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Comparison of State Department of Transportation Practices in Analyzing Risks for Large Infrastructure Projects

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Construction projects are inherently associated with various risks that can increase the project costs. Identifying and analyzing such risks are essential to successfully managing construction budgets at state Departments of Transportation (DOTs). While many state DOTs have developed and/or adopted risk assessments methodologies and tools, Tennessee DOT (TDOT) lacks a comprehensive methodology and tool to analyze construction project risks. This study reviewed state DOT practices of analyzing various risks associated with large infrastructure construction projects. The comparison of risk assessment practices among state DOTs are summarized in three sections: a) risk management, b) major categories affecting project costs, and c) risk estimating tools and practices. The review finds that many state DOTs have similar practices of analyzing project risks and have developed spreadsheet-based tools to automate such analysis. While some risk analysis tools are used primarily for qualitative risk analysis, other tools are developed for qualitative and quantitative risk analysis. Such tools with qualitative and quantitative risk analysis can be used to quantify contingencies for various projects for budgeting purposes.

Keywords: risk-based-cost-estimation, risk-analysis, risk-factors, Monte-Carlo-Simulation

Introduction

The Project Management Body of Knowledge (PMBOK®) Guide defines risk as “an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives” (Project Management Institute (PMI), 2017). Issues are risks that becomes a reality. Ideally, all negative risks should be avoided, but some risks cannot be avoided. As such, project stakeholders need to be prepared to assess the potential impacts of the risks that can become a reality. Thus, various risk assessment techniques and tools are developed by various organizations including state Departments of Transportation (DOT). For state DOTs, various project risks such as unexpected site conditions can dramatically increase the project costs, duration, and complexity. If such risks are not identified and analyzed during the planning phase, they can have ripple effect in state DOT’s construction budget management. For example, if a project cost overruns its initial budget, other projects may be delayed or removed from the fiscal year plan, the project itself may be halted, or the scope of the project may be reduced. If a project cost underruns its initial budget, them remaining budget may be unused and potentially frozen or claimed back by the federal government. Thus, proper risk analysis is essential to optimize the use of available budget in state DOTs. However, Tennessee DOT (TDOT) currently lacks a comprehensive methodology and tool to analyze various risks and their potential cost impacts. As such, this study reviews existing literature on various risk analysis methodologies and tools developed and used by other state DOTs.

Background

Several studies have identified and classified major factors affecting construction cost overruns such as poor estimating, engineering and construction complexities, scope changes, market conditions, unforeseen conditions, and faulty execution (AASHTO, 2013; Gransberg et al., 2015; Schexnayder et al., 2009; Washington State Department of Transportation, 2014). The theories of risk-based estimating can be applied to produce more reliable estimates (Kermanshachi & Safapour, 2020). Some states have already taken initial steps to towards implementing risk-based estimating in their business practices (Ashuri et al., 2015; California Department of Transportation, 2012; Nevada Department of Transportation, 2012; New York State Department of Transportation, 2009; Shane, 2015; Texas Department of Transportation, 2015; Washington State Department of Transportation, 2014).

Risk Based Cost Estimating

According to AASHTO Guidebook (2013) risk-based estimating combines traditional estimating methods for known items and quantities with risk analysis techniques to estimate uncertain items, uncertain quantities, and risk events. The risk-based portion of the estimate typically focuses on a few key elements of uncertainty and combines Monte Carlo sampling and heuristics to rank critical risk elements. This approach is used to establish the range of total project cost and to define how contingency should be allocated to critical project elements.

Several studies have been conducted to aid state highway agencies in implementing risk-based estimating practices (Gransberg et al., 2015; National Academies of Sciences, 2017; Schexnayder et al., 2009). These includes theoretical framework and practical tool developments. DOTs from states such as Georgia, Texas, Washington, New York, and California have also developed guidebooks and tools highlighting the importance of considering various types of risks in project development phases using risk register, influence diagram, Monte Carlo Simulation, and risk mitigation for major projects (Ashuri et al., 2015; California Department of Transportation, 2012; New York State Department of Transportation, 2009; Texas Department of Transportation, 2015; Washington State Department of Transportation, 2014).

