilde{d}_j$, and are mentioned in the braces just beside durations. Meanwhile, the time-dependent resource availabilities are also mentioned in brackets, which are extended up to the value of $\sum_j \tilde{d}_j$. The resource demands and availabilities were further treated as unstable and may take different numbers, even 0, and the uncertain durations were allowed to increase by a certain percentage more than their deterministic durations.

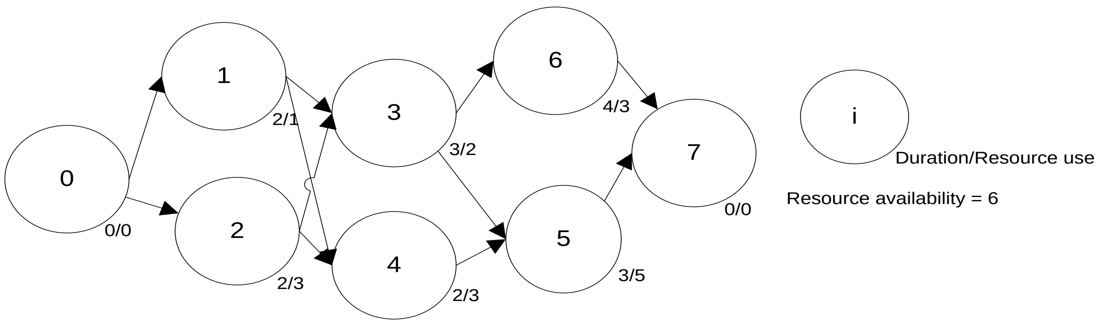


Fig 6: Sample deterministic-RCPSP example

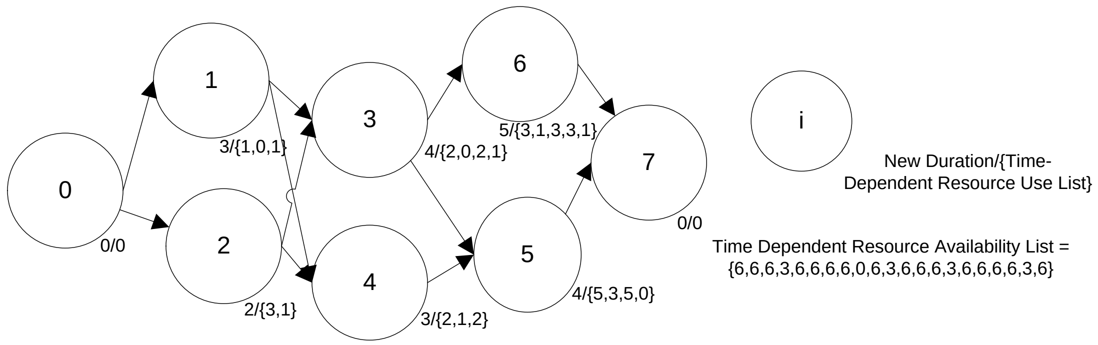
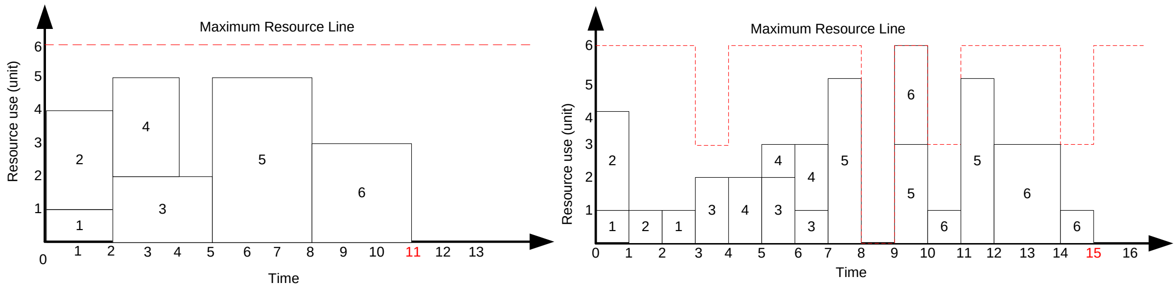


Fig 7: Sample RCPSP/t$\tilde{d}$ example

After solving with the ELSH algorithm, the resource histogram for the optimized schedule under both deterministic and dynamic resource usage condition is shown in Figure 8 (the number in the box is the activity number). As can be seen, instead of 11, the make span for this updated schedule is 15 units of time, while resource usages (i.e., height of those rectangles), activity durations (i.e., length of those rectangles) and maximum resource availability line (i.e., the red dotted line) are varied or dynamic.



