An Evaluation of Engineer's Estimates for Transportation Projects: A Michigan Case Study

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Transportation agencies around the world are facing problems associated with the reliability of their projects' cost estimates. Literature has documented multiple cases of cost overruns associated with large scale and high-visibility transportation projects. Construction cost estimates prepared during the project development phase play an important role in the delivery of an efficient highway program. The authors in this paper evaluate the accuracy of engineer's cost estimates for transportation projects using data collected from the Michigan Department of Transportation website. Different estimate reference points were evaluated in the literature to evaluate the accuracy of the engineer's estimate. This paper uses three different reference points (letting price, means of submitted bids, and the final project authorized amount) to do the evaluation. In addition to that, statistical analysis (Factorial ANOVA) between groups is performed to examine the accuracy of engineer's estimate against the project characteristics identified in literature. However, the data collected in this research was not enough to draw statistically significant conclusions and additional data will be needed. Knowledge about the inaccuracy of the engineer's estimate level need to be studied further using a greater sample of projects.

Key Words: Engineer's Estimate, Transportation projects, Michigan Department of Transportation, Bid Letting

Introduction

Transportation agencies around the world are facing problems associated with cost estimates reliability of their projects. Literature has documented multiple cases of cost overrun associated with large scale and high-visibility transportation projects (Jacoby, 2001; Hendrickson and Au 1998; Jahren and Ashe, 1990). Construction cost estimates prepared during the project development phase play an important role in the delivery of an efficient highway program (Sinha and Labi, 2007). At most transportation agencies, the development of a project starts with the conceptualization of the project need and scope, and ends with the letting of the project for construction. As shown in Figure 1, this period can be divided into six stages: (a) Planning, (b) Programming and Preliminary Design, (c) Design, (d) Final Design and Detailed Engineering, (d) Bid, and (e) Construction.

During the conceptual planning stage, a feasibility study justifies the need of the project and defines the project scope, scale, complexity, alternatives, environmental and community impacts. A preliminary estimate of the cost is prepared for each alternative that is considered viable for a project during the planning process based on very limited information such as project length, project work type, number of lanes, pavement type, type of bridge etc. The proposed cost is considered as an order of magnitude estimate and is generally prepared by using average unit cost information. The unit averages are generally determined based on cost information of similar projects that were constructed in the past (Meyer and Miller, 2001).

During the programming stage, all project proposals from across the entire state are reviewed, evaluated and selected for inclusion in the transportation improvement program of the state. The project proposals are ranked in order of their importance, relevance, need, cost-effectiveness and their ability to meet the highway agency's goals and objectives within the specified budget constraints. During this stage, the submitted cost estimates of the proposed alternatives are reviewed, evaluated and revised if required. After programming, the preliminary design stage gets underway and detailed information about the project is sought for the preparation of preliminary construction plans. At this point, a cost estimate is prepared based on the preliminary design specifications and any additional details acquired about the project scope and complexity. During this phase, the method of estimation used vary significantly in complexity across the DOTs. The methods that are most widely used can be broadly divided into two main categories: (a) Detailed estimation methods, and (b) Historic bid-based cost estimation methods. The detailed estimation method uses information such as procedures used for construction, labor cost, material cost, and market conditions specific to the project location. The historic bid price estimation method is, however, simple, fast and the most widely used method for cost estimation (Damnjanovic et. al., 2008).

