A Machine Learning and Statistical Analysis Framework for Enhanced Engineer's Estimate Accuracy in Highway Infrastructure Projects, Phase I

University

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Research Needs

State Transportation Agencies (STA) personnel are responsible for preparing accurate engineer's estimates for projects within their program. The Federal Highway Agency (FHWA) guidelines indicate that these estimates are crucial in ensuring precise budget allocation for the STAs and are essential tools for comparing bids submitted by contractors (FHWA 2021). However, recent assessments have revealed significant inaccuracies in the engineer's estimates prepared by several STAs. Of the fifty-one DOTs surveyed in 2012, the Office of the Inspector General at the FHWA found that only one produced an Engineer's Estimate as accurate and detailed as a contractor who submits a winning bid (Ryan et al. 2018). The FHWA suggested adding a 10% contingency to the engineer's estimate in response to this discovery (Ryan et al., 2018). However, the study showed that contracts awarded in California, North Carolina, and Ohio between 2012 and 2014 had 42% of the projects outside the recommended ±10% contingency. This trend still continues, and the major reasons behind it are considered poor raw data, lack of experience with similar projects, length of the planning horizon of the project, not fully understanding the work involved in completing the project, expecting that the resources will work at maximum productivity, failure to identify risks and to prepare adequate contingency plans and reserves, not updating the cost estimates after the project scope change, creating hasty

estimates because of stakeholder pressure and making it fit a fixed budget (Idaho Department of Transportation 2020). The engineers' estimated quantities and unit prices also vary from the contractor's because of variations in estimating methods, overhead, and profit margins, material costs, labor costs, risk assessment, market competitive factors, and project specifics (Gransberg and Riemer 2009). This discrepancy in the estimates allows contractors bid-rigging and price manipulation (Xing et al., 2020). Thus, it's a necessity to standardize engineers' estimates to maintain a level of accuracy and competent budgeting of the projects and limit the monopoly of the contractors. A significant deviation between the agency's estimated construction costs and the lowest winning bids also leads to considerable financial risks for both parties (Baek and Ashuri 2019), this further highlights the need to minimize the deviation in the estimates. The prevailing trend shows that 77% of the highway projects in the US experience cost escalation, which might lead to the postponing or canceling of scheduled projects and loss of public faith, so a proper explanation of the cost deviation from engineers' estimate is necessary to prevent the waste of public funds (Carr 2005).

A quick analysis of the Wyoming Department of Transportation (WYDOT) bid data shows that WYDOT is not an exception, and the issue of inaccuracies in the engineer's estimate needs to be addressed. For instance, an examination of projects awarded by WYDOT in 2019 revealed an average deviation of 25% between the awarded bid and the engineer's estimate. This data, compiled from 38 projects with a total award amount of $219.4 million and a cumulative engineer's estimate of $187.3 million, showcased a concerning range of deviation spanning from -46.34% to 125.9%. Notably, 34% (13 out of the 38 projects) exhibited a deviation of more than 25% between the engineer's estimate and the awarded bid. Because the engineers' estimate process is less detailed than the winning bid, (Ryan et al., 2018) revealed that accuracy issues still exist. In certain situations, the method utilized to create an engineer's estimate is insufficient for contract award budgeting, and every heavy highway project is different, with particular specifications and conditions that have an impact on cost. When microeconomic factors are disregarded or not known at the time the engineer's estimate is created, this problem could become even more complicated. The preliminary literature and WYDOT's data analysis reveal that the deviation between engineers' estimates and bidders' estimates is significant, and a more detailed analysis of historical data is needed to support the development of estimating tools to enhance the accuracy of the engineer's estimate.

Research Objectives

The objectives of this research are listed as follows:

1. Evaluate the accuracy of the WYDOT Engineer's estimate against historical bid amounts

2. Evaluate the consequences of inaccurate Engineer's estimates on project performance (i.e., budget and schedule), frequency of change orders, poor contractor performance, and other negative impacts. The hypothesis to be tested regarding this objective is that the accuracy of an engineer's estimate in a construction project is inversely related to the frequency of change orders, positively correlated with schedule adherence, and influences the overall performance of the contractor.