Some additional relevant studies include Chen et al. (Chen et al., 2020) that introduced a qualitative and quantitative methods based on risk allocation in a probabilistic Monte Carlo simulation. Sadeh et al. (2021) introduced a new model to evaluate and assess risk in terms of cost impact, utilizing a fuzzy Monte Carlo simulation approach for the first time. The method consists of ranking the top risks using a fuzzy logic system utilized in an objective manner by setting criteria for experts to rank the risk based on cost impact and probability to reduce human biases, then evaluating their cost impact through a Monte Carlo simulation both pre- and post-mitigation. Gündüz et al. (2013) identified 81 delay factors on construction projects, analyzed these factors with the relative importance index method, and provided recommendations to minimize and control delays in construction projects.

Tomek and Matějka (2014) and Zou et al. (2017) reviewed impacts of BIM in managing construction risks by comparing traditional risk management methods with BIM technologies and concluded that BIM, as a tool for risk management, is still in its infancy.

Although the existing studies have attempted to identify and evaluate the project risks, most of them focus primarily on the cost growth during the construction phase. However, one of the major reasons of cost growth over time are changes in scope and specification that occur before the construction. As such, a study needs to be conducted to evaluate the cost growth over the project development from the conceptual phase to the construction phase so that the TDOT management team can make more informed budgeting decisions.

Methodology

This study was guided by the research question: what is the state of practice among state DOTs in analyzing risks in large infrastructure projects? To answer this question, we utilized a systemic method to identify various DOT practices related to risk analysis and risk-based estimating. First, the authors reviewed cost estimation processes and practices of several states by visiting the DOT websites. The information of the DOT websites was the main basis for this comparative study. Next a through literature search was conducted focusing on published journal articles, reports, and conference proceedings on the topic. The literature review identified several major areas of similarities and contrasts which are presented in this paper.

Comparison of Risk Assessment Practices Among State DOTs

This section summarizes existing studies on risk analysis for large infrastructure projects and provides a) an overview of current practices for risk management, b) major categories of risk factors affecting construction projects, and c) overview of current risk estimation tools and practices.

Risk Management

State DOTs have many similarities in risk management for construction projects. For example, state DOTs have common tasks associated with risk analysis: a) risk registers, b) risk analysis, c) risk response, and d) risk monitoring and control (Shane, 2015; Texas Department of Transportation, 2015). Risk registers are frequent practice for any construction company, public or private. Risk registers are basic notes on the risk which include cost, likelihood, and date. Most existing risk quantification tools create the risk register automatically based on the user’s inputs. Many state DOTs have developed spreadsheet-based tools to analyze project risks. State DOTs have recommended various tools to analyze risk and determine contingencies such as Monte Carlo Analysis, Probability x Impact Matrix (P x I), and Crawford Slip Method. Risk response can be one of the four: avoid, mitigate, accept, or transfer. Finally, risk monitoring and control acts as a feedback loop to improve the risk management process.

Major Categories Affecting Project Costs

The categories in which risk factors may be divided into two generic types. The first type involves a more conceptual determination and is mostly found in academia. These may include external risks, internal risks, enterprise risks, program risks, and project risks (D’Ignazio et al., 2011). External risks are risks that are unavoidable and an example of this may be inclement weather delays. Internal risks are risks specific to the project itself. Enterprise risks are risks amongst the design staff of the project. Program risks are risks generated by upper-level management, and an example of this may be the breakdown of communication between management and the workers on site. Project risk are risks from the workers at the site and an example of this may be noncompliance with safety protocols.

The second type of classification are risks classified by more tangible and realistic issues seen on large infrastructure projects. The most important of these risks is right of way. There are countless department of transportation studies around the costs associated with this, and it is by far the most researched. Right of way risks are any costs to acquire the land around projects. These costs are especially prevalent in large highway projects. The value of the land, court costs (Cox, 2016), and negotiation are all examples of right of way costs (Tennessee Department of Transportation, 2021). Even when the academic classifications are used, right of way remains a top risk priority (Georgia Department of Transportation, 2020). Another important risk factor are geotechnical issues. Soils are typically tested in increments of ten feet or more, which may leave gaps in the soil tests. Then, upon excavating the soil, hidden issues are uncovered, which will cause schedule and monetary changes. Another interesting factor is payment and contract structure (Michigan Department of Transportation (MDOT), 2015). A time and materials contract would shift risk to the owner because any schedule delays come directly from the owner's budget.