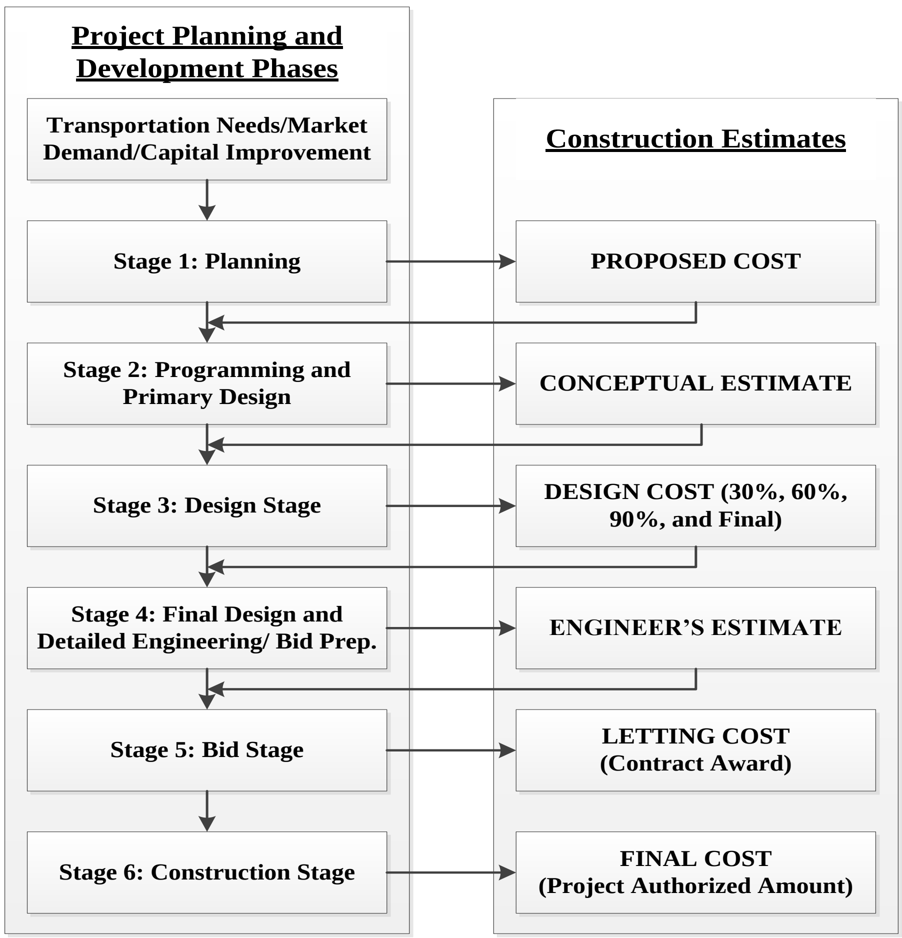

Figure 1: Project Planning and Development Stages

A preliminary engineering design is prepared for the project once it has been included into the state's transportation improvement program. By the end of the preliminary design phase, in most cases, the scope of the project becomes clear and the project is ready for developing a detailed engineering design. Estimates of construction cost during the design stage are generally prepared using computer software. Item level details are fed into the software and the unit costs for each item are adopted either from the software based on default settings or specified by the estimator based on current trends. Information about the quantities of each item is available from the detailed design plans.

The final design stage is followed by the project letting. Projects at the same location or involving the same type of work are often lumped together to form a “contract” before they are awarded to the contractor (bid stage) for construction. An engineer’s estimate of the construction cost is prepared before a contract is advertised for bidding. The engineer's estimate is based on the completed plans and specifications as compared to the design estimate that was prepared when the construction plans were being finalized. The state departments of transportation often use the services of design consultants for preparing the engineer’s estimate of the cost taking into account the contractors appropriate overheads and profits (Hendrickson and Au, 1998).

After a contract has been advertised and the bids have been received by the department of transportation, a letting date is set for the contract to be awarded. The bid amounts are compared to the engineer’s estimate and the contract is often awarded to the contractor with the lowest responsive bid as long as it is not lower or higher than the engineer’s estimate by a certain specified percentage. The project development process described above is reflective of the general practice. Details may vary across state highway agencies. Some agencies choose to disintegrate the entire project development process into more or fewer stages depending on the type and the time available to plan and prepare the project (Hendrickson and Au, 1998).

