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Construction Materials-based Methodology for Time-Cost-Quality Trade-off Problems

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Abstract

Time, cost, and quality (TCQ) as a triple constraint of construction projects have dependent and conflicting objectives. Considering the limited resources, estimation of the approximate TCQ is a complex and dynamic problem. In addition, the uncertain nature of construction projects and highly variable alternatives make the decision making process a complicated issue. In order to overcome these difficulties, many researchers in the related academic literature introduced different mathematical models on the TCQ trade-off problem so far. In these models, two different approaches were used to estimate TCQ-related data. In the continues approach, it was assumed that the relationship among these three components could be expressed by continuous functions. In the discrete approach, it was accepted that (i) the construction method, (ii) the crew formation, and (iii) the crew overtime policy have some impacts on the project TCQ and that the relationships among these three components become discrete. However, in previous studies, construction materials that have a significant impact on TCQ of construction activities and projects were not taken into account completely during the data formation process. As an exception, El Rayes and Kandil [1] considered different strengths of concrete as material alternatives in a highway construction project. In fact, all the studies focused on proving the applicability of different optimization techniques instead of optimizing TCQ of a real construction project. In this context, some simple projects including a limited number of activities were used to evaluate the applicability of the developed models. Therefore, in the present study, it is aimed to outline a new two-step methodology, including the alternative construction material utilization, for TCQ trade-off problems, especially for building projects which enable the utilization of the high variety of construction materials. For this purpose, the impact of construction materials on TCQ of a project was explained in a detailed manner.

Keywords: Time-cost-quality trade-off, construction material, construction management

1. Introduction

The primary objective of project management is to finish a project within a desired time, cost, and quality. Due to the technological development in today's construction industry, different construction methods, materials, and equipment, which serves to same purposes, can be utilized. During the planning process, by considering these different construction methods, materials and equipment, alternatives are generated, evaluated, and the most suitable one is selected [2, 3]. Thus, the planning process turns to a decision-making process and optimization, which is simply defined as the selection of the best alternative for a given purpose [4], is located in the center of it. Although decisions made in the planning process have a considerable impact on TCQ of a project, they are made with limited information [5]. Therefore, for an effective optimization, all alternatives should be detailed as much as possible. In addition, the uncertain nature of construction projects and highly variable alternatives make the decision making process a complicated issue. In order to overcome these difficulties, many researchers in the related academic literature have introduced different mathematical models on the TCQ trade-off problem by using different optimization techniques so far. However, in previous studies, construction materials that have a significant impact on TCQ of construction activities and projects were not taken into account completely during the data formation process. As an exception, El Rayes and Kandil [1] considered different strengths of concrete as material alternatives in a highway construction project. Therefore, in the present study, it is aimed

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to outline a new two-step methodology, including the alternative construction material utilization, for TCQ trade-off problems, especially for building projects which enable the utilization of the high variety of construction materials.

2. Theorical Background

Components of TCQ as a triple constraint of construction projects are always in interaction with each other. Any changes made in one of these constraints will likely affect the others negatively or positively. Therefore, generating a construction schedule that allows finishing a project within its scope become an important issue in theory and practice. However, the uncertainties caused by the dynamic environment of construction projects and the highly variable alternatives that can be utilized makes the decision making process complicated. In the literature, to facilitate this process, many researchers developed new models by using different optimization tools to analyze the trade-off among TCQ. In this context, by means of Critical Path Method (CPM), researchers generated alternative construction schedules by considering alternative resource utilizations of each construction activity. Since TCQ constraints of each schedule were compromised by means of optimization tools, it is accepted that none of alternatives predominates the other ones.

Numerous researches were conducted on the time-cost optimization of projects since the development of CPM in the late 1950's. The quality concept was first included to the optimization process by Babu and Suresh [6]. In their study, they argued that the quality of a construction project may be affected by crashing the time and accordingly suggested that the quality concept should also be considered during the optimization process.

In construction projects, time and cost are one dimensional concepts. In other words, time and cost can be expressed by a simple value that creates a common perception among project participants. On the other hand, quality has many dimensions and each dimension creates different perceptions among different practitioners. For example, Foster [7] introduced five different views for quality as follows,

1. ***Transcendent view:*** Quality can be perceived intuitively but cannot be expressed easily, such as beauty or love.
2. ***Product-based view:*** The features and attributes of a product define the quality.
3. ***User-based view:*** If the product satisfies users' needs, then it has a good quality.
4. ***Manufacturing-based view:*** If the product matches the design specifications, then it has a high quality.
5. ***Value-based view:*** If the product offers good value for its price, then it has a high quality.

