Moving Forecasting Error: A Risk-Based Cost Forecasting Approach

by

Cesar Fernando Mayorga Amaya

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Approved by

Jorge Rueda-Benavides, Chair, Assistant Professor of Construction Engineering and Management
Michael Perez, Assistant Professor of Construction Engineering and Management
Wesley Donald, Research Fellow of Construction Engineering and Management
Jeffrey LaMondia, Associate Professor of Transportation Engineering

ABSTRACT

The large amounts of historical pricing data the state transportation agencies (STAs) have collected during the last couple of decades, combined with the information technologies available today, have facilitated greater effectiveness in construction cost estimating procedures through the implementation of data-driven procedures. Ten years ago, these procedures would be considered too advanced or impractical, but current computational tools have made them a feasible option for STAs. However, the application of those data-driven procedures has mainly focused on the pre-forecasting phase of the cost estimating process (to develop cost estimates in current dollars). Cost forecasting activities still rely on antiquated techniques developed before the "computer era," or are performed with annual inflation rates recommended by external entities, and whose suitability to the local construction market is unknown. This dissertation presents a complete analysis of the state-of-the-practice of construction cost estimating in the transportation industry. It proposes data-driven methodologies to address knowledge gaps and opportunities for improvement identified from that analysis.

Two data-driven methodologies have been proposed to address the two main phases of an ideal construction cost forecasting process: 1) the development of a construction cost index (CCI) that represents past behavior of the construction market for the intended scope of work and 2) analysis of that scope-based CCI to generate effective annual inflation rates. The development of scope-based CCIs was achieved by the careful application of a data collection and cleaning protocol, which allowed the developed and implementation of a Multilevel Construction Cost Indexes (MCCI) system. Other researchers have previously proposed this cost indexing system, but it has been modified in this dissertation to serve the cost forecasting needs of STAs better.

The method used to generate reliable inflation rates from scope based CCIs developed with the proposed MCCI system is called Moving Forecasting Error (MFE). This is a novel method designed to maximize the value of the limited available historical pricing data by evaluating several forecasting scenarios within that data. The output of the MFE methodology is yielded in the form of a risk-based forecasting timeline showing a probabilistic estimate of the future costs for the intended construction activities along different forecasting time horizons.

The proposed cost forecasting methodologies were developed and validated through three case studies conducted with three different STAs: the Colorado, Minnesota, and Delaware Departments of Transportation. To satisfy the forecasting needs of STAs, the proposed methodologies should be applicable to at least 20-year forecasts, such as those involved in the Long-Range Transportation Plans (LRTPs) required by federal regulations. To ensure their suitability for long-term forecasting, the MCCI and MFE methods were developed and validated with 20 years of historical bid data from each case study agency. To the best knowledge of the author, this dissertation presents the largest data processing effort to assess and improve STA's cost forecasting procedures.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
BCI	Building Cost Index
CCI	Construction Cost Index
CCIS	Construction Cost Index System
CDOT	Colorado Department of Transportaion
DelDOT	Delaware Department of Transportaion
DOT	Department of Transportaion
FHWA	Federal Highway Administration
LS	Lump Sum
MAD	Median Absolute Deviation
MCCI	Multilevel Construction Cost Index
MnDOT	Minnesota Department of Transportaion
MPO	Metropolitan Planning Organization
NCHRP	National Cooperative Highway Research Program
NLR	Non-linear Regression
ROUT	Robust Regression and Outlier Removal
SD	Standard Deviation
STA	State Transportation Agency
UP	Unit Price
TCCE	Technical Committee on Cost Estimating

INTRODUCTION

1.1 Introduction

By definition, a project is "a temporary endeavor undertaken to create a unique product, service, or result" (Rose 2013), and transportation construction projects are no exception. Each transportation project is characterized by a unique combination of several factors, including project objectives, deliverables, location, environmental requirements, and technical complexity. This uniqueness makes construction cost estimating a particularly challenging process, and it becomes even more challenging when the estimating process requires cost forecasting efforts over long time horizons, such as those commonly involved in transportation planning. State Transportation Agencies (STAs) are often required to forecast construction costs over long-time horizons of more than 10 or 20 years. Some of those forecasted cost estimates are performed at a program level, based on broad infrastructure performance goals and calculated under several assumptions with minimum or no project-specific information. The longer the forecasting time horizon, the higher the estimating uncertainty (Molenaar, Anderson, and Schexnayder 2011). Numerous changes to anticipated scopes of work, schedule, right-of-way cost/alignment, and environmental requirements occur during long cost forecasting periods (and these are just a few of the many uncertainty sources), challenging, and often refuting, estimating assumptions (Shane et al. 2009).

Cost forecasting is just part of the overall cost estimating process, but it is an essential component of STA's planning and programming processes. Accurate cost estimation early during project development is critical to making sound financial decisions and optimizing the use of limited available resources (Anderson, Molenaar, and Schexnayder 2007). The lack of effective cost estimation methodologies for long time horizons is preventing STAs from ensuring efficient use of public capital (Janacek 2006). This situation has led STAs to use methodologies that other government divisions suggest that uses data from different projects, follow the advice of external consultants without knowing the background behind the calculations, or even use indexes that are not designed for the sector.

However, an adequate projection of construction costs into the future is challenging due to many factors affecting the construction market and the high volatility in the price of some construction commodities.

1.2 Research Objectives

The research efforts described in this Dissertation were intended to *determine if cost forecasting effectiveness in the transportation construction industry can be improved through the implementation of alternative data-driven procedures aimed to leverage historical bid data stored by STAs.* The author strategically designed and followed a research plan to achieve the primary research objective through the following two sub-objectives:

1. Define the state-of-the-practice of cost forecasting in the transportation construction industry, identifying knowledge gaps and opportunities for improvement.
2. Design, develop, and validate data-drive procedures to address the knowledge gaps and opportunities for improvement identified in sub-objective 1.

1.3 Background

Regardless of the length of the forecasting period, there are two essential elements involved in the cost forecasting process: Construction Cost Indexes (CCIs) and annual inflation rates. CCIs are time series aimed to quantify average price fluctuations in the construction market over time. Inflation refers to the overall increase in the price of goods and services at a microeconomic (for an individual, group, or industry) or macroeconomic (national economy) level (Munday 1996). Thus, an inflation rate is the average measure for that increase during a given period of time (e.g., annual inflation rate). A negative inflation rate is called deflation, and it corresponds to an overall decrease in the price of goods and services under consideration.

By definition, a cost index "shows the average percentage change of prices from one point of time to another" (Fisher 1922). In other words, a cost index measures the average price fluctuation on a specific commodity, group of commodities, or market. Construction cost indexes are widely used by State Transportation Agencies to support different types of cost estimating procedures across all project development phases, as a point of reference to negotiate contract prices and price adjustments, and in general, they are assumed to represent the overall behavior of the construction market.

Construction cost indexes are typically created and maintained by tracking prices over time for a fixed set of commodities or construction activities (index inputs). Index values are the result of the weighted integration of the price fluctuations observed across all index inputs, with the weights representing the relative relevance of each input on the market. Index inputs are carefully selected to fairly represent the entire market when they are all integrated. Therefore, their use at a market or macroeconomic level is considered appropriate. However, index inputs are frequently used at the program- and project-level for specific scopes of work (defined at various levels of detail) that might not align with the index inputs and weights. Rueda-Benavides and Gransberg (2015) have identified the following two assumptions made by STAs when traditional construction cost indexes are used on specific scopes of work:

1. Changes in the construction market from period to period have an equal or similar impact on all types of work.
2. Weighted price changes between construction periods in a few significant materials or construction components represent an overall construction cost change during the same period.

Rueda-Benavides and Gransberg (2015) also found that these assumptions are severely and repeatedly violated. With regard to the first assumption, they demonstrated that market prices for different scopes of work fluctuate at different rates. Thus, it is not possible to identify a single group of index inputs to represent all possible scopes of work. Even if such a set of index inputs existed, it is not possible to find a set of input weights that aligns with all scopes of work (violation of the second assumption). Based on their findings regarding these two assumptions, Rueda-Benavides and Gransberg (2015) emphasized the need for alternative CCIS with the flexibility to adapt to different scopes of work. They also defined two fundamental principles that should be met to achieve the required level of flexibility: the matching and proportionality principles.

The matching principle refers to the degree of similarity between the index inputs and the actual activities/elements that comprise the intended scope of work. Once the matching principle is met, the proportionality principle appears. The proportionality principle refers to the degree of consistency between the input weights and the actual relevance of each input to the overall scope of work (Rueda-Benavides and Gransberg 2015).

Early research efforts conducted as part of the study presented in this document have revealed another significant issue associated with typical index calculation procedures. The issue is that those procedures do not include factor economies of scale principles into the cost indexing process. “Economies of scale refers to a reduction in total cost per unit as output increases” (Betts 2007). In other words, lower unit prices should be expected for larger quantities of work, and vice versa. There are three different equations commonly used in the calculation of construction cost indexes. These equations have been named after those who proposed them: Laspeyres, Paasche, and Fisher (Pakalapati 2018).

Laspeyres price index:

$$L(p) = \frac{\sum_{j=1}^{n} p_{j,t}\, q_{j,0}}{\sum_{j=1}^{n} p_{j,0}\, q_{j,0}} \tag{0.1}$$

Paasche price index:

$$P(p) = \frac{\sum_{j=1}^{n} p_{j,t}\, q_{j,t}}{\sum_{j=1}^{n} p_{j,0}\, q_{j,t}} \tag{0.2}$$

Fisher price index:

$$F(p) = \sqrt{\frac{\sum_{j=1}^{n} p_{j,t}\, q_{j,0}}{\sum_{j=1}^{n} p_{j,0}\, q_{j,0}} \times \frac{\sum_{j=1}^{n} p_{j,t}\, q_{j,t}}{\sum_{j=1}^{n} p_{j,0}\, q_{j,t}}} \tag{0.3}$$

Where: $n = Length\ of\ forecasting\ time\ horizon\ in\ years$
$p_{j,t} = Prevailing\ price\ of\ item\ j\ in\ period\ t$
$q_{j,t} = Quantity\ of\ item\ j\ purchase\ in\ period\ t$
$p_{j,o} = Prevailing\ price\ of\ item\ j\ in\ period\ 0$
$q_{j,o} = Quantity\ of\ item\ j\ purchase\ in\ period\ 0$

First, it is crucial to understand that these equations were proposed in the 1920s or before (Fisher 1922). They were proposed before the "computer era," when the estimation of index values was limited to hand-made calculations, constraining data processing, and analysis capabilities. This could explain the simplicity of these equations and the reason why they are unable to consider economies of scale principles. Their inability to factor the relationship between unit prices and quantities is better illustrated with the following simple example.

Figure 1-1 shows two curves that represent the market conditions for two commodities for a given STA: asphalt and concrete. These curves were created with historical cost data from a given indexing period (Period 1 [P1]). For the purposes of this example, it is assumed that market conditions will remain unchanged during the next indexing period (Period 2 [P2]). Thus, the same curves would also represent the market in Period 2, as shown in Figure 1-2. Since the market has not changed in between these two indexing periods, an active composite cost index calculated with two inputs should show no change at Period 2 concerning Period 1. In order words, the index values for both periods should be the same. However, if only the four data points shown in Figures 1-1 and 1-2 are used in the calculation of the index values at their respective periods, the traditional cost indexing equations would perceive an inexistent overall decrease of about 23% ([1.00 – 0.77]/100%) in market prices, as shown in Table 1-1.

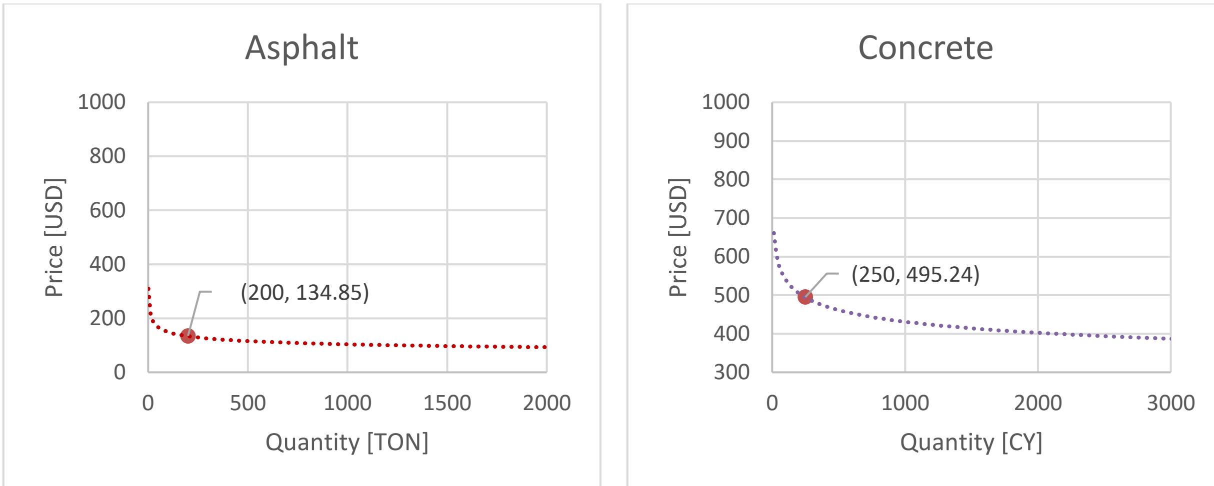

Figure 0-1 Asphalt and Concrete Quantity vs Price Curves for Period 1

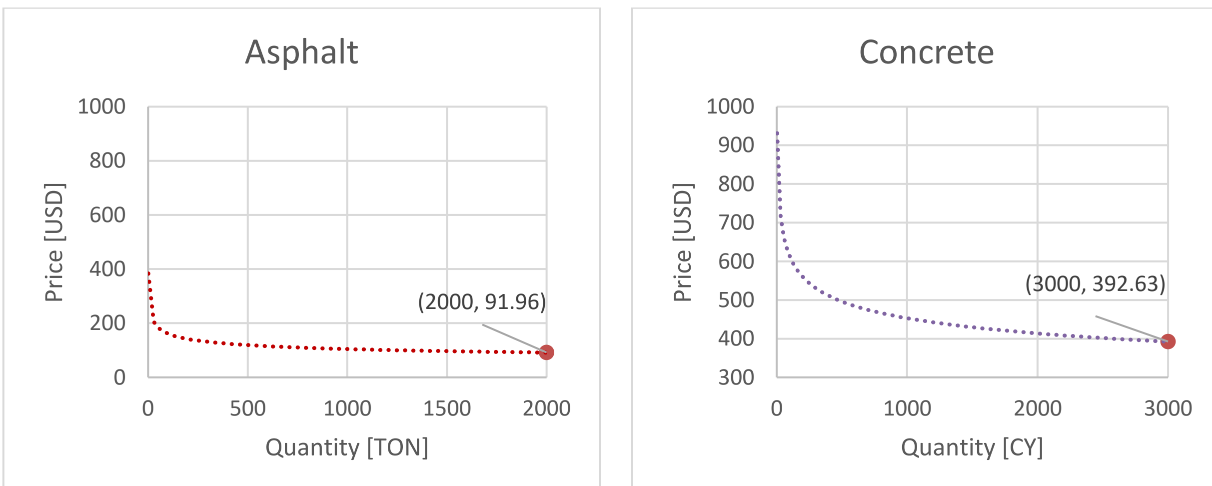

Figure 0-2 Asphalt and Concrete Quantity vs Price Curves for Period 2

Table 1-1 Traditional Cost Indexing Approaches

Period	Asphalt		Concrete		Traditional Indexes		
	Quantity [TON]	Price [$]	Quantity [CY]	Price [$]	Laspeyres	Paasche	Fisher
P1	200	134.06	250	495.24	1.00	1.00	1.00
P2	2000	91.96	3000	392.63	0.774	0.777	0.775

A considerable portion of the Dissertation efforts were focused on addressing two critical factors in effective cost forecasting: 1) the selection of a suitable construction cost index (CCI) and 2) the appropriate analysis of the selected CCI to produce a constant inflation rate. The CCI is intended to illustrate the past behavior of the construction market. At the same time, the inflation rate is a simplified mathematical representation of behavior that is expected to continue along the intended forecasting time horizon, which is considered a typical cost forecasting process. These two factors are deemed critical since both should be adequately addressed in order to produce cost forecasts effectively. There is no point in implementing a mechanism to identify the most suitable CCI if the agency does not know how to analyze it to generate a reliable inflation rate. Likewise, the skills to produce reliable inflation rates from the analysis of any CCI would not be sufficient if the composition of the selected CCI does not somewhat match the scope of work under consideration.