This paper evaluates the accuracy of engineer’s cost estimates for transportation projects using data collected from the Michigan Department of Transportation website. Different estimate reference points were evaluated in the literature to evaluate the accuracy of the engineer’s estimate. The authors uses three different reference points (letting price, Means of submitted bids, and the final project authorized amount) to do the evaluation. In addition to that, statistical analysis (Factorial ANOVA) between groups is performed to examine the accuracy of engineer’s estimate against the project characteristics identified in literature. The following section summarizes literature studies on factors affecting the accuracy of the engineer’s estimates. Research method and preliminary results will be presented and discussion will be followed. Finally, the paper conclusion and future research directions will be presented.

Previous Work

Engineer’s pricing activities affect quality of the estimate in relation to many factors. Raftery (1995) attributed the variation in the estimate quality to systematic biases such as heuristics in decision-making, personal biases and reporting biases. Skitmore (1991) established that estimating performance is dependent on the project characteristics. Table 1 summarizes empirical evidences on project characteristics which affects quality of the estimate.

Table 1: Empirical evidences of project characteristics affecting quality of the estimate.

Researcher	Evidence
Number of bidders	
• Harvey (1979)	Estimates lower with more bidders
• Flanagan and Norman (1983)	Estimates lower with more bidders
• Skitmore (2002)	Consistency decrease with additional number of bidders in seven data sets
Price intensity	
• Gunner and Skitmore (1999)	High value contract were underestimated and low value contracts over estimated
• Skitmore and Drew (2003)	High value contract were underestimated and low value contracts over estimated

Contract period	
• Skitmore (1991)	No difference between groups of contract period
• Gunner and Skitmore (1999)	No conclusion due to different result obtained

Several researchers (Jacoby, 2001; Jahren and Ashe, 1990) studied the difference between the contract award amount and the accuracy of the engineer's estimate to determine the overrun of the final construction cost. Also, Hendrickson and Au (1998) noted that the misalignment between the engineer's estimate and the final cost could result from mismanagement, lack of coordination and communication between the planners, designers, decision makers and contractors. Additionally, Jahren and Ashe (1990) found that the risk of high cost overrun rates was greater when the winning bid amount was less than the engineer's estimate and further identified some cost overrun factors such as the contract document quality, nature of interpersonal relations on the project, and contractor policies.

Research Methodology

This research evaluates the reliability of the engineer's estimate by comparing the bid price (letting price and mean bid prices), and the project completion cost to the engineer's estimate. In addition, this research explores the significant relationship between some project variables and the engineer's cost estimate accuracy. Data were collected from the MDOT website for 719 projects. Engineer's estimate and data related to submitted bids as well as the location and the contract number were taken from the Bid letting website (MDOT Bid Letting Website, August 2016). Using the contract number, additional data were collected from the Construction Contract Inquiry website such as the final authorized project amount and the project starting date and project completion date (MDOT Construction Contract Inquiry Website, August 2016).

Different studies have used different reference points to measure the estimating performance. Some studies agree that the lowest letting price is the estimating target (Herdsman and Ellis 2006; Murdoch and Hughes 2007; Runeson 2000; Gunner and Skitmore 1999; Skitmore 1998). However, McCaffer (1976) used the mean of bids instead. Others studies used the final completed cost as the target because it provides total commitment cost to the client (Shane et al 2009). This research uses three measures to study estimate accuracy; the percentage between the engineer's estimate and the lowest bid price, the percentage between the engineer's estimate and the average bid prices, and the percentage between the engineer's estimate and the final authorized project cost amount. These three factors are used to measure the estimate quality.

Additionally, Factorial ANOVA between groups examines the accuracy of engineer's estimate against the project characteristics identified in literature. It looks into the main effect of one project characteristics on the estimate accuracy's measures while ignoring the effects of all other project variables. The Shapiro-Wilk test examines the normality of the data and Levene's test measures the homogeneity of variance because it is less sensitive to skew distribution.

Results

Research results are presented in five sections. The first three sections present the monthly aggregate data to study estimate accuracy; the percentage between the engineer's estimate and the lowest bid price, the percentage between the engineer's estimate and the average bid prices, and the percentage between the engineer's estimate and the final authorized project cost amount. Finally, the statistical analysis results are presented between groups to examine the accuracy of engineer's estimate against the project characteristics identified in literature.