Research Methods

The research methodology, depicted in Figure 1, adopted for enhancing engineer's estimate accuracy in transportation projects comprises a multifaceted technical approach. The initial phase involves a systematic literature review, drawing upon scholarly publications and transportation agencies' reports. Thematic analysis is employed to discern common trends, challenges, and recommendations related to the engineer's estimate accuracy. Subsequently, a structured questionnaire survey will be designed and administered to contracts and estimates personnel in STAs. Quantitative analysis techniques are applied to glean insights from survey responses, uncovering patterns and trends related to the impacts of inaccurate engineer's estimate on project performance. Additionally, the survey results will capture the latest developments and advancements regarding the use of cost-estimating models to support the engineer's estimate. The research then delves into using historical bid tabulation data from WYDOT for statistical analysis. This includes the use of statistical methods such as regression analysis and time series analysis to discern trends and challenges associated with the engineer's estimate accuracy.
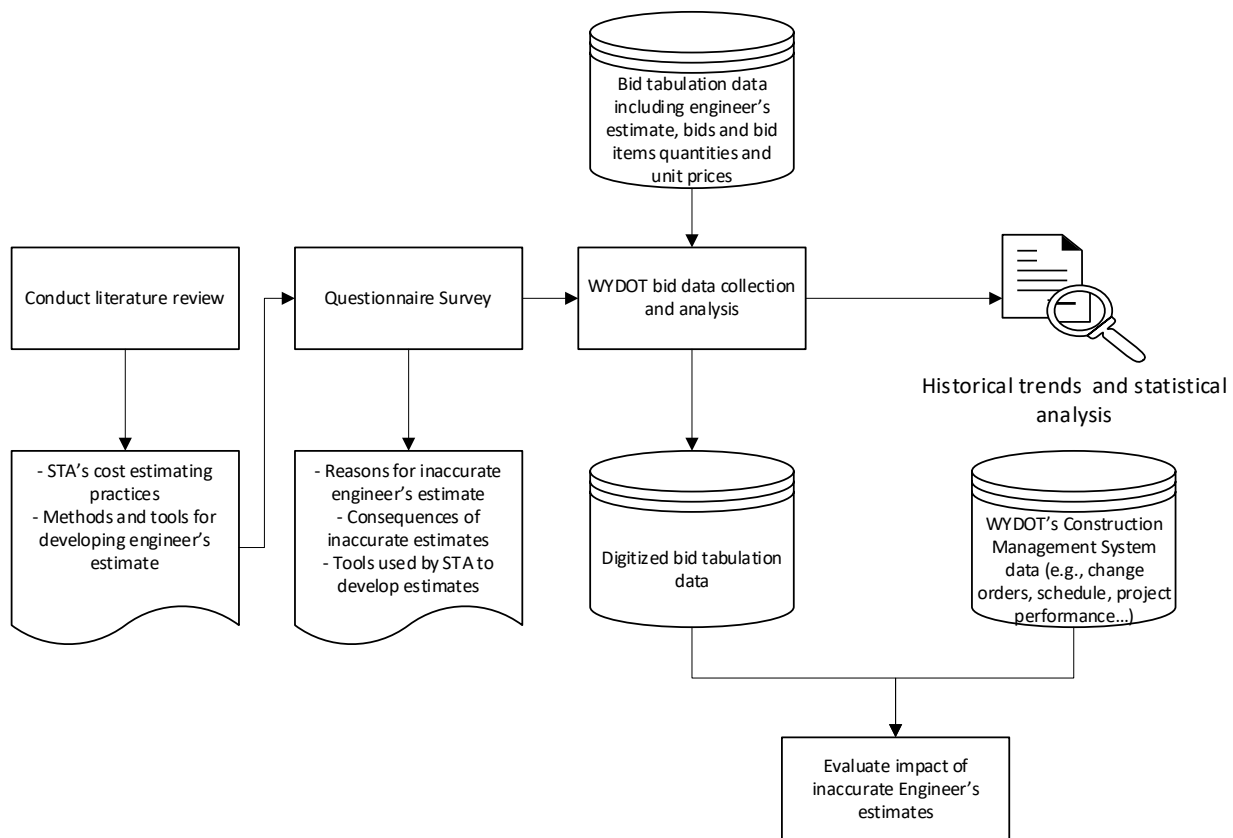
Figure 1. Research Methodology

Relevance to Strategic Goals

The proposed research supports the USDOT strategic goal of *Economic Strength and Global Competitiveness* by improving the accuracy of engineer's estimates for highway projects. The research aims to streamline project planning and execution processes. Accurate estimates ensure that resources are allocated efficiently, reducing the likelihood of budget overruns and delays.

This also increases reliability and accountability regarding program budgeting. These benefits provide local economies and businesses with reliable access to transportation infrastructure, facilitating the movement of goods and services and supporting economic growth.

Educational Benefits

This project will support one graduate student for two years towards earning a master's degree. In addition, the outcomes of this project can be used to support the construction management preconstruction services classes, specifically cost estimating.

Outputs through Technology Transfer

The technology transfer efforts associated with this research project encompass a multifaceted approach, including direct dissemination to agency personnel, publication in academic journals and conferences, and interactive educational webinars with local agencies. By leveraging these dissemination channels, the team seeks to maximize the impact of the research outcomes, promote widespread adoption of innovative tools and methodologies, and ultimately contribute to the advancement of the transportation infrastructure sector. The proposed technology transfer efforts are listed as follows:

1. **Dissemination to Contracts and Estimate Personnel:** The proposed cost-estimating model developed through this research will be made readily accessible to contracts and estimate personnel WYDOT. By providing access to this tool, personnel involved in engineer's estimate preparation will benefit from enhanced accuracy and efficiency in their estimation processes. This technology transfer initiative aims to empower agency staff with state-of-the-art resources, enabling them to make more informed decisions and optimize project planning and budgeting.