(a) Deterministic RCPSP

(b) RCPSP/t$\tilde{d}$

Fig 8: Resource histogram for deterministic RCPSP and RCPSP/t$\tilde{d}$

Generation of test instances for the RCPSP/t$\tilde{d}$

As we do not have the uncertain values for resource usage and duration at the beginning of a project (when planning and scheduling the activities), we need to come up with some realistic estimated values. Having a near-perfect estimation will help the practitioners to predict more reasonable makespan, even in adverse situations. To estimate the consequence of having different uncertainties (e.g., duration and resource uncertainties), we propose a pragmatic approach to generate realistic instances for our considered RCPSP/t$\tilde{d}$ setting. Despite of having several instance generators for project scheduling, to the best of our knowledge, time-dependent resource parameters with uncertain activity durations are not considered by any of the generators. For generating different instances, we extended the standard RCPSP instances found in PSPLIB by varying the originally constant activity durations, resource availabilities and resource requests. The basic outline for generating test instances is given below:

i. Each resource request r_{jk} is replaced by a list $r_{jk1}, \ldots, r_{jk\tilde{d}_j}$. Note that the number of resource requests (r_{jk}) for any activity j depends on the magnitude of the uncertain activity duration $\tilde{d}_j$ for that activity.

ii. Each resource capacity R_k is replaced by a list $R_{k1}, \ldots, R_{kT}$, with $T = \sum_j \tilde{d}_j$ being the sum of all realized durations.

iii. If the realized duration of any activity j (i.e.,$\tilde{d}_j$) becomes larger than its deterministic duration (d_j), then we need to extend the relevant resource demands (r_{jkt}) list up to its new realized duration (i.e. each resource request r_{jkt} is replaced by a list $r_{jk1}, \ldots, r_{jk\tilde{d}_j}$). To do so, we employed two different parameters to control the variation of the resource availabilities and requests. Probabilities P^R and P^r control whether or not a reduction is applied to the availability and the request, respectively. Factors F^R and F^r determine the strength of the reduction for the availability and the request, respectively. To further understand the functionality of those parameters, interested readers are referred to the research work of Hartmann (2012).

iv. For better representation of real world problems and motivated from Bruni *et al.* (2011), we considered two different types of statistically distributed duration sets; discrete and continuous. In particular, for the continuous conditions, we have assumed that the real activity duration is a uniform random variable $U(0.75d, 2.85d)$, where d has been set equal to the deterministic duration, and for the discrete condition, a Poisson distribution with mean d was considered. Meanwhile, for the continuous types, the obtained random numbers from uniform distribution were discretised to fit this problem setting. All activity durations are assumed to be independent.

v. These reductions are applied to periods (either of the project tenure or of activity's realized duration) as a whole. That is, if it is decided that the capacity or resource request is reduced in a period, this reduction is applied to all resources.

As a foundation, we used the same HB project for generating realistic test instances. Six sets of test instances for each of two types of statistically distributed activity duration sets were generated, and are denoted as $HBt1dd, \dots, HBt6dd$ and $HBt1cd, \dots, HBt6cd$, respectively, where t indicates the time dependency, dd represents activity durations following a discrete distribution, cd represent activity duration following a continuous distribution and the number refers to the parameter setting for the calculation. The reduction probabilities have been varied between 0.05 and 0.2. The probabilities are the same for availability and request, that is $P^R = P^r$. The strength of the reduction is either half of the original capacity or down to 0. Here also, the factors are the same for capacity and demand ($F^R = F^r$). The design of the test sets is displayed in Table 1, which will assist any practitioners to generate more realistic test instances under similar settings.

Table 1: Parameter settings for generation of RCPSP/t$\tilde{d}$ test sets

Set no.	Discrete condition, $\widetilde{dd} = poisson(d)$						Continuous condition, $\widetilde{cd} = U(0.75d, 2.85d)$					
	t1dd	**t2dd**	**t3dd**	**t4dd**	**t5dd**	**t6dd**	**t1cd**	**t2cd**	**t3cd**	**t4cd**	**t5cd**	**t6cd**
P^R	0.05	0.1	0.2	0.05	0.1	0.2	0.05	0.1	0.2	0.05	0.1	0.2
P^r	0.05	0.1	0.2	0.05	0.1	0.2	0.05	0.1	0.2	0.05	0.1	0.2
F^R	0	0	0	0.5	0.5	0.5	0	0	0	0.5	0.5	0.5
F^r	0	0	0	0.5	0.5	0.5	0	0	0	0.5	0.5	0.5

Propositions for Handling Uncertainties

After successfully handling and solving those generated RCPSP/t$\tilde{d}$ instances, some very important findings for the real-life schedulers are summarized in the following remark. This summary primarily highlights some structural similarities and differences between RCPSP and RCPSP/t$\tilde{d}$. For RCPSP/t$\tilde{d}$, the following propositions hold:

(i) An activity is only eligible for scheduling, if it can be feasibly started (in accordance with precedence and resource availability) at the schedule time t_g, while the resource availability and demands change with time.

