Mark-up size estimation in railway projects using the integration of AHP and Regression Analysis Techniques

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Abstract

The construction industry is commonly characterized by high level of competition. Since the large majority of the contractors win jobs through the bidding process and the owners predominantly select the contractors, who offer the lowest bid price, estimating the bid price accurately is critical for winning the contract and achieving business continuity. The bid price mainly consists of two components, which are: the base estimate and the bid mark-up. In general, the bid mark-up is estimated as the percentage of the base estimate based on the estimators’ intuitions and past experiences. While the base estimate is found to be more or less same by competitor contractors, the offered bid prices greatly differ due to the variations in the bid mark-up size estimations. The bid mark-up size is affected by several factors. Therefore, determining the appropriate bid mark-up size is a complex decision problem. The main objective of this study is to propose an integrated approach, which may assist contractors in estimating the bid mark-up size more accurately and systematically. The main steps in the proposed approach include: 1) identifying the factors that may affect the bid mark-up size and categorization of these factors and developing a decision hierarchy of the mark-up size estimation problem (i.e., identifying the main criteria and sub-criteria), 2) determining the weights of the main criteria and sub-criteria in the mark-up size estimation problem using the Analytic Hierarchy Process (AHP) approach by top managers considering the long-term strategies of the company, 3) identifying the importance levels of the main criteria and sub-criteria for the projects for which the company management is willing to offer bids, 4) determining the overall risk score of the projects in question by incorporating the weights and importance levels of the main criteria and sub-criteria, 5) estimating the bid mark-up size using the regression analysis, and 6) measuring the performance of the developed regression model. The proposed approach was applied in a contracting company, which is specialized in railway projects. Actual data of 10 railway projects completed in foreign countries within the last five years were collected from the top managers and estimators of the studied company. It was found that the bid mark-up size can be accurately estimated by the proposed approach.

Keywords: Analytic hierarchy process, bid mark-up, case study, railway projects, regression analysis.

1. Introduction

In the bidding environment, contractors should win new contracts in order to achieve their business continuity. Since owners generally tend to select the contractors, who offer the lowest bid price, estimating the bid price accurately is critical. The bid price mainly comprises the direct costs (e.g., the costs of laborers, materials and equipment) and indirect costs (e.g., field supervision cost) of the project in question. The bid mark-up consists of general overhead cost, profit, and contingency. In general, the bid mark-up is estimated as the percentage of the base

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estimate based on the estimators’ intuitions and past experiences. While the base estimate is found to be more or less the same by competitor contractors, the offered bid prices greatly differ due to the variations in the bid mark-up size estimations. Therefore, determination of the right amount of bid mark-up is very important for contractors.

Determining the right amount of bid mark-up is a complex decision problem as it is affected by several factors. The aim of this study is to propose an integrated approach, which may help contractors in estimating the bid mark-up size more accurately and systematically. In the proposed approach, the analytical hierarchy process (AHP) method is used to determine the weights of the factors that affect the bid mark-up size and the regression analysis method is employed to estimate the bid mark-up size considering the weights of the factors and the importance levels of these factors for the projects for which the contractors are willing to offer their bids. The proposed approach was applied in a contracting company, which is specialized in railway projects. Actual data of 10 railway projects completed in foreign countries within the last five years were collected from the top managers and estimators of the studied company. It was found that the bid mark-up size can be accurately estimated by the proposed approach.

2. Research Methodology

The main steps in the proposed approach include: 1) identifying the factors that may affect the bid mark-up size and categorization of these factors and developing a decision hierarchy of the mark-up size estimation problem (i.e., identifying the main criteria and sub-criteria), 2) determining the weights of the main criteria and sub-criteria on the mark-up size estimation problem using the Analytic Hierarchy Process (AHP) approach by top managers considering the long-term strategies of the company, 3) identifying the importance levels of the main criteria and sub-criteria for the projects for which the company management is willing to offer bids, 4) determining the overall risk score of the projects in question by incorporating the weights and importance levels of the main criteria and sub-criteria, 5) estimating the bid mark-up size using the regression analysis, and 6) measuring the performance of the developed regression model.

2.1 The AHP Method

The Analytic hierarchy process (AHP) is one of the most commonly used multi criteria decision making method. It was first developed by Thomas Saaty in 1980 [1]. There are four main steps in this method [2-3]. In the first step, the decision hierarchy is established by identifying the problem goal, selection criteria and possible alternatives. In the second step, decision maker(s) compare the importance of the selection criteria in pairs by using the nine-point rating scale developed by Saaty (1980) [1]. Saaty's rating scale is represented in Table 1. In the third step, the weights of the selection criteria are calculated by dividing each element in the pair-wise comparison matrices to the sum of its own column. After that, arithmetic mean of each row is calculated. The result of this calculation represents the weights of the selection criteria. In the last step, consistencies of the decision maker(s)' judgments are measured. For this purpose, Consistency Ratios (CRs) of the pair-wise comparison matrices are calculated. If the CR is less than 0.1, it can be concluded that the decision maker(s)' judgments are consistent. Otherwise pair-wise comparisons should be re-made until the judgments become consistent.