The other risk factors that present in several other DOT articles were environmental, right of way (Abd El-Karim et al., 2017), utilities, public information, third party agreements, drainage, traffic handling, design, and other (Missouri Department of Transportation, 2022). These are the risk factors affecting preconstruction that need to be quantified in this study because these tangible factors are focused on by every state DOT.

Risk breakdown structure is a way of further breaking down these risks. It is similar a flowchart with the nine risks at the top, and the examples of each are the subsequent boxes under each risk.

Risk Estimation Tools and Practices

To effectively identify how states are quantifying and using risks factors, a further look into current estimation practices is required. Tennessee's unique geographic position and political agendas create an individual set of risk factors. To gain insight into these, the eight states that border Tennessee were evaluated for their cost estimation techniques. Their proximity allows for a similar set of risks and needs for construction projects on a state governmental level. Alabama, Missouri, and Kentucky had no readily available information on their cost estimation procedures. North Carolina (Kluckman, 2021), Georgia (Georgia Department of Transportation, 2019), and Mississippi (Mississippi Department of Transportation, 2017) all used cost-based estimation for heavy civil construction. It is important to note that cost based is simply the final form of estimation, and that each line item is evaluated based on the estimator's experience or the historical data. Naturally, historical data has some of the risk factors built into them, but there is no way to isolate each risk and quantify it. For instance, if a project encountered risks X, Y, and Z and the budget ran over by two million, the next project that uses this historical data will already have X, Y, and Z allocated for in its budget. Virginia uses RS Means as a basis for all construction estimates (Virginia Department of Transportation, 2012). The main advantage to using RS Means is that it is the most up-to-date cost data, so it can account for external risks.

Most state departments of transportation are very conservative with their risk-based estimation software and tools, so information is lacking on practices across the board. However, leading state

DOTs, such as Washington, California, Nevada, and Montana have limited information available to the public. Washington is ahead of the curve as they already have an Excel based tool and user manual (Washington State Department of Transportation, 2022). This manual incorporates a Monte Carlo simulation to find the most likely costs as well as other advanced statistics measures to quantify risks. The main disadvantage to this Excel file is it is incredibly complex to use, and the average construction estimator would have to train from months to become accustomed to it. The goal of the tool for TDOT is an Excel file that can be taught in a reasonable timeframe. Additionally, there are no quantities associated with certain risks, all those values are input on a project-by-project basis, which is not standardized. Standardization of risk factors and their respective markup factors is another important goal of this study, however the probability of each risk factor occurring may be input into the tool by the user or calculated with a Monte Carlo simulation. The Nevada DOT uses a Monte Carlo simulation for their risk-based estimates as well (Nevada Department of Transportation, 2021).

"A Stochastic Three-Dimensional Cost Estimation System for Hot Mix Asphalt in the State of Alabama" goes about evaluating probabilities of risks another way using percentage errors (Karen Xu, 2018). This article takes each contractors' itemized bids and compares them to the state's estimate. For each bid, the actual value of the construction was compared to each line item, and the line item with the highest percentage error is the most influential risk factor.

In summary, the Monte Carlo simulation is the most popular way of evaluating the probability and potential impact of risk factors. Excel based tools are the best as they are readily available in most offices, relatively cheap compared to dedicated software, and most people know how to use Excel.

Conclusion

This study reviewed state DOT practices of analyzing various risks associated with large infrastructure construction projects. The study finds a wide variety of practices and tools utilized to analyze project risks. The comparison of risk assessment practices among state DOTs were summarized in three sections: a) risk management, b) major categories affecting project costs, and c) risk estimating tools and practices. Many state DOTs follow similar risk management approaches consisting of four steps. Many state DOTs have already developed and implemented various risk analysis tools. Some state DOT tools are capable of qualitative analysis only while other tools are capable of both qualitative and quantitative analysis. Quantitative tools can be used for estimating contingencies for project costs. Major categories affecting project costs includes external risks, internal risks, enterprise risks, program risks, and project risks. Most state DOTs have excel based tools for risk estimating.

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