Accuracy of Engineer's Estimate Based on Letting Amount

The following table compared the monthly letting amounts (Awarded Contracts) to the engineer's estimate to determine the reliability of the procedures for cost estimation (Table 2). On average, the total engineer's estimates were higher by an average of 3% than the awarded amount. For the individual projects, Figure 2 shows that 30-35% of the projects were overestimated by more than 10% while 5-10% of the projects were underestimated by 10%.

Table 2: Monthly Report of Accuracy of Engineer's Estimate at Michigan Department of Transportation (Based on Awarded Contract Amount)

Month/ Year	No. of Contacts Analyzed	Total Engineer's Estimated Cost	Total Awarded Contract Amount	Monthly Overrun ($)	Monthly Overrun (%)
January	48	$150,060,569	$141,885,456	$(8,175,113)	-5%
February	51	$163,616,016	$160,222,959	$(3,393,057)	-2%
March	86	$182,948,214	$179,487,959	$(3,460,255)	-2%
April	54	$58,832,756	$54,929,337	$(3,903,419)	-7%
May	64	$88,182,680	$79,371,624	$(8,811,056)	-10%
June	54	$66,822,225	$64,282,238	$(2,539,987)	-4%
July	86	$63,253,901	$58,826,203	$(4,427,698)	-7%
August	54	$36,706,042	$35,848,604	$(857,438)	-2%
September	55	$59,368,238	$54,480,995	$(4,887,243)	-8%
October	57	$70,090,850	$73,823,201	$3,732,351	5%
November	51	$52,918,689	$75,340,118	$22,421,429	42%
December	59	$214,309,790	$186,692,565	$(27,617,225)	-13%
Total	**719**	**$1,207,109,969**	**$1,165,191,258**	**$(41,918,711)**	**-3%**

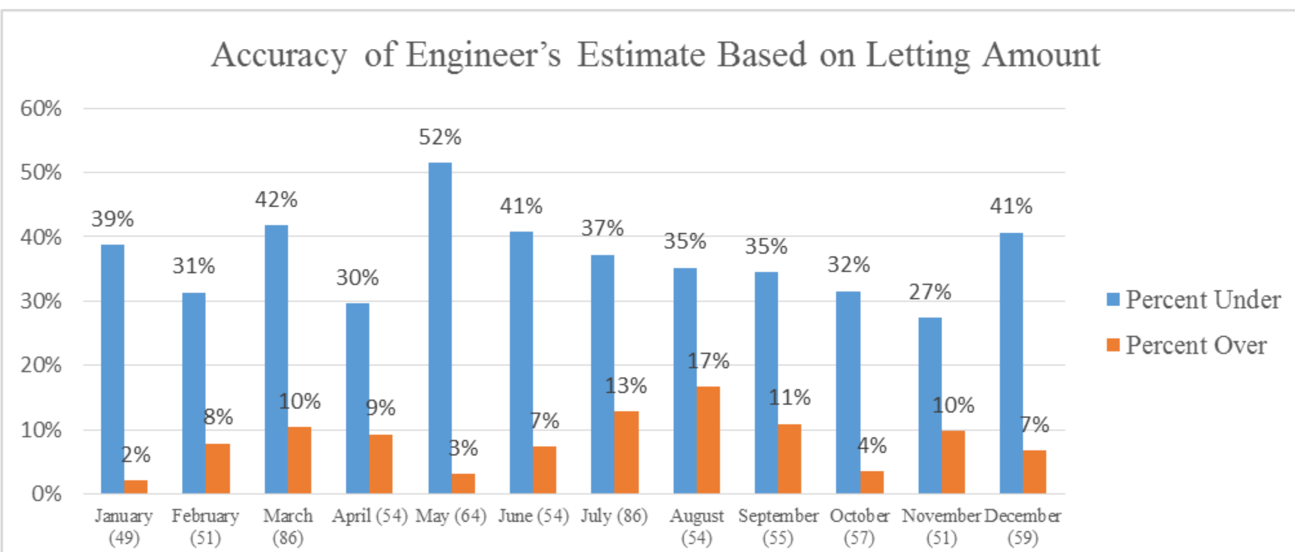

Figure 2: Percentage of projects (by months) that were overestimated or underestimated by more than 10% based on letting amount

By reviewing the collected data, 5 projects had major changes approved by MDOT which caused an aberration of the data during the month of November. In this study, approved change orders were not considered as an independent variable.

