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Discrete time–cost–environment trade-off problem for large-scale construction systems with multiple modes under fuzzy uncertainty and its application to Jinping-II Hydroelectric Project

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Abstract

This paper presents a discrete time–cost–environment trade-off problem for large-scale construction systems with multiple modes under fuzzy uncertainty. A multi-objective decision making model is established in which the total project duration is regarded as a fuzzy variable. To deal with the uncertainty, the fuzzy numbers in the model are defuzzified by using an expected value operator with an optimistic–pessimistic index. The objective functions are to minimize the total project cost, project duration, crashing cost, and environmental impact. Furthermore, a fuzzy-based adaptive-hybrid genetic algorithm is developed to find feasible solutions. The one-point crossover and repairing strategy for mutations are designed to avoid infeasible solutions. Finally, the Jinping-II Hydroelectric Project is used as a practical example to demonstrate the practicality and efficiency of the model. Results and a sensitivity analysis are presented to highlight the performance of the optimization method, which proves to be very effective and efficient compared to other algorithms.

Keywords: Time–cost–environment; Trade-off; Construction project; Fuzzy; Genetic algorithm

1. Introduction

In recent years, as China has experienced rapid growth in both the economy and society, the need for energy has also exponentially grown. New and renewable sources of energy have become more important and consequently hydropower resources have also become more important. Hydropower resource plays an important role in China, especially in Sichuan Province. The Chinese government has emphasized renewable energy development particularly in the areas of water conservancy and hydropower. The Ertan Hydropower Development Company, Ltd. (EHDC) has been appointed to supply clean and renewable energy to support the economic and social development of the Sichuan-Chongqing region through the development of hydropower resources on the Yalong River in Sichuan. The Jinping-II Hydroelectric Project is one of EHDC's projects under construction. This paper focuses on a discrete time–cost–environment trade-off problem (DTCETP) in the Jinping-II Hydroelectric Project for minimizing the total project cost, project duration, crashing cost, and environmental impact.

Time and project cost are crucial aspects of construction projects and have received significant attention for several years (Akkan et al., 2005; Leu et al., 2001). The discrete time–cost trade-off problem (DTCTP), which was introduced by Harvey and Patterson (1979) and Hindelang and Muth (1979), is an important subject in project scheduling theory and applications (Peng and Wang, 2009). Every activity can

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be executed in the crashing way in which the project direct costs are used to shorten the activity duration. The crashed duration of activities was introduced to DTCTP in (Ahn and Erenguc, 1998), where the duration/cost of an activity is determined by the mode selection and the duration reduction (crashing) applied within the selected mode. This leads to a multi-mode DTCTP.

Recently, the construction industry has been accused of causing environmental problems ranging from the excessive consumption of global resources both in terms of construction and operation to the polluting of the surrounding environment (Ding, 2008). In particular, hydroelectric projects significantly contribute to changes in river environments (Chen et al., 2011), in which eco-environmental impact may arise during all project phases (Brismar, 2004). In this paper, it is suggested that the environment of a construction project may be affected by mode selection. As such, when a hydroelectric project is being planned, its environmental impact should be taken into consideration along with the time and cost trade-offs.

