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Multi-objective genetic optimization of linear construction projects

Fatma A. Agrama

Civil Engineering Department, Menofia University, Shebien El-Koom, Egypt

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Abstract In the real world, the majority cases of optimization problems, met by engineers, are composed of several conflicting objectives. This paper presents an approach for a multi-objective optimization model for scheduling linear construction projects. Linear construction projects have many identical units wherein activities repeat from one unit to another. Highway, pipeline, and tunnels are good examples that exhibit repetitive characteristics. These projects represent a large portion of the construction industry. The present model enables construction planners to generate optimal/near-optimal construction plans that minimize project duration, total work interruptions, and total number of crews. Each of these plans identifies, from a set of feasible alternatives, optimal crew synchronization for each activity and activity interruptions at each unit. This model satisfies the following aspects: (1) it is based on the line of balance technique; (2) it considers non-serial typical activities networks with finish–start relationship and both lag or overlap time between activities is allowed; (3) it utilizes a multi-objective genetic algorithms approach; (4) it is developed as a spreadsheet template that is easy to use. Details of the model with visual charts are presented. An application example is analyzed to illustrate the use of the model and demonstrate its capabilities in optimizing the scheduling of linear construction projects.

Introduction

Traditionally, network techniques such as CPM have been used throughout the construction industry for scheduling and controlling all types of construction projects. Network techniques, however, exhibit major drawbacks when applied to schedule repetitive projects [1,2]. Such techniques require a large number of activities to represent a repetitive project, thus making it difficult for practitioners to visualize the large amount of data involved. Moreover, resource-leveled networks do not guarantee work continuity. CPM based network techniques were used by practitioners has been dictated by the lack of availability of commercial software for scheduling repetitive projects [3]. In recognition of the disadvantages of network techniques, a number of traditional scheduling techniques in addition to a variety of special techniques have been developed. The line of balance LOB graphical scheduling technique has a simplistic formulation to maintain work continuity and represents a start point for most mathematical formulation

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E-mail address: fatmagrama@hotmail.com

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developed since the 1960's [2,4]. The application of work continuity improves the overall productivity of construction crews due to: minimizing their idle time during their frequent movements on site; and maximizing their benefits from learning curve effects [5]. Despite the advantages of crew work continuity, its strict application can lead to longer overall project duration [6,7]. This led to a number of research studies that investigated the impact of crew work continuity on the scheduling of repetitive construction projects [8,9]. Several mathematical models have been developed for time or cost optimization of repetitive projects.

A dynamic programming model to minimize project duration of non-typical repetitive works was proposed [6]. However, this model did not study work interruptions.

A modification of mentioned model was developed to consider a user-defined set of optional interruptions [7]. However, the two models are limited for serial network. A dynamic programming model which handles non-serial activities within multiple non-overlapping loops was developed to optimize total construction cost [10]. None of the optimization models mentioned earlier could handle not constrained non-serial network, crew synchronization or resource constraints, simultaneously. Moreover, the mathematical optimization techniques do not guarantee a global optimum solution and may be trapped in local optima in case of large-scale problems [11]. All these models presented a single objective optimization that either minimizes the projects time or cost of linear construction projects. There is a need for advanced models that can help construction planners to generate optimal construction schedule that satisfies the specific requirements with respect to time and cost of the linear construction project being considered.

A multi-objective optimization for scheduling repetitive construction projects was developed [5]. The model enables construction planners to generate and evaluate optimal construction plans that establish optimal tradeoffs between project duration and crew work continuity, simultaneously. However, a genetic algorithm-based multi-objective optimization model that performs trade-off among project time and cost was proposed [12]. However, the crew synchronization or resource constraint is not considered in the two models. These items could be effectively treated by the cost optimization model which presented another view for multi-objective genetic optimization by converting all goals to cost [9]. A CPM/LOB based model which performs time-cost trade-off analysis by determining the number of synchronized crews and crew work interruptions within resource and interruption limitations by using general penalty cost for each to minimize their utilization. However, two LOB based models for time and for cost optimization were developed [13]. Different resource and interruption penalty costs for each activity are used to relatively limit key resources, in the cost optimization model.

The scope of this paper is to present a multi-objective genetic optimization model for scheduling linear construction projects. The model enables construction planners to generate optimal/near-optimal construction plans that minimize project duration, crew work interruptions, and the number of synchronized crews.

Model formulation

To simplify the modeling task and present a model in a format that is customary to practitioners, a spreadsheet tool, Excel, is used for implementation [14]. The spreadsheets have been proven suitable as a tool for developing computerized models, such as the one at hand. The spreadsheet formulation for multi-objective optimization is carried in the following subsections on the case study project described in the literature to validate the model. The used simple example originally presented for a linear construction project of five units [9], each have a ten activities network as shown in Fig. 1. The spreadsheet model that comprises activities' data is shown in Fig. 2, with the model details provided in the next subsections along with the description of the calculations.

Crew synchronization calculations

A basic relationship that determines a linear progress rate $R(i)$ of activity i with associated duration $D(i)$ and number of crews $C(i)$, without crew-work interruption, can be found by examining the synchronized crew movement as shown in Fig. 3. In this figure, three crews are utilized to complete an activity that is repeated at five units. Only one crew for an activity is assumed to work in a unit until completed then moves to another unit. Dividing the duration $D(i)$ of activity i by the number of crews $C(i)$, implies that each crew starts work in a unit after a time $D(i)/C(i)$ relative to its preceding unit. Consequently, the equation governing uninterrupted crew utilization can be determined by examining the small triangle in Fig. 3, as follows [15]:

$$R(i) = C(i)/D(i) \quad i = 1, 2, \ldots, I \tag{1}$$

where, I is the total number of activities.

However, one objective of the model is to find the minimum combination of synchronized crews which satisfies the available number of crews $C_v(i)$ for each activity. The number of crews $C(i)$ is a variable which ranges from a single crew to the available limit $C_v(i)$. Thus, the initial calculation of the activity's progress rate, stated by the author, must be based on only one crew, i.e. Eq. (1) becomes:

$$R_0(i) = 1/D(i) \quad i = 1, 2, \ldots, I \tag{2}$$

Repetitive activities that have more than one crew require further examination to determine whether using some or all of the available crews. However, speeding those activities may positively affect the total project duration. The use of additional crews $C_d(i)$ is allowed only to activities that have a slower progress rate than their predecessors or those have no predecessors; thus speeding those slow activities and thereby reducing project duration, Fig. 4. The additional crews $C_d(i)$ is an integer variable that must be less than the available limit, Eq. (3). The initial progress rate of an activity $R_0(i)$ which has predecessors is compared with the real progress rate of its predecessors $R_r(p)$, will illustrate next, to determine the crew multiplier variable $\mu1(i)$ of zero-one value for each activity to signal whether the

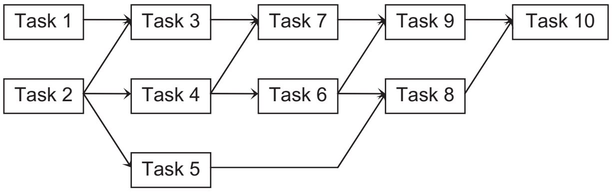

Fig. 1 Precedence network for one unit of case study.