

## DEVELOPMENT OF COST ADJUSTMENT FRAMEWORK TO IMPROVE ACCURACY OF PRELIMINARY COST ESTIMATES

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**ABSTRACT:** Accurate cost estimates are essential for proper planning, budgeting, and execution of infrastructure construction projects. However, the issue of the cost growth is prevalent in the construction industry. Past studies have focused on developing parametric cost estimating models, allocation of fixed contingencies, and use of risk registers to improve the accuracy of the cost estimates. However, these methodologies have various issues. For example, parametric models generally do not offer sufficient level of accuracy once some design details are available. Fixed contingencies fail to address the variability of cost changes based on project characteristics. Finally, the risk registers require extensive amount of subjective input. Further, such subjective inputs require additional time and effort from the estimators, and subjective inputs can be less reliable than the objective inputs based on the historical data. A new framework is needed to improve the accuracy of estimates, which also addresses these issues related to existing methodologies. This study introduces a novel framework to adjust preliminary cost estimates to make it more reflective of the likely final estimates using historical trend of changes in cost estimates. The framework consists of project level simple and project level detail analyses. The first analysis provides a macroanalysis by ignoring the project characteristics and focusing more on the overall trend for all projects. The second set of analyses adjusts the preliminary cost estimates based on project characteristics such as work type and project location. The results are aggregated in two phases to produce the adjusted preliminary estimates. The validation of the framework shows that for six out of nine projects, the accuracy of the preliminary estimates was improved by an average of 29%.

### 1. INTRODUCTION

Accurate cost estimation is essential for proper planning, budgeting, and executing transportation infrastructure projects. It helps in optimizing the use of the available budget and ensuring adequate funds are available for planned projects. However, cost overruns remain a persistent challenge, often stemming from complex project requirements, unpredictable economic conditions, and inherent uncertainties in long-term planning. Transportation projects – particularly those with extended planning and construction timelines – are highly susceptible to cost escalation due to fluctuations in material costs, labor rates,

regulatory changes, and unforeseen site conditions. Flyvbjerg et al. (2002) suggested that up to 90% of cost estimates for transportation infrastructure projects are underestimated, with final costs averaging 20% higher than initial projections. The Tennessee Department of Transportation (TDOT) was also seeing cost growth over various phases of project development which impacted their ability to properly plan and execute legislative projects that advances statewide legislative agendas. Studies that are focused on improving the accuracy of the cost estimates can be broadly categorized into three categories: a) building improved parametric estimating models, b) allocating contingencies to ensure the availability of sufficient funding to execute the projects, and c) development of risk registers based on engineers' subjective inputs.

**Parametric Models:** The parametric estimating is more useful at the conceptual phase of the project development when design details are not available. Once some level of design details is available, engineers can often calculate more accurate estimates by analyzing costs of various components of the project. The desire is to use these component-based cost estimates and improve its accuracy further.

**Contingencies:** Many studies focus on allocating fixed percentage of the base estimate as a contingency. This approach can have two issues. First, different values of contingencies should be applied based on project characteristics, but that is generally not the case. Second, the contingencies are additional fund allocated beyond the base estimate. As such, it is not playing any role in improving the accuracy of the estimates.

**Risk Registers:** Finally, the risk register-based approach has two issues. First, additional time and effort is required from experienced engineers, which is a challenge as the size of public agencies is perceived to be decreasing. Thus, the approach may be useful only for large sized projects. Second, this approach is typically based on subjective inputs from experienced engineers. These subjective inputs are less reliable than the inputs based on the actual data.

Thus, there is a need to develop a new framework that utilizes existing estimates and improve its accuracy, does not rely on fixed contingencies, and requires minimal efforts from engineers, is objective based on historical data.

## 2. LITERATURE REVIEW

Many studies have focused on developing parametric models for estimating project costs. However, these parametric models become less relevant as soon as some design details becomes available. The traditional deterministic methods, which apply fixed contingencies, fail to account for dynamic variables such as fluctuating material costs, regulatory changes, and evolving project scopes, resulting in inaccurate projections (Amade and Akpan 2014; Ankit Vishwakarma et al. 2016). Molenaar (2005) critiqued deterministic methods, particularly in highway megaprojects, where unaccounted risks frequently lead to budget overruns.

