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Particle swarm optimization for resource-constrained project scheduling

Hong Zhang [a,*], Heng Li [b,1], C.M. Tam [a,2]

[a] Department of Building and Construction, City University of Hong Kong, Tat Avenue, Kowloon, Hong Kong

[b] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

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Abstract

This paper introduces the particle swarm optimization (PSO)-based approach to resolve the resource-constrained project scheduling problem (RCPSB) with the objective of minimizing project duration. Activities priorities for scheduling are represented by particles and a parallel scheme is utilized to transform the particle-represented priorities to a feasible schedule according to the precedence and resource constraints so as to be evaluated. Then the framework of the PSO scheme for the RCPSB is developed. Computational analyses are provided so as to investigate the performance of the PSO-based approach for the RCPSB. The study aims at developing an alternative and efficient optimization methodology for solving the RCPSB and opening the application of PSO to the optimization issues for construction project management.

Keywords: Particle swarm optimization; Resource-constrained project scheduling; Priority-based scheduling; Managing projects; Construction industry

1. Introduction

Traditional project scheduling approaches such as the critical path method (CPM) and program evaluation and review technique (PERT) focus on logical dependencies by assuming unlimited resource availability. However, the assumption of unlimited variety of resources may not be justified in many construction circumstances since only a fixed amount of resources are available or the cost of acquiring additional resources is very high. Therefore, many analytical or heuristic approaches have been proposed to solve such a resource-constrained construction scheduling problem (RCPSB).

Analytical methods for the RCPSB often adopt mathematical models such as integer programming [1] and dynamic programming [2], as well as branch-and-bound [3] or enumeration approaches to search for optima by considering the RCPSB as NP-complete [4]. But the analytical approaches may be computationally infeasible or face ‘‘combinatorial explosion’’ problem if the project under study is larger or more complicated [5,4,6].

Heuristic methods for the RCPSB [7,8] are aimed at searching for optima in efficient ways. Most existing heuristic methods use priority rules such as shortest activity duration (SAD), minimum late finish time (MILFT), or minimum total float (MITF) to determine which activity is to be scheduled earlier than others. However, there is little basis for choosing one among different heuristic rules and no priority rule dominates all other or performs consistently better than others

* Corresponding author. Tel.: +852 3442 6505; fax: +852 2788 7612.
E-mail addresses: bczhangh@cityu.edu.hk (H. Zhang), bshengli@polyu.edu.hk (H. Li), bctam@cityu.edu.hk (C.M. Tam).
[1] Tel.: +852 2766 5879; fax: +852 2764 5131.
[2] Tel.: +852 2788 7620; fax: +852 2788 7612.

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[9]. Therefore, the heuristic methods based on heuristic rules are problem dependent (i.e., variable effectiveness on different cases) and may be trapped within local optima [10,5,6].

Genetic algorithm (GA), an evolutionary computation technique, has been widely employed to solve the RCPSB [5,6]. The GA approach searches for the optima from a lot of generations of the chromosome-represented schedules that are reproduced through cross-over and mutation, without referring to any heuristic rules. The internal updating mechanism of chromosomes enables GA to search for global optima by escaping from local optima. Therefore, the GA approach can overcome the drawbacks of the analytical and heuristic approaches. Nevertheless, some deficiencies in GA performance including premature convergence or slow convergence process (i.e., requiring a large number of generations) have been also identified [11].

Particle swarm optimization (PSO) is an evolutionary optimization technique that simulates the social behavior of bird flocking to desired places. Like GA, PSO starts by initializing a population of random solutions and searches for optima by updating generations. But PSO does not use any evolution operators. In PSO, particles fly through the problem space by following its own experience and the best experience attained by the swarm as a whole. In contrast to analytical or general heuristic methods, PSO is computationally efficient and has great capability of escaping local optima [13]. In addition, PSO has advantages over GA due to its easy implementation, relatively faster search process or effective performance [13,14]. PSO has been applied to other industrial areas like electrical engineering for power flow optimization [23,24]. To our knowledge, however, there have not been any applications of PSO to the RCPSB.

In this paper, a PSO-based approach is proposed for the RCPSB with project-duration minimization as the objective. Activities' priorities for scheduling, instead of permutation of sequences, are considered as a candidate solution to the RCPSB and represented by a PSO particle. Through a parallel scheme, each particle can be transformed to a feasible schedule according to resource constraints and precedence constraints, facilitating evaluation of potential solutions (i.e., schedules corresponding to particles) during PSO search.

2. Description and formulation of the RCPSB

A project scheduling problem can be characterized by the objective function, features of resources, and the preemption condition [4]. Minimization of project duration is often used as an objective of a general project scheduling problem, while other objectives such as minimization of total project cost, maximization of net present value of cash flows, and leveling of resource usage are also considered. Resources involved in a project can be single or multiple varieties, and can be renewable (i.e., recovered after serving an activity, e.g., crew) or nonrenewable (limited in amount over project process and the consumed part cannot be recovered, e.g., money). Preemption means that some activities (e.g., frame-installing in construction) can be interrupted during their execution, while non-preemption means that some activities such as concreting operation are not allowed to be interrupted once they are scheduled to start.

The RCPSB under study is based on the following assumptions: (1) the activities composing a construction project have certain and known durations; (2) all predecessors must be finished before an activity can start (i.e., precedence constraints); (3) resources can be multiple varieties, available in limited amounts and renewable from period to period (multiple resource constraints); (4) activities are non-preemptive, that is, cannot be interrupted when in progress; (5) managerial objective is to minimize the project duration.

In addition, a project is considered to be represented by activity-on-node network topology, where two dummy activities with zero duration may be included for indicating the single start and end nodes of the project. In consideration of the above assumptions and the activity-on-node representation, the formulation of the RCPSB used to be proposed by Talbot [1] and Patterson [10], which is as follows:

$$\min\{\max f_i | i = 1, 2, \ldots, N\} \tag{1}$$

subject to :

$$f_j - f_i \geqslant d_i \quad \forall j \in P_i; \quad i = 1, 2, \ldots, N, \tag{2}$$

$$\sum\nolimits_{A_t} r_{ik} \leqslant R_k, \quad k = 1, 2, \ldots, K; \quad t = s_i, s_2, \ldots, s_N, \tag{3}$$

where N is the number of the activities involved in a project and f_i is the finish time of activity i ($i = 1, \ldots, N$); d_i is the duration of activity i, P_i is the set of activities that have been already scheduled (i.e., predecessors) before activity i can be scheduled to start; R_k is available amount of resource k ($k = 1, \ldots, K$) and K is the number of the resource types; r_{ik} is the amount of resource k required by activity i, and A_t is the set of ongoing activities at t and s_i ($=f_i-d_i$) is the start time of activity i. Eq. (1) represents the objective, while Eqs. (2) and (3), respectively, represent precedence constraints and resource constraints.

3. Principle of particle swarm optimization

PSO simulates a social behavior such as bird flocking to a promising position or region for food or other objectives in an area or space [15,16]. Like evolutionary