| Importance Level | Definition                | Explanation                                                      |
|------------------|---------------------------|------------------------------------------------------------------|
| 1                | Equal Importance          | Two factors contribute equally to the objective.                 |
| 3                | Somewhat more important   | Experience and judgment slightly favor one over the other.       |
| 5                | Much more important       | Experience and judgment strongly favor one over the other.       |
| 7                | Very much more important  | Experience and judgment very strongly favor one over the other.  |
| 9                | Absolutely more important | Experience and judgment absolutely favor one over the other.     |
| 2-4-6-8          | Intermediate values       | When compromise is needed.                                        |

2.2 Simple Regression Analysis

Regression analysis is a statistical method, which explains the cause and effect relationships between the dependent and independent variables by establishing a linear equation [4]. A typical simple regression equation between the dependent variable (Y) and the independent variable (X) is shown in Equation 1:

\[ Y' = a + bX \]  \hspace{1cm} (1)
Where $X$ represents the independent variable, $Y'$ represents the predicted $Y$ value for the $X$ value, and $a$ and $b$ represent the regression coefficients.

2.3 Performance Measurement of the Proposed Approach

In the literature, several criteria have been proposed to evaluate the performances of developed models. In this study, correlation coefficient ($R$), coefficient of determination ($R^2$), mean absolute percentage error (MAPE), and root mean square error (RMSE) were used to measure the performance of the developed regression model. Correlation coefficient ($R$) examines the direction and strength of the relationship between variables [5]. Coefficient of determination ($R^2$) measures the level of accuracy of the regression equation [6]. Mean Absolute Percentage Error (MAPE) is the average of the percentage absolute errors. It can be calculated using Equation 2.

$$MAPE = \frac{1}{n} \sum_{i=1}^{n} \frac{|x_i - y_i|}{x_i} \times 100$$

(2)

where $x_i$ represents the actual value, $y_i$ represents the predicted value, and $n$ represents number of the variables.

Root-mean-square error (RMSE) is a statistical measure of the differences between the values actually observed from the thing being modelled or estimated and the values predicted by a model or an estimator.

$$RMSE = \sqrt{\frac{1}{n} \sum (x_i - y_i)^2}$$

(3)

where $x_i$ represents the actual value, $y_i$ represents the predicted value, and $n$ represents number of the variables.

3. Case Study

The proposed approach was applied in a contracting company, which is mainly specialized in railway projects. The studied construction company has been working in the construction industry for 15 years, has 650 employees, has completed the projects with the cost of $3.4 billion, submitted bids for the projects with the cost of $1.2 billion in 2013, and the hit rate was 17% in 2013.

3.1 Identification of the Factors That May Affect the Bid Mark-Up Size in Railway Projects and Development of the Decision Hierarchy

In the literature, there was no study focusing on the identification of the factors that may affect bid mark-up size in railway projects. Therefore, an extensive literature review about the factors affecting bid mark-up size in construction projects was conducted and numerous factors were identified. Then, the validity of these factors in railway projects was discussed with the tendering engineers working in the studied company. As a result, it was concluded that 35 factors may affect bid mark-up size in railway projects [7-17]. These factors were categorized into 6 main groups (i.e., $F_i$). The main and their constituent sub-factors ($F_{iy}$) are presented in the first column of Table 2. It should be noted that these factors may vary from company to company depending on the specialization area, size, financial status of the company, the market conditions, the economic conditions, etc.

| Main and Sub-Factors                              | Weights* (%) |
|--------------------------------------------------|--------------|
| F1. Project-related factors                      | 32.00        |
| F1.1 Size of the project                         | 2.24         |
| F1.2 Type of the project                         | 7.68         |
| F1.3 Type of the railway                         | 17.28        |
| F1.4 Duration of the project                     | 3.52         |
| F1.5 Weather and soil conditions                 | 1.28         |
| F2. Contract-related factors                     | 17.00        |
| F2.1 Type of contract                            | 4.25         |
| F2.2 Strict contractual terms and specifications  | 1.70         |
| F2.3 High penalties in case of delay             | 1.53         |
| F2.4 Guarantees & insurance & bonds              | 0.51         |
3.2 Determination of the Weights of the Main and Sub-Factors Using the Analytical Hierarchy Process (AHP)

Having determined the factors that may affect the bid mark-up size in railway projects and developed the decision hierarchy of the problem, the weights of the main factors and sub-factors in the mark-up size estimation problem using the Analytic Hierarchy Process (AHP) approach by top managers considering the long-term strategies of the company. Super Decision software program was used for AHP calculations and the results are presented in the second column of Table 2. Based on these findings, "Type of the railway" (F1.3) has the highest importance (17.28%) on the mark-up size estimation problem. "Lack of necessary equipment that are needed for the project" (F4.1) (13.92%), and “Type of the project” (F1.2) (7.68%) have also high importance. On the other hand, “Poor legal system in the host country” (F5.3) (0.36%), and “Language barriers” (F5.4) (0.36%) are two the factors that have very low impact on this problem.

