Optimization Based - Approach for Organizing the Bidding of Nonserial Repetitive Projects

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ABSTRACT

In practice, the number of contracts and the categories of contractors to be called for bidding on non-serial repetitive projects under one major program are often estimated based on intuition and experience. It may involve emotional reactions to existing surrounding conditions. Accordingly, the factors that form the possible different scenarios should be properly analyzed and evaluated. This paper introduces an analytical model that allows for decisions on the number of contracts and projects per contractors for different contractors’ categories within major construction infrastructure programs. These optimum decisions are reached using an integrated time and cost objective. Genetic Algorithm has been employed for performing optimization. A computer-based model has been developed and validated.

Keywords:
Nonserial Repetitive Projects; Bidding Analysis; Optimization; Time Cost Trade-Off.

INTRODUCTION

Nonserial repetitive construction projects, in this paper, are representing multi-subprojects under a major program with one defined budget. Therefore, the word repetitive projects here refers to projects level not activities level. Those sub-projects are typical in their work packages, activities, and construction methods. However, they can have different quantities, locations, list prices, and different contractors. Each subproject is independently related to the others in terms of starting and finishing dates. In other words, it is not a condition for one subproject to start after another one is finished. Examples of this kind of projects can be mostly noticed in infrastructure projects such as roads, railways, tunnels, bridges, pipelines, etc. In this study, the word cost refers to the cost of owner and the word price refers to the bid price of a contractor.

In projects that have a nonserial repetitive nature under a grand project, there can be many different scenarios when deciding upon the number of contracts and contractors’ categories to be called for bidding. These estimations have to be properly determined in order to minimize the cost and time of the grand project especially for infrastructure projects that takes a big share of governments’ capital.

The dilemma is that if the contracts are divided into a small numbers with high contract value, limited contractors from high categories have to be called for bidding in order to undertake the project. In this case, this category of contractors has a high
overhead, which incur high cost on the owner. Moreover, the risk of delaying a big portion of the grand project would be higher in case a contractor encountered problems and failed to finish the sub-project on time.

On the other hand, if the contracts under a grand project are divided into more numbers with low contract value, more contractors from lower categories can be called for bidding. In this case, the risk of delaying a great portion of the grand project will be lower; however, the risk of coordination among contractors will be high. As such, in one grand project, there are always a big number of scenarios and, largely, each scenario would differ from the other in terms of cost and time. Determining the optimum Scenario remains the main challenge that faces decision takers, as it has to be performed while there is still a shortage of information and enormous pressure to speed up the bid preparation. Therefore, the existence of powerful and reliable approach that can analyze all the available information and consider controlling factors will much improve the ability of decision takers when they have to decide.

This paper introduces a new approach by which decision takers in construction projects can easily decide on the optimum number of contracts and contractors’ categories that enables attaining the minimum cost and time. The approach will provide decision takers with the ability to minimize cost, time, or both combined.

LITERATURE REVIEW

In order to achieve the objective of the proposed approach in the present paper, different multi-optimization techniques used recently in construction management field have been surveyed. (Zheng et al. 2004) developed a technique that can be utilized for time cost optimization in one objective function. The paper presented a novel multi-objective approach that aims to optimize total time and total cost simultaneously by utilizing appropriate GAs concepts and tools. It introduced a MAWA “modified adaptive weight approach”. This approach has been developed to overcome the drawbacks of the previously developed multi-objective approach “AWA” developed by (Gen and Cheng 2000). (Zheng etal 2004) compared both approaches utilizing hypothetical data and concluded that MAWA overcomes many of the drawbacks of AWA. (Ng and Zhang 2008) developed an ant colony-based optimization algorithm to solve the multi-objective time-cost optimization problems. The MAWA approach developed by (Zheng et al. 2004) was exploited to integrate the time and cost into a single objective. When the performance of the proposed model compared to other analytical methods previously used for time–cost modeling, the results show that the ant colony system approach is able to generate better solutions without utilizing much computational resources, which provides better time–cost decisions efficiently.

