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An efficient method for scheduling construction projects with resource constraints

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Abstract

In construction scheduling, conflicts can arise when activities require common resources that are available only in limited quantities. To overcome this, while retaining minimum project durations, mathematical techniques have been developed for allocating resources. However, these produce a 'hard' inflexible approach to resource-constrained schedules. The authors propose an efficient resource allocation algorithm (LINRES) which offers a more flexible approach. To study its performance, an experiment was conducted on 10 small network examples (6 to 29 activities) and the results were compared with those generated by a total of 32 existing heuristic rules. The results show that the LINRES algorithm outperformed most other heuristic rules, including the widely used MINSLK rule in both single- and multi-resource networks. It also provides a reasonable trade-off between the resource-aggregation profiles and the durations.

Keywords: Heuristic rules; Planning and scheduling; Precedence networks; Resource-constrained scheduling

1. Introduction

Construction industry projects involve complex packages of work for which the design and contracting organisations are responsible; the product is generally large, discrete and prototypical. These and other characteristics of the industry make particular demands upon the planning and scheduling techniques that have to be developed to serve it. It has been argued that the more sophisticated planning methods used in other industries do not suit the construction industry. For example, Johansen [1] in a study of small and medium-sized UK building projects found that site managers tended to discard the formal systematic schedules they inherited from head office, which they mistrusted as 'theoretical', and adopted their own more 'flexible' approach to scheduling work. To dismiss this as unenlightened site management, or as a response to the inevitable uncertainty of construction projects is to ignore the evidence that many network-derived schedules simply do not work in the field. Woodworth and Shanahan [2] have shown that schedules based on time-oriented networks are exceeded by an average of around 38%.

1.1. Schedules based on time-oriented networks

Conventional critical path method (CPM), and programme evaluation and review technique (PERT) scheduling procedures start with an assumption of unlimited availability of resources for each project activity [3–5]. In other words, the analysis is based solely on the time requirements of the activities regardless of the resource needs of each activity. The early and late dates calculated with the critical path algorithm are based on the duration of the activities in the project and the relationships or technological constraints between them. It produces a schedule that minimises the overall project duration. In these calculations, the issue of resource availability is either not taken into account or neglected until after the initial time-oriented calculations [6]. Many of the problems with real-life projects arise when activities require resources that are available only in

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limited quantities and the demands of concurrent activities cannot be satisfied [2]. Recognition of this limitation has directed many researchers towards the problem of scheduling activity networks under resource constraints.

1.2. Resource scheduling

Resource scheduling explicitly and systematically incorporates decisions about the capacity into the scheduling process. Gordon and Tulip [7] have outlined its history and development and describe the basic steps of *aggregation, smoothing* and *levelling* of resources. Matthews [8] identifies two approaches to resource scheduling as:

- Time-constrained scheduling
- Resource-constrained scheduling

Both methods begin with a time analysis (CPM) (which fails to consider capacity and therefore contains 'unrealistic' dates) and proceed to resolve resource overloads by moving activities into periods when the capacity to undertake the activity exists. Time-constrained resource scheduling assumes that time constraints are fixed, and seeks to resolve capacity overloads by manipulating the timing of activities *within* their total float, and without affecting the initial project completion time. Resource-constrained scheduling accepts the priority of fixed resource availability, and permits not only sequencing and float times to be altered, but (if necessary) the project duration to be increased beyond the initial non-constrained project duration. In many cases therefore, time analysis and time-constrained scheduling should be considered only as intermediate steps in the process of schedule development [8]. In terms of performing resource scheduling, Gordon and Tulip [7] identify two main approaches, the 'serial approach' (where priority indices are determined *once*, before starting the scheduling operation) and the 'parallel approach' (where priority indices are updated *each time* an activity is scheduled). A parallel approach with allowable relaxation of 'total resource limitation' and 'total time limitation' was considered suitable for 'construction type' projects since they tend to contain a high proportion of activities which can be split.

1.3. Optimising the results of resource-constrained scheduling

The general resource-constrained project scheduling problem (RCPSP) arises when a set of interrelated activities (precedence relations) is given and when each activity can be performed in one of the several ways (modes). Questions arise regarding which resource-duration mode should be adopted, and when should each activity begin so as to optimise some pre-specified managerial goal. The general version of the problem is that each activity could be performed in one of the several ways, i.e. a continuous duration-resource function. For simplicity, this study has been restricted to a discrete duration-resource function where only one execution mode for each activity will be assumed. It also operates with a version of the problem where resources are renewable, activities cannot be interrupted, and the managerial objective is to minimise project duration. Numerous modifications to the original critical path method algorithm have been proposed for solving the scheduling problem under resource constraints. Two broad approaches have been used, namely (a) optimisation by mathematical programming techniques, and (b) heuristic techniques [9,10].

1.4. Solutions based on mathematical optimisation

These techniques seek to define the problem as a mathematical programming problem. The best solution is the one that gives the shortest project duration or the one which provides the smoothest resource profile. In some cases, these two objective functions are combined, resulting in preferred trade-offs; for example, in a slight increase in project duration with a decrease in resource level variation. However, such optimisation techniques remain computationally impractical for most real-life large projects because of the enormous number of variables and constraints.

1.5. Solutions based on heuristics

The alternative approach is to develop heuristics which allow a process of choosing between activities that are competing for the use of a scarce resource. The inherent variables in any project scheduling process are *time* and *resources*. When these are constrained, the resulting outcomes can vary along a *constraint continuum* — a spectrum of combinations of time and resources with an assumption of unlimited availability at each extremity. The various heuristics and their algorithms assist in deciding upon the point on the continuum at which the schedule should end up. Many heuristic models have been developed and are available as computer packages. Each works differently, produces different schedule outcomes, and is likely to be better in some situations than in others.

1.6. Research objectives

The research described in this paper has two objectives:

1. to develop a new heuristic, as close as possible to the CPM output, for scheduling activities under resource constraints in which the project duration