Researchers have increasingly turned to risk-based and probabilistic approaches to address the limitations of traditional deterministic cost estimation methods, which often fail to account for project uncertainties. These risk-based and probabilistic approaches integrate risk analysis with expert input to quantify uncertainties, model interdependencies, and simulate cost variations using probabilistic distributions. Unlike deterministic methods, probabilistic models generate various possible cost outcomes with associated probabilities, offering a more realistic assessment of financial risks (Dillon et al. 2002; Lhee et al. 2009; Lockhart et al. 2008). Molenaar (2005) introduced the Cost Estimating Validation Process (CEVP), which employed Monte Carlo simulations and peer reviews to enhance cost reliability and transparency. Similarly, Anderson et al. (2006) identified challenges such as scope changes and inconsistent contingency allocation, advocating for a structured framework incorporating probabilistic risk modeling and sensitivity analysis. Their approach emphasized early project planning stages, where cost influences are most significant, ensuring more accurate budgeting and financial decision-making. Kermanshachi and Safapour (2019) reinforced the need for refined methodologies through a gap analysis involving Department of Transportation (DOT) professionals. They emphasized integrating probabilistic techniques, risk matrices, and simulation models to bridge gaps between existing practices and best practices, enhancing cost

predictability in transportation infrastructure projects. Sadeh et al. (2021) introduced a fuzzy logic-based risk management framework to address uncertainties often overlooked by deterministic methods. This framework captured risk interdependencies and cost variability by integrating probabilistic modeling and scenario-based planning, improving decision-making under uncertain conditions. Recent studies have further refined probabilistic cost estimation by challenging traditional techniques. Vegas-Fernández (2022) critiqued the Expected Value (EV) method, demonstrating through Monte Carlo simulations of over 270 projects that it often underestimates risk, particularly when cost distributions are skewed or interdependent. To address this, a regression-based enlargement factor was proposed to improve accuracy. Similarly, Paquin et al. (2022) introduced the Expected Cost Overrun (ECO) metric, a coherent risk measure that accounts for the average severity of overruns beyond a defined confidence level. Unlike percentile-based methods, ECO provides a more robust and risk-aware estimate of potential cost exposure, aligning with financial risk models like Expected Shortfall and emphasizing the need for data-driven contingency planning. The AASHTO (2013) further supports integrating deterministic and probabilistic methods, emphasizing techniques such as Monte Carlo simulations, sensitivity analysis, and historical data integration to improve project cost forecasting.

Many state DOTs including those in Washington, California, Nevada, and Montana, have implemented risk-based estimating practices (Shrestha et al. 2023). However, they continue to face significant challenges, which includes the lack of standardized tools, difficulties in isolating and quantifying individual risk factors, and the complexity of advanced risk estimation models that require specialized training. Additionally, most risk-based studies primarily address cost overruns during construction. In contrast, pre-construction risks, such as scope changes and right-of-way acquisition, remain underexamined despite their substantial impact on cost escalation.

The Tennessee Department of Transportation (TDOT) needed some methodology to improve the accuracy of their early cost estimates. Some level of design information was already available, which means the parametric models would probably provide even less accurate estimates. The fixed contingency-based approach would not be able to address the problem properly. And, TDOT did not have risk register templates, and even if one was developed, it would face the same issues as other state DOTs have faced. The solution was to develop a new framework for cost adjustment based on historical pattern of cost changes over time for projects with various characteristics, such as work type and location.

### **3. METHODOLOGY**

#### **3.1 Data Collection and Preparation**

The dataset includes preliminary cost estimates and the final cost estimates for 212 TDOT projects from year 2010 to 2022. It also includes key project attributes, such as county, region, program type (e.g., Legislative), and type of work (e.g., bridge replacement, intelligent transportation systems, turn lane construction, and intersection improvements), preliminary estimates, and final estimates. Projects with incomplete information (e.g., missing preliminary estimates, work type) were removed to reduce misinterpretation. Additionally, project data prior to 2013 were excluded, as TDOT underwent significant changes in its cost estimation practices starting that year. Further, bundled projects were also removed as their inclusion will unnecessarily complicate the dataset. Such projects do not accurately reflect regional or location-specific variability. The final dataset consisted of 183 projects. Additionally, inflation adjustments were made using the National Highway Construction Cost Index (NHCCI) to account for economic fluctuations, facilitating accurate cost comparisons over time.

#### **3.2 Statistical Analysis**

Cost variability was assessed by analyzing the percentage differences between preliminary and final cost estimates. This standardized approach provided a structured evaluation of how cost projections evolved throughout the project lifecycle. By examining these variations, the study identified patterns of cost deviation, assessing whether specific work categories or geographic regions were more prone to underestimation or overestimation. Proper understanding of these deviations is essential for refining cost

estimation practices and minimizing budget overruns in transportation infrastructure projects. To further analyze these variations, key statistical metrics, including mean and standard deviation were computed to quantify cost distribution and assess reliability. The mean percentage difference was calculated to understand whether preliminary estimates were overall higher or lower than the final project estimates. The standard deviation measures the dispersion of differences between the cost estimates around the mean difference, which offers insights into the consistency of the pattern of cost changes across projects..