Accuracy of Engineer's Estimate Based on Means of Submitted Bids

Unlike the previous presented data, the following table compared the monthly means of submitted bids to the engineer's estimate to determine the reliability of the procedures for cost estimation (Table 3). On average, the total engineer's estimates were lower than the means of submitted bids by more than 5%. For the individual projects, Figure 3 shows that 30-35% of the projects were equally overestimated or underestimated by more than 10%.

Table 3: Monthly Report of Accuracy of Engineer's Estimate at Michigan Department of Transportation (Based on Means of Submitted Bids)

Month/ Year	No. of Contacts Analyzed	Total Engineer's Estimated Cost	Total Means of Submitted Bids	Monthly Overrun ($)	Monthly Overrun (%)
January	48	$150,060,569	$151,548,874	$1,488,305	1%
February	51	$163,616,016	$174,529,591	$10,913,575	7%
March	86	$182,948,214	$195,217,860	$12,269,646	7%
April	54	$58,832,756	$60,054,621	$1,221,865	2%
May	64	$88,182,680	$88,525,862	$343,182	0%
June	54	$66,822,225	$70,157,612	$3,335,387	5%
July	86	$63,253,901	$65,710,600	$2,456,699	4%
August	54	$36,706,042	$38,960,096	$2,254,054	6%
September	55	$59,368,238	$60,142,678	$774,440	1%
October	57	$70,090,850	$80,039,116	$9,948,266	14%
November	51	$52,918,689	$80,994,183	$28,075,493	53%
December	59	$214,309,789	$202,099,051	$(12,210,738)	-6%
Total	**719**	**$1,207,109,968**	**$1,267,980,143**	**$60,870,175**	**5%**

