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Genetic algorithm-based multi-objective model for scheduling of linear construction projects

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ABSTRACT

This paper presents a genetic algorithm-based multi-objective optimization model for the scheduling of linear construction projects. The model allows construction planners to generate and evaluate optimal/near-optimal construction scheduling plans that minimize both project time and cost. The computations in the present model are organized in three major modules. A scheduling module that develops practical schedules for linear construction projects. A cost module that computes the project's costs. A multi-objective module that searches for and identifies optimal/near-optimal tradeoffs between project time and cost. An application example is analyzed to illustrate the use of the model and to demonstrate its capabilities in optimizing the scheduling of linear construction projects.

1. Introduction

Linear construction projects are characterized by repetitive activities. Examples of such construction projects include highways, tunnels, railways, pipeline networks, high-rise buildings, and housing development projects. In linear construction projects, construction crews repeat the same work in various sections of the project, moving from one section to another.

It is well documented that network scheduling methods such as CPM and PERT are not suitable for the scheduling of linear construction projects. Graphical methods, such as the line of balance [1,2] have been developed for the scheduling of linear construction projects. These methods provide tools suitable for the overall planning as well as summary level scheduling of such projects. However, they are not efficient in scheduling large linear construction projects.

In the last three decades, a number of computerized methods for the scheduling of linear construction projects were developed. Selinger [11] presented the framework of the first dynamic programming solution of linear construction projects. This formulation, however, did not incorporate activity costs as decision variables in the optimization process. Russell and Caselton [10] formalized Selinger's approach into a two-state variable, *N*-stage dynamic programming solution that determines the minimum project time. This formulation also did not incorporate activity costs as decision variables in the optimization process. Reda [9] took another scheduling approach and developed a linear programming formulation to minimize project costs by maintaining constant production rates. The method can only be used for the scheduling of linear projects with identical activity durations within each section. Eldin and Senouci [6] developed a two-state variable, *N*-stage dynamic programming formulation that included both activity durations and costs in the optimization formulation whose objective formulation was to determine the minimum project cost. Hegazy and Wassef [8] presented a genetic algorithm model for the scheduling of non-serial linear construction projects. The objective of the model was to minimize project costs.

All these models are capable of generating a single optimal solution that either minimizes the project time or cost of linear construction projects. There is a need for advanced models that can help construction planners in generating and evaluating all the feasible trade-off between project times and costs in order to select an optimal schedule that satisfies the specific requirements with respect to time and cost of the linear construction project being considered.

The objective of this paper is to present the development of a multi-objective model for the scheduling of linear construction projects. The model provides planners and decision makers in

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linear construction projects with an optimization model that is capable of: (1) generating optimal/near-optimal resource utilization plans that optimize construction time and cost and (2) visualizing the trade-offs among project time and cost in order to support decision makers in evaluating the impact of various resource utilization plans on project performance.

2. Model formulation

The primary purpose of this development stage is to formulate a robust optimization model that supports a two-dimensional time-cost trade-off analysis. To this end, the present model is formulated in two major steps: (1) determining the major decision variables in this resource utilization problem and (2) formulating the two major objectives of optimizing construction time and cost in a robust optimization model.

2.1. Decision variables

For each construction activity in the project, the present model is designed to consider all relevant decision variables that may have an impact on project time and cost. This include: (1) the construction method, which indicates the availability of different types of materials and/or methods that can be utilized; (2) the crew formation, which represents feasible sizes and configurations for construction crews; and (3) the crew overtime policy, which represents available overtime hours and nighttime shifts. In order to control the complexity of the optimization model, the present model combines these three major decision variables into a single variable called a resource utilization option.

For example, the feasible resource utilization options for performing the concrete paving activity in a highway project may include the utilization of: (1) construction material of concrete that provides a strength of 30 or 35 MPa; (2) a crew formation A that consists of one paving machine, one grader, and a labor force of one foreman, three laborers, two equipment operators, and one cement finisher, or crew B that has the same composition except that it has a larger and more powerful concrete paving machine; and (3) and overtime policy of 0 or 4 h of overtime. Various combinations of these available options can be represented by different resource utilization options, as shown in Table 1. Each of these feasible resource utilization options has an expected daily production rate and cost rate; and accordingly it leads to a time and cost for this activity, as shown in Table 1.

Similarly, each of the remaining activities in the project can have a similar set of feasible resource utilization options that can be used to construct the activity. The major challenge confronting construction planners in this problem is to select an optimal resource utilization option, from the available set of feasible alternatives ($n = 1$ to N), for each activity ($i = 1$ to l) in the project. The possible combinations of these alternatives create a large search space, where each solution in this space represents a possible resource utilization option for delivering the project. For example, a small-size project that includes 20 activities and 5 possible resource utilization for each activity creates a search space of approximately 95 trillion (i.e. 5^{20}) possible solutions. The present model is designed to help planners in the challenging task of searching this large solution space in order to identify optimal resource utilization plans that achieve multiple project objectives.

Table 1
Feasible resource utilization options for concrete paving

Resource utilization option (n)	Resource composition			Performance	
	Material (MPa)	Crew	Overtime (h)	Cost ($/m^2)	Productivity (m^2/day)
1	30	A	0	42	2100
2	30	B	0	47	2500
3	35	A	0	43	2100
4	35	B	0	48	2500
5	30	A	4	48	2600
6	30	B	4	54	3100
7	35	A	4	43	2600
8	35	B	4	56	3100

2.2. Optimization objectives

The present optimization model is formulated in order to provide the capability of minimizing construction time and cost. The model is also designed to quantify and measure the impact of various resource utilization decisions on performance in each of the identified two project objectives. It incorporates two major objectives functions as shown in the following two equations to enable the evaluation of project performance in construction time and cost, respectively

$$\text{Minimize project time} = \sum_{i=1}^{l} T_i^n$$

where T_i^n is the duration of activity (i) on the critical path using resource utilization (n). In this model, the project time is computed using previously developed algorithms for scheduling linear construction projects [6]

$$\text{Minimize project cost} = \sum_{i=1}^{l} [(M_i^n + D_i^n \times R_i^n) + (B_i^n)]$$

where M_i^n is the material cost of activity (i) using resource utilization (n); D_i^n is the duration of activity (i) using resource utilization (n); R_i^n is the daily cost rate in \$/day in activity (i); and B_i^n is the subcontractor lump sum cost for resource utilization (n) in activity i, if any.

3. Model implementation

In order to support decision makers in their search for optimal trade-offs between time and cost, the present model is implemented using a multi-objective genetic algorithm. Genetic algorithms are search and optimization tools that assist decision makers in identifying optimal or near-optimal solutions for problems with large search space. They are inspired by the mechanics of evolution and they adopt the survival of the fittest and the structured exchange of genetic materials among population members over successive generations as a basic mechanism for the search process [7]. As such, the present model is implemented in three major phases: (1) initialization phase that generates an initial set of (S) possible solutions for this resource utilization problem; (2) fitness evaluation phase that calculates the cost and time of each generated solution; and (3) population generation phase that seeks to improve the fitness of solutions over successive generations. The detailed computation procedure in these three phases is explained in the following sections and is shown in Fig. 1.

3.1. Phase 1: initialization

The main purpose of this phase is to initialize the optimization procedure in the present model, using the following two major steps.

(1) Read project and genetic algorithm parameters needed to initialize the search process. The project parameters include: (1) number of project activities and sections; (2) number of resource utilization options for each activity; (3) activity