Research efforts and findings associated with the two critical factors mentioned above are discussed in this Dissertation. The implementation of this methodology is illustrated in the three case study agencies as it is applied to assess and compare the suitability of several cost indexing alternatives. Those alternatives include external and in-house CCIs, as well as an alternative cost indexing system called a Multilevel Construction Cost Index (MCCI). MCCIs were developed for each agency using the collected historical bid data. The quantitative analysis demonstrated the superior accuracy of the MCCI in tracking price fluctuations over time, as well as its ability to better adapt to different scopes of work and to handle other program-/project-specific considerations.

Later in this document, various approaches for the generation of annual inflation rates from CCIs as they are applied to the case study agencies will be discussed. Those approaches include the use of simple and compounded inflation rates, as well as regression analysis and an alternative method proposed by the author called Moving Forecasting Error (MFE). Cost forecasting approaches were evaluated on their forecasting accuracy and reliability over different forecasting time horizons; their ability to factor geographic considerations and program-/project-specific requirements; and their associated staffing, data, and information technology requirements.

1.4 Motivation

Survey data was collected with an online survey sent to STAs, targeting professionals working in multiple offices usually involved in the development of mid-term, intermediate, and long-range cost estimates. A total of 20 responses were received through the online survey platform, including one from a local transportation agency (Contra Costa Transportation Authority [CCTA], California). Some STAs replied to the survey by sending electronic documents to the author describing their standard procedures for the development of Long-Range Transportation Plans (LRTP) or State Transportation Improvement Programs (STIPs). Further efforts were made to collect relevant policy documents from all other STAs in order to facilitate a better understanding of current transportation planning and cost forecasting practices. Manuals and standard procedures from *all 50 STAs* were reviewed in this study, including documents from STAs that also completed the survey. Figure 1-3 shows the STAs that responded to the online survey.

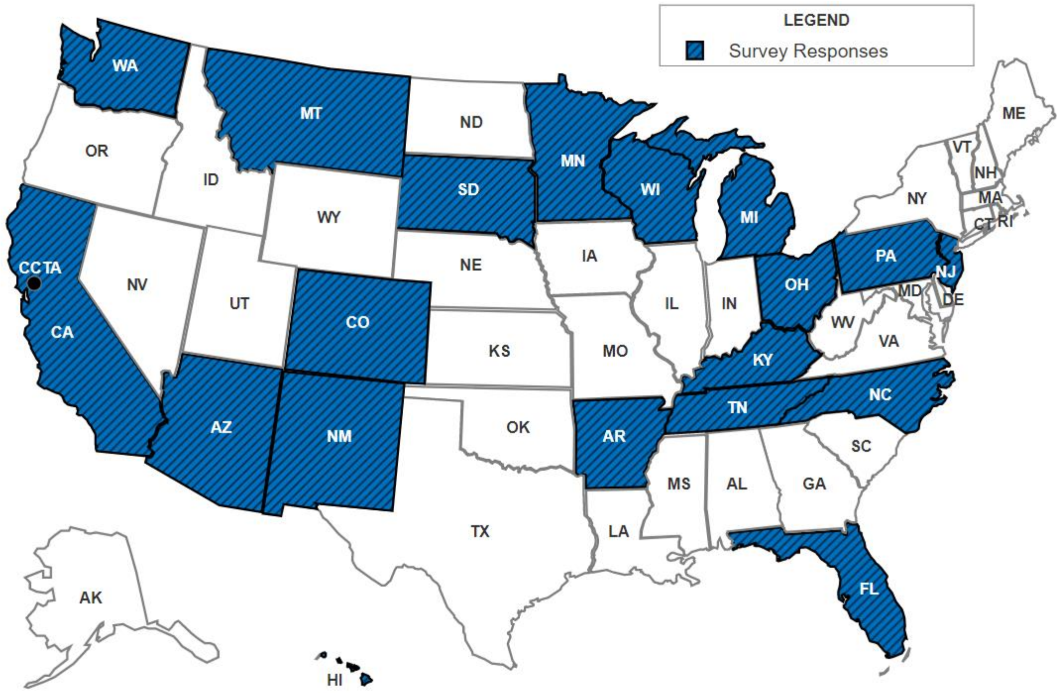

Figure 0-3 Survey Responses and Policy Documents Reviewed.

The current state-of-the-practice of construction cost forecasting is represented in Figure 1-4. It shows a fair representation of the typical cost forecasting process currently implemented by STAs. In general, once the scope of a given program has been defined, a cost estimate in current dollars is performed, which is projected into the future using a given inflation rate. Ideally, the inflation rate should be determined as a function of the intended scope of work, but that does not seem to be the case among STAs. In fact, a number of agencies use standard one-size-fits-all inflation rates to forecast costs for all transportation programs regardless of their anticipated scopes.

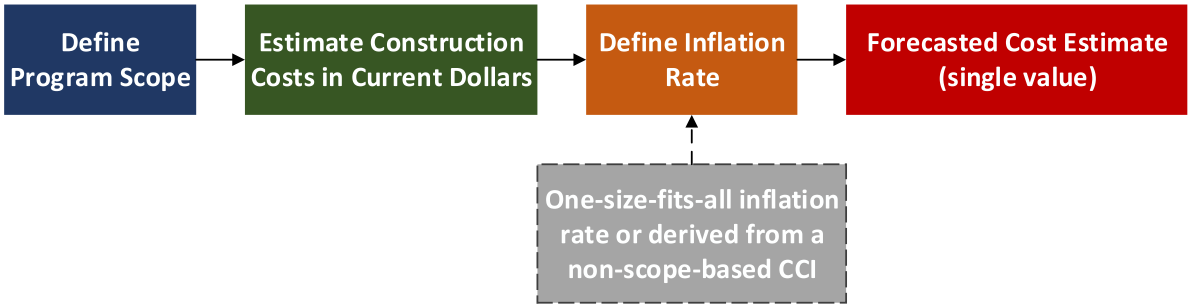

Figure 0-4 Current Typical Cost Forecasting Process.

A few agencies estimate inflation rates using CCIs to identify market trends; however, the CCIs being used are also usually one-size-fits-all indexes or CCIs with calculation inputs that do not align or are completely unrelated to the intended scope of work. The mathematical procedure to apply the inflation rate across the desired forecasting time horizon depends on the type of rate (i.e., fixed simple, fixed compounded, or variable), but regardless of the calculation approach, it usually yields a single-value estimate that ignores the unavoidable uncertainty inherent in the cost forecasting process. It was found that the longer the forecasting time horizon, the less likely formal risk analysis methods are used by STAs to account for estimating uncertainty.

Using the state-of-the-practice in construction cost forecasting over long time horizons the ideal cost forecasting process was design, as shown in Figure 1-5. This state-of-the-practice was defined via a thorough analysis of information collected through a comprehensive literature review, an online survey administered to STAs, and feedback provided by the AASHTO Technical Committee on Cost Estimating (TCCE). It was concluded from a discussion with TCCE members that an ideal cost forecasting system should be able to handle different scopes of work at various levels of detail and for different forecasting time horizon. STAs are dealing with a certain degree of variability in the level of detail in the scope of construction activities forecasted across long time periods. For example, LRTPs usually involve broad scopes of work, but sometimes, they could include specific capital projects defined at a higher level of detail, and whose associated costs are forecasted over 20-25 years. TCCE members also indicated that forecasting a capital project expected cost over a 20-year period does not necessarily mean that the agency is planning to execute the project in approximately 20 years. Rather, it means that decision-makers are considering executing the project within the next 20 years. It could potentially be approved and awarded in 15 years or less. Therefore, it would be more appropriate to provide decision-makers with a forecasting timeline showing the progression of the cost forecast as it moves across the desired forecasting time period. Finally, the TCCE highlighted the importance of producing risk-based outputs to account for estimating uncertainty and to facilitate the communication of such uncertainty to different types of stakeholders and decision-makers. This led the author to propose the risk-based forecasting timeline shown in Figure 1-5 as the ideal cost forecasting output.

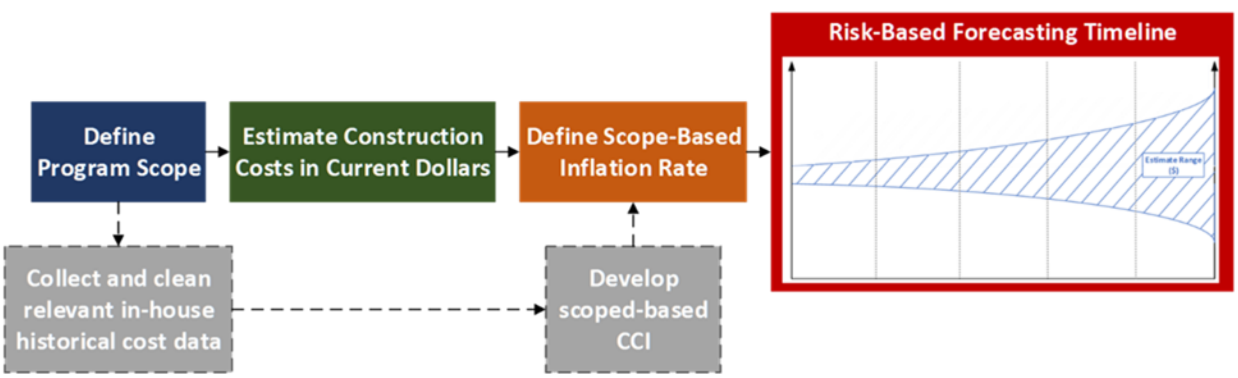

Figure 0-5 Ideal Cost Forecasting Process.

From the Federal Highway Administration's (FHWA) perspective, an ideal cost forecasting system should use in-house historical cost data as the main reference for the determination of applicable inflation rates. “Local historic cost data and experience with cost inflation are valuable data sources for use in projecting future rates” (FHWA 2017). This logic explains the use of in-house historical cost data suggested in Figure 1-5.

There has also been a concurrent study sponsored by the FHWA aimed towards developing a methodology to improve cost estimating accuracy and reliability through the appropriate use of CCIs. This study has recognized the need for flexible cost indexing methodologies that allow the customization of CCIs to the specifics of each project, such as the scope-based CCIs shown in Figure 1-5 that facilitate the generation scope-based inflation rates. Cost indexing systems with that level of flexibility, and built through a similar methodology, have been developed by two separate studies conducted for MnDOT (Gransberg and Rueda 2014) and the Alabama Department of Transportation (ALDOT) (Pakalapati and Rueda 2018). Those studies have demonstrated the ability of an innovative cost indexing system to overcome the limitations of traditional CCIs. This innovative system is called Multilevel Construction Cost Index (MCCI).

An MCCI consists of a group of indexes organized in a multilevel arrangement, allowing to forecast each individual cost element in a program or project with the MCCI index that best matches its scope. Costs for different programs/projects are forecasted with different sets of indexes, offering great flexibility to customize the forecasting process to the specifics of each scope of work. Although the MCCIs developed and evaluated in this study follow a similar arrangement of multiple indexes, the author has taken advantage of this opportunity to improve the methodology used in the previous studies by proposing a more effective method to calculate and update index value. This approach is considerably different from the one used in the previous two studies, and this is the first time that the MCCI methodology is tested for a forecasting application.

Additionally, a more reliable methodology was designed and applied to assess the forecasting performance of cost indexing systems. As explained in Chapter 4, it was used to find the best MCCI configuration and to evaluate the suitability of external and/or in-house CCIs. Thus, the STA that decides not to implement the proposed MCCI system could still use this methodology to identify the most suitable non-MCCI alternative.

1.5 Cost Indexes and Inflation Rates

Calculating an inflation rate for a single item or commodity is a fairly easy task. It becomes more difficult when the needed inflation rate is intended to represent a group of items or commodities. The following is a hypothetical example used to explain the difficulty in calculating the latter. An STA estimates that the price for Commodity A has increased 200% over the last five years, while the price for Commodity B decreased by 10% during the same period of time. What is the combined inflation rate for these two items (single rate)? The considerable increase in the price of Commodity A could suggest a positive combined inflation rate. However, what if Commodity B is asphalt and Commodity A is steel. As occurs with most STAs, asphalt is the most significant material for the agency under consideration in terms of cost, while the cost of steel has a considerably lower impact on the STA's budget.

In order to calculate the combined inflation rate for this example, it is first necessary to determine how much more significant Commodity B is compared to Commodity A, in terms of usage. After determining the relative relevance of each commodity, the agency would need to find a mechanism to facilitate an "apples-to-apples" integration of these two commodities. That mechanism is a CCI. Cost indexes can track prices for a single item or can be designed to integrate multiple goods and services into a single economic indicator taking into consideration the level of relevance (relative weight) of each item. That is called a composite CCI. Thus, a composite CCI between Commodities A and B could be developed and analyzed to define current market trends that would provide an overall combined inflation rate for both commodities.