(ii) Under any schedule time t_g, the resources might be 0 units, which impedes the generation of active schedules for any schedule generation scheme packages.

(iii) For some instances, due to uncertain duration and time-varying resource parameters, the solver might not find an existing optimal solution (Hartmann, 2012; Sprecher *et al.*, 1995).

(iv) At any schedule time t_g, even if the resource availability turns to 0, there still a chance to generate active schedules only if the resource demands for all resources for that time period t_g are also 0.

(v) If for any activity i, the realized uncertain duration $\tilde{d}_i$ is greater than its deterministic duration d_i, the expected makespan for any realized schedule will likely be higher. This may be further reinforced if this case is true for a large number of activities. However, due to the effect of time-dependent resource demands, the increment of expected makespan may be affected, which may sometimes even decrease makespan. This is because, for time-dependent resource demands, sometime those demands may generate lesser values than before, including even zero.

(vi) For any activity set J, if their realized duration sets $\tilde{d}_J$ is lower than their deterministic duration sets d_J, the expected makespan for any realized schedule will likely also be lower. But, if the list of time-dependent resource availabilities are tighter (i.e., decreased significantly than their original capability), even for $\tilde{d}_J < d_J$, the expected makespan can increase.

(vii) If for any particular time period t, $R_{kt} = 0$ and $r_{jkt} = 0$, then the effect of time-dependent resource demands and capacities, or even the effect of uncertain durations, is insignificant.

Conclusion

Initially this paper demonstrates the effectiveness of resource constrained project scheduling problems over the traditional critical path methods. The contribution of optimised resource allocation or levelling along with their relationship with project portfolio management is also explained. We then consider an extension of the resource constrained project scheduling problem (RCPSP) with time-dependent resource capacity and demand, while activity durations are assumed to have uncertain durations (RCPSP/t$\tilde{d}$). Because of the practical relevance of RCPSP/t$\tilde{d}$ to modern industry, efficient algorithms are valuable. The proposed guidelines for RCPSP/t$\tilde{d}$ can meet the requirements of handling large projects under dynamic environments, with minimum computational complexity. Practitioners can benefit from the proposed approaches, because they can be easily implemented in generating realized schedules under varied conditions on a real-time basis. Organisations can also reduce significant financial and time losses by applying these approaches if any duration uncertainty is experienced. Further extensions of RCPSP/t$\tilde{d}$ are also possible, in terms of considering multiple modes to reflect alternative speeds of the production processes, considering multiple projects, and taking into account different objective functions such as the maximization of the net present value.

References

Bruni, ME, P. Beraldi, F. Guerriero, & E. Pinto. (2011). A heuristic approach for resource constrained project scheduling with uncertain activity durations. *Computers & Operations Research, 38*(9), 1305-1318. doi:10.1016/j.cor.2010.12.004

Chakrabortty, Ripon K, Ruhul A Sarker, & Daryl L Essam. (2017). Resource Constrained Multi-project Scheduling: A Priority Rule Based Evolutionary Local Search Approach *Intelligent and Evolutionary Systems* (pp. 75-86): Springer.

Hartmann, Sönke. (2012). Project scheduling with resource capacities and requests varying with time: a case study. *Flexible Services and Manufacturing Journal, 25*(1-2), 74-93. doi:10.1007/s10696-012-9141-8

Hartmann, Sönke. (2015). Time-Varying Resource Requirements and Capacities *Handbook on Project Management and Scheduling Vol. 1* (pp. 163-176): Springer.

Padovani, Marisa, & Marly M Carvalho. (2016). Integrated PPM Process: Scale Development and Validation. *International Journal of Project Management, 34*(4), 627-642.

Payne, John H. (1995). Management of multiple simultaneous projects: a state-of-the-art review. *International Journal of Project Management, 13*(3), 163-168.

Sprecher, Arno, Rainer Kolisch, & Andreas Drexl. (1995). Semi-active, active, and non-delay schedules for the resource-constrained project scheduling problem. *European Journal of Operational Research, 80*(1), 94-102.

Tran, D-H, M-Y Cheng, & M-T Cao. (2016). Solving resource-constrained project scheduling problems using hybrid artificial bee colony with differential evolution. *Journal of Computing in Civil Engineering, 30*(4).

Tseng, Ching-Chih, & Po-Wen Ko. (2016). Measuring schedule uncertainty for a stochastic resource-constrained project using scenario-based approach with utility-entropy decision model. *Journal of Industrial and Production Engineering*, 1-10.