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Using Ant Colony Optimization algorithm for solving project management problems

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ABSTRACT

Network analysis provides an effective practical system for planning and controlling large projects in construction and many other fields. Ant Colony System is a recent approach used for solving path minimization problems. This paper presents the use of Ant Colony Optimization (ACO) system for solving and calculating both deterministic and probabilistic CPM/PERT networks. The proposed method is investigated for a selected case study in construction management. The results demonstrate that – compared to conventional methods – ACO can produce good optimal and suboptimal solutions.

1. Introduction

Effective project management techniques are important to ensure successful project performance; a poor strategy can easily turn expected profit into loss. With the availability of computer facilities the design, calculation, modeling, managing and checking processes and projects can be done in a more efficient and effective manner. The management of construction project involves planning of tasks from large numbers of disciplines which require different pieces of information at various times. This results in the production of a huge quantity of complex information, which must be managed efficiently. Network analysis provides a comprehensive practical system for planning and controlling large projects in construction and many other fields. One of the most needed tasks is to accomplish a forecast of optimal and suboptimal paths of the network for construction management due to the complexity of the project and the possibility of crash or delay occurrence which is not so easy with conventional methods. The integration of optimization algorithms based on metaheuristic opens new perspectives of applications in real life. Ant Colony System has been introduced in the early 1990s. It mimics the performance of natural ants while searching food and finding the shortest path between the nest and the food source thanks to local message exchange (Bonabeau, Dorigo, & Theraulaz, 1999).

This paper proposes the use of Ant Colony System to analyze PERT network problems to solve decision making problem in project management.

2. Network analysis

Network is a graphical representation of a project. Network analysis provides a practical way to monitor the progress of the project till its accomplishment in the minimum time; it can also be used to assist in allocating resources and to minimize total cost. The solution of network models is accomplished through a variety of network optimization algorithms.

2.1. Critical Path Method (CPM)

CPM (Critical Path Method) models are extremely useful for the purpose of planning, analyzing, controlling the progress and the completion of large and complex projects (Paul Loomba, 1978). We must use some definition to complete the computation:

A typical network is shown in Fig. 1 to show its components.

The purpose of the Critical Path Method (CPM) is to identify critical activities on the critical path so that resources may be concentrated on these activities in order to reduce project length time. Besides, CPM has proved very valuable in evaluating project performance and identifying bottlenecks. Thus, CPM is a vital tool for the planning and control of complex projects (Yao & Lin, 2000). To identify the critical path, three parameters for each of its activities are determined: (1) earliest event time, (2) latest event time and (3) slack time.

Paths other than the critical path offer flexibility in scheduling because thy take less time to complete less than the critical path.

2.2. Stochastic activity network

One of the most important theoretical problems in project management is to obtain the probability distribution of the total completion time in PERT networks (Paul Loomba, 1978).

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In project management, the duration of tasks is seldom precisely known in advance, at the time when the plan of the project is designed. Detailed specification of the methods and resources involved for the realization of activities are often not available when the tentative plan is made up. In stochastic network, the activity duration is a random variable with a known probability density function. Authors that introduced the PERT approach have noticed this difficulty very early. They proposed to model the duration of tasks by probability distributions and tried to evaluate the mean value and standard deviation of earliest starting times of activities. Since then, there is an extensive literature on probabilistic PERT. Even if the task durations are independent random variables, it is admitted that the problem of finding the distribution of the ending time of a project is intractable, due to the dependencies induced by the topology of the network. Another difficulty is the possible lack of statistical data validating the choice of activity duration distributions. Even if statistical data are available, they may be partially inadequate because each project takes place in a specific environment and is not the exact replica of past projects. Standard PERT assumes three point estimates for probabilistic duration times in order to approximate project completion and the relative probability at each milestone using the normal distribution function (Paul Loomba, 1978). PERT and CPM are similar, however they differ in two terms:

- 1-PERT activity estimates are probabilistic while in CPM activity time is deterministic,
- 2-PERT activity costs are not provided while in CPM they are explicitly provided.

