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Resource leveling using normalized entropy and relative entropy

Jianfeng Qiao[a,*], Yu Li[b,c]

[a] School of Safety and Environmental Engineering, Capital University of Economics and Business, Fengtai, 100070 Beijing, China
[b] Post-doctoral Research Station of China Life Insurance (Group) Company, Xicheng District, 100033 Beijing, China
[c] PBCSF, TsingHua University, Haidian district, 10083 Beijing, China

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ABSTRACT

The resource leveling problem (RLP) involves the development of a project schedule that specifies the starting time of each activity constrained by the project deadline and precedence, aimed at the minimizing the variation of the resource utilization. To shorten project duration and to find more effective and flexible object functions, normalized entropy and relative entropy are proposed. The former considers shortening the project duration, improved based on the entropy model; the latter measures the similarity of two distributions, that is the actual versus the theoretical resource allocation based on the resource assignments per activity, and which covers not only entropy itself, but also cross entropy. Finally, discrete particle swarm optimization (DPSO) is encoded to investigate the performance of the proposed normalized entropy and relative entropy with other objective functions.

1. Introduction

Creating a realistic project schedule is one of the biggest challenges at the beginning of project development, and comprises not only resource-constrained problems but also resource leveling problems (RLPs). The first approach is to reduce the project duration without exceeding the constraints of resource availability, known as the resource-constrained project scheduling problem (RCSP). The second approach is to achieve the most efficient resource consumption without increasing the prescribed deadline of the project, known as the RLP. Both problems are defined as non-deterministic polynomial-time hard (NP-hard) problems and the complexity increases substantially with the project's network size [1].

Resource leveling aims at minimizing the resource usage fluctuations, and this is accomplished by moving non-critical activities within their floating time [2]. In project management, generally slight resource variations represent a financial burden or heightened risk of accidents, so reducing the fluctuations in the pattern of renewable resource usage is crucial, and this involves the determination of a project baseline schedule that specifies the planned activity starting times while satisfying both the precedence constraints and the project deadline constraint under the objective of minimizing the variation in the resource utilizations [3].

There are many objective functions to measure the variation of the resource utilization in the literature. In general, they can be classified into four types of models: (1) square models (simple squares of daily resource units) [4–9]; (2) deviation models (resource deviations with prescribed values) [10,11]; (3) fluctuation models (variations of resource utilizations from period to period) [6,12,13]; (4) entropy models, based on entropy theory [14,15]. Neumann et al. [9] gave a summary of the former three types of objective functions and that are all based on traditional mathematical statistics. For the entropy model, Christodoulou et al. [14,15] presented two entropy formulations realized in different ways. One is the ratio of required resource over assigned resource, which provides a good measure of the project progress. The other is the ratio of daily resource units over total assigned resource units, which provides a good measure of the resource leveling utilization.

Parallel to the research into objective functions, several optimization algorithms have been investigated to solve such problems, which can mainly be classified as exact procedures and heuristic procedures. Exact approaches are mainly based on dynamic programming [11,16], zero–one programming [17,18], integer programming [2], mixed-integer programming [19,20], and branch and bound methods as proposed by Brucker and Knust [21]. Heuristics approaches are mainly based on the minimum moment algorithm [5], pack method [6], tabu search (TS) [22], genetic algorithm (GA) [1,3,23–25], greedy method [26], path-relinking [27], ant colony optimization [28,29], and particle swarm optimization (PSO) [30–32].

In summary, existing resource leveling models are designed to measure and penalize the difference between fluctuations in resource profiles. When objective functions of mathematical statistics are applied

* Corresponding author.
E-mail addresses: qiaojianfeng@cueb.edu.cn (J. Qiao), liyu@chinalife.com.cn (Y. Li).

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to the multiple types of RLPs, it is difficult to obtain good results because there is no unified dimension to measure the leveling degree of various resource types. By introducing an entropy model, one can not only effectively avoid the dimensional problem, but also obtain a better reflection of the degree of resource balance. Christodoulou et al. [15] pointed out that entropy has two principal properties: subadditivity and maximality. Both mean that the longer the duration of the project the greater the maximization of the entropy, which conflicts with the target of minimizing project duration. To consider shortening project duration and to find more effective and flexible models, we propose the use of normalized entropy and relative entropy to establish RLP objective functions. The performance of these objective functions is analyzed using a heuristic algorithm. A recent analysis showed that the PSO algorithm is an effective method of resource management, and generally has better performance than other heuristic methods, such as GA, simulated annealing (SA), and TS [30,32,33]. Thus, we chose the PSO algorithm to analyze the performance in this paper.

The remainder of this paper is organized as follows. Section 2 gives a precise formulation of the RLP, especially categories of objective functions. Section 3 introduces the entropy and normalized entropy model. Section 4 presents the relative entropy model that is a new way to measure the resource balance. Sections 5 deals with discrete particle swarm optimization (DPSO). Section 6 contains a detailed experimental performance analysis of all objective functions based on DPSO. Section 7 draws conclusions.