Macroeconomic inflation rates in the U.S. are commonly estimated using the Consumer Price Index (CPI) published by the Bureau of Labor Statistics (BLS). The CPI is calculated from monthly price fluctuations of about 80,000 items in a market basket of goods and services purchased by urban consumers (BLS 2018a). A wide range of goods are used in the calculation of the CPI, including items such as milk, shampoo, rent, household keeping supplies, apparel, gasoline, medical care, recreation services, college tuition and fees, and funeral services (BLS 2018b). The Bureau of Economic Analysis (BEA) maintains a similar broad index called the Personal Consumption Expenditures (PCE) price index. The PCE price index is calculated for a slightly different market basket using other quantitative methods and under different assumptions than those applied to the CPI, but it is still based on a broad set of goods and services regularly consumed by the general public. Despite the fact that the CPI and PCE are not calculated with construction-related inputs, they seem to be a popular option among STAs to support cost estimating processes. That is not a practice recommended by this study due to the evident lack of connection between the index inputs and the construction industry.

Two separate indexes developed for the same purposes, such as the CPI and PCE, are likely to yield different inflation rates (Rueda Benavides 2016). Such differences would depend on the data source, index composition, and index calculation approach, and might pose a dilemma for STAs when a CCI needs to be selected. Rueda and Gransberg (Rueda-Benavides and Gransberg 2015) approached this dilemma by suggesting that the most suitable index should be the one that best satisfies two principles: the matching and proportionality principles, as mention in 1.2.

The FHWA also discusses the possibility of using external construction cost indexes (CCIs) to estimate inflation rates, but also in the absence of better information and methods. In this study, an external CCI refers to a cost index not developed by the agency or exclusively for the agency. Some external CCIs are published by the BLS, BEA, the Engineering News-Record (ENR), and the FHWA itself, which publishes the National Highway Construction Cost Index (NHCCI) on a quarterly basis.

1.5.1 Types of Inflation Rates

Inflation rates are used to estimate future construction costs in "year of expenditure dollars." Basically, when used in cost forecasting, an inflation rate is intended to represent an anticipated future trend in the construction market inferred from the analysis of relevant historical data. However, there are different approaches that can be used to approximate and incorporate inflation rates into the cost forecasting process. This study has identified two main types of inflation rates:

- Fixed Annual Inflation Rate – Simple (Not Compounded)
- Fixed Annual Inflation Rate – Compounded Annually
- Variable Annual Inflation Rate

Variable Annual Inflation Rate

A variable annual inflation rate means that different inflation rates can be considered for different years within the intended forecasting time horizon. This is a suitable approach when the historical cost data shows seasonal or cyclical effects or if estimators foresee specific future events that might affect construction costs. Table 1-2 shows the variable inflation rate used by the Florida Department of Transportation (FDOT) during fiscal year 2018/2019 to forecast construction costs over one to ten years (FDOT 2018). The multiplier in the third column of this table is intended to simplify the calculation of construction cost in future dollars. After calculating costs in current dollars, the forecasted value is obtained by adjusting the current estimate using the multiplier from the desired forecasting time horizon. For example, Equations 1.4 to 1.5 show how the multiplier for fiscal year 2023/2024 is calculated. Likewise, Equation 1.7 shows how this multiplier would be used to forecast construction costs for a project to be executed during fiscal year 2023/2024 with a current cost estimate of $10 million (in 2018/2019 dollars; five-year forecast). STAs forecast construction costs using either the letting date or the mid-point of the construction period as the end point of the inflation calculation. The FDOT's document from which Table 1-2 was taken (FDOT 2018) does not specify the end-point of the forecasting period; therefore, for the purposes of this study, it is assumed that the project under consideration will be awarded and completed during fiscal year 2023/2024.

Table 1-2 FDOT Construction Cost Inflation Rates (FDOT 2018)

Fiscal Year	Annual Inflation Rates	Multiplier
19/20	2.6%	1.026
20/21	2.6%	1.053
21/22	2.7%	1.081
22/23	2.8%	1.111
23/24	2.9%	1.144
24/25	3.0%	1.178
25/26	3.1%	1.214
26/27	3.2%	1.253
27/28	3.3%	1.295
28/29	3.3%	1.337

$$FCE_n = CCE \times (1 + i_1) \times (1 + i_2) \ldots \times (1 + i_n) \quad (0.4)$$

$$FCE_5 = CCE \times (1 + 0.026) \times (1 + 0.026) \times (1 + 0.027) \times (1 + 0.029) \times (1 + 0.029) \quad (0.5)$$

$$FCE_5 = CCE \times 1.144 \quad (0.6)$$

$$FCE_5 = \$10{,}000{,}000 \times 1.144 = \$1{,}144{,}000 \quad (0.7)$$

Where: $n = Length\ of\ forecasting\ time\ horizon\ in\ years$
$FCE_n = Forescasted\ cost\ estimate\ over\ n\ years\ (in\ future\ dollars)$
$CCE = Current\ cost\ estimate\ (in\ current\ dollars)$
$i_n = Inflation\ rate\ at\ year\ n$

Fixed Annual Inflation Rate – Compounded Annually & Simple

Some STAs have set fixed annual inflation rates, which represent the average annual growth in construction prices to be expected along the forecasting time horizon. This is a common practice among STAs, but not all STAs apply the fixed inflation rate in the same way. It could be either a compounded or a simple inflation rate. A compounded annual inflation rate is applied every year to the cumulative inflation up to the previous year. This is the approach adopted by the Pennsylvania Department of Transportation (PennDOT), which is currently using a 3% inflation rate compounded annually. Equations 1.8 and 1.9 show how PennDOT would apply this interest rate to develop a five-year forecast for a $10 million project. The calculation process is the same as the one shown in Equation 1.4 for the variable inflation rate, but since in this case the inflation rate is the same every year, Equation 1.4 can be reduced to Equation 1.8.

$$FCE_n = CCE \ \times (1 + i)^n \tag{0.8}$$

$$FCE_5 = \$10{,}000{,}000 \ \times (1 + 0.03)^5 = \$11{,}592{,}740.74 \tag{0.9}$$

Where: $n = Length\ of\ forecasting\ time\ horizon\ in\ years$
$FCE_n = Forescasted\ cost\ estimate\ over\ n\ years\ (in\ future\ dollars)$
$CCE = Current\ cost\ estimate\ (in\ current\ dollars)$
$i = Fixed\ annual\ inflation\ rate$

When a simple interest rate is used (not compounded), the projected cost is increased by the same number of dollars every year, and the magnitude of the increase is equal to the cost estimate in current dollars multiplied by the fixed annual inflation rate. The New Jersey Department of Transportation (NJDOT) uses a 3% fixed annual inflation rate to forecast construction costs, but unlike PennDOT, NJDOT does not apply this inflation rate in a compounded manner. Equations 1.10 and 1.11 show the forecasted cost estimate for the same example used above if a 3% simple interest rate is used.

$$FCE_n = CCE + (CCE \times i \times n) \tag{0.10}$$

$$FCE_5 = 10{,}000{,}000 + (10{,}000{,}000 \times 0.03 \times 5) = \$11{,}500{,}000 \tag{0.11}$$

Where: $n = Length\ of\ forecasting\ time\ horizon\ in\ years$
$FCE_n = Forescasted\ cost\ estimate\ over\ n\ years\ (in\ future\ dollars)$
$CCE = Current\ cost\ estimate\ (in\ current\ dollars)$
$i = Fixed\ annual\ inflation\ rate$

Figure 1-6 shows the difference between a 5% simple and a 5% compounded inflation rate when applied to a $10-million project (current-dollar estimate) over 20 years. Even though the two curves start deviating from each other after the first year, the difference between them starts becoming evident after the fifth year, suggesting that there is no significant difference in applying a simple and compounded inflation rate for mid-term forecasts. The difference between the approaches increases as the forecasted time horizon is extended. This is always the case for positive fixed annual inflation rates, which is the common assumption made by STAs. Even though it is not unusual for STAs to experience deflation in their construction prices due to the drop in the price of key commodities, these are usually short-term downward trends. As shown in Figure 1-6, a fixed compounded inflation rate is more suitable when an exponential increase in construction prices is expected or assumed while a simple inflation rate assumes a linear growth trend.

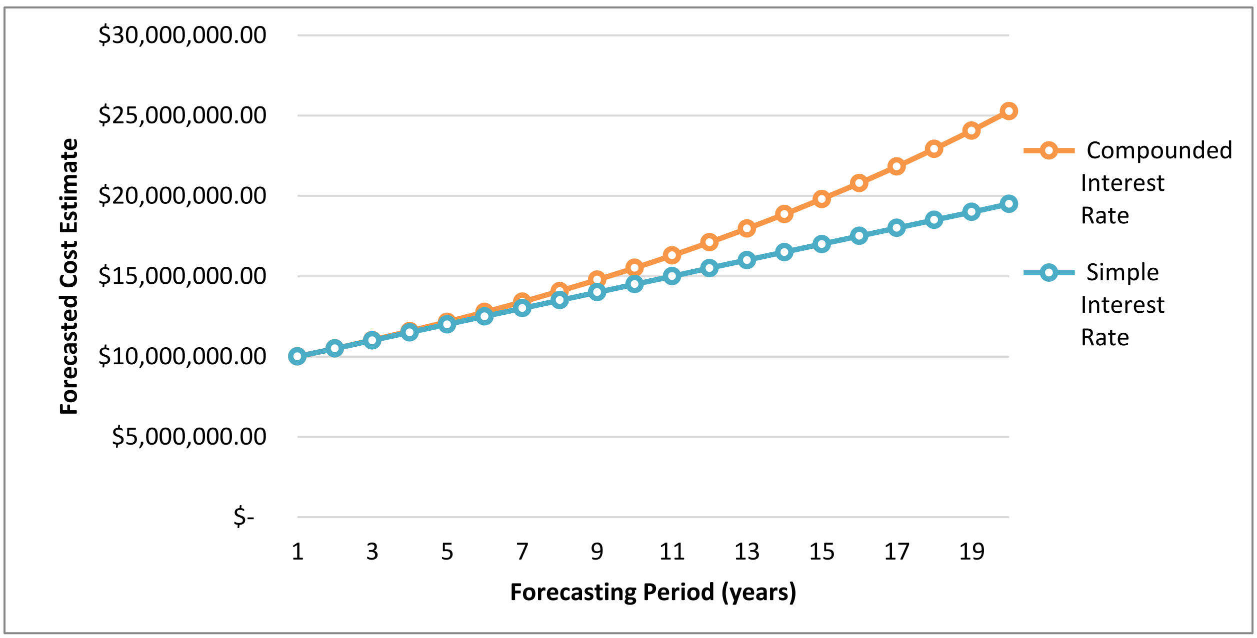

Figure 0-6 Fixed Compounded Inflation Rate vs. Fixed Simple Inflation Rate at 5% inflation

1.6 Organization of the Dissertation

To provide a comprehensive description of the research performed, this Dissertation was divided into eight chapters and they were organized as follows:

- **Chapter 1: Introduction.** Chapter 1 presents some background information to facilitate a better understanding of the purpose and content of the Dissertation. The chapter includes general information, a brief comparison between current and ideal cost forecasting practices, and some relevant information on the use of CCIs and inflation rates.
- **Chapter 2: Literature Review and State-of-the-Practice in Construction Cost Forecasting**. discusses the state-of-the-practice in long-term cost forecasting for transportation construction projects and programs. Information presented in this chapter is the result of a comprehensive literature review on current practices used by STAs and by practitioners in other industries, an online survey administrated to STAs, and feedback provided by the EAP.
- **Chapter 3: Research Methodology.** Discusses the methodology followed by the author to conduct case studies with MnDOT, CDOT, and DelDOT. The chapter also presents some general information on the development and use of MCCIs.
- **Chapter 4: Data Collection and Cleaning Protocol.** Presents all the detailed steps followed in order to illustrate the process that other agencies would need to follow to gather all the required information required for the following phases.
- **Chapter 5: Protocol to develop scope-based MCCIs.** Details a process to conduct a comparative suitability analysis to identify the most suitable cost indexing alternative for a given scope of work. The process is explained as it is applied to identify the best cost

indexing alternative for different geographic regions associated with each case study agency.

- **Chapter 6: Protocol to develop scope-based Inflation Rates.** Continues with the case studies by applying various forecasting approaches on sample scopes of work. The purpose of this chapter is to illustrate the application of different cost forecasting approaches, as well as to assess their ability to handle mid-term, intermediate, and long-range forecasting periods.
- **Chapter 7: Conclusions and Recommendations.** Discusses the final recommendations and cost forecasting methods resulting from this Dissertation.

2. LITERATURE REVIEW AND STATE-OF-THE-PRACTICE IN CONSTRUCTION COST FORECASTING

2.1 Introduction

This chapter summarizes the state-of-the-practice in construction cost forecasting over long time horizons defined via a thorough analysis of information collected through a comprehensive literature review, an online survey targeted at state transportation agencies' (STAs') staff working in offices/groups involved in cost forecasting processes, and input provided by an Expert Advisory Panel (EAP) formed by members of the AASHTO Technical Committee on Cost Estimating (TCCE). This chapter discusses some aspects related to STAs' cost forecasting practices, including cost estimating practices in transportation programs, distribution of responsibilities; factors considered in the forecasting process; forecasting methods and tools; and current risk analysis practices in cost forecasting.

2.2 Transportation Programs and Forecasting Time Horizons

The maintenance, improvement, and rehabilitation of the national transportation infrastructure is a never-ending effort led by STAs. These efforts are carried out with financial resources administered on a fiscal year basis. However, the number of infrastructure's needs at any given time exceeds the funding, staff, and management capabilities of STAs within a single fiscal year. This often forces these agencies to commit funds from future fiscal years in order to meet these needs, which results in postponing lower priority projects. Approved projects could also be postponed to future fiscal years for non-monetary reasons such as environmental mitigation, permitting, right-of-way, utility relocation issues, or simply because they are part of a strategic schedule for a multi-year infrastructure maintenance, rehabilitation, or expansion program. In summary, even though financial resources are managed on a fiscal year basis, financial planning efforts must consider longer periods of time, sometimes covering periods of over 20 years. It also results in the long-term commitment of resources required to implement these long-term plans.