(Ezeldin1 and Soliman 2009) developed a hybrid technique that integrates genetic algorithms (Gas) with dynamic programming to solve construction projects time-cost trade-off problems under uncertainty. The formulation of the approach developed based on the sum of the cost-duration relationship for each activity in the nonserial repetitive subproject then modified with multiplier factors. The results obtained using the developed system, when applied to a case study, outperformed
those obtained using Solver in both the value of the optimum and the consistency of finding it.

Harmony search (HS) was first devised based upon the correspondence between music improvisation and the optimization process by (Geem et al. 2001), then successfully employed to various combinatorial optimization problems. (Geem 2010) employed HS to perform time-cost trade-off optimization. When HS applied to two test examples, good Pareto solutions were obtained when compared with other algorithms, such as the genetic algorithm and the ant colony optimization algorithm. It explored only a small amount of total solution space in order to solve this combinatorial optimization problem.

(Zhang and Xing 2010) introduced a fuzzy-multi-objective particle swarm optimization methodology to solve the fuzzy time-cost-quality tradeoff problem. The time, cost and quality were described by fuzzy numbers. A fuzzy multi-attribute utility methodology incorporated with constrained fuzzy arithmetic operations is employed to evaluate the elected construction methods. The particle swarm optimization is applied to search for the optimum solutions by incorporating the fuzzy multi-attribute utility methodology. The methodology has been demonstrated by solving the time-cost-quality tradeoff problem of a bridge project, which proved its effectiveness. Two years later, (Ashuri and Tavakolan 2012) also used fuzzy enabled hybrid genetic algorithm–Particle swarm optimization approach. However, this time the approach was used to solve another kind of problems, which is time-cost-resource optimization problem (TCRO). The results generated from the application of the developed approach to planning problems showed that it is faster than concurrent existing methods in terms of processing time for solving complex TCRO problems in construction project planning.

A newly proposed approach utilizing multi-objective optimization considering uncertainty was introduced by (Hazir et al. 2011). It proposed three models to formulate a robust discrete time/cost trade-off problem (DTCTP) which could be the first implementation of robust optimization to this kind of problems. Results generated from the approach could be useful base for developing robust project schedules for multi-mode project networks.

Several other approaches and models have been developed and published with regard to multi-objective optimization problems in construction management such as (Diao et al. 2011), (Kalhor et al. 2011), (Deniz et al. 2012), and (Ghoddousi 2013). Each approach addresses a certain kind of problems with a certain technique for optimization. What has been noticed is that each researcher decides to use a certain technique such as genetic algorithm, ant colony, or sometimes integrates fuzzy logic without predefined reasons for using such a technique. Perhaps if other techniques or algorithms were used in solving a certain problem otherwise the one utilized, better results would have been generated.

MODELING AWA AND MAW APPROACHES

The two approaches AWA and MAWA found in the literature have been analyzed and a spreadsheet model has been developed based on each as shown in Figure 1 and 2 to employ one of both in the optimization performed in this paper. The example given in the literature has been utilized to verify that the model is working
properly. Evolver 5.5 software add-on to excel based on genetic algorithm has been used for optimization instead of manual iterations. Unexpectedly, after almost 2000 iterations, the developed software model showed better results than indicated in the given paper. The best result generated from the developed software model is $233500 and 60 days, which is better than the results generated from the manual iterations in the paper that are $236500 and 66 days. Although Aw approach showed better results than MAW approach, the latter is utilized in the optimization process in this study since it overcomes many drawbacks of AW approach listed in the literature.

PROPOSED APPROACH

In order to achieve the main objective of the paper, the proposed approach indicated in figure 3 is developed. The approach is divided into 5 modules; categorization, estimations, manipulation, optimization, and results. The main idea of the approach is to estimate the number of contracts and contractors’ categories through determining the scenario that gives the minimum cost and time for the grand project.
Module 1: Categorization.
Defining contractors’ categories & Limitations.

Module 2: Estimations.
Obtaining the estimated total price and duration of each category of contractors.

Module 3: Manipulation.
Developing scenarios of different prices and their equivalent duration for each contractor.

Module 4: Optimization.
Performing Time-Cost trade off optimization.