2. Formulation of the resource leveling

Resource allocation can be analyzed using a network diagram, as used in project management, where nodes represent activities and arcs represent precedence relations. Performing activities takes periods and resource units, and then the resource leveling schematic of the horizon can be displayed as in Fig. 1, combined with the network diagram.

2.1. Scheduling activities

Identify the activities (jobs or tasks) based on project deliverables.

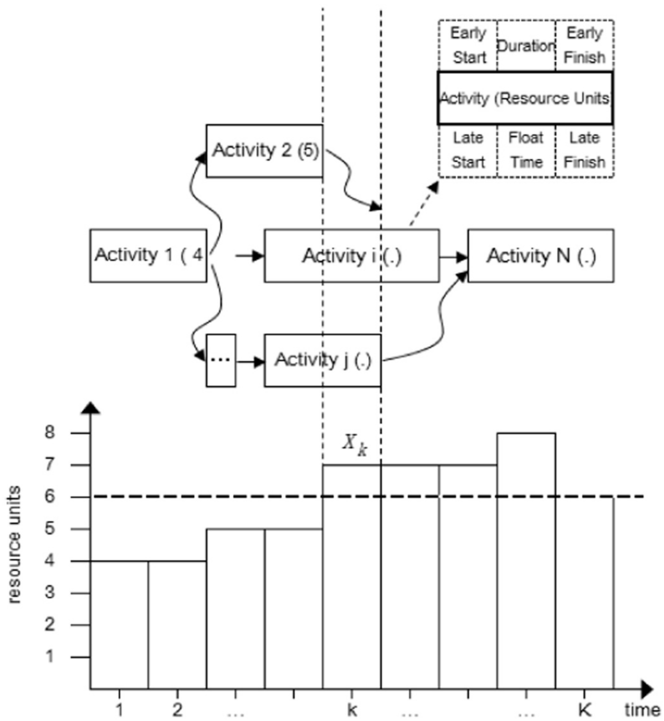

Fig. 1. Network diagram and resource leveling schematic.

The set of activities, A, is

$$A = \{a_1, a_2, ..., a_N\} \tag{1}$$

We use N to denote the total number of activities in a network. The activity once started must be completed without interruption. The set of start times of each activity, T, is

$$T = \{t_1, t_2, ..., t_N\} \tag{2}$$

The set of durations of each activity, D, is

$$D = \{d_1, d_2, ..., d_N\} \tag{3}$$

The dependencies between the activities can be expressed as

$$t_i + d_i \leq t_j,\ i, j = 1, 2, ...N \tag{4}$$

This means that activity j can only start once activity i is finished. The critical path method (CPM) calculates the longest path of planned activities to logical end points or to the end of the project. The set of early start times, T^{es}, and the set of late start times, T^{ls}, are

$$T^{es} = \{t_1^{es}, t_2^{es}, ..., t_N^{es}\} \tag{5}$$

$$T^{ls} = \{t_1^{ls}, t_2^{ls}, ..., t_N^{ls}\} \tag{6}$$

Each activity is constrained:

$$t_i^{es} \leq t_i \leq t_i^{ls},\ i, j = 1, 2, ...N \tag{7}$$

Based on these assumptions, activities can be scheduled in many different ways, according to the different project targets including time, cost, and resource utilization.

2.2. Resource leveling

The set of renewable resource units of each activity (e.g. manpower, machines, and spaces), R, is

$$R = \{r_1, r_2, ..., r_N\} \tag{8}$$

The resource consumption of each day, x_k, is

$$x_k = \sum_{i \in I_k} r_i,\ k = 1, 2, ...K \tag{9}$$

or

$$x_k = \sum_{i=1}^{N} c_i r_i \begin{cases} c_i = 1,\ if\ t_i \leq k \leq t_i + d_i - 1 \\ c_i = 0,\ \ if\ k < t_i\ or\ k \geq t_i + d_i \end{cases} \tag{10}$$

Here K is the project duration time and I_k is the activity set, when the activity works in the kth day, as illustrated in Fig. 1 by the vertical parallel dotted lines.

The horizontal dashed line represents the average daily resource usage. Obviously, resource leveling is required in project scheduling to avoid the difficulties associated with the large variations in resource usage. There is a large number of different possibilities to schedule T, according to logic and restrictions on the project to be performed. Each of these schedules has significant differences regarding the efficiency of resource consumption.

Eq. (9) or Eq. (10) was originally developed for single-type resource leveling, and later extended to multiple-type resource leveling that means there are several types of resources to complete these activities.

2.3. Objective functions of resource leveling

Different objective functions are considered in the literature [7,8], depending on how variations in resource utilizations are measured. If time t is discrete, the objective function of discrete RLP can be written as

$$f(x) = \sum_{m=1}^{M} \sum_{k=1}^{K} f_m(x_{mk}) \tag{11}$$