Estimation of Highway Project Cost using Probabilistic Technique

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ABSTRACT: Accurate assessment of effort, time and resources for estimation of project cost is a challenging task for project managers. Several methodologies are commonly practiced around the globe for project cost estimation based on the project’s scope, type, and availability of resources. In developing countries like Pakistan most of the construction projects face delay and cost overrun, and construction industry continues to use traditional methodologies for preparation of project cost estimates. Present study developed a probabilistic framework for project cost estimation using Monte Carlo Simulation. A probabilistic model is proposed for estimation of total project cost using data on key risk factors that included (1) labour efficiencies, (2) machine efficiencies, (3) construction material wastages, and (4) construction items’ prices. Using data from completed highway projects, model validation results revealed that developed model has the ability to predict reliable future project cost.

INTRODUCTION AND MOTIVATION

Cost estimation is an important step in project management life cycle as it establishes the baseline for the project cost at various phases of the project development process (Buertey et al., 2012). Accurate cost estimation is a key element in the successful execution of any project (Love et al., 2013; Clough et al., 2000). Several techniques have been used worldwide for project cost estimation, based on the project’s scope, type of the estimate and availability of project resources (Buertey et al., 2012). Project cost overrun is a usual phenomenon and one of the major responsibilities for project managers is to control cost overrun during project execution (Barraza and Bueno, 2007). A project is said to have cost overrun when its final cost exceeds the original estimated cost (Leavitt, Ennis and McGovern, 1993; Love et al., 2013). In order to overcome this issue, cost contingency is added into the estimated cost of a project to mitigate risk of cost overrun (Flyvbjerg et al., 2002; Agyakwa-Baah, 2007). The inability of the project managers to complete projects on time and within allocated budget continues to be a challenging problem issue for project managers (Alinaitwe et al., 2013). Present environment of construction industry demands use of reliable techniques for project cost estimation to overcome the issue of cost overrun (Ogunlana and Butt, 2000).

Construction industry in Pakistan uses traditional methodologies for preparation of project cost estimates and generally there is lack of awareness about latest techniques. Also, traditional, contingency reserves technique that are practiced around the globe are used to set aside a fixed percentage of the estimated project cost as cost...
contingency reserve (Thompson and Perry, 1992; Mills, 2001). Most of the projects in Pakistan that follow traditional methodology for estimation of cost contingency reserve suffer from cost overrun. For most of the public sector projects schedule of rates issued by Pakistan Public Works Department (PWD), Punjab Finance Department, Military Engineering Services (MES), and National Highway Authority (NHA) are used for project cost estimation. The estimation of project cost for different scenarios is an important step in successful execution of a project. In order to address this key issue and other associated factors, the objective set forth for present research was to develop probabilistic model for cost estimation of highway construction projects and to design rational contingency reserves.

A REVIEW OF RELEVANT LITERATURE

Several cost estimation techniques are used worldwide. The “analytical technique” is an activity based costing method in which the cost of individual work items is estimated and summed up to get total project cost (Makovšek, 2014; Duverlie and Castelain, 1999). The “analogical technique” of cost estimation is based on a comparison of the new system with a prior one (Molcho et al., 2014; Duverlie and Castelain, 1999). “Parametric technique” employs statistical methods, to relate the historical construction costs with a few relevant project parameters (Makovšek, 2014). “Expert systems” is another technique that combines different techniques such as decision trees and specialized cost estimation software etc. for project cost estimation (Molcho et al., 2014; Dagsotino and Peterson, 2011).

Project management institute (PMI) defines cost contingency as “the amount of money or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization” (PMI, 2000). Traditional percentage is a widely used technique for establishing project contingency reserves around the globe. Traditionally for the construction projects contingency reserves are set between 1-10% of the estimated project cost (Thompson and Perry, 1992; Mills, 2001). This is an arbitrary technique that is difficult to justify (Thompson and Perry, 1992; Lhee et al., 2009; Cioffi and Khamooshi, 2009). Project cost overruns and associated contingency funds are also predicted using predictive model (usually multiple regression analysis) and set of identified risks (Baccarini, 2005; Federle and Pigneri, 1993). Monte Carlo Simulation (MCS) is an advanced probabilistic quantitative technique for analysing risk and provides a opportunity for estimating the contingency value for total cost of the project (Clark, 2001).

Sonmez et al., (2007) using data of 26 construction projects from 21 different countries studied bidding stage financial risk factors of construction projects. Using correlation and regression analysis techniques, different significant risk factors impacting cost contingency were identified and model was developed to support bidding contingency decisions. Barraza and Bueno (2007) proposed cost contingency management model using Monte Carlo simulation. The application of the methodology was tested on hypothetical industrial project with 32 different activities.

STUDY METHODOLOGY

The detailed methodology adopted for present study is shown in Figure 1. Description of each step is herein discussed:
Identification of Cost Risk Factors

Literature review revealed that the cost of project is influenced by its resources (material, labour and machine) and their uncertainty (Thal et al., 2010; Yang, 2005). Based on resources required for rate analysis, cost risk factors were identified which directly affect the estimated cost of activities and project, that includes (1) labour efficiencies, (2) machine efficiencies, (3) road construction material wastages, and (4) construction items’ prices.

Data Collection and Collation

For each risk factor, detailed methodology was adopted for data collection. Data on labour and machine efficiencies were collected using two separate questionnaires. Survey for labour efficiencies comprised of 24 questions about 9 different labour activities, whereas, 18 different questions were asked about 18 efficiencies of machine activities. Questionnaires were distributed to academia, clients, consultants and contractors and over 100 responses were collected for each. Data on percentage of material wastages were collected using expert opinion. Onsite interviews were conducted from site supervisors and project managers for material wastages about different construction items. It was revealed through onsite interviews that percentage wastage for various materials used in road construction varied between 3% to 7%.