Unlike CPM, in stochastic activity networks the duration time of individual activities varies and so activities are critical for some combinations of duration times and may not be critical for other combinations. Therefore, activities have a given probability of being critical. PERT assumption of a normally distributed project completion time typically leads project managers into optimistic planning based on less than actual project completion estimates due to a failure in considering the absolute bounds to project completion. These bounds arise from the fact that the project completion time is the maximum sum of the duration of each and every path, which in turn is the result of adding the bounded durations of its activities (Copertari & Archer, 2001). Project completion cannot be an unbounded random variable because the sum of bounded (beta distributed) activity duration times yields bounded path (and project) completion times. Thus, the normal distribution, which is unbounded, should not be used to portray completion times.

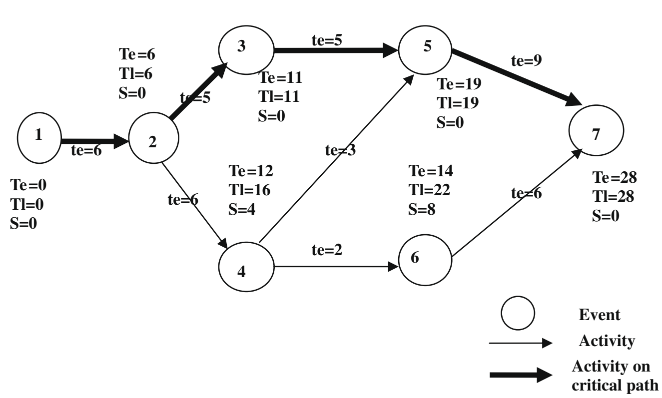

Fig. 1. A typical PERT network showing its components, earliest time, latest time and slack time.

For a normalized beta density function the mean value is given by

$$\mu = \alpha_s/\alpha_s + \beta_s. \quad (1)$$

The corresponding variance value is given by

$$\sigma^2 = \alpha_s\beta_s/(\alpha_s + \beta_s)^2(\alpha_s + \beta_s + 1), \quad (2)$$

where (α_s, β_s) are shape (skewing) parameters.

The beta function has various shapes according to different combinations of shape parameters (α, β). It is a common practice to portray activity duration times using bell-shaped beta distribution (Malcolm, Roseboom, Clark, & Fazar, 1959). To ensure a bell-shaped beta distribution the sum of $\alpha_s + \beta_s \geqslant 4$ as shown in Fig. 2.

The PERT textbook formula to calculate expected (mean) activity duration times-which are supposed to follow beta density functions – is given by

$$\mu = (a + 4m + b)/6, \quad (3)$$

where *a*, minimum time; *m*, most likely; and *b*, maximum time.

The PERT textbook formula considers three parameters when in fact the beta distribution has four parameters (two range parameters and two shape parameters). It turns out that the PERT formula used to calculate the mean as a function of the minimum, most likely, and maximum activity duration time estimates, ignores how the biases to the right or left affect the shape of the beta distribution.

In fact, the PERT formula assumes a fixed value for the sum of the shape parameters ($\alpha_s + \beta_s = 4$) to calculate the mean, and it calculates the variance as an approximation to that assumption. Furthermore, PERT does not consider the variance when determining which path is the longest, since the variance of the project completion time is assumed to be the same as the variance of the path with the longest sum of mean duration times.

These assumptions typically lead to optimistic planning due to less than actual project completion times (Copertari & Archer, 2001).

2.2.1. Forward calculation

Traditional forward pass calculations such as those performed in CPM are employed. Each event has duration according to equation

$$D_{\text{new}} = D + \Delta D. \quad (4)$$

The mean value of the beta function

$$\mu = \Delta D * (\alpha_s/\alpha_s + \beta). \quad (5)$$

The mean value of each event

$$\mu \text{ event} = D + \mu. \quad (6)$$

The variance value of each event

$$\sigma^2 = \Delta D^2 * \alpha_s\beta/(\alpha_s + \beta)^2(\alpha_s + \beta + 1). \quad (7)$$

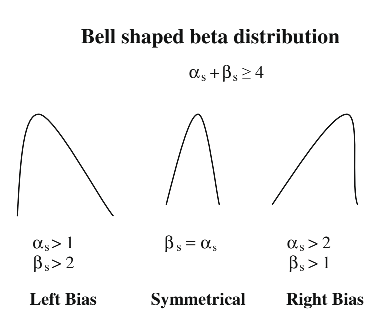

Fig. 2. Shapes of the beta distribution that ensures a bell-shaped beta distribution.