In this regard, all the dimensions of quality should be perceived equally to create a common perception of quality among project participants. Considering above-mentioned quality dimensions, it can be asserted that subjective evaluations come to the forefront for defining the quality. Only product quality is open to objective evaluations as long as it can be expressed by estimative technical features or attributes. Since quality is not a quantitative parameter [8], it cannot be expressed with a simple value like time and cost by nature. Although the difficulty and complexity of calculating the quality was underlined by many researchers [1, 8, 9, 10], quality was digitized in the literature after some assumptions. In this context, researchers in the field of the TCQ trade-off can be categorized under two groups regarding to the relation among TCQ as follows,

1. **Continuous approach:** In this approach, it was argued that the relation among TCQ could be expressed by continuous functions [6, 8, 9, 10, 11, 12]. Here, time was independent whereas cost and quality were dependent variables in the models. Only Ghodsi et.al. [10] suggested that the quality loss caused by crashing the time could be prevented by spending extra money and thus considered the quality as an independent variable. Since quality is correlated only with time and cost, it can be claimed that only workmanship quality was optimized in these studies. In other words, it was accepted that the workmanship quality will decrease by crashing the time.

2. **Discrete approach:** The first study with this approach, which also provided a basis for the other ones, was conducted by El-Rayes and Kandil. In this approach it was assumed that TCQ of an activity appears discretely depending on the construction method, crew formation, and crew overtime policy that will be utilized for that activity. To simplify the calculations, these three decision variables were combined into a single variable called resource utilization. Differently from the continuous approach, in discrete approach, the performance quality of a project was optimized. For digitizing the quality, some estimative

quality indicators were considered. For example, El-Rayes and Kandil [1] accepted compressive strength, flexural strength, and ride quality as quality indicators for concrete pavement. Since all quality indicators of an activity and all activities do not affect the total quality of a project equally, some weights were determined for each indicator and activity to calculate the total quality value.

Although the common purpose of these studies was to optimize TCQ of a construction project, different quality concepts were addressed in these two approaches. As a result, some researchers criticized the studies with different approach. For example, Ghodsi et. al. [10], who used the continuous approach, stated that the discrete approach makes the problem complicated to solve because gathering data is not practical for project managers. Especially in projects with many resource utilization alternatives, discrete models lose their applicability. However, Kim et. al. [13], who used the discrete approach, indicated that the continuous approach may be theoretically significant, but not applicable to real problems because contractors do not accept the quality reduction. Similarly, Khang and Myint [9], who applied the continuous model proposed by Babu and Suresh (1996) to a real cement factory construction project, stated that, according to the practicing managers and engineers, the quality reduction due to overtime is negligible and cannot exceed 2±3% even if the maximum amount of overtime is used. In addition, activities with quantitative quality indicators are not greatly affected by the use of overtime. Independently from their time, all the activities must be completed conformably to the contract or science and craft rules.

Expressing the total quality of a project with a simple value is another issue that can be criticized in both approaches. As mentioned before, quality has many dimensions, and for a common perception, all the dimensions should be perceived same among project participants. In other words, if the quality is expressed by a simple value, participants cannot clearly find out which quality indicator or activity reduces the total quality and whether the quality level obtained will satisfy the expected project performance.

Finally, in most of past studies, impacts of construction materials on TCQ were not taken into account completely during the data formation process. As an exception, El Rayes and Kandil considered different strengths of concrete as material alternatives in a highway construction project. As known, building projects are the most common project type in the construction industry, and in such projects, many construction materials which serve to the same purpose can be utilized. Technical specifications of these materials directly affect TCQ of an activity and thereby the total TCQ of a project. For example, according to the Unit Price Analyses of the Ministry of Environment and Urban Planning in Turkey, using gas concrete bricks instead of clay bricks will shorten the duration of the wall building activity by 40%. In this context, besides the crew formation and crew overtime policy, utilizing alternative materials should also be evaluated for crashing the project time. Similarly, using alternative construction materials will also affect the indirect and maintenance costs of a project as well as direct costs of activities. Finally, attributes such as aesthetics, comfort, insulation, strength, and lifetime of alternative construction materials vary. Therefore, each material will compensate project requirements in different quality levels. In this context, it is argued that for an effective TCQ trade-off analysis, the use of alternative construction materials should also be included in the optimization process.