The construction and maintenance activities associated with these multi-year planning efforts are broken down into multiple plans/programs (hereinafter referred to as programs) varying by scope, purpose, and number of years. Different STAs could implement different sets of planning programs. A STA may be required to deal with some overlapping in scope and content between programs as a result of efforts to comply with regulations at different government levels. The following are brief descriptions of programs commonly implemented by STAs. It should be noted that descriptions for some of these programs may vary between agencies.

- ***Long-Range Transportation Plan (LRTP)*****:** "A document resulting from regional or statewide collaboration and consensus on a region or state's transportation system and serving as the defining vision for the region's or state's transportation systems and services" (FHWA 2017). LRTPs are required to cover a period of no less than 20 years (Title 23 U.S. Code 2018). For metropolitan areas, LRTPs are usually referred to as *Long-Range Metropolitan Transportation Plans (MTPs)*.
- ***Intermediate Range Plan (IRP):*** Some STAs have implemented "an intermediate-range plan forming a bridge between short-range programming […] and long-range planning" (Idaho Transportation Department 2009). "The baseline project definition, cost, and

schedule should be set prior to programming a project into the IRP or no later than before a project is included in the STIP" (Molenaar, Anderson, and Schexnayder 2011).

- ***State Transportation Improvement Programs (STIP):*** The STIP is a mid-term transportation and capital improvements program. It "lists Federally-funded transportation projects that are located outside Metropolitan Planning Organization (MPO) boundaries (GDOT 2016).
- ***Transportation Improvement Program (TIP):*** "The metropolitan transportation planning process shall include development of a transportation improvement program (TIP) for the metropolitan planning area by the MPO in cooperation with the State and public transit operators" (Title 23 U.S. Code 2018). A TIP is included into the STIP directly or by reference, without making any modifications to the plan approved by the MPO (Title 23 U.S. Code 2018). The TIP updating cycle must match the cycle of the STIP (Title 23 U.S. Code 2018).
- ***Transportation Asset Management Program (TAMP):*** "Transportation Asset Management Plans (TAMPs) act as a focal point for information about the assets, their management strategies, long-term expenditure forecasts, and business management processes" (FHWA 2017).
- ***Bridge Management Program (BMP):*** The BMP is usually part of the TAMP. It is intended to manage the bridge inventory, as well as to "evaluate bridge condition, predict deterioration, and guide decision-making" (INDOT 2013).
- ***Pavement Management Program (PMP):*** The PMP is also part of the TAMP. The PMP: "1) assesses the current pavement condition, 2) predicts future pavement condition, 3)

determines maintenance and rehabilitation needs, and 4) prioritizes these needs to make the best use of anticipated funding levels (i.e., maximizing benefit while minimizing costs)" (Mississippi Department of Transportation 2017).

Some programs may be of mandatory implementation due to federal, state, or local regulations. For example, according to the US Code of Federal Regulations (US-CFR), when federal funds are involved, STAs are required to develop LRTPs with a minimum 20-year forecast period as well as mid-term STIPs (Title 23 U.S. Code 2018). Likewise, MPOs must coordinate with their respective STAs to prepare MTPs and TIPs consistent with statewide LRTPs and STIPs (Title 23 U.S. Code 2018). Table 2-1 is an example of a set of transportation programs implemented by a DOT, this table lists some of the transportation programs developed by the Texas Department of Transportation (TxDOT) and MPOs in Texas (TxDOT 2015).

The Moving Ahead for Progress in the 21st Century Act (MAP-21), enacted in 2012, "requires all State DOTs to develop a risk-based TAMP that, at a minimum, addresses pavements and bridges on the National Highway System" (NYSDOT 2014). The TAMP must be reviewed and approved "not less frequently than once every four years" (Title 23 U.S. Code 2018). To comply with this act, some STAs have broken down their TAMPs into multiple smaller programs, such as BMPs and PMPs. TAMPs are not exclusively intended for budgeting purposes. In fact, they are mainly aimed to monitor the physical condition of existing infrastructure assets, predict deterioration, and coordinate maintenance and construction activities across the state. However, TAMPs are required to include a financial plan and lifecycle cost analyses (Title 23 U.S. Code 2018), whose effectiveness relies on the agency's cost forecasting practices. This is where this Dissertation will contribute to the effective development of TAMPs. It must be noted that some states are still in the process of developing their TAMPs.

Table 2-1 TxDOT Transportation Plans and Programs (TxDOT 2018)

Program	Developed by	Approved by	Time Period	Content	Update Cycle
TxDOT Strategic Plan	TxDOT	TTC	5 Years	TxDOT's operational goals and strategies	Every 2 years
Texas Transportation Plan (LRTP)	TxDOT	TTC	20+ Years	Future goals, strategies, and performance measures for the multimodal transportation system	Every 4 years
MTP - Attainment	MPOs	MPO Policy Board	20+ Years	Policies, programs, and projects for development that respond to adopted goals and expenditures for state and federal funds over the next 20+ years	Every 5 years
MTP - Non-Attainment	MPOs	MPO Policy Board	20+ Years	Policies, programs, and projects for development that respond to adopted goals and expenditures for state and federal funds over the next 20+ years	Every 4 years
Unified Transportation Program (UTP)	TxDOT	TTC	10 Years	Multi-modal projects to be funded in a 10-year period	Annual
TIP - TxDOT Rural	TxDOT Districts	Governor	4 Years	Multi-modal transportation projects/investments	Every 2 years
TIP - MPO	MPOs	MPO Policy Board	4 Years	Multi-modal transportation projects/investments	Every 2 years
STIP	TxDOT	USDOT (FHWA/FTA)	4 Years	Multi-modal transportation projects/investments	Every 2 years
State Implementation Plan (SIP)	TCEQ & Non-Attainment MPOs	EPA	N/A	A description of control strategies, or measures to deal with pollution, for areas that fail to achieve national ambient air quality standards (NAAQS)	Revised as needed

TCEQ = Texas Commission on Environmental Quality; TTC = Texas Transportation Commission

IRPs are not mandated by federal regulation, but they may be implemented by some agencies to comply with state/local statutes. As stated by the Idaho Transportation Department (Idaho Transportation Department 2009), an IRP works as a "bridge between short-range programming […] and long-range planning." This means that when STAs do not use an IRP, projects are moved from the LRTP directly into the STIP (Molenaar, Anderson, and Schexnayder 2011).

LRTPs, IRPs, and STIPs may also mark the first steps of the cost estimating process in transportation construction before entering into a short-term planning phase. The estimation of transportation construction costs is an iterative process that occurs at multiple points during the project life cycle (Schwaber 2003). As shown in Figure 2-1, the longer the time horizon, the greater the estimating uncertainty due to the fact that many factors influencing construction costs are undefined at early project development phases (Touran and Lopez 2006). In fact, specific projects are usually undefined and unknown in a LRTP, and when they are identified, they are defined at a conceptual level. Cost estimates in LRTPs are usually presented on a lump sum basis or broken down into broadly defined goals, such as "maintain state of good repair for existing state-owned bridges" (TxDOT 2015). As a program evolves into downstream planning and programing activities, more details are available to facilitate and define specific projects, and consequently, allowing for more accurate cost estimations (Gransberg, Scheepbouwer, and Loulakis 2015).

Figure 2-1 illustrates the increasing cost certainty experienced by transportation programs as they move from a long-range planning stage to their actual execution through the award of construction contracts. Additionally, this figure links the different forecasting time horizons with their respective estimate range based on the *AASHTO Practical Guide for Cost Estimating* (Molenaar, Anderson, and Schexnayder 2011). The "Estimate Range" in this figure refers to estimating accuracy. Thus, early in the planning phase, when developing LRTPs for time horizons over 20 years, construction cost estimates are expected to be either as low as half of the actual construction cost at program completion, or as high as twice that amount (see Figure 2-1). Although the AASHTO Practical Guide for Cost Estimating is not completely clear about the sources of uncertainty considered in the proposed estimate ranges, they seem to represent the total uncertainty accumulated throughout the entire cost estimating process.

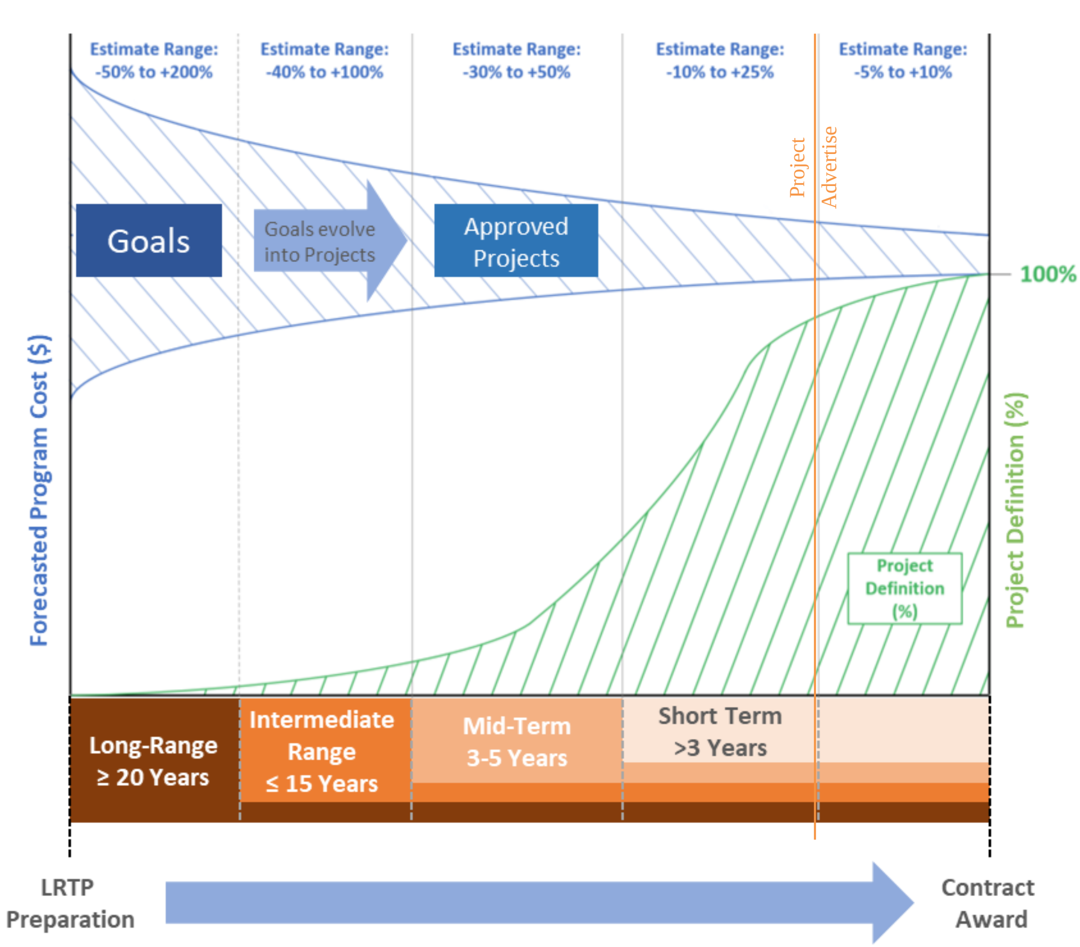

Figure 2-1 Cost Forecasting Uncertainty over Time.

Mid-term (3 to 5 years), intermediate-range (up to 15 years), and long-range (more than 20 years) forecasting time horizons are generally associated with LRTPs, IRPs, and STIPs/TIPs, respectively. However, survey responses and policy documents show some variability in the length of the forecasting periods for these programs, as well as in TAMPs, BMPs, and PMPs. Figure 2-2 illustrates the variability in the length of forecasting periods for different transportation programs and the different updating frequencies adopted by STAs across the state.

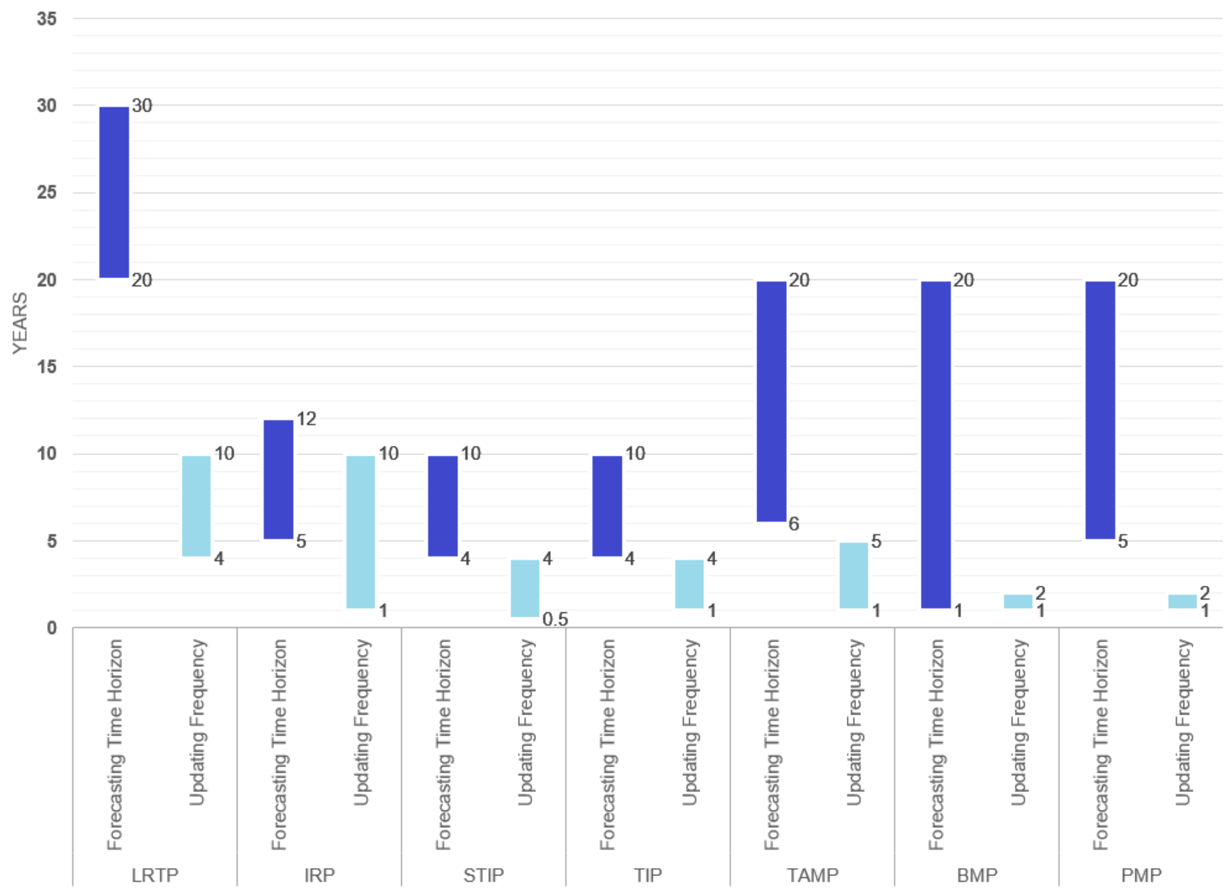

Figure 2-2 Forecasting Time Horizons and Updating Frequency for Transportation Programs.

