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An improved ant colony optimization algorithm for nonlinear resource-leveling problems

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ABSTRACT

The notion of using a meta-heuristic approach to solve nonlinear resource-leveling problems has been intensively studied in recent years. Premature convergence and poor exploitation are the main obstacles for the heuristic algorithms. Analyzing the characteristics of the project topology network, this paper introduces a directional ant colony optimization (*DACO*) algorithm for solving nonlinear resource-leveling problems. The *DACO* algorithm introduced can efficiently improve the convergence rate and the quality of solution for real-project scheduling.

1. Introduction

Given the finite nature of resource availability, a project scheduling may have to be modified so that the project can be successfully performed. Resource-leveling optimization as a project scheduling management technique has been widely studied in the construction and manufacturing industries for solving nonlinear resource allocation problems by searching for the best start time for each activity. Many analytical and heuristic models have been developed for solving nonlinear resource-leveling optimization problems. In computational biology, meta-heuristics such as genetic algorithms, particle swarm optimization approaches and taboo searches have been used for solving such nonlinear resource-leveling problems. For example, Leu [1] suggested a genetic algorithm optimization for tackling the resource-leveling issue in construction; Roca [2] proposed a multi-objective genetic algorithm-based solver for optimizing the extended resource-leveling problem. However, the premature convergence and poor exploitation, which are the main drawbacks of meta-heuristics, have attracted increasing attention from researchers and engineers.

This paper employs a directional ant colony optimization (*DACO*) approach to solve nonlinear resource-leveling problems. The activity-on-node-based *DACO* technique is effective and efficient in dealing with premature convergence or poor exploitation, and it has an advantage of not translating the real data into code, as compared with genetic algorithms. Simple random exploitation is carried out in the *ACO* approach, while the *DACO* algorithm is designed to search for a promising path in the area considered. It is a directional search that combines a globally optimized trail, the local best path and random exploitation for resource-leveling optimization. The original idea of *ACO* was proposed by Dorigo [3,4] for searching for the optimal path in a graph.

2. Resource-leveling optimization

Resource-leveling optimization is an important part of project management. It is carried out by adjusting the float time of non-critical activities in the project network, which consists of a set of activities together with certain precedence relations

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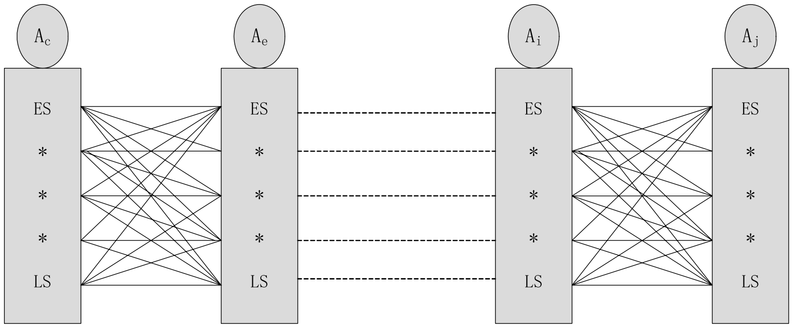

Fig. 1. Dummy network topology. Note: $A_c, A_e, \ldots, A_i, A_j$ represent non-critical path activities; *ES***LS* denote the total float of a non-critical path activity.

among them. There are three assumptions for the project network optimization, which are: (a) the total project duration is fixed; (b) each activity cannot be split; (c) resource demand is kept constant throughout the whole project scheduling. Project scheduling is based on two kinds of topology networks, i.e., activity-on-node (*AoN*) networks and activity-on-arc (*AoA*) networks. In this study, a network of the former kind (*AoN*) is used as the optimized network since each project scheduling can be uniquely described by an *AoN* network. *ACO* algorithms use ants to search for a promising path by sensing the depositing of information on the edge between the two nodes by other ants. *AoN* networks use nodes to represent project activities $A_i = (A_0, A_1, A_2 \ldots A_n, A_{n+1})$. A_0 is the dummy start activity that has no predecessor, and A_{n+1} is the dummy end activity that has no successor. The dummy start and end activities have no resource requirements and have no time consumption.

In the traditional project management, *CMP* and *PERT* techniques are used to search for the critical path, the earliest start time (*ES*), the earliest finish time (*EF*), the latest finish time (*LF*), the latest start time (*LS*) and the total project duration. However, the two techniques have very poor performance on controlling the nonlinear resource-leveling issues because it is difficult to determine what time is the best for non-critical path activities. The non-critical path activities can use the slack time between *ES* and *LS* to influence the construction resource profiles. This means that each non-critical path activity A_j has a set of numerical arrays $[ES_{Aj}, LS_{Aj}]$ and these activities build up a dummy network topology as shown in Fig. 1.

How to choose the best start time for the non-critical path activities is the core issue in nonlinear resource-leveling optimization. Mathematical models such as integer programming, dynamic programming and branch-and-bound models have been used to search for an accurate solution, but these analytical models are either computationally infeasible or may lead to combinatorial explosion if the project under study is large or complicated. To overcome these defects, ant colony optimization, which is one of the heuristic approaches, is improved in this paper.

3. Improved ant colony optimization

ACO shares many similarities with other evolutionary algorithms for solving nonlinear resource-leveling optimization. The main idea of *ACO*'s search capability simulates a social behavior such as an ant searching for a promising path between the food and the nest from others' deposited pheromone trails. Dorigo [5] suggested *ACO* for solving the traveling salesman problem. In 2002 Markle et al. [6] were the first to employ *ACO* to solve the resource-constrained project scheduling problem (*RCPSP*). Chen [7] combined the ant colony optimization with the scatter and local search methods for *RCPSP* in 2010.

3.1. The principle of the ACO algorithm

The general principle of the *ACO* algorithm is to use an ant for choosing the next subject on the basis of the following formula:

$$p_{ij}^k = \frac{[\tau_{ij}]^\alpha [\eta_{ij}]^\beta}{\sum\limits_{l \in A} [\tau_{il}]^\alpha [\eta_{il}]^\beta}, \tag{1}$$

$$\tau_{ij}(t+1) = (1-\rho) * \tau_{ij}(t) + \rho \Delta\tau_{ij}(t), \tag{2}$$

$$\Delta\tau_{ij}(t) = \begin{cases} 1/T, & \text{if } (i,j) \in \text{ the best schedule,} \\ 0 & \text{otherwise,} \end{cases} \tag{3}$$

$$\eta_{ij} = \max LF(j, -) - LF(j) + 1, \tag{4}$$

where p_{ij}^k is the probability of the kth ant selecting activity j from the ith activity; τ_{ij} is the pheromone concentration on the edge from activity i to activity j; η_{ij} is the visibility [6], which is a heuristic value with different specific meanings in different problems; α is the importance of the pheromone information; β denotes the importance of the heuristic information;