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Multi-Objective Resource-Constrained Scheduling in Construction Projects

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Abstract. The resource-constrained scheduling problem (RCSP) is one of the most challenging problems in project management. It is a combinatorial optimization problem with multiple and contradictory objectives (resource allocation within resource availability levels, project completion prior to a given deadline, resource leveling throughout the project length) and constraints (precedence constraints between activities) while its complexity grows as the number of activities increases. In this study, the objective function includes a number of sub-objectives that result from practical considerations of actual construction projects. These are the cost of daily resources exceeding the resource availability, the cost from the day by day resource movement in and out of the project work, and the cost of prolonging the project duration or exceeding the project completion deadline. Due to the large solution space size (even for a small-sized project), genetic algorithms are employed in this study to develop the optimal or a near optimal solution. The model is applied on a case study project and tested for different constraints and goal scenarios, in order to provide insight regarding the effectiveness of the method in different optimization criteria and project management priorities. Evaluation results indicate that the proposed approach can effectively approximate the optimal solution in all cases.

Keywords: Resource-constrained scheduling, Resource allocation, Resource leveling, Multi-objective optimization, Genetic Algorithms

1 Introduction

The resource-constrained scheduling problem (RCSP) has been extensively studied in the past and it is still a case of great interest for researchers because of its importance in project management. The aim of project scheduling analysis is to develop optimal schedules with regard to time and resource allocation and leveling within resource availability margins and project completion deadlines.

Existing research efforts have led to a variety of methods and algorithms for addressing the resource-constrained scheduling problem. They can be categorized in exact methods, heuristic and meta-heuristic or evolutionary algorithms. Exact methods, such as linear/integer programming, attempt to tackle the problem by forming mathematical relationships describing the problem objective and constraints in linear form and solving with a pertinent method (e.g., Simplex method) [1-2]. Although these methods can provide exact solutions, they become unproductive in setting up the computerized problem structure as the project size and parameters increase.

Heuristic approaches, such as branch and bound algorithms, initially develop lists of potential solutions but, because the solution space is often too vast to fully traverse, they handle the problem by bounding and pruning. Main limitations of such methods are that there is no universal bounding algorithm working for all problems and that the optimal solution is not guaranteed. In this class of methods, the works of Brucker and Knust [3] and Moukrim et al. [4] can be mentioned.

When the employment of previous methods is ineffective to develop or the exact solution is computationally expensive to obtain, metaheuristic methods or evolutionary algorithms are used in order to approximate the global optimum. Evolutionary algorithms operate through the selection process in which the least fit members of the population set are eliminated whereas the fit members are allowed to survive and continue until better solutions are determined. Researchers have used Genetic Algorithms for the exploration of near optimum solutions in resource-constrained scheduling problems (Leu and Yang [5], Alcaraz et al. [6], Besikci et al. [7], Kaiafa and Chassiakos [8], Mathew et al. [9]). Genetic Algorithms have also been used for leveling the daily usage of resources and minimizing project duration (Roca et al. [10], Ponz-Tienda et al. [11]). Other studies have combined Genetic Algorithms with other evolutionary algorithms or methods to form hybrid ones so as to obtain better solutions (Lova et al. [12], Bettermir and Sonmez [13]).

Previous studies regarding the resource-constrained scheduling problem are typically based on a single (and rather theoretical) decision parameter, such as some type of statistical moment of the obtained resource histogram, to evaluate the effectiveness of the produced resource allocation. In this study, alternative decision parameters, closer to the ones encountered in practice, are explored developing different optimization structures which are comparatively evaluated to provide performance indications as well as practical implications regarding the employment of the alternative parameters.

2 Proposed model

The objective function of the proposed model represents the total cost to be minimized and is formulated as the cost summation of all optimization sub-objectives. The sub-objectives are the project completion goal within a deadline (or as soon as possible), the confinement of the daily resource usage within the availability level, and the development of a flat daily resource usage pattern throughout project execution. Unit cost values are used in order to indicate the weight of each sub-objective in this multi-objective formulation. More specifically, the total cost (objective function) consists of the following elements:

- The project direct cost which represents the cost of the required resources for project execution. This cost is proportional to the resource-days needed to complete the project under normal execution and is invariant to different solutions.
- The indirect cost which represents the general project expenses. It is practically considered to be proportional to the project duration.
- The cost of exceeding a given project completion deadline which represents the financial impact of delaying the project beyond a specified time frame.
- The cost of exceeding the daily resource availability which represents the (increased) expenditures needed for recruiting additional resources than initially planned.
- The cost associated with the deviations in daily resource usage which represents the cost for moving resources in and out of the construction site day by day.
- The cost associated with the deviations in daily resource usage which (alternatively to the previous case) is considered on the basis of the standard deviation of the daily resource usage histogram.