Forecasting time periods and updating frequencies for transportation programs are usually regulated by federal, state, or local statutes, which establish minimum standards that must be met or exceeded by STAs. For example, the US-CFR establishes that LRTPs must be developed with a minimum 20-year forecast period (Title 23 U.S. Code 2018), which allows for time periods longer than 20 years. Research has found 30-year LRTPs prepared by some STAs, including the California Department of Transportation (Caltrans) (CalTrans 2006). Likewise, the current LRTP implemented by the Connecticut Department of Transportation (ConnDOT) covers a 32-year period ranging from 2018 to 2050 (ConnDOT 2018). The time period for LRTPs may also vary within a STA. For example, the current LRTP of the Georgia Department of Transportation (GDOT) covers a 25-year period, from 2015 to 2040. It was developed to replace GDOT's 30-year LRTP with goals and infrastructure needs to be addressed between 2005 and 2035 (GDOT 2016). Table 2-2 shows other examples of forecasting time horizons found in previous and current LRTPs for each of the 50 STAs (one example per STA).

According to federal regulations, STIPs must "cover a period of no less than 4 years and shall be updated every 4 years, or more frequently" (Title 23 U.S. Code 2018). Some STAs have decided to exceed this minimum federal requirement by implementing longer STIPs and more frequently updating schedules. This is the case of the New Jersey Department of Transportation (NJDOT) and North Carolina Department of Transportation (NCDOT), whose 10-year STIPs are updated every two years (NJDOT 2018; NCDOT 2018). Wisconsin Department of Transportation (WisDOT) STIP is updated every six months and its forecasting periods may vary from six to ten years (WisDOT 2018). STAs may decide to exceed federal requirements by implementing longer forecasting time periods and/or more frequent updating schedules in order to either meet stricter state or local regulations or because it could better fit their planning needs and management practices. For example, longer STIPs may be motivated by the need to facilitate a better transition from the LRTP to the STIP without implementing an IRP. Federal and state statutes associated with transportation programs seem to be less restrictive for TAMPs, BMPs, and PMSs regarding required time horizons and updating cycles. Forecasting periods for these programs range from 5 to 20 years.

Table 2-2 Forecasting horizons for the Statewide Transportation Plans (LRTP)

State	LRTP Period	State	LRTP Period	State	LRTP Period
Alabama	**2017-2040**	Louisiana	**2012-2042**	Ohio	**2014-2040**
Alaska	**2016-2036**	Maine	**2018-2050**	Oklahoma	**2014-2040**
Arizona	**2016-2040**	Maryland	**2018-2040**	Oregon	**2006-2031**
Arkansas	**2015-2040**	Massachusetts	**2019-2040**	Pennsylvania	**2016-2040**
California	**2010-2040**	Michigan	**2005-2030**	Rhode Island	**2013-2035**
Colorado	**2008-2035**	Minnesota	**2015-2040**	South Carolina	**2014-2040**
Connecticut	**2018-2050**	Mississippi	**2016-2040**	South Dakota	**2010-2030**
Delaware	**2010-2030**	Missouri	**2018-2043**	Tennessee	**2017-2040**
Florida	**2018-2044**	Montana	**2017-2045**	Texas	**2014-2040**
Georgia	**2016-2040**	Nebraska	**2012-2030**	Utah	**2015-2040**
Hawaii	**2015-2035**	Nevada	**2018-2038**	Vermont	**2016-2040**
Idaho	**2018-2040**	New Hampshire	**2010-2030**	Virginia	**2005-2025**
Illinois	**2017-2037**	New Jersey	**2008-2030**	Washington State	**2010-2035**
Indiana	**2013-2035**	New Mexico	**2015-2040**	West Virginia	**2017-2045**
Iowa	**2012-2040**	New York	**2005-2030**	Wisconsin	**2000-2030**
Kansas	**2008-2028**	North Carolina	**2012-2040**	Wyoming	**2014-2040**
Kentucky	**2014-2035**	North Dakota	**2015-2040**	-	**-**

2.2.1 Transportation Programs Content and Configuration

In addition to the different forecasting time horizons involved in transportation, STA must also deal with great variability in the configuration and level of detail in the content transportation programs. Federal and state statutes offer general guidance on the required content and structure of transportation programs, providing STAs with some flexibility in the processes to develop and organize their programs. For example, besides being required by the CFR to consider all modes of transportation across the state, MAP-21 requires STAs and MPOs adopt a performance-based approach for all federally required transportation programs. Transportation agencies have been required to establish performance targets associated with the seven national performance goals summarized in Table 2-3, in addition to other specific state/local goals and infrastructure needs. Regardless of these requirements, STAs have wide latitude in the determination of planning strategies and methodologies that they believe best facilitate the achievement of the national performance goals.

Table 2-3 National Performance Goals (23 U.S. Code §150, 2018)

Goal Area	National Performance Goals
Safety	To achieve a significant reduction in traffic fatalities and serious injuries on all public roads
Infrastructure condition	To maintain the highway infrastructure asset system in a state of good repair
Congestion reduction	To achieve a significant reduction in congestion on the National Highway System
System reliability	To improve the efficiency of the surface transportation system
Freight movement and economic vitality	To improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development
Environmental sustainability	To enhance the performance of the transportation system while protecting and enhancing the natural environment
Reduced project delivery delays	To reduce project costs, promote jobs and the economy, and expedite the movement of people and goods by accelerating project completion through eliminating delays in the project development and delivery process, including reducing regulatory burdens and improving agencies' work practices

The level of detail in a transportation program mainly refers to the degree of detail in the definition of the strategies, methods, and anticipated projects required to achieve the intended performance targets. The level of detail of a given program is also reflected in the configuration of its financial plans and cost estimates. Figure 2-3 summarizes survey responses on the configuration of cost estimates for each type of program. This figure shows how the cost estimate configuration tends to move from a lump sum approach into a more detailed itemized estimate as infrastructure needs, and projects move from LRTPs to STIPs/TIPs. The online survey did not show a clear trend in the configuration of cost estimates in TAMPs, BMPs, and PMPs, which could be explained by the wide range of possible forecasting time horizons associated with these programs. For instance, a lump sum approach may be used to better deal with the higher uncertainty of long-range TAMPs, while the availability of project-specific information would facilitate the preparation of itemized and more accurate cost estimates for a 6- to10-year TAMP.

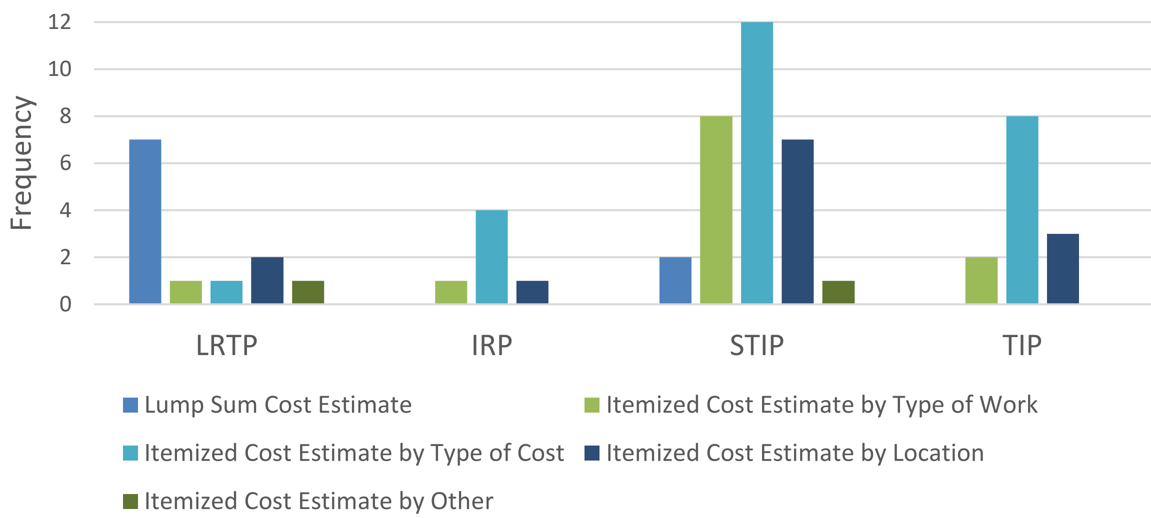

Figure 2-3 Cost Estimate Configuration per Transportation Program – Survey Responses.

According to Title 23 of the CFR, MPOs are required to include financial plans in all MTPs and TIPs. However, federal regulations seem to be more flexible for statewide LRTPs and STIPs, as they "may include a financial plan" (Title 23 U.S. Code 2018), portraying it as an optional part in these programs. Whether optional or mandatory, financial plans are expected/required to demonstrate how the intended program will be implemented, indicate all public and private resources reasonably expected to be made available to execute the program, and recommend strategies and innovative financial techniques that could contribute to the achievement of the established performance targets (Title 23 U.S. Code 2018). Additionally, transportation programs may include (also optional) additional projects that the state would consider if additional resources beyond those identified in the financial plan become available (Title 23 U.S. Code 2018).

2.2.1.1 Examples of Cost Estimate Configurations in Transportation Programs

Since the enactment of the MAP-21 in 2012, STAs have started transitioning into a performance-based transportation planning approach. For instance, the TxDOT prepared its first performance-based LRTP in 2015 with a multi-year transportation plan projected until 2040 (TxDOT 2015). Long-range plans usually depict costs in a general manner, estimating lump sum amounts required to facilitate the accomplishment of the intended goals (Molenaar, Anderson, and Schexnayder 2011). However, the TxDOT 2040 LRTP (referred to by TxDOT as Texas Transportation Plan [TTP]) is a good example of a long-range itemized cost analysis with above average level of detail. In that program, TxDOT first identified the different transportation modes that integrate the state transportation system and then proceeded to quantify the needs of each mode (in dollars) based on the level of performance required to satisfy the intended performance goals.

A transportation mode in Texas is said to have reached a state of good repair (SGR) when its associated performance goals are reasonably achieved. Table 2-4 shows the transportation modes considered in TxDOT 2040 LRTP, a summary of the methodology used to quantify their respective needs (which also defines SGR for each mode), and the funding required to achieve SGR (needs in dollars). It should be noted that the budget presented in Table 2-4 corresponds to an unconstrained cost estimate, meaning that it represents the level of funding required to reach SGR in all transportation modes. TxDOT recognizes that this is an unlikely situation; thus, the agency also prepared four different, and more realistic, investment scenarios, which were presented to key stakeholder during an outreach meeting. Detailed information on each of these investment scenarios can be found in the TxDOT 2040 LRTP (TxDOT 2015).

Table 2-4 State of Good Repair Needs to 2040 by Mode (Adapted from TxDOT 2015)

Mode	Methodology (SGR Definition)	SGR Needs through 2040 (2014 dollars)
Highways – Pavement	Life-cycle cost analysis on road operated and maintained by TxDOT to determine cost-beneficial investments to achieve roadways that are pothole free and support a smooth ride	$103.7 B ($4.0 B/year)
Highways – Bridge/Culvert	Life-cycle cost analysis to determine cost-beneficial investments to achieve bridges that are structurally sound and open for use	$40 B ($1.5 B/year)
Highways – Expansion	Statewide Analysis Model (SAM)-v3 used to identify the additional lane miles needed to achieve a statewide average of LOS C and the associated implementation costs based on unit cost assumptions	$239.2 B ($9.2 B/year)
Transit (excluding Passenger Rail)	Life-cycle cost analysis to determine cost-beneficial investments that result in buses, trains, and associated facilities in all areas of the state that are comfortable and reliable for existing assets; coordination with MPO plans and transit agencies to determine expansion needs by region	$101.2 B ($3.9 B/year) - $93.6 B (Metropolitan Transit Authority (MTAs)) - $7.6 B (non-MTAs)
Passenger Rail	Costs to construct and operate two new high speed rail systems from Oklahoma City to south Texas and from Dallas-Fort Worth to Houston; costs to expand existing AMTRAK services	$21.6 B ($0.8 B/year)
Bicycle and Pedestrian	MPO transportation plans compiled to develop needs along with information from recreation agencies and interest groups on opportunities for expansion; additional needs ($0.4 B) assumed for rural areas	$2.19 B ($0.08 B/year)
Aviation	Needs extrapolated from TxDOT's RAMP and TADS systems and other costs identified by Commercial Services and General Aviation airports	$20.4 B ($0.8 B/year)
ITS	Costs to operate/maintain/replace existing ITS devices and to implement/operate/maintain future planned devices as identified by TxDOT	$13 B ($0.5 B/year)
Non-Highway Freight	In addition to highway bottleneck reduction and all pavement and bridge needs identified in the TTP, additional freight needs for the TTP horizon include private needs for rail and ports based on TFMP and other existing data sources	$5.7 B ($0.22 B/year) $3.9 B (freight rail) $0.8 B (port & waterway) $1.0 B (air cargo)
	Total	**$547 B ($21 B/year)**

Baseline cost estimates at the project level are usually forecasted for IRPs, setting the point of reference for cost control and management (Molenaar, Anderson, and Schexnayder 2011). It means that sufficient information is usually available to break down cost estimates at the project level when transportation programs moved into an intermediate forecasting range (into the IRP, if any). The first 4-5 years of the IRP usually correspond to the STIP. For example, an IRP developed by the Minnesota DOT (MnDOT 2018) for a 10-year period, from 2019 to 2028, includes 1,493 projects, from which 726 projects (49%) correspond to MnDOT's 2019-2022 STIP. To comply with federal regulations, MnDOT has broken down its IRP and STIP into 14 investment categories that align with national and state performance goals. These 14 investment categories are described in Table 2-5.