Module 5: Results.
Obtaining the number of contracts to be bided for each category of contractors which leads to the optimum cost and time for the grand project.

Figure 3: Proposed Approach

Module 1: Categorization.
In each country contractor firms are categorized from small, medium, to big enterprises according to many factors such as their capital, employees, equipment, etc. Each country has its own system for this kind of categorization. In Egypt, for example, the Egyptian Federation for construction & Building Contractors (EFCBC) classifies contractor firms into seven categories according to their capabilities and the type of projects as well. In this module of the proposed approach, the categories of contractors as well as the limitation value of contract for each category have to be well identified. This limitation values can, to a great extent, helps in assuring the contractor’s ability to finish the assigned work properly. This paper considers the categorization system applied in Egypt according to the Egyptian Federation for construction & Building Contractors.

Module 2: Estimations.
The price and duration applied by contractors from different categories can be greatly different according to each one’s capabilities and the assigned overhead. The price and duration applied by a contractor from a certain category to get a contract can be predicted by construction estimators experienced in this discipline considering...
studying the market and its prevailing conditions. This paper does not address this kind of estimation, but rather it is assumed that these data is obtainable by construction estimators.

Module 3: Manipulation.

In this module, the data obtained from estimators is stored and organized to develop scenarios of different prices and their equivalent duration for each contractor. In other words, contractors from each category can apply different prices according to different durations for a project. Therefore, this data for each different category is organized properly to facilitate the process of manipulation of different scenarios and the division of the number of contracts.

Module 4: Optimization.

This module is concerned with Performing Time-Cost trade off optimization. It considers the optimization process which result in the optimum number of contracts with their values and contractors with their categories that achieve as much as possible the optimum cost and time for a grand project. In this optimization process, the variables are contractors’ categories with their different scenarios of price and duration and the number of contracts for each category maintaining the constraints of contractors’ availability and the maximum number of contracts to be a warded to a single contractor. The number of contractors willing to apply for bidding can be determined from invitation for bidders process. The maximum number of contracts to be a warded to a single contractor is estimated on the basis of the contractor capabilities.

Module 5: Results.

The main desired result from the proposed approach is to determine the number of contracts to be bided for each category of contractors which results in getting the optimum cost and time for a grand project. In other words, it facilitates the process of dividing a grand project into nonserial repetitive sub-projects maintaining that each sub-project has its own independent contract. It is well understood that the optimum cost in terms of an owner’s perspective which is the price from contractors’ perspective and duration of grand project resulted from the above mentioned optimization do not have a high level of accuracy since they are estimated based on predictions and can be deviated in reality. However, they give to great extent guidance for estimating the main desired objective in a properly systematic process.

DEVELOPED MODEL

In order to facilitate the application of the proposed approach, a spreadsheet model has been developed and hypothetical data has been utilized to test its validation. The model is composed of three consequent sections as follows.

Section 1- Contractors’ Information

Section 1 is concerned with recording contractors’ categories, their limitations, availability, and Max number of contracts to be awarded for each contractor as indicated in figure 4. Contractors’ categories and limitations for each
category have been obtained from (EFCBC). The number of available contractors assumed to be obtained from the process of invitation for bidders. The max number of contracts to be awarded for each contractor is assumed to guarantee the ability of each contractor to finish the assigned work properly.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Limitations</th>
<th>No. of Available contractors</th>
<th>Max no. of contracts to be awarded for each contractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Category</td>
<td>no limitation</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>2nd Category</td>
<td>250000000</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>3rd Category</td>
<td>150000000</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>4th Category</td>
<td>100000000</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>5th Category</td>
<td>50000000</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>6th Category</td>
<td>20000000</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>7th Category</td>
<td>50000000</td>
<td>21</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 4: Contractors’ information

Section 2- Storing Different Scenarios for Contractors’ Categories

In this Module, the different scenarios of total cost and time assumed to be obtained from estimators are stored in a format that facilitates calculations as indicated in figure 5. For each category of contractors, it was assumed that there are three different options/scenarios of cost to complete the project based on the duration.