The above sub-objectives are considered with different unit cost values in order to compare different optimization structures and criteria. For instance, if the unit cost value of exceeding the daily resource availability is set at 1 while all other unit cost values at 0, the optimization aims at minimizing the cumulative (along the project length) number of daily resources above the resource availability level.

A single resource type for all activities and a single execution mode for every activity (in terms of duration and daily resource usage) are considered in this study and the optimization is performed by rescheduling activities according to their precedence relationships and time slacks.

The optimization model has been implemented in an Ms-Excel spreadsheet and the resource graph is automatically produced with all quantitative characteristics that describe the effectiveness of the solution in accomplishing the optimization objectives. The optimization is performed through genetic algorithms (GAs) via a commercial optimization software (Palisade Evolver 7.5) which works as an Excel add-in.

3 Results

A case study with a simple project consisting of 10 activities is considered to illustrate the algorithm application. The project activities and durations, the precedence relations, and the resource requirement per activity are shown in Table 1. Figure 1 presents the network diagram of the project and Figure 2 the resource histogram for the early project schedule (initial solution). The normal project duration is 17 days. This is also considered as the desired project deadline and set as a constraint in the optimization model. The resource availability level is set at 6 units per day.

A number of scenarios considering different optimization criteria are evaluated as indicated in Table 2. Case 1 represents the initial project schedule with the earliest start of the activities (Figure 2). Case 2 provides the result of minimizing the cost of exceeding the daily resource availability (Figure 3). It can be seen that a considerable amount of leveling has been achieved compared to the initial solution. Case 3 provides the result of minimizing the standard deviation of the daily resource usage. In this particular case study, the resource allocation histogram is identical to the previous one (Figure 3) and this is due to the relatively small project size that does not develop a large number of alternative resource allocation patterns. However, the experimentation with other examples shows some deviation in the final resource allocation between the two sub-objetives but this deviation is typically not enormous. In fact, the results of these two cases indicate their quite similar performance since both focus on a smooth resource histogram within the resource availability constraint. On the other hand, the optimization in Case 4 shows (rather surprisingly) that if the criterion is the minimization of the cumulative number of resources in and out of the project along its duration, the "best" histogram is not a leveled one but rather one that is leveled at different project phases. Case 5 provides an optimization result following the combination of sub-objectives of Cases 3 and 4. The resulting resource allocation histogram lies somewhere in between those produced by the individual sub-objectives.

Table 1. Project data for the application example.

Activity	Predecessors	Duration	Resources
A	Start	5	2
B	Start	10	2
C	Start	4	2
D	A	7	2
E	C	5	2
F	A	4	2
G	E,D,B	3	2
H	C	6	2
I	Start	4	2
J	F,G,H,I	2	2

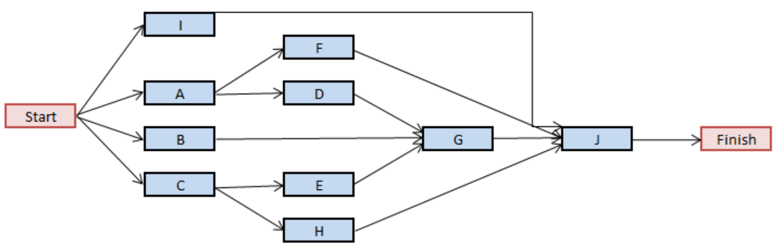

Fig. 1. Network diagram of the example project

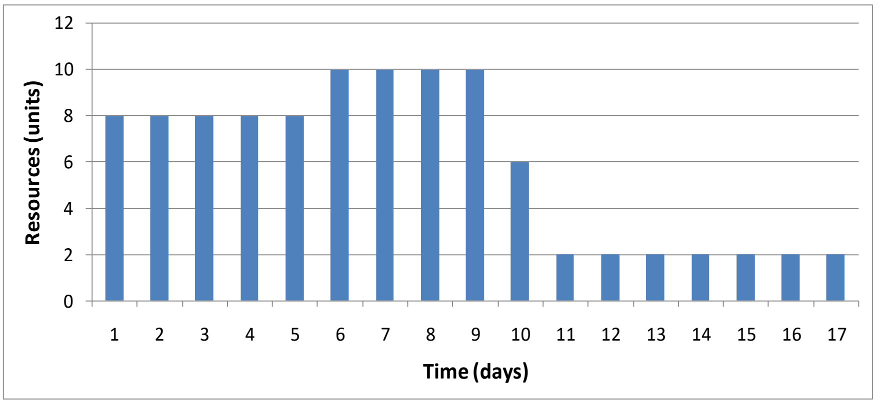

Fig. 2. Resource histogram for the early start project schedule.