Table 2-5 MnDOT's IRP/STIP Investment Categories (MnDOT 2018)

INVESTMENT CATEGORY	CATEGORY DESCRIPTION
Pavement Condition	Pavement Condition investments include overlays, mill and overlays, full-depth reclamations, and reconstructions of existing state highway pavement.
Bridge Condition	Bridge Condition investments include replacement, rehabilitation, and painting of state highway bridges. The Bridge Condition category does not include supporting elements for bridges, such as signs, pavement markings, or lighting.
Roadside Infrastructure Condition	Roadside Infrastructure Condition elements include drainage and culverts, traffic signals, signs, lighting, retaining walls, fencing, noise walls, guardrails, overhead structures, rest areas, Intelligent Transportation Systems (ITS), and pavement markings.
Jurisdictional Transfer	Jurisdictional Transfer investments allow MnDOT to continue to work with our local government partners to agree on and commit to additional roadway transfers that would align the travelers expectations of the facility with the proper level of investment and also lower future maintenance and capital costs to MnDOT.
Facilities	Facilities investments include rehabilitation and replacement of the 52 MnDOT-owned rest areas and 10 weight enforcement operational buildings and weigh scales. The Facilities investment category does not include buildings such as district headquarters or other operational facilities.
Traveler Safety	MnDOT currently uses a combination of three types of safety investments in its effort to improve safety and reduce the number of annual fatalities and serious injuries on Minnesota roads; Proactive lower cost, high-benefit safety feature; Sustained crash locations treatment; Improvements at sustained crash locations; Railway-Highways Crossings
Twin Cities Mobility	MnDOT pursues the following strategies to address regional mobility issues in the Twin Cities metro area: **Active Traffic Management.** Operational improvements to help manage the effects of congestion, which include variable message signs (traveler information systems), freeway ramp metering, dynamic signing, bus-only shoulder lanes, reversible lanes, dynamic speed signs, and lane specific signaling. **Spot mobility improvements.** Lower cost, high-benefit projects that improve traffic flow and provide bottleneck relief at spot locations. These projects include freeway and intersection geometric design changes, short auxiliary lane additions, and traffic signal modifications to ease merging and exiting traffic. **Priced managed lanes.** Priced managed lane projects that provide a predictable, congestion-free travel option for transit users, those who ride in carpools, or those who are willing to pay. In the Twin Cities, this system is called MnPASS, which currently operates on I-394, I-35E, and I-35W. **Strategic capacity enhancements.** Projects in the form of new interchanges, non-priced managed lanes, and limited general-purpose lanes that may be needed to address corridor congestion and/or provide lane continuity for an existing facility or to complete an unfinished segment of the Metropolitan Highway System.

Table 2-5 MnDOT's IRP/STIP Investment Categories (Cont.) (MnDOT 2018)

INVESTMENT CATEGORY	CATEGORY DESCRIPTION
Greater Minnesota Mobility	The Greater Minnesota Mobility investment category replaced the Interregional Corridor Mobility category used in the previous MnSHIP. Through federal legislation, the National Highway System was expanded and performance measures for mobility on the NHS has been developed. For these reasons, the investment category was modified to reflect that the NHS is now the priority network for mobility investment in MnSHIP. Improvements in this category include projects that improve travel time reliability for people and freight on the NHS outside of the Twin Cities area. Typical investments include low-cost improvements such as upgraded signals, turn lanes, intersection improvements, or passing lanes.
Freight	Freight includes the movement of all goods that originate or terminate in Minnesota across all modes. Investment in this category comes from the National Highway Freight Program created in the FAST Act.
Bicycle Infrastructure	MnDOT typically constructs bicycle improvements concurrently with pavement and bridge projects, but also implements some stand-alone projects.
Accessible Pedestrian Infrastructure	Most pedestrian improvements are implemented as part of a pavement or bridge project. Stand-alone projects, especially ADA improvements, are implemented as well.
Regional & Community Improvement Priorities	RCIPs are collaborative investments that respond to regional and local concerns beyond system performance needs. Typical improvements include intersection improvements, projects that support multimodal connectivity, landscape improvements, bypass or turning lanes, access management solutions, improvements that support complete streets, and regional or spot capacity projects.
Project Delivery	Project Delivery includes components of projects that are critical to ensure the timely and efficient delivery of highway projects. These components include right-of-way costs, consultant services, internal project delivery, supplemental agreements, and construction incentives.
Small Programs	The Small Programs category includes investments that are not specifically identified or prioritized within MnSHIP, but make up a part of MnDOT's overall capital investment. Small Programs typically respond to short-term, unforeseen issues or are used to fund one-time specialized programs that do not fit into a MnSHIP investment category. If funding is required beyond the short-term, an effort is made to incorporate the program into a MnSHIP investment category during the next MnSHIP update.

In addition to estimating construction costs for each project contained in the IRP and STIP, MnDOT breaks down the IRP/STIP expected cost into the 14 investment categories listed in Table 2-5. Figures 2-4 and 2-5 illustrate the investment plans by category for the IRP and STIP, respectively. In both cases, the pavement conditions, project delivery, and bridge condition are the top three categories consuming more than 70% and 65% of the total IRP and STIP cost, respectively. Investment categories in Figures 2-4 and 2-5 are represented using the same color scale used in Table 2-5. It should be mentioned that MnDOT is only committed to deliver projects in the STIP. Funding approval is still pending for projects in years 5 to 10 of the IRP. This IRP is referred to by MnDOT as the 10-Year Capital Highway Investment Plan (CHIP).

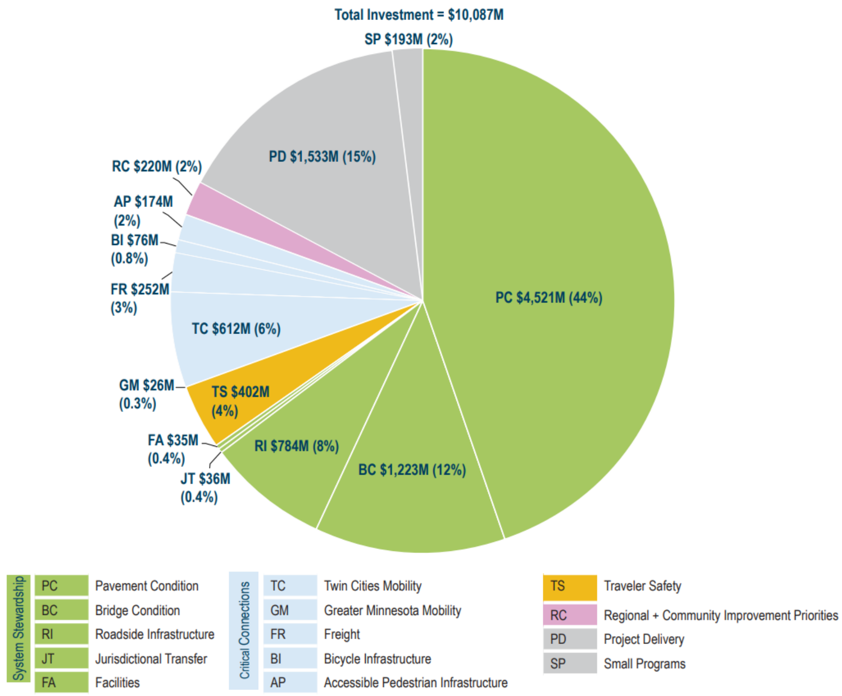

Figure 2-4 MnDOT 10-year IRP 2019-2028 (MnDOT 2018)

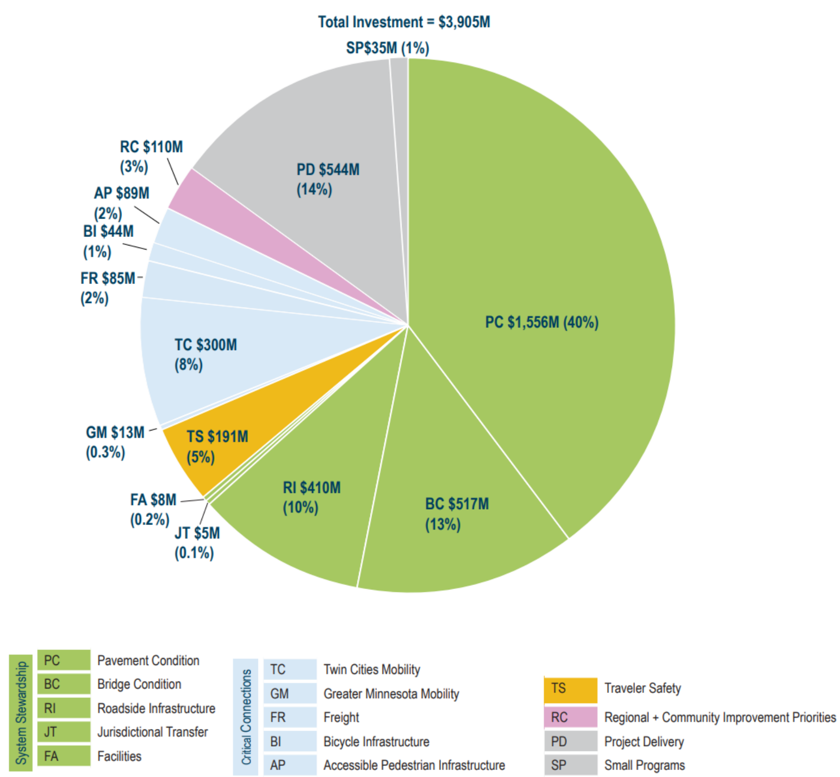

Figure 2-5 MnDOT 4-year STIP 2019-2022 (MnDOT 2018)

MAP-21 also requires TAMPs to align with the seven national performance goals. However, unlike LRTPs and STIPs, TAMPs are not required to cover all transportation modes or assets. The consideration of pavement and bridge assets on the National Highway System (NHS) seems to be sufficient to comply with federal regulations. The NHS "consists of roadways important to the nation's economy, defense, and mobility" (FHWA 2017). The NHS is divided into the five highway subsystems described in Table 2-6.

Table 2-6 National Highway System – Subsystems (FHWA 2017)

Highway Subsystem	Description
Interstate	The Eisenhower Interstate System of highways retains its separate identity within the NHS.
Other Principal Arterials	These are highways in rural and urban areas which provide access between an arterial and a major port, airport, public transportation facility, or other intermodal transportation facility.
Strategic Highway Network (STRAHNET)	This is a network of highways which are important to the United States' strategic defense policy and which provide defense access, continuity and emergency capabilities for defense purposes.
Major Strategic Highway Network Connectors	These are highways which provide access between major military installations and highways which are part of the Strategic Highway Network.
Intermodal Connectors	These highways provide access between major intermodal facilities and the other four subsystems making up the National Highway System. A listing of all official NHS Intermodal Connectors is available.

As occurs with the other transportation programs described in this chapter, there are a number of different approaches used by STAs for the preparation and organization of TAMPs. Some TAMPs, like the one from New Mexico DOT (NMDOT), are mainly focused on NHS pavements and bridges, as requested by the MAP-21. Table 2-7 summarizes the results of the financial analysis included in NMDOT's 10-year TAMP ending in 2026 (NMDOT 2018). NMDOT's TAMP presents two investment scenarios for each of the two types of assets under consideration, separating interstate from non-interstate pavements. For each scenario, the TAMP presents the performance targets by 2026, the average annual funding required to achieve the intended targets, and the expected outcomes as percentages of NHS pavements and bridges in good, fair, and poor condition.

Table 2-7 New Mexico DOT 10-Year TAMP 2017-2026 (NMDOT 2018)

NHS Asset	Investment Scenario	Performance Target by 2026	Asset Condition (%) (Expected Outcome)			Annual Funding Required
			Good	Fair	Poor	
Interstate Pavements	Current Condition	-	58.5%	40.6%	0.8%	-
	Scenario 1	Keep interstate pavements in poor condition from exceeding 2%	51%	47%	2%	$81.5M
	Scenario 2	Maintain the good sections of interstate pavements at current condition	60%	32%	8%	$62.0M
Non-Interstate Pavements	Current Condition	-	37.4%	59.3%	3.4%	-
	Scenario 1	Keep non-interstate pavements in poor condition from exceeding 4%.	54%	42%	4%	$212.5M
	Scenario 2	Maintain the good sections of non-interstate pavements at current condition	34%	49%	17%	$68.0M
Bridges	Current Condition	-	37.0%	59.9%	3.1%	-
	Scenario 1	Keep bridges in poor condition from exceeding 5%.	26%	69%	5%	$40.0M
	Scenario 2	Keep bridges in poor condition from exceeding 10%.	19%	71%	10%	$24.5M

Other STAs have exceeded federal requirements for TAMPs by considering non-NHS assets, including assets other than pavements and bridges. Figures 2-6 and 2-7 illustrate the financial analysis presented in a 10-year TAMP prepared by the California DOT (Caltrans) covering from 2017 to 2026. Besides NHS pavements and bridges, this TAMP includes infrastructure assets from the California State Highway System (SHS). The SHS contains "all assets within the boundaries of the highway system including 49,644 lane miles of pavements, 13,160 bridges, 205,000 culverts and drainage facilities, and 18,837 Transportation Management System (TMS) assets" (CalTrans 2018). As shown in Figure 2-6, Caltrans has conducted separate financial analysis on the overlapped and non-overlapped portions of the NHS and SHS. Likewise, for each asset classification, Caltrans has considered three different investment scenarios associated with different levels of funding and performance targets. Like in the NMDOT's TAMP, Caltrans has estimated the 10-year annual funding required under each scenario and has defined the expected outcomes in terms of the percentage of assets in good, fair, and poor condition.