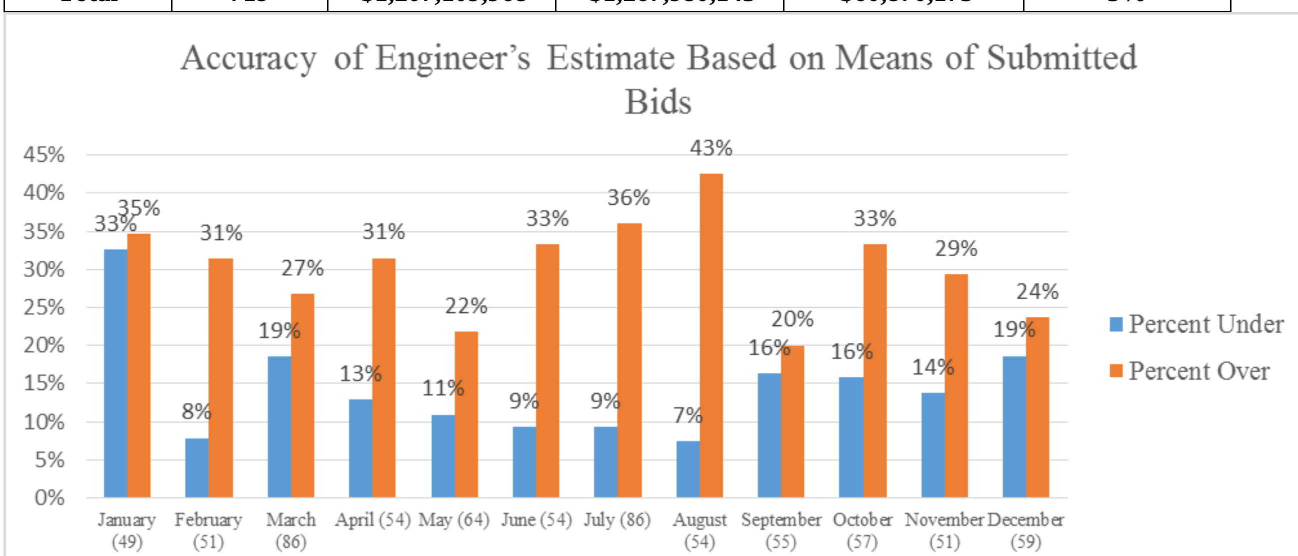

Figure 3: Percentage of projects (by months) that were overestimated or underestimated by more than 10% based on Means of Submitted Bids

Accuracy of Engineer's Estimate Based on Final Authorized Contract Amount

The following table compared the monthly means of submitted bids to the engineer's estimate to determine the reliability of the procedures for cost estimation (Table 4). On average, the engineer's estimates were lower than the means of submitted bids by more than 6%. For the individual projects, Figure 4 shows that 40-45% of the projects were equally overestimated by more than 10% while 10-15% of the projects were equally underestimated by more than 10%.

Table 4: Monthly Report of Accuracy of Engineer's Estimate at Michigan Department of Transportation (Based on Final Authorized Contract Amount)

Month/ Year	No. of Contacts Analyzed	Total Engineer's Estimated Cost	Total Authorized Contract Amounts	Monthly Overrun ($)	Monthly Overrun (%)
January	48	$150,060,569	$147,020,898	$(3,039,671)	-2%
February	51	$163,616,016	$150,409,342	$(13,206,674)	-8%
March	86	$182,948,214	$181,755,937	$(1,192,277)	-1%
April	54	$58,832,756	$55,413,244	$(3,419,511)	-6%
May	64	$88,182,680	$77,746,928	$(10,435,752)	-12%
June	54	$66,822,225	$63,180,274	$(3,641,951)	-5%
July	86	$63,253,901	$59,886,453	$(3,367,448)	-5%
August	54	$36,706,042	$35,490,780	$(1,215,262)	-3%
September	55	$59,368,238	$61,402,120	$2,033,882	3%
October	57	$70,090,850	$77,085,368	$6,994,518	10%
November	51	$52,918,689	$74,931,419	$22,012,730	42%
December	59	$214,309,789	$152,478,757	$(61,831,032)	-29%
Total	**719**	**$1,207,109,968**	**$1,136,801,520**	**$(70,308,447)**	**-6%**