#### 4. PRELIMINARY COST ESTIMATE ADJUSTMENT FRAMEWORK

The cost estimate adjustment framework developed in this study is designed to provide a comprehensive understanding of cost variability and behavior for various projects (Figure 1). The framework is structured into two levels of analysis: a) Project-Level Simple Analysis and b) Project-Level Detail Analysis. These levels work in tandem to capture both high-level trends and more granular insights, and they enable an in-depth evaluation of cost estimation accuracy and variability. For both level of analysis, the differences in the preliminary and final estimates are calculated. As the preliminary and final estimates are computed in different times, inflation adjustment is made before computing the differences. Once the differences are calculated for all historical projects, various statistics, including mean and standard deviations of the differences are calculated. The historical differences between the estimates are anticipated to be continue in the future projects. As such, these mean and standard deviations of the differences are used to adjust the preliminary estimates to be more reflective of the final estimates. These adjusted estimates are further adjusted to account for anticipated inflation from the preliminary estimate year to the anticipated construction year. Further, instead of calculating a single adjusted estimate, a lower, likely, and upper adjusted estimates are produced at various confidence levels.

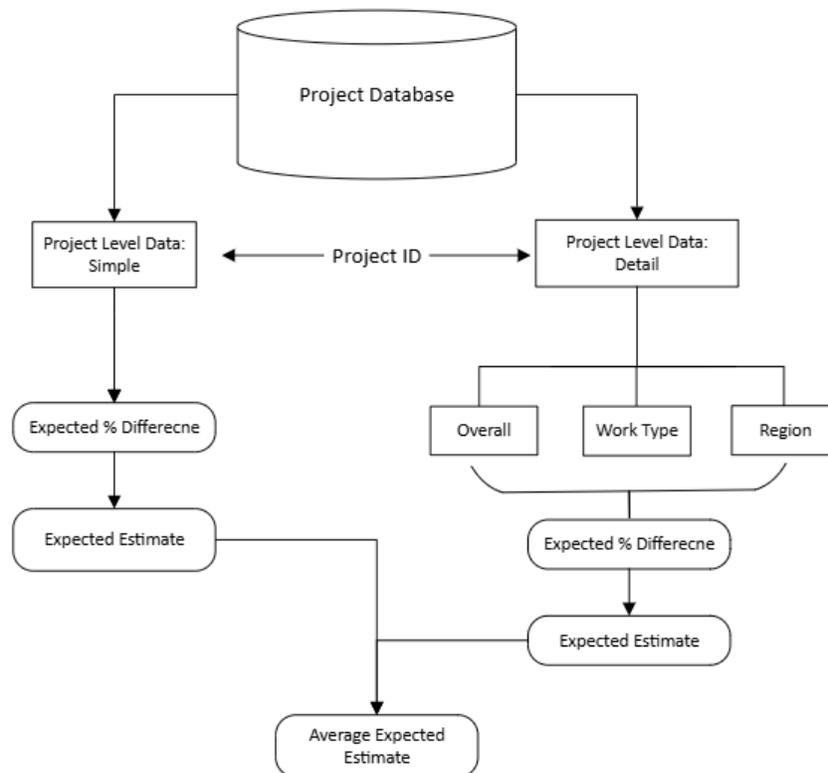


Figure 1: Preliminary Cost Estimate Adjustment Framework

The Project-Level Simple Analysis offers a broad assessment of cost trends across the entire dataset, providing a high-level evaluation of cost deviations between preliminary and final estimates. This macroscopic approach considers all projects at once without consideration of project characteristics. It establishes baseline cost relationships and identifies consistent cost change patterns. The Project-Level Detail Analysis considers various project characteristics (e.g., work type and region) which will provide more relevant adjustments for the projects under consideration. Finally, the adjusted estimates from the two levels are aggregated into a final adjusted estimate.

## **5. RESULTS**

The main findings obtained by applying the framework on the TDOT data are presented below for the Project-Level Simple and Project-Level Detailed Analyses. The results can be applied to adjust the preliminary cost estimates to be more reflective of the expected final estimates.

### **5.1 Project-Level Simple Analysis**

The average cost growth for all projects was found to be 45% relative to the inflation-adjusted preliminary estimates, with total project estimates increasing from \$931,511,269.36 at the preliminary estimating stage to \$1,301,210,599.92 at the final estimating stage. A standard deviation of 133.01% underscores the substantial variability in cost deviations across projects, which highlights the need for enhanced cost control mechanisms.