<table>
<thead>
<tr>
<th>Options</th>
<th>1st Category</th>
<th>2nd Category</th>
<th>3rd Category</th>
<th>4th Category</th>
<th>5th Category</th>
<th>6th Category</th>
<th>7th Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost</td>
<td>Duration</td>
<td>Cost</td>
<td>Duration</td>
<td>Cost</td>
<td>Duration</td>
<td>Cost</td>
</tr>
<tr>
<td>1</td>
<td>EGP 40,750,000</td>
<td>180</td>
<td>EGP 58,500,000</td>
<td>160</td>
<td>EGP 56,700,000</td>
<td>160</td>
<td>EGP 55,500,000</td>
</tr>
<tr>
<td>2</td>
<td>EGP 54,000,000</td>
<td>180</td>
<td>EGP 52,400,000</td>
<td>180</td>
<td>EGP 49,900,000</td>
<td>180</td>
<td>EGP 48,500,000</td>
</tr>
<tr>
<td>3</td>
<td>EGP 48,950,000</td>
<td>210</td>
<td>EGP 48,100,000</td>
<td>230</td>
<td>EGP 46,920,000</td>
<td>230</td>
<td>EGP 45,510,000</td>
</tr>
</tbody>
</table>

Figure 5: Storing Different Scenarios for Categories Module

Section 3- Performing Optimization

In this module, the optimization process is performed get the optimum cost and time for a grand project which leads to estimating the number of contracts to be bided for each contractor’s category. Evolver 5.5, that uses genetic algorithm
approach, has been utilized as an ad-on to excel in order to run as much number of iterations for better optimization. In this section, the variables are the options that represent different scenarios of prices and their equivalent durations in addition to the number of contracts. The constraints are that each contract value does not exceed the limitation of the equivalent category and the number of contracts to be awarded for each contractor does not exceed the predefined number as shown in figure 4.

The optimization process has been performed twice. The first considered the objective function to be the total cost to be minimized and this process led to a total cost of 41,810,440 L.E in 180 days after 15000 trials as shown in figure 6. Figure 7 represents a visualization tool that can be monitored during optimization and facilitates getting more information in less time. From Figure 10 & 11, it can be noticed that, the number of contacts that should be bid for each contractor category and achieve the minimum cost is two contracts with the first scenario for the 4th category, nine contracts with the second scenario for the 6th category, and twelve contracts with the first scenario for the 7th category.

The second operation that considered the M.A.W.A approach addressed earlier in the previous sections of the paper. In this operation, the objective function set to be the fitness function that combines time and cost according to M.A.W approach. This operation resulted in a total cost of 41,832,353 L.E with a duration of 160 days which might be a better solution for decision takers. From Figure 8 it can be noticed that, the number of contracts that should be bid for each contractor category and achieve the optimum cost and time is two contracts with the first scenario for the 4th category, nine contracts with the first scenario for the 6th category, and twelve contracts with the first scenario for the 7th category.

It can be noticed from the results of the two operations that changing the objective function does not only affect the number of contracts to be bid for each category, but rather affects the scenario to be bid for each category of contractors. Based on the above, It can be perceived that the developed model is flexible to be adjusted for each user according to her/his interests in terms of the objective function.

![Figure 6: First operation of optimization](image-url)
CONCLUSION

This paper addressed projects that have a nonserial repetitive nature on the projects’ level, not activities’ level, under a grand project like infrastructure projects. In order to estimate the number of contracts and contractors’ categories to be called for bidding under a grand project, based on more intuitive and realistic procedures, a novel approach has been proposed.

The approach was built based on developing different scenarios and select the one that generates the optimum or near optimum total cost and duration. MAW approach has been adopted for integrating the two objectives time and cost into a single objective. Genetic Algorithm has been employed for performing optimization. Based on the proposed approach, a prototype software- based model has been developed to facilitate all the calculation and analysis processes. Evolver 5.5, that uses genetic algorithm approach, has been utilized as an ad-on to excel in order to run as much number of iterations for better optimization.

Hypothetical data has been utilized to test the model’s validation, and after a short processing time, solutions have been reached and logical results have been
generated. One advantage of the developed model is that it is flexible to be adjusted for each user according to her/his interests in terms of defining the objective function.

REFERENCES