Table 2. Optimal results for example project

Case no	Case description	Resource constraint	Project duration	Resource standard deviation	Resource exceedance	Resource fluctuations
1	Initial early time schedule	-	17	4.00	26	10
2	Resource allocation under resource constraint – minimizing resource availability exceedance	$R \leq 6$	17	3.11	6	12
3	Resource allocation under resource constraint – minimizing resource standard deviation	$R \leq 6$	17	3.11	6	12
4	Resource allocation under resource constraint – minimizing resource fluctuations	$R \leq 6$	17	3.56	20	6
5	Resource allocation under resource constraint – minimizing resource standard deviation and fluctuations	$R \leq 6$	17	3.16	8	6

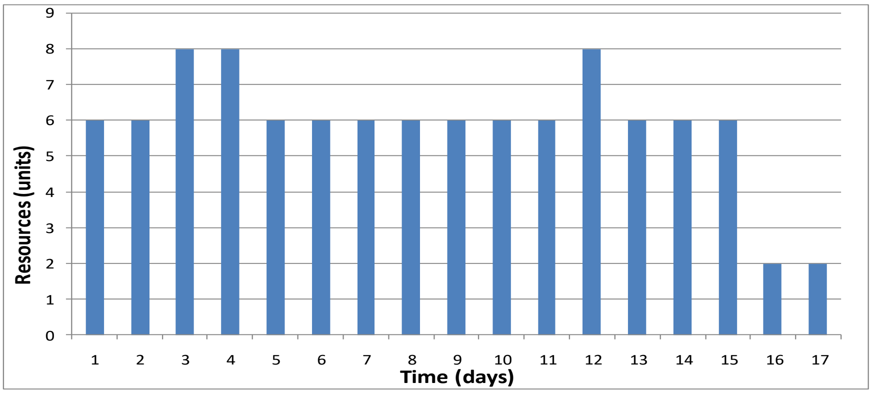

Fig. 3. Resource histogram for Cases 2 and 3.

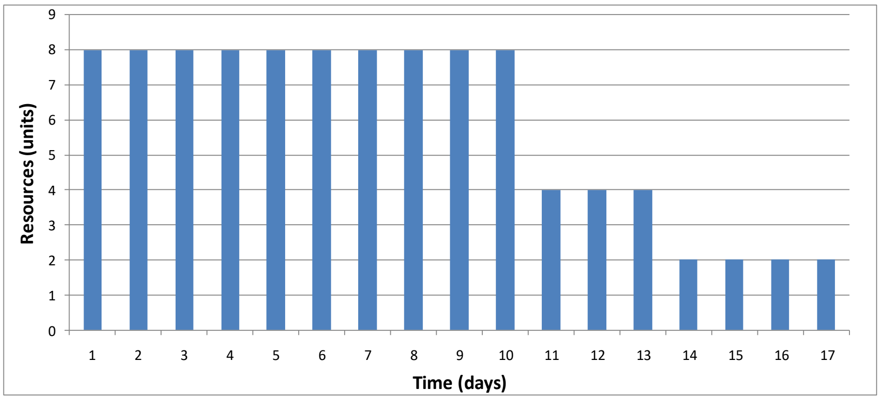

Fig. 4. Resource histogram for Case 4.

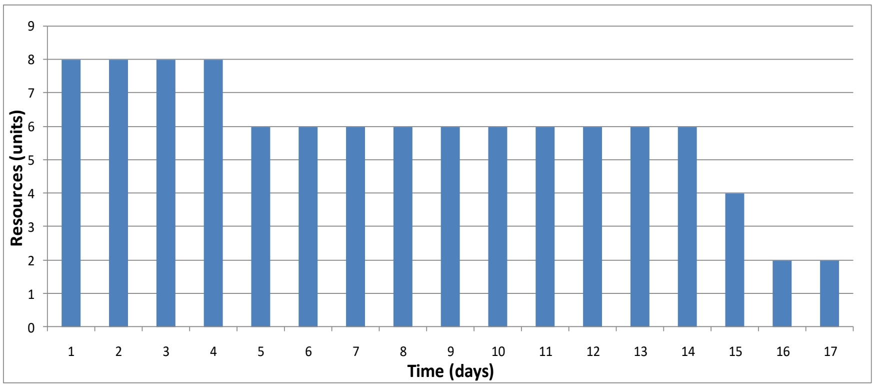

Fig. 5. Resource histogram for Case 5.