One of the major cost risk factor was uncertainty in price of different road construction items. For analysis of uncertainties/ variation of construction item’s price, past 10 years data on material, labour and machines were obtained from...
Pakistan Bureau of Statistics, and Punjab Finance Department. Data for approximately 2960 different construction items, 90 different types of construction machineries and 130 different types of labourer’s trades were collected for year 2004 to 2013. Summary of methodology used for data collection is presented in Table 1

**Development of Traditional Project Cost Estimation Model**

A 10 Kilometer long section of a two-lane highway (12 feet wide lane and 8 feet wide shoulder) was selected and its basic project cost estimation model was developed using Microsoft Excels. Bill of quantities (BOQs) sheet was developed as per the work break down structure of project representing project activities. For each activity as per designed BOQ, separate rate analysis sheets were developed. Also the quantity sheet, based on project design and specifications, was developed and incorporated into basic model.

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Data Collection Methodology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour Efficiencies</td>
<td>Questionnaire Survey</td>
<td>24 questions about 9 different labour trades.</td>
</tr>
<tr>
<td>Machine Efficiencies</td>
<td>Questionnaire Survey</td>
<td>18 questions about 18 types of different machines.</td>
</tr>
<tr>
<td>Material Wastages</td>
<td>Expert Opinion</td>
<td>Top 15 materials identified with likely high wastage rate</td>
</tr>
</tbody>
</table>
| Construction Items Prices | Field data collection | a. Past 10 year data (2004-13)  
b. Price data were collected from:  
(1) Pakistan Bureau of Statistics  
(2) Punjab Finance Department |

**Incorporation of Risk Factors in Traditional Model**

Questionnaire survey technique was used to determine labour and machine efficiencies. Twenty-four different questions related to nine different labour categories (both skilled and unskilled) and eighteen different questions related to eighteen different commonly used machines were used to collect data on labour and machine efficiency. Using risk analysis tool Palisade @RISK probabilistic mean and standard deviation of efficiency of different labour categories and machine efficiencies were obtained. The efficiency of labour for excavation in ordinary soil and Grader (150 horse power (HP)) for sub-grade with the best fitted probability distribution along with their probabilistic mean and standard deviation with a confidence level of 90% are shown in Figure 2.
Expert opinion was used to identify top 15 items that are high wastage rate in road construction. Expert opinion was sort from contractors, quantity surveyors and house owners. Materials were ranked using Likert scale ranging from 0-5. Triangular distribution was fitted to maximum (Mx), minimum (Mn) and most likely value (ML) values of material wastages rates, obtained using expert opinion of the professional. Figure 3 shows the triangular distribution fitted to wastage rate of aggregate (3/4”-3/8”) and asphalt liquid (90% of confidence level).

In order to cater for fluctuation in construction price of construction item due to inflation construction price index (CPI) were established for individual construction items, using data from past ten years. CPI values were established by selecting a base item price and future CPI’s were determined using base price. If, same quantity of an item is sold at a different price during base period and time period for which CPI is to be determined, then following Deaton and Zaidi (2002) CPI is given as follows:

\[
\text{CPI} = \frac{P_z t_i \cdot Q_z t_i}{P_z t_b \cdot Q_z t_b}
\]

(1)

Where, \(t_b\) and \(t_i\) are the base and time period for which CPI is required, \(P_z t_i\) denotes the price of item “z” in period \(t\), \(Q_z t_b\) denotes the quantity of item “z” in period \(t\). Project duration was estimated as the sum activity duration on critical path.

In order to develop probabilistic schedule, 18 activities were identified and expert opinion was sought on duration on these activities. A questioner survey was distributed to project managers, contractors and schedulers to get an estimate of
different activities. Probabilistic mean and standard deviation were calculated by fitting PERT distribution to different activity estimates in order to develop probabilistic schedule. Project schedule duly accounted for relationship/dependency between different activities. Using Palisade @RISK probable project duration (PPD) was obtained duly considering different distributions for activities duration and efficiency of workmanship and machinery.

RESULTS AND ANALYSES

Once the probabilistic model was obtained by incorporating risk factors, into traditional cost model, cost for ten different projects using data from 2004 to 2013 was estimated using both traditional model and probabilistic model that incorporated different risks factors such as labour and machine efficiencies, material wastages and material price fluctuation. It was revealed that both the models predicted different project cost which is intuitive as traditional model is unable to account for risk factors. In next step actual completion cost of ten different projects was compared with predicted cost using probabilistic model. It was revealed that predicted probabilistic costs by developed model was close to the actual completion costs. To further validate the model, Mean Absolute Percentage Error (MAPE) was estimated as follows:

\[
MAPE = \frac{1}{n} \sum_{i=1}^{n} |E_i| \tag{2}
\]

Where, \(E_i = \frac{(A_i - P_i)}{A_i}\) is the percentage error for project \(i\) of the actual and predicted project cost respectively. A MAPE value of 0.0186 was obtained for the developed model. A value close to zero indicates better prediction accuracy of the model. In this case MAPE values indicated that on average model overpredicts or underpredicts the true cost by only about 1.86%.

RESEARCH SUMMARY AND CONCLUSIONS

This research mainly focused on development of probabilistic cost estimation model for highway projects using Palisade @RISK. The developed model has the capability to predict future project cost by duly incorporating the effect of different cost risk factors. It was revealed that the traditional project cost estimation techniques that do not account for different cost risk factors are inefficient and project estimates based on traditional techniques may result into project delays due to cost overrun. The developed probabilistic cost estimation model can predict project cost for highway construction projects with reasonable accuracy (minimum risk). Using data from completed projects, model validation revealed that the developed model on average overpredicts or underpredicts the true cost by only about 1.86%.

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