3. Development of a New Methodology

In the literature, the parameter 'material' was neglected and only crew formation and crew policy were included in the formation of alternative resource utilizations. In the current study, it is argued that alternative construction materials should also be included in the resource utilization formation and hence a two-step methodology was introduced. In the first step, effects of alternative construction materials on TCQ of a project under the same conditions should be compared. Toward this aim, alternative resource utilizations of an activity should have the same crew formation and crew policy. The main purpose of the first step is to determine which material will be used in activities. In fact, the determination of materials will also give an idea of the expected quality of a project. In other words, since the quality is determined at the end of the first step, it should not be included in the second step. The second step should only start if project participants attempt to crash the time or reduce the cost of the optimum construction schedule obtained by the first step. Therefore, in the second step, a time-cost trade-off analysis should be conducted by considering alternative crew formation and crew policy. Since in the literature there are numerous studies about the time-cost trade-off problem, only the first step will be outlined in this study.

Unlike the models developed in the literature, in this methodology, it is argued that estimative quality indicators which constitute the total quality of a project should be calculated separately. This approach will create a common perception of quality among project participants, and hence, an effective trade-off analysis can be conducted. On the other hand, the performance delivered throughout the lifecycle of a building determines its quality. In this regard, it was assumed that independently from their intended use, common quality indicators of buildings are change order or maintenance cost and annual energy need, all of which depend on their lifetimes. Similarly, it was also accepted that the time-cost curve and daily number of labor would affect the project management quality. Under these assumptions, besides time and cost, some other parameters such as the number of labor, lifetime of the construction material, change order or maintenance cost of the material, and technical data concerning the building insulation, should be included in each alternative resource utilization data.

In the literature, the main optimization methods for the model development were linear programming and metaheuristic algorithms. As known in the linear programming, only one function can be optimized under some constraints. In this respect, in previous studies, three different models were developed representing each objective. Therefore, these three objectives were not optimized concurrently. Instead, only one objective was optimized under certain values of the other two. However, metaheuristic algorithms allow multi-objective optimizations. In these methods, the solution set is created by the model [14] by searching near optimum solutions [15]. This means that, for each objective, the upper and lower boundary is determined by the model and alternative schedules which are not within boundaries are not included in solution sets as shown in Figure 1. However, in fact, there is time and budget limitations devoted for each project, together with an expected quality level after completion (Figure 2). In this context, it was argued that the devoted time and budget are upper boundaries of a project, and each alternative schedule which lies under these boundaries should be included in the solution set. In addition, to calculate the time depending the indirect cost and change order or maintenance cost of each alternative schedule, both the expected daily cost of a project and the lifetime of a building should be included in project-related data. In this regard, at the end of the methodology, alternative schedules with different time, cost, and quality indicator values, which also satisfy the project's devoted time and budget, will be generated by considering project- and activity-related data as shown in Figure 3.