2. **Publication in Peer-Reviewed Journals and Conferences:** The outcomes of this research project will be disseminated widely through publication in peer-reviewed journals and presentations at conferences relevant to the transportation infrastructure sector. By sharing our findings with the broader academic and professional community, we aim to contribute to the body of knowledge in cost estimation accuracy and project performance. This dissemination strategy ensures that our research insights reach a diverse audience of researchers, practitioners, policymakers, and industry stakeholders, facilitating knowledge exchange and fostering collaborative partnerships.

3. **Educational Webinars with Local Agencies in Wyoming:** In addition to traditional publication channels, the research team will seek to conduct educational webinars to present the findings of this research to local agencies in Wyoming. These webinars will serve as interactive platforms for knowledge dissemination, allowing participants to engage directly with the research team and gain actionable insights into improving engineer's estimate accuracy and project performance. By tailoring the content to address the specific needs and challenges faced by local agencies, we aim to facilitate meaningful dialogue and foster adoption of best practices in cost estimation and project management.

Expected Outcomes and Impacts

There are two main research outcomes of this proposed research project listed as follows:

1. **Application of Cost Estimating Models by STAs:** The research focuses on uncovering the prevailing methods and tools utilized by STAs for formulating engineer's estimates, with a meticulous examination of existing models and techniques employed in accurately estimating project costs. Additionally, the study aims to evaluate the effectiveness of current cost-estimating models through a combination of literature review and survey responses from contracts and estimates personnel. This assessment will offer valuable insights into the strengths and limitations of these models, shedding light on their real-world impact on the accuracy of engineer's estimates. Furthermore, the research will conduct a comprehensive analysis to gauge the extent to which STAs comply with guidelines and recommendations set forth by state and federal agencies. This in-depth understanding is crucial for identifying areas where improvements or adjustments in practices may be warranted, thereby contributing to the overarching goal of enhancing engineer's estimate accuracy in transportation projects.

2. **Empirical Evidence of Inaccurate Engineer's Estimates Impact on Project Performance:** The research endeavors to quantify the impact of inaccurate engineer's estimates on transportation projects by conducting rigorous statistical analyses on project performance data retrieved from WYDOT's Construction Management Systems (CMS) and bid tabulation data. This comprehensive analysis extends to assessing the influence of inaccurate estimates on crucial aspects such as budget adherence, project schedules, and contractor performance. Through the use of regression and correlation studies, the study seeks to establish empirical evidence, providing a clear understanding of the intricate relationships between inaccurate engineer's estimates and various project performance metrics. This empirical evidence is paramount for not only validating assumptions but also offering concrete insights into the tangible consequences of estimation inaccuracies. Moreover, the research aims to identify key variables within the project performance data, examining a diverse range of factors that significantly contribute to the impact of inaccurate estimates. This information is instrumental in developing targeted strategies to address specific challenges associated with estimate accuracy, thereby contributing to a more nuanced and effective approach in managing the repercussions of inaccurate engineer's estimates in transportation projects.

These main outcomes collectively contribute to the overarching goal of the research: to enhance engineer's estimate accuracy in transportation projects and provide actionable insights and tools for WYDOT to improve their estimating practices.

Work Plan

Task 1 – Conduct literature review

This task carefully examines existing academic literature and technical reports from state and federal transportation agencies. The goal is to understand key aspects related to the accuracy of engineer's estimates and their consequences in transportation projects. Here are the specific areas to focus on:

1. **Engineer's Estimate Inaccuracies:** Review studies and reports that discuss why engineer's estimates in transportation projects may be inaccurate. The team will look for common factors contributing to inaccuracies and identify any trends.

2. **Impact of Inaccurate Engineer's Estimates:** Examine studies that explain the consequences of having inaccurate engineer's estimates. The team will document how these inaccuracies can affect project budget, timelines, and overall success.

3. **State and Federal Guidelines and Recommendations:** Explore literature that outlines the guidelines and recommendations provided by state and federal transportation agencies on creating engineer's estimates. This includes understanding the rules and procedures aimed at improving accuracy.

This literature review aims to build a solid understanding of engineers' estimates in transportation projects, setting the stage for the following research tasks.