4 Discussion

On the basis of the results presented in Section 3 and from further elaboration with other case studies, the following observations can be made:

- The resource-constrained scheduling problem is a very complex one taking into account that activities should not only be optimally shaped (resource requirement, duration, placement at the right time frame) but also that there are other types of constraints that need to be satisfied (activities precedence relations, resource availability, completion deadline). As a result, metaheuristic algorithms seem to be more appropriate for solving the problem than exact optimization methods.
- The application of genetic algorithms (or any other type of metaheuristics) to solve the resource-constrained problem does not guarantee finding the optimal solution in a single run of the algorithm (or ever). To improve the success rate (i.e., to minimize the deviation from the optimal solution), it is suggested to run the algorithm repetitively to make use of the fact that, due to the stochastic nature of the algorithm, the results do not generally coincide from run to run.
- Different optimization criteria should be developed in order to find the one that better fits the individual problem objectives and characteristics. Focusing solely on a single sub-objective may exclude alternatives with a higher generalized resource allocation impact.

5 Conclusions

The resource–constrained scheduling problem is one of the most challenging in the area of project management. It is a combinatorial optimization problem which incorporates conflicting objectives (resource allocation within resource availability thresholds, project completion within certain deadlines, resource leveling) and constraints (e.g., precedence relation constraints between activities) while its complexity grows as the number of activities increases. The size of the solution space in such cases leads to the need for employing metaheuristics to obtain an approximation of the optimal solution.

In this work, an optimization model is developed for multi-objective resource-constrained scheduling. The aim of this optimization is to minimize a cost function which is composed by the sum of individual cost parameters associated with (a) resource availability exceedance, (b) day-by-day resource fluctuations and (c) project completion beyond a given deadline. The present study examines different objectives and criteria, either separately or in combination, to evaluate the degree that each optimization structure facilitates certain or prevailing objectives in actual projects. The optimization is performed with the employment of genetic algorithms as an effective tool to handle large combinatorial problems. The evaluation indicates that the proposed method can provide reliable solutions for the multi-objective resource-constrained scheduling considering the priorities and individual objectives in every project case.

References

1. Shtub, A., Bard, J., Globerson, S.: Project Management: Engineering, Technology, and Implementation. Prentice Hall International Editions (1994).
2. Damay, J., Quilliot, A., Sanlaville, A.: Linear programming based algorithms for preemptive and non-preemptive RCPSP. European Journal of Operational Research 182, 1012–1022 (2007).
3. Brucker, P., Knust, S.: Lower Bounds for Resource-constrained Project Scheduling Problems. European Journal of Operational Research 149, 302-313 (2003).
4. Moukrim, A., Quilliot, A., Toussaint, H.: An effective branch-and-price algorithm for the Preemptive Resource Constrained Project Scheduling Problem based on minimal Interval Order Enumeration. European Journal of Operational Research 244 (2), 360–368 (2015).
5. Leu, B.S., Yang, C.H.: GA-based multicriteria optimal model for construction scheduling. Journal of Construction Engineering and Management 126 (6), 420–427 (1999).
6. Alcaraz, J., Maroto, C., Ruiz, R.: Solving the multi-mode resource-constrained project scheduling problem with genetic algorithms. Journal of the Operational Research Society 54 (6), 614–626 (2003).
7. Besikci, U., Blige, U., Ulusoy, G.: Multi-Mode Resource Constrained Multi-Project Scheduling and Resource Portfolio Problem. European Journal of Operational Research 240, 22-31 (2014).
8. Kaiafa, S. and Chassiakos, A.P.: A genetic algorithm for optimal resource-driven project scheduling. Procedia Engineering 123, 260-267 (2015).
9. Mathew, J., Brijesh, P., Dileeplal, J., Tinjumol, M.: Multi Objective Optimization for Scheduling Repetitive Projects using GA. Procedia Technology 25, 1072 – 1079 (2016).
10. Roca, J., Pugnaghi, E., Libert, G.: Solving an extended resource leveling problem with multi-objective evolutionary algorithms. World Academy of Science, Engineering and Technology 46, 712–723 (2008).
11. Ponz-Tienda, H., Yepes, V., Moreno-Flores, J.: The Resource Leveling Problem with multiple resources using an adaptive genetic algorithm. Automation in Construction 29, 161-172 (2013).
12. Lova, A., Tormos, P., Cervantes, M., Barber, F.: An efficient hybrid genetic algorithm for scheduling projects with resource constraints and multiple execution modes. International Journal of Production Economics 117 (2), 302–316 (2009).
13. Bettemir, Ö. H., Sonmez, R.: Hybrid Genetic Algorithm with Simulated Annealing for Resource-Constrained Project Scheduling. Journal Of Management In Enineering 31 (5), (2015).