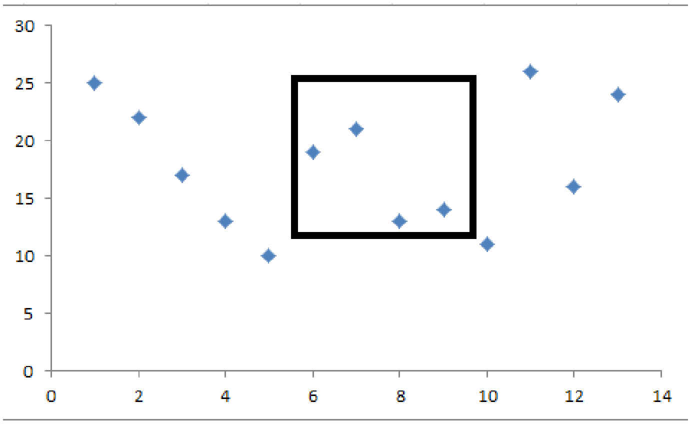

Figure 1. An example of the solution set of metaheuristic algorithms

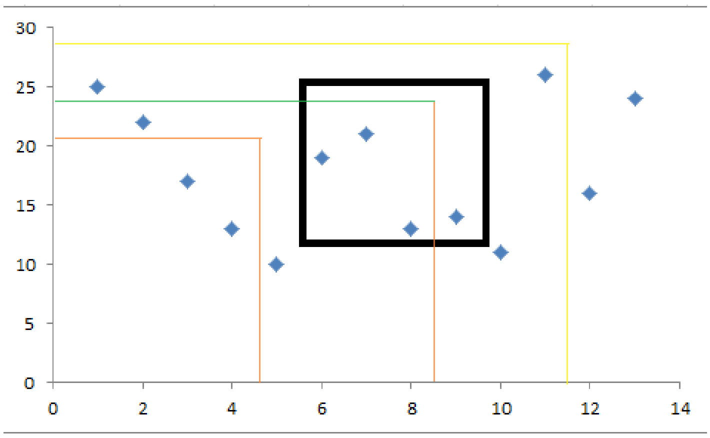

Figure 2. An example of the solution set of new methodology

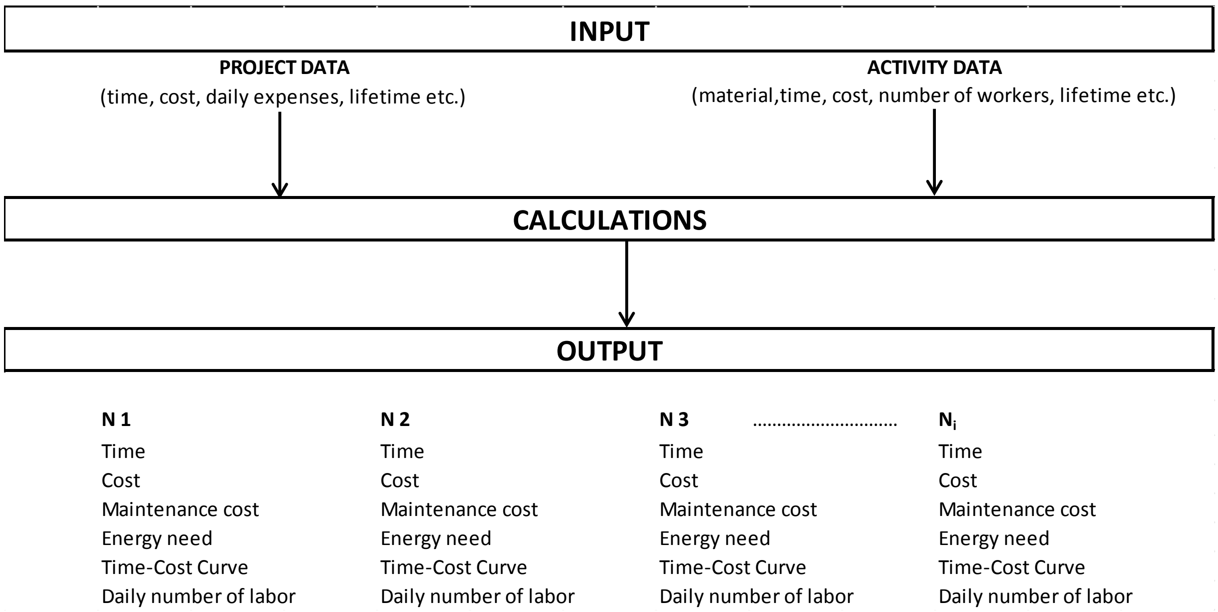

Figure 3. The optimization process of the newly developed methodology

4. Conclusion

Together with the expected quality after completion, the devoted time and cost determines the scope of a project. In this regard, the main objective of project management is to finish a project within its scope. However, in today's construction industry, either the high variety of construction materials or numerous alternatives of crew formation or crew policy allow to use a large number of resource utilizations in construction projects. In addition, the complexity of construction projects, mainly caused by relations among construction activities, makes a complicated environment for evaluating all of alternative resource utilizations during the planning process. To overcome these difficulties, many researchers developed different trade-off models by using different optimization methods. In these models, alternative resource utilizations were considered, and as a result, different construction schedules with different TCQ values were obtained. However, in most of past studies, alternative construction materials were ignored during the formation of resource utilizations, and accordingly, the effect of construction materials on the total TCQ was left out of assessment. Similarly, although quality has many dimensions and is open to the subjective perception among different individuals, the total quality level of projects were expressed by a single value.

In this study, it was aimed to outline a new two-step methodology to overcome the deficiencies determined in the literature. According to the new methodology, in the first step, effects of construction materials on time, cost, and estimative quality indicators of a project should be compared under the same crew formation and crew policy. In fact, at the end of the first step, besides construction materials, the expected quality of a project will also be determined. Therefore, the quality should not be included in the second step. The second step should only be started if the planning engineer wants to make some changes on time and cost of the optimum schedule obtained from the first step. In this context, only time and cost of a project should be optimized concurrently by considering alternative crew formation and crew policy for each activity.

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