### **5.2 Project-Level Detail Analysis**

#### **5.2.1 Work Type Analysis**

The analysis of cost deviations across different work types revealed significant variability in estimation accuracy. Work categories such as Modify Interchange (204.55% increase, SD = 181.65%) and Signalization (119.61% increase, SD = 343.48%) exhibited the highest cost escalations, which indicates considerable uncertainty. In contrast, work types, such as, Mitigation - Rockfall (9.74% increase, SD = 6.44%) and Safety (9.17% increase, SD = 26.75%) demonstrated more stable cost behaviors. Additionally, some categories, such as, Interchange Lighting (-2.03%), Mitigation - Slide (-1.34%), and Right-of-Way (-4.01%), showed negative cost differences, suggesting potential overestimation at the preliminary estimating stage.

#### **5.2.2 Regional Cost Variability**

The state of Tennessee is divided into four administrative regions (region 1, 2, 3, and 4) for transportation planning and execution purposes. The region level analysis showed a significant impact of the region on the differences in the cost variability over time. Region 4 exhibits the highest cost growth (109.54%) and most significant variability (SD = 224.10%), indicating significant uncertainty in estimation accuracy. Region 1 follows with a 48.99% increase and high variability (SD = 183.28%), reflecting substantial fluctuations. In contrast, Regions 2 and 3 show more stable cost trends, with increases of 39.51% and 33.37% and lower variability levels (SD = 86.06% and 73.78%, respectively).

## **6. VALIDATION**

The framework was validated with a data from 15 projects that were not a part of the model development. It consisted of five bridge projects, three safety projects, three legislative projects, and four economic development projects. Overall, the framework reduced the difference between the preliminary and final estimates in 9 projects while it increased the difference in 6 projects. The improvements in accuracy were observed in one bridge project, one safety project, three legislative projects, and four economic development projects.

## **7. CHALLENGES AND LIMITATIONS**

Despite the advancements in the development of the cost estimate adjustment framework, several challenges persist, which can impact its accuracy and applicability. While the framework integrates probabilistic methods to address certain uncertainties (e.g., fluctuating material costs, inflationary trends), extreme economic shifts and unforeseen disruptions, such as supply chain crises, may introduce significant deviations that are difficult to model precisely. Another limitation stems from the scope of the study. Although the analysis provides valuable insights, it does not capture county-level cost variations, contractor-specific performance metrics, or localized bidding conditions, which can significantly influence cost estimations. Additionally, the framework primarily focuses on project-level simple and detail analyses, which, while helpful in identifying broad trends, do not fully account for bid item-level variations. Infrastructure projects involve multiple bid items (e.g., asphalt, concrete, drainage components), each exhibiting distinct pricing behaviors influenced by market conditions, procurement strategies, and supply chain constraints. A more granular bid item-level analysis would enhance forecasting accuracy, improve cost control mechanisms, and enable precise cost adjustments. Furthermore, the regional analysis is confined to four TDOT regions, which may not fully capture localized cost dynamics at the county level. Variations in labor availability, material accessibility, and subcontractor participation can lead to significant cost disparities within a single region. Future research should incorporate county-level cost assessments to refine the estimation models and better account for these localized factors. Addressing these limitations will enhance the framework's predictive capabilities, providing transportation agencies and their estimators with more reliable tools for cost estimation. This, in turn, will improve budget planning, resource allocation, and risk management in infrastructure projects, which will ultimately support more efficient and effective project delivery.

## **8. CONCLUSION AND FUTURE WORK**

This research establishes a comprehensive cost estimate adjustment framework that is expected to enhance the accuracy and reliability of cost estimates for legislative transportation infrastructure projects. By integrating probabilistic cost adjustment with statistical modeling, the framework addresses the limitations of traditional deterministic methods and provides actionable insights for improving cost control and risk mitigation. Future research should incorporate county-level and bid-item-level analyses to refine this framework further, as these factors may play a significant role in overall project costs. County-level analysis would provide a more localized understanding of cost variability by capturing economic, environmental, and regulatory factors unique to each jurisdiction. Additionally, accounting for labor market fluctuations and supply chain impacts at the county level would enable more precise regional cost adjustments. Bid-item-level analysis would enhance cost adjustment accuracy by evaluating the pricing behaviors of individual materials and labor components, allowing for better budgeting, procurement planning, and targeted contingency strategies. By incorporating these additional layers of analysis, future studies can enhance predictive capabilities, reduce estimation errors, and improve budget planning, ultimately strengthening resource allocation and financial decision-making in transportation infrastructure projects. Finally, a tangible tool should be developed to implement the theoretical framework so that state DOT engineers can utilize the findings of the study with minimal effort. The tool should be integrated with the existing cost estimation process.

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