Nowadays, the quantity and scale of construction projects world wide have developed rapidly. Construction project managers often face the challenges to compromise among different conflicting aspects of a project (Liang, 2010; Xu and Zeng, 2011a). Generally, the project management decisions focus on the minimization of project completion time, and/or the minimization of total project cost through crashing or shortening the duration of particular activities (Akkan et al., 2005; Eshtehardian et al., 2009; Leu et al., 2001). Thus, a project decision maker may be able to shorten project completion time, realizing savings on indirect costs, by increasing direct expenses to accelerate the project (Liang, 2010). Additionally, although various project management decision techniques have been developed to minimize project duration and/or total project cost, most do not minimize the environmental impact (Ammar, 2011; Wang et al., 2010). Therefore, this paper considers that construction managers need to develop a project management methodology for directing and controlling not only the total project duration and project cost, but also the environmental impact to achieve management objectives. This leads to a discrete time–cost–environment trade-off problem (DTCETP), an extension of DTCTP. The objective of the project management decision is to find a starting time and a crashing time (Klerides and Hadjiconstantinou, 2010) for each activity such that the makespan is minimized and the schedule is feasible with respect to some constraints, such as precedence (Al-Fawzana and Haouari, 2005), crashing time, total budget, and duration (Long and Ohsato, 2008). In this paper, four objectives for the DTCETP are considered: (1) the minimization of the total project cost; (2) the minimization of the total project duration; (3) the minimization of the total crashing cost; (4) the minimization of the environmental impact.

Existing techniques for DTCTP can be categorized into two areas: namely, exact and heuristic. Exact algorithms, including linear programming (Liu et al., 1995; Pagnoni, 1990), dynamic programming (De et al., 1995), enumeration algorithm (Harvey and Patterson, 1979), or branch and bound algorithm (Demeulemeester et al., 1996), have been extensively employed to solve DTCTPs (Eshtehardian et al., 2009). However, none of the exact algorithms are able to solve large and hard instances measured in terms of, say, the number of activities. In terms of what current state-of-art algorithms can do, and considering the structure of the project networks as well as the number of modes per activity, instances with a large number of activities cannot be solved optimally in reasonable amount of time (Tareghian and Taheri, 2007). De et al. (1997) has shown that the DTCTP is an NP-hard problem and difficult to be solved (Deineko and Woeginger, 2001). Consequently, the DTCETP, which is an extension of the classical DTCTP, is also NP-hard. It follows that the search for exact algorithms which are also formally efficient is all but futile and that one should instead search for effective heuristic algorithms to solve a general DTCTP. The work by Akkan (1998) is an example of a heuristic based on Lagrangian relaxation applied to activity-on-arc (AoA) networks. Feng et al. (1997) also proposed models using genetic algorithms and a Pareto front approach to solve the DTCTP. While these studies have significantly improved computation efficiency for the DTCTP, to our best knowledge there is no known research which has developed an effective algorithm for solving the DTCETP in a large scale construction project.

In non-routine projects (e.g., new construction projects) (Long and Ohsato, 2008), the duration of each activity and completion time may be uncertain, and the project manager must handle multiple conflicting goals in an uncertain environment with information that may be incomplete or unavailable. Uncertainty in the activity durations can be modeled by two groups of methods such as probability-based methods and fuzzy set-based methods (Demeulemeester and Herroelen, 2002; Weglarz, 1999), the use of which depends on the situation and the project manager's preference. In a new construction project, because activities tend to be unique, and therefore lack historical data, it is difficult for a project manager to characterize these random variables correctly. For this reason, the fuzzy method is considered an effective approach for such situations. First proposed by Zadeh (1965), and consequently developed by researchers such as Dubois and Prade (1988), and Nahmias (1978), fuzzy theory has been a useful tool in dealing with ambiguous information.

In order to cope with the larger and more complex instances of the DTCETP and improve the computation efficiency, this paper presents a fuzzy-based adaptive hybrid genetic algorithm ((f)a-hGA). Further, a one-point crossover operator for chromosomes and a repairing strategy for the mutation operator are proposed according to a crashing time decision. Finally an iterative hill climbing routine and an adaptive regulation mechanism are introduced to carry out local searches around a convergence solution in the genetic algorithm (GA) loop to obtain a faster algorithm convergence.

This paper effectively solves the DTCETP under fuzzy uncertainty. The remainder of this paper is organized as follows: Section 2 states the relevant literature for this problem. In Section 3, a multi-objective DTCETP under fuzzy uncertainty is described, and the assumptions and notations are presented. A multi-objective fuzzy optimization model is then proposed