3.3 Identification of the Importance Levels of the Factors for the Projects for Which the Company Management is Willing to Offer Bids

Four tendering engineers were asked to rate the importance level of 35 factors for 10 international railway projects that were constructed by the studied company in the last 5 years on a scale of 0-5, where “0” represents no importance and “5” represents the highest importance. The general characteristics of 10 international railway projects are presented in Table 3.
3.4 Determination of the Overall Risk Score of the Studied Projects By Incorporating the Weights and Importance Levels of the Main Criteria and Sub-Criteria

After identifying the importance levels of 35 factors for the studied 10 projects, the overall risk scores of the studied projects were calculated. For this purpose, each factor’s weight obtained from the AHP calculations was multiplied by the importance level of this factor determined by four tendering engineers for the project in question and then the sum is taken.

3.5 Estimation of the Bid Mark-Up Size Using the Regression Analysis

After calculating the overall risk scores of the studied projects, a simple regression analysis was conducted among the overall risk scores of the projects and the actual mark-up size allocated for the studied projects. In this analysis, the overall risk scores of the projects are defined as the independent variable and the actual mark-up size allocated for the studied projects are defined as the dependent variable. Simple regression analysis was carried out via Statistical Package for the Social Sciences (SPSS) software program. The regression analysis yielded the formula presented in Equation 4.

\[ Y = 0.174 \times X + 1.235 \]  \hspace{1cm} (4)

In this equation, “Y” is the estimated mark-up size and “X” is the overall risk score of the project.

By using Equation 4, the estimated mark-up sizes for the studied international railway projects were calculated. The estimated mark-up sizes for the studied projects are presented in Table 4 with the projects’ actual mark-up size and calculated overall risk scores.

| Project No | Overall risk score | Actual Mark-up size | Estimated Mark-up size |
|------------|--------------------|---------------------|-----------------------|
| 1          | 3.6191             | 1.946               | 1.86                  |
| 2          | 3.4652             | 1.802               | 1.84                  |
| 3          | 3.4255             | 1.798               | 1.83                  |
| 4          | 3.3752             | 1.795               | 1.82                  |
| 5          | 3.0908             | 1.793               | 1.77                  |
| 6          | 3.0708             | 1.793               | 1.77                  |
| 7          | 3.0494             | 1.773               | 1.77                  |
| 8          | 2.9754             | 1.705               | 1.75                  |
| 9          | 1.6538             | 1.540               | 1.52                  |
| 10         | 1.6475             | 1.516               | 1.52                  |

3.6 Performance Measurement of the Developed Regression Model

In order to measure the prediction performance of the developed regression model, correlation coefficient (R), coefficient of determination \( (R^2) \), mean absolute percentage error (MAPE), and root mean square error (RMSE) were calculated. The results are shown in the Table 5.

| Table 5. Performance of the regression model | Coefficient of correlation (R) | 0.954 |
|                                            | Coefficient of determination \( (R^2) \) | 0.911 |
Coefficient of correlation (R) was calculated as 0.954, which means that there was a linear relationship between the actual mark-up size and the overall risk scores of the projects. Coefficient of the determination (R²) was calculated as 0.911, which means that the overall risk scores of the projects highly explain the differences between actual mark-up sizes and estimated mark-up sizes of these projects. MAPE measures the accuracy of the model. Since MAPE was calculated as 1.677%, which is less than 10%, the proposed model can be accepted as successful. In this model, RMSE was calculated as 0.0366, thus it can be stated that the error rate of the model is satisfactory.

4. Conclusions

Since there are several factors that may affect bid mark-up estimating the right size is not an easy task. In this study, an integrated approach was proposed to help construction companies in estimating the bid mark-up size more accurately and systematically. The proposed approach consists of 6 main steps, which are; 1) identifying the factors that may affect the bid mark-up size and categorization of these factors and developing a decision hierarchy of the mark-up size estimation problem (i.e., identifying the main criteria and sub-criteria), 2) determining the weights of the main criteria and sub-criteria in the mark-up size estimation problem using the Analytic Hierarchy Process (AHP) approach by top managers considering the long-term strategies of the company, 3) identifying the importance levels of the main criteria and sub-criteria for the projects for which the company management is willing to offer bids, 4) determining the overall risk score of the projects in question by incorporating the weights and importance levels of the main criteria and sub-criteria, 5) estimating the bid mark-up size using the regression analysis, and 6) measuring the performance of the developed regression model. The case study revealed that the bid mark-up size can be accurately estimated by the proposed approach.

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