The three investment scenarios in Caltrans' TAMP are defined as follows:

- **Scenario 1 –** 10-year Baseline (pre-SB1) Performance: This investment scenario is based on average annual revenues prior to the passage of Senate Bill 1 (SB1), which has provided Caltrans with a significant new consistent funding source for transportation infrastructure projects.
- **Scenario 2 –** 10-year Expected (post-SB1) Performance: Investment scenario based on average annual revenues after to the passage of SB1.
- **Scenario 3 –** 10-year Target (DSOR) Performance: This investment scenario corresponds to the annual funding required to achieve the desired state of repair (DSOR)

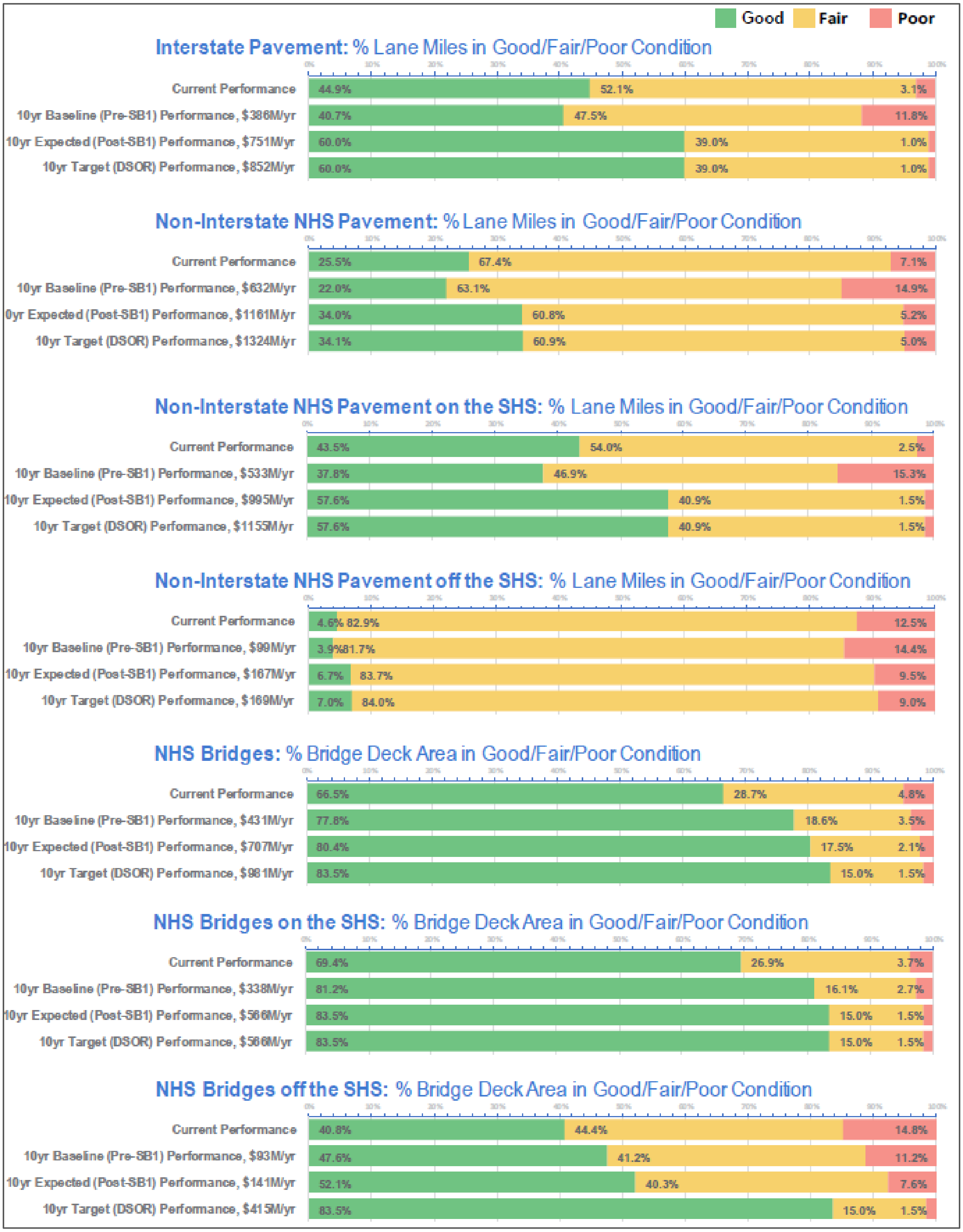

Figure 2-6 Caltrans TAMP – NHS Financial Analysis (Caltrans 2018)

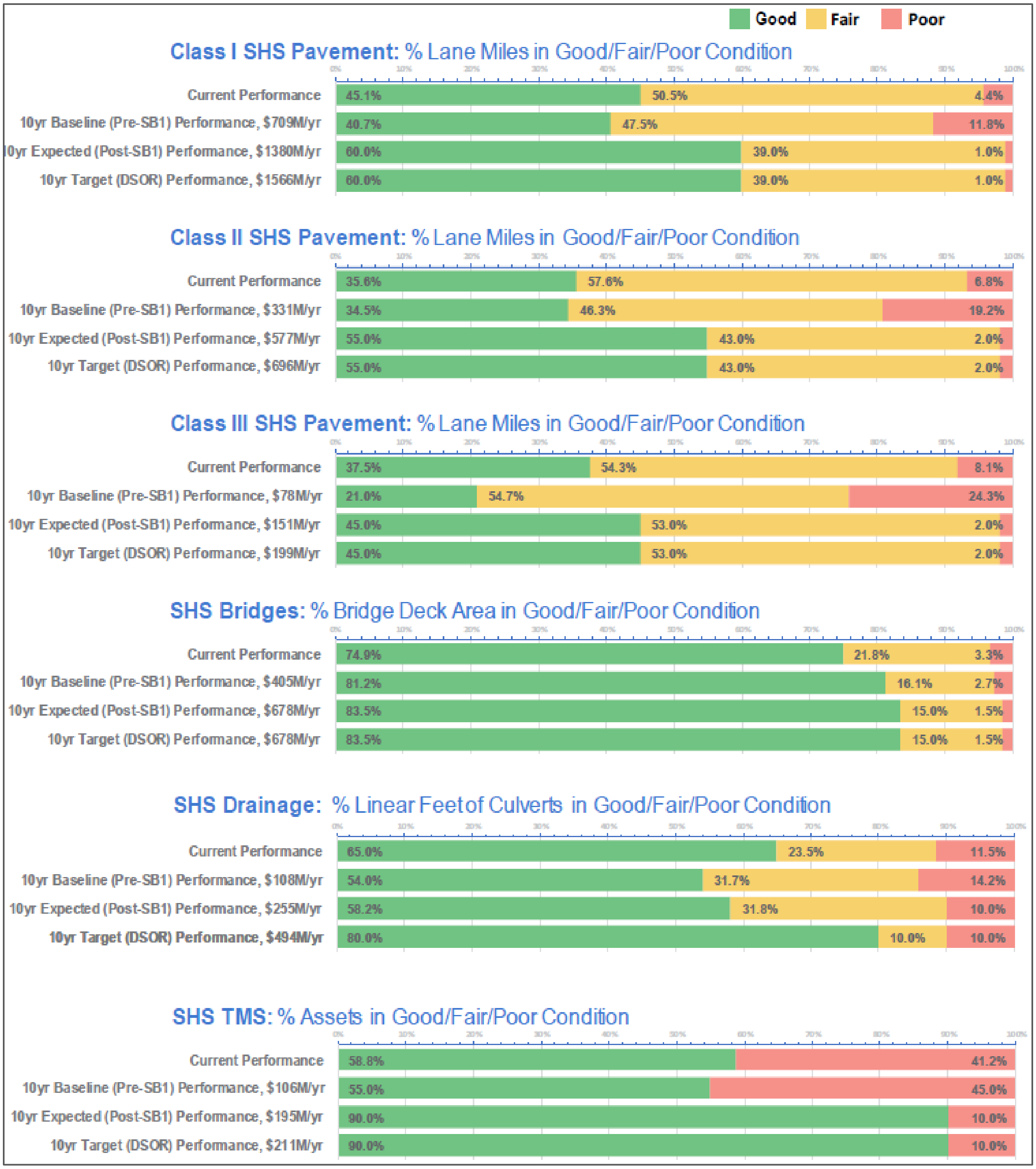

Figure 2-7 Caltrans TAMP – SHS Financial Analysis (Caltrans 2018)

2.2.1.2 Types of Costs Considered in Transportation Programs

Another important aspect about the configuration of cost estimates in transportation programs is the types of costs considered in the forecasting process; with "types of costs" referring to the different cost categories that make up program cost estimates. Having a clear understanding of the composition of the intended costs to be forecasted is critical to effectively determine a suitable forecasting approach. This are the following types of costs are usually considered by the agencies for the different transportation programs:

- **Engineering/Design Costs**: Cost of all design and engineering activities from the time the projects are programmed at the scoping phase through the time the project is awarded. It includes all activities required to process projects for award. It does not include right-of-way, environmental, or utility relocation costs.
- **Right-of-Way Costs**: Cost of all activities associated with the assessment and acquisition of property required to construct the projects.
- **Environmental Costs**: Cost of all activities associated with environmental studies, environmental mitigation, environmental permitting activities, and the production of environmental documentation.
- **Utility Relocation Costs**: Cost of all activities associated with the assessment of utility conflicts and the relocation of utilities, as well as the cost of other activities intended to mitigate utility impacts during the construction of the projects.

- **Construction Costs***:* Cost of all activities required to physically construct the projects based on approved plans. It includes the cost of labor, materials, equipment, mobilization, and profit.
- **Contract Administration***:* Cost of all activities associated with administering the projects from the date of award until final acceptance. It includes payroll and expenses accrued by DOT or consultant inspection forces, material testing and evaluation by the DOT or consultant forces, central office administrative and business-related efforts, and field reviews by the DOT or design staff.

Survey participants were asked to answer this question even if their programs do not depict costs across these cost categories, or if their program cost estimates are non-itemized lump sum amounts. This information is particularly important because a lump sum amount intended to represent only construction services would be lower than a lump sum for design, right-of-way, and construction services, and the latter might require a different forecasting approach. Figure 2-8 summarizes the survey responses on the composition of cost estimates in transportation programs.

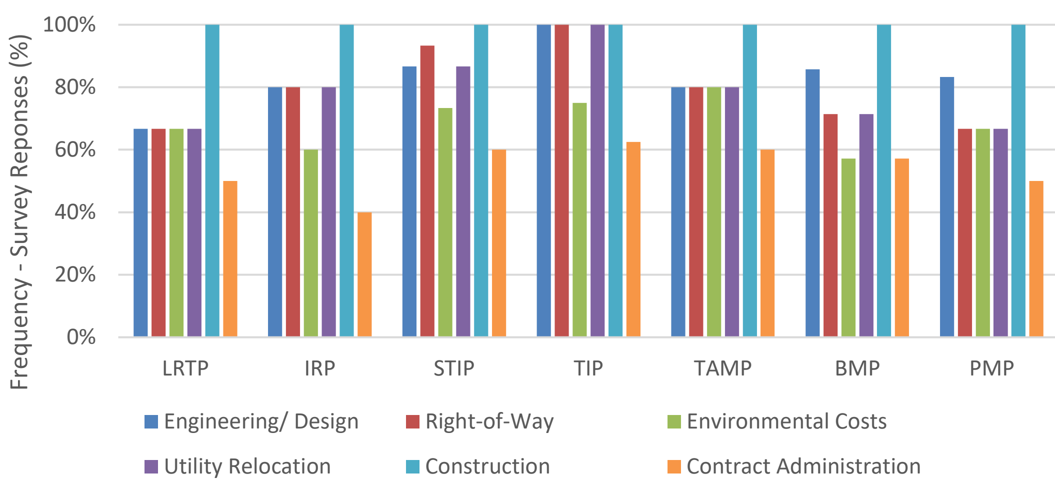

Figure 2-8 Composition of Cost Estimates in Transportation Programs

Each percent value illustrated in Figure 2-8 was calculated over the total number of survey participants answering this question on each transportation program. Based on Figure 2-8, it is reasonable to conclude that an effective cost forecasting system for mid-term, intermediate, and long-range cost forecasts should be able to account for all six cost categories described above. In fact, this observation aligns with guidance provided by FHWA on the preparation of contract cost estimates:

> "[T]he program cost estimate should include all costs and the value of any resources needed to complete the NEPA work, design, right-of-way activities, environmental mitigation, public outreach, construction, overall project management, specific management plans (e.g. transportation management plans), appropriate reserves for unknowns, etc. as well as costs and resources paid to others for work related to the project such as utility adjustments, environmental mitigation, and railroad relocations." (FHWA 2006).

2.3 Cost Forecasting Process

Having gained a better understanding of the different transportation programs involved in STAs' planning processes, it is now necessary to take a closer look at the cost forecasting process itself, which is the purpose of this section. This section starts with a discussion on the typical distribution of responsibilities within STAs to undertake cost forecasting efforts. The discussion will then turn to the factors considered by STAs in mid-term, intermediate, and long-range cost forecasting, as well as to the forecasting methods and tools used by STAs. This section also summarizes current STAs' review, approval, and monitoring procedures associated with cost forecasts across long time horizons. Finally, this section discusses the staff and information technology (IT) capabilities and resources currently used or available to facilitate cost forecasting activities.

2.3.1 Distribution of Responsibilities

Based on the information reviewed in this study, it could be reasonably concluded that in the transportation construction industry there are as many different cost forecasting approaches as STAs in the U.S. This variability in forecasting practices across STAs can also be seen in the distribution of responsibilities associated with cost forecasting over mid-term, intermediate, and long-range time horizons. Some STAs may have a specific set of groups/offices in charge of developing, monitoring, and updating transportation program cost estimates, while others have adopted a less formal approach assembling program development panels on a program-per-program basis. Thus, the approach adopted to distribute responsibilities tied to the overall level of standardization of cost forecasting practices, which seems to be higher for shorter time horizons when more program- and project-specific information is available. Figure 2-9 shows how the use of cost forecasting manual and standardized procedures is more common as the forecasting time horizon is reduced. Figure 2.9 was created based on survey responses.

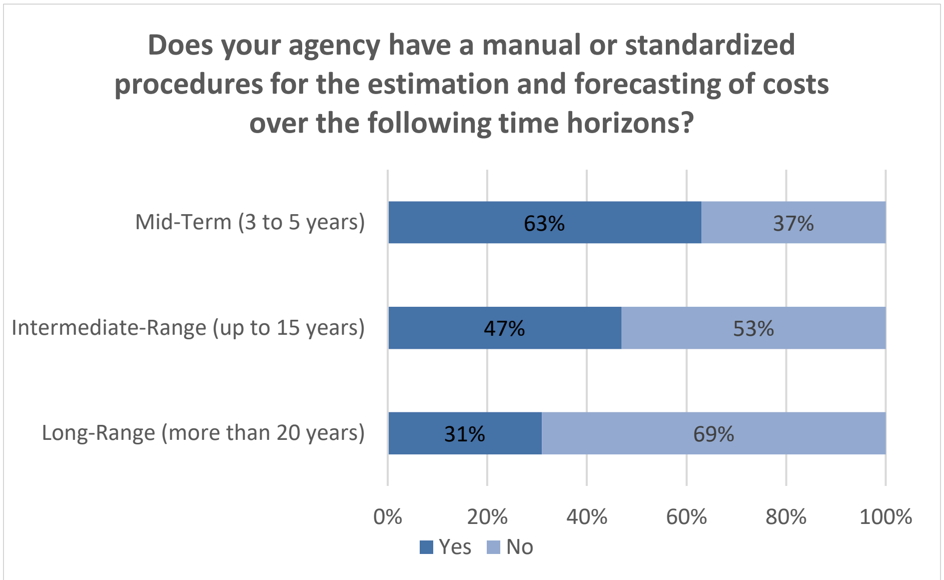

Figure 2-9 Use of Cost Estimating/Forecasting Manuals and Standardized Procedures

The survey responses, the review of policy documents, and the feedback provided by the EAP revealed different levels of integration in the performance of the different tasks required to forecast construction costs over long time horizons; with "integration" referring to the number and level of collaboration of groups/offices involved in these efforts. Thus, a fully integrated transportation cost forecasting system would be one in which all forecasted cost estimates, for all time horizons, are produced by a single office formed by an interdisciplinary team with experienced estimators and experts in all planning and construction areas. In an opposite non-integrated approach, the required expertise would be provided by a number of offices across the agency on a program-by-program basis. All STAs have shown some level of horizontal (across time horizons) and/or vertical (within a given time horizon) integration in their cost forecasting practices. However, there seems to be a trend towards the non-integrated side of the spectrum.

