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Stochastic time–cost tradeoff analysis: A distribution-free approach with focus on correlation and stochastic dominance

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ABSTRACT

The present study explores how correlated Monte Carlo simulation (MCS) coupled with a multiobjective particle swarm optimization algorithm can expand the time–cost tradeoff analysis in the presence of uncertainty. The goal of the proposed framework is to find the optimal set of activity options, whose objectives are evaluated as value-at-risk measures of project duration and total cost. The proposed framework incorporates the Gaussian copula into MCS to treat statistical dependence between uncertain variables, with no restriction on the estimation process and distribution type. This paper elucidates the definition of stochastic dominance relations, based on which a decision rule is established to prescreen dominated solutions so as to alleviate computational burden. A practical project has been used to validate the proposed framework by comparisons with enumeration and NSGA-II (non-dominated sorting genetic algorithm). In addition to nondominated solutions, the proposed framework provides insightful risk assessments.

1. Introduction

Time–cost tradeoff (TCT) analysis is a well defined subject in management of construction projects. The analysis is based on the assumption that an acceleration of activity requires more labor and more efficient equipment, and thus higher cost [21]. The earliest goal is to crash project duration to fall within the contractual time limit at a minimum cost. A more generalized goal is to obtain the complete time–cost curve, which indicates the minimum cost at various project durations. This goal represents a bi-objective optimization problem. A solution on the time–cost curve can be related to a set of activity options, which identifies a selected set of working method, equipment choice, and crew selection for each activity.

The literature of TCT analysis is flourishing. The pioneering work used manual calculation to sequentially reduce the durations of activities on critical paths to crash the project [16]. Others approached the problem by different means of mathematical programming methods, such as network flow computations [17,40], linear programming [38], integer programming [33,42], hybrid of linear and integer programming [30], and network decomposition [12]. With the aid of increasing computer power, computationally intensive meta-heuristics have recently been applied to find good solutions in a reasonable period of time. The most popular tool is genetic algorithms [13,20,27–29,60]. Recent advances have been made to make use of particle swarm optimization [55], scatter search [47], ant colony system [35], and neural network [37].

The estimation of activity time and cost is usually made long before project commencement, and thus with limited accuracy. Moreover, during the course of project implementation, many uncertain factors may dynamically affect the times and costs of activities. Examples of the uncertain factors include weather condition, material price and supply, labor skill, and equipment capacity. As a result, it has been extensively argued that activity time and cost in the TCT analysis should be estimated as probabilistic distributions to reflect the relatively large variances and to better manage inherent risks [9,22,23]. This class of problem is called the stochastic time–cost tradeoff (STCT) problem.

The STCT problem has been tackled by several studies. Modern approaches adopt multiobjective meta-heuristics to find the optimal set of solutions so as to optimize project duration and cost, both of which are evaluated through simulation. The goal is to approximate the non-dominated set of solutions, which dominates the other solutions found during the process. Here, a solution is said to dominate the other by having shorter duration and lower cost. Feng et al. [15] developed genetic algorithms to perform optimization when activity durations and costs are assumed normally distributed. Their algorithm is a double loop. The outer loop searches for better activity options whereas the inner loop performs Monte Carlo simulation (MCS) to evaluate the mean values of objectives. Since the mean values are point estimates, different trials of simulation would produce different mean values, even for the same set of activity options. This creates a problem that one cannot be sure whether the dominance relation between solutions is consistent or just by chance.

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