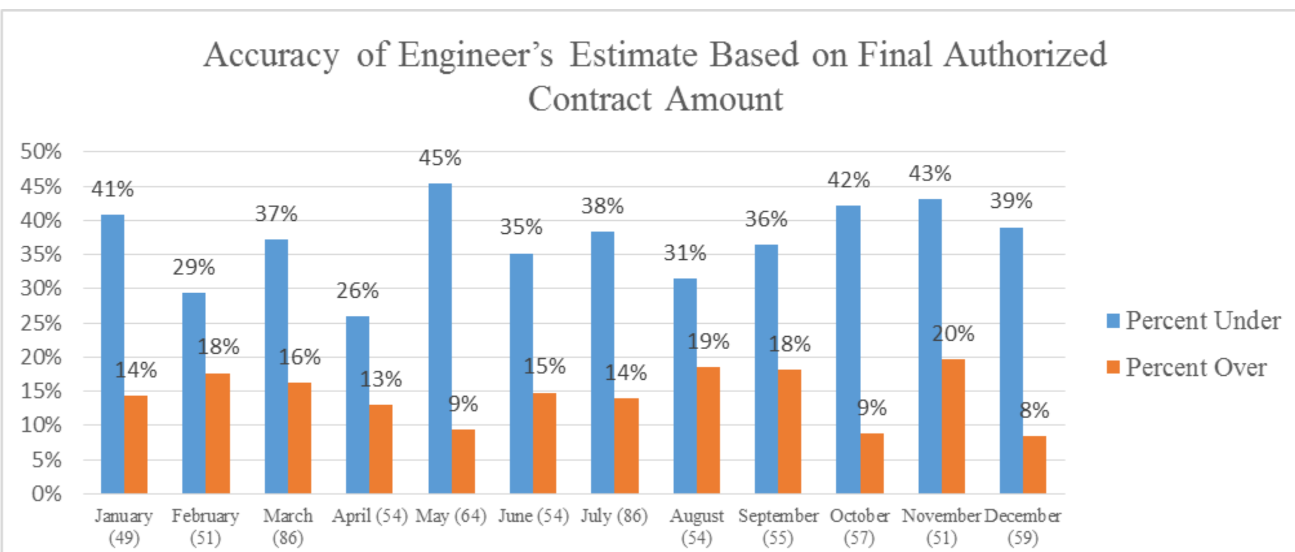

Figure 4: Percentage of projects (by months) that were overestimated or underestimated by more than 10% based on letting amount

Accuracy of Engineer's Estimate Based on Project Characteristics

Table 5 illustrated the identified groups. ANOVA test is used to examine means accuracies of the estimate when studying different project characteristics as identified in literature. Although the Shapiro-Wilk test shows that most groups are not equally distributed ($P<0.05$), the ANOVA test is still considered a robust test against the normality assumption. This means that it tolerates violations to its normality assumption. Additionally, it was found that all the groups are equally distributed and there is no difference between the mean differences when comparing the different groups. Finally, the Levene's test shows that the accuracy variances are equal across the groups.

Table 5: Initial Analysis of Project Characteristics

Project Value ($ Millions)	**No. Of Bids**	**Contract Period (Weeks)**	**No. Of Bids**	**Number of Bidders**	**Number of Bidders**
0.00-0.50	343	1-9 weeks	199	1-3 Bidders	293
0.50-1.00	161	9-19 weeks	183	4-7 Bidders	333
1.00-3.00	119	19-44 weeks	184	8-11 Bidders	64
> 3.00	75	>44 weeks	132	>11 Bidders	8

Using the Letting bid data, ANOVA test results shows that there are a significant difference between the accuracy measure in the groups of factors ($P<0.05$) and the Number of Bidders ($F=8.107$, $\mu2= 0.034$). Using the authorized project amount, ANOVA test results shows that there are a significant difference between the accuracy measure in the groups of factors ($P<0.05$), the Number of Bidders ($F=8.107$, $\mu2= 0.034$), and the contact period ($F=3.649$, $\mu2= 0.016$). Despite violating the normality assumption, the one-way ANOVA is considered a robust test against the normality assumption (Elliott and Woodward, 2007). This means that it tolerates violations to its normality assumption rather well. As regards the normality of group data, the one-way ANOVA can tolerate data that is non-normal (skewed or kurtotic distributions) with only a small effect on the Type I error rate.

Conclusion

Construction cost estimates prepared during the project development process play an important role in the delivery of an efficient highway program. Literature has focused on comparison of final cost and letting cost. However, the overrun of the final cost relative to the design estimate, engineer's estimate or proposed cost has been rarely studied in the past. Most Transportation agencies have resorted to calculation of cost accuracies and cost overrun in the form of simple averages for all contracts within their jurisdiction, to measure the severity of the final cost overrun relative to the letting cost. This approach often results in serious underestimation of the construction cost overrun problem. This is because large positive cost overruns (>10%) are compensated for by large negative cost overruns (< -10%) and thus a simple average may be close to zero. Knowledge about the inaccuracy of the engineer's estimate level needs to be studied further. Statistical analyses between groups were conducted to examine the accuracy of engineer's estimate against the project characteristics identified in literature. However, the data collected in this research was not enough to draw statistically significant conclusions and additional data will be needed. The next phase of this research is to cover a larger sample of projects over a 15 years period to draw statistically sound conclusions.

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