Task 2 – Administer a questionnaire survey to contracts and estimates personnel in STAs

This task involves designing and implementing a targeted questionnaire survey aimed at gathering insights from contracts and estimates personnel within STAs. The primary objectives of the survey are to discern the reasons behind inaccuracies in engineers' estimates, understand the impacts of inaccurate estimates, and identify the tools employed by STAs to enhance the accuracy of these estimates. Here is a breakdown of the key components of the survey:

1. **Reasons for Engineers' Estimate Inaccuracies:** Develop questions focused on understanding the factors contributing to inaccuracies in engineers' estimates. Query participants on their experiences and perspectives regarding the challenges and hurdles encountered during the estimation process.

2. **Impact of Inaccurate Engineers' Estimates:** Craft survey questions to gauge the perceived and real-world impacts of inaccurate engineers' estimates. This may include inquiries about financial repercussions, project delays, and broader implications on project success.

3. **Tools Adopted by STAs:** Inquire about the specific tools and methodologies embraced by STAs to enhance the accuracy of engineers' estimates. Explore participants' insights on the effectiveness of these tools and any challenges faced in their implementation.

The survey should be designed to elicit detailed responses, providing a comprehensive understanding of the perspectives and practices within STAs regarding engineers' estimates. By engaging contracts and estimates personnel directly, this task aims to gather valuable firsthand information to complement the findings from the literature review and contribute to a robust analysis of the research problem.

Task 3 – Collect and analyze WYDOT bid tabulation data

This task involves obtaining bid tabulation data from WYDOT archives, specifically focusing on historical bids. The collected data will encompass essential elements such as engineer's estimates, bidding amounts from all participants, and detailed information on quantities and unit prices for bid items. The subsequent steps involve digitizing this bid tabulation data to facilitate comprehensive statistical analysis. The analysis aims to identify trends and challenges related to

inaccurate engineer's estimates, including factors such as quantities, unit prices, the number of bidders, market conditions, and other pertinent variables.

1. **Data Collection:** Acquire historical bid tabulation data from WYDOT archives, ensuring inclusivity of engineer's estimates, bidding amounts, and detailed breakdowns of quantities and unit prices for bid items. Ensure the data covers a sufficiently extensive timeframe to capture variations and trends. WYDOT has publicly published historical bids since 2002. The research team will use this data to achieve the goals of this research.

2. **Digitization of Bid Tabulation Data:** Digitize the collected bid tabulation data to enable efficient and accurate statistical analysis. This process involves transforming the historical data into a format conducive to advanced quantitative techniques, ensuring the preservation of essential details for subsequent modeling.

3. **Statistical Analysis:** Utilize statistical methods such as time series analysis to analyze the digitized bid tabulation data comprehensively. Identify trends and challenges associated with inaccurate engineer's estimates, considering variables such as quantities, unit prices, the number of bidders, and market conditions. The research team will also employ appropriate statistical tests such as analysis of variance and regression analysis to extract meaningful insights regarding the potential negative impacts of an inaccurate engineer's estimate.

Through this task, the research team will gain valuable insights into the specific challenges associated with inaccurate engineer's estimates in the context of transportation projects.

Task 4 – Evaluate the impact of inaccurate engineer's estimate on project performance

This task focuses on leveraging WYDOT's Construction Management Systems (CMS) data to thoroughly examine the ramifications of inaccurate engineer's estimates on project performance. The research team will systematically retrieve project performance data, including budget adherence, schedule outcomes, and contractor performance, from the CMS. Rigorous data cleaning and preprocessing will be conducted to ensure the integrity and reliability of the dataset. The team will use quantitative analysis techniques, such as regression and correlation analysis, to scrutinize the relationships between inaccurate engineer's estimates and project performance metrics. Specific attention will be given to assessing the impact of inaccurate estimates on budgetary outcomes, project schedules, and contractor performance. The team aims to validate assumptions regarding these relationships through hypothesis testing, providing statistical significance to observed patterns. This detailed investigation seeks to offer empirical insights into the nuanced dynamics between inaccurate engineer's estimates and project performance.

Task 5 – Prepare final report

In this concluding task, the research team will compile and present the culmination of the entire research process in a comprehensive final report. The report will systematically summarize the results, insights, and outcomes derived from each phase of the research, ranging from the literature review and data collection to the analysis of historical data. It will include a detailed presentation of findings from the historical data analysis. The final report aims to serve as a comprehensive resource for stakeholders, providing valuable insights, recommendations, and

potential avenues for further research in the domain of improving engineer's estimate accuracy. The schedule of the project tasks is shown below.

Task	2024					2025						
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1. Conduct literature review	■	■	■	■	■							
2. Conduct questionnaire survey				■	■	■	■					
3. Collect and analyze WYDOT bid data						■	■	■	■	■		
4. Evaluate impact of engineer's estimate inaccuracies									■	■	■	
5. Prepare final report										■	■	■

Project Cost

Total Project Costs: $103,220
CTIPS Funds Requested: $ 51,610
Matching Funds: $ 51,610
Source of Matching Funds: Wyoming Department of Transportation

References

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