A clear example of horizontal integration can be seen in those agencies using IRPs, such as MnDOT. In MnDOT, the Office of Transportation System Management is in charge of coordinating the efforts of various groups in the central office and districts for the concurrent development of IRPs and STIPs, with the current STIP corresponding to the first four years of the IRP (MnDOT 2018).

The vertical integration of cost estimating/forecasting efforts at the program level can be seen in those STAs creating separate offices to deal with a specific transportation programs. For example, the Office of Work Program and Budget of the FDOT is responsible for developing and managing FDOT's Five-Year Adopted Work Program, which is required by Florida Statutes and corresponds to a longer version FDOT's 4-year STIP (FDOT 2018). Similarly, the North Carolina DOT (NCDOT 2018) has created the STIP Unit, which "develops Statewide, Regional and Division tier budgets" to support mid-term and intermediate cost forecasting efforts. As mentioned in Section 2.2, NCDOT is one of the agencies implementing 10-year STIPs. One more example of vertical integration was provided through the online survey by the Tennessee DOT (TDOT), which has formed a Long-Range Planning Division and a Strategic Transportation Investments Division to prepare mid-term and long-range program cost estimates, respectively.

High levels of horizontal and vertical integration in the cost forecasting process at the program level are expected to improve estimating accuracy, but it also demands greater coordination and collaboration between the involved parties. Such level of integration is achieved by centralizing efforts or by enhancing communication between the groups working on the different programs. This hypothesis was discussed with the EAP and, in general, the members of the EAP agreed with it. However, a more divided opinion was provided by EAP members when asked about whether or not their agencies would be willing to invest efforts and resources to improve cost forecasting accuracy by enhancing coordination and communication between planning and construction groups. To the maximum extent possible, this study will attempt to test this hypothesis, taking into consideration the different attitudes of STAs toward integration, as well as technical and policy constraints that might limit the degree of integration in cost forecasting processes.

2.3.2 Factors Considered in Cost Forecasting

During the literature review, nine main factors commonly considered (or that should be considered) when forecasting construction costs over long-time horizons were identified. These nine factors are listed in Figure 2-10. This figure also illustrates survey responses on a question intended to determine which of these factors are actually considered by STAs when performing mid-term, intermediate, and long-range cost forecasts. Likewise, survey participants were asked to indicate whether these factors are considered on an objective or subjective manner based on the following definitions:

- **Objective Approach:** Using standardized procedures or quantitative models to prevent forecasted cost estimates from being influenced by estimators' personal perspectives, biases, or opinions.
- **Subjective Approach:** Based on estimators' experience and professional judgement.

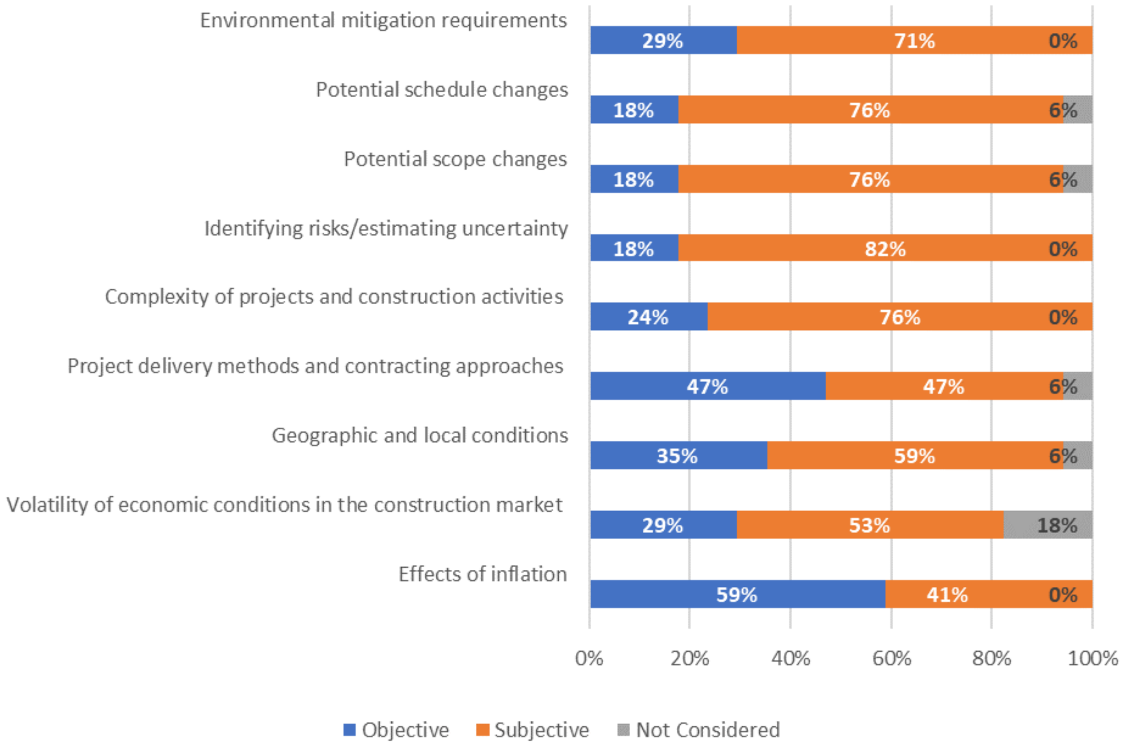

Figure 2-10 Factors considered when forecasting Costs

Figure 2-11 shows that cost forecasting processes implemented by STAs for the time horizons considered in this study tend to be more subjective, mainly relying on estimators' experience and professional judgement. A subjective approach is the most common way to consider each of the factors listed in Figure 2-11, expect for two of them: 1) anticipated project delivery methods/contracting approaches and 2) inflation. Previous research has demonstrated the impact that procurement methods could have on final project costs, making this factor very relevant for cost estimating purposes. The increasing research efforts towards the optimization of contracting procedures during the last decade seems to have facilitated the implementation of formal objective approaches to incorporate this factor into the cost forecasting process, making objective and subjective approaches equally common for this factor among STAs. Given to the fact that contracting methods are determined at the project level, this information is more likely to be used for mid-term and intermediate-range forecasts, when specific projects have been identified, or for capital projects included in LRTPs.

On the other hand, the larger percentage of survey responses indicating the use of objective approaches to account for the effects of inflation in forecasted cost estimates could mainly refer to STIPs and metropolitan plans (MTP and TIPs), which are required to use in their cost estimates “an inflation rate to reflect ‘year of expenditure dollars,’ based on reasonable financial principles and information, developed cooperatively by the State, MPOs, and public transportation operators” (Title 23 U.S. Code 2018). In other words, the agency must be able to demonstrate the appropriateness of the inflation rate used to forecast construction costs, which could be easier to justify if objective methods are used. The next section presents some methods and tools used to set inflation rates.

The “year of expenditure dollars” implies that STAs must anticipate the year(s) during which each project and other construction/maintenance activities in the program will be performed, making it unviable for LRTPs since these long-range programs are usually broadly defined. It may be the reason why the calculation LRTP cost estimates in “year of expenditure dollars” is not required by federal regulations. However, federal statutes require a greater level of detailed for 20-year (or over 20 years) MTPs, at least for the first ten years of the program, for which MPOs must use an inflation rate to calculate costs based on anticipated construction schedules (Title 23 U.S. Code 2018). “For the outer years of the metropolitan transportation plan (i.e., beyond the first 10 years), the financial plan may reflect aggregate cost ranges/cost bands, as long as the future funding source(s) is reasonably expected to be available to support the projected cost ranges/cost bands” (Title 23 U.S. Code 2018).

2.3.3 Forecasting Methods and Tools

Before discussing construction cost forecasting methods and tools currently used, or that could be used by STAs, it is important to first understand the cost estimating process. Figure 2-11 is a simplified representation of cost estimating process. To apply this process at the program level, STAs must divide the construction activities contained in the intended program into meaningful and workable scopes of work (e.g. program content organized per type of work, type of asset, corridor, and/or project). Thus, the sequence of tasks in Figure 2-11 is to be applied to each scope of work or program work package. After understanding the scope of work for which expected costs are to be estimated, the STA proceeds to collect and analyze relevant data to define recent/current construction market trends and conditions, which are then used to estimate construction costs in current dollars, and to design the cost forecasting process.

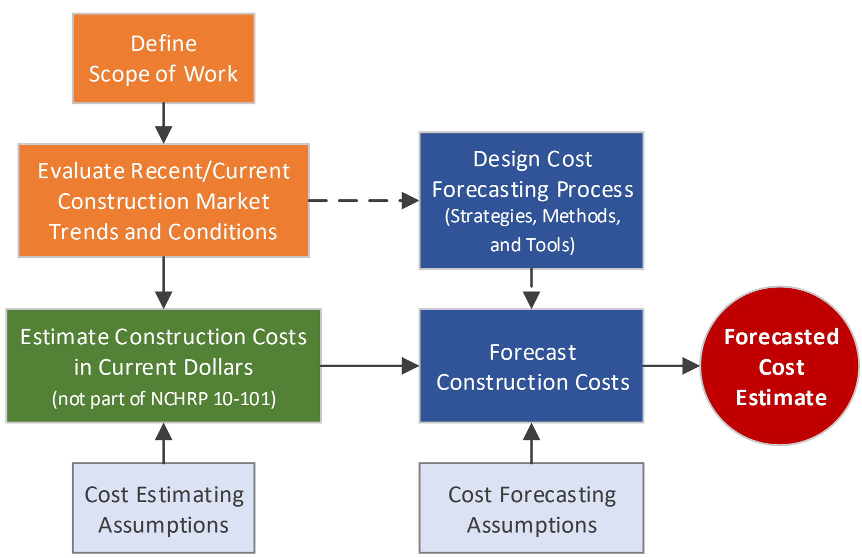

Figure 2-11 Construction Cost Estimating Process

Figure 2-11 also shows estimating assumptions made during the preparation of cost estimates in current dollars, as well as a separate set of assumptions made later during cost forecasting. For instance, a STA may need to make assumptions on the type of hot mix asphalt (HMA) to be used on a major anticipated capital project. Later, during the forecasting phase, the estimator might also need to decide whether the forecasting process will assume the continuation into the future of an observed trend in HMA prices without considering potential significant changes in that trend. Alternatively, the estimator could consider the possibility of having abrupt fluctuations in asphalt prices within the forecasting time horizon under consideration, such as the significant increase in asphalt prices experienced by STAs in 2008 (Cardinal 2018).

The cost forecasting methods and tools described in this section are intended to facilitate one or more steps of the cost estimating process illustrated in Figure 2-11. Table 2-8 shows eight different methods and tools usually involved in cost forecasting processes in transportation planning as well as in other industries. This table also indicates whether they are used to assist in the calculation of current construction costs, to facilitate the analysis of recent construction market trends, or to forecast costs based on identified trends.

Table 2-8 Forecasting Methods and Tools

Methods and Tools	Used to Facilitate:		
	Analysis of Market Trends	**Cost Estimating in Current Dollars**	**Projection of Trends into the Future**
Outsourced cost estimating services	X	X	X
Historical bid data	X	X	
Major cost items using standardized sections		X	
Input from a panel of experts	X	X	X
Parametric estimating		X	
Cost-based estimating		X	
Risk-based estimating		X	X
Regression Analysis	X	X	X

Survey participants were also asked to indicate which of the eight methods and tools listed in Table 2-8 are implemented by their agencies for cost forecasting purposes in mid-term, intermediate, and long-range planning. Responses to this question are summarized in Figure 2-12. This figure shows that the outsourcing of cost forecasting services for mid-term, intermediate, and long-range time horizons does not seem to be a common practice among STAs. On the contrary, historical bid data is widely used to define market trends and to estimate current construction cost using the most recent bid data.

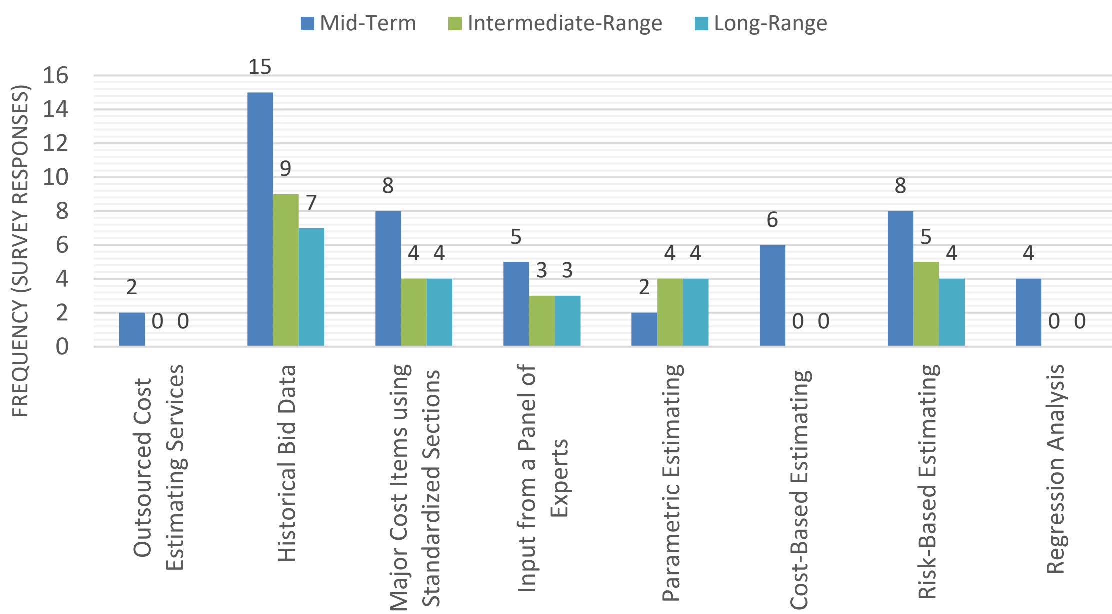

Figure 2-12 Cost Forecasting Methods and Tools

Standard sections for major cost items, parametric estimating, and cost-based estimating techniques are mainly used to estimate construction costs in current dollars (see Table 2-8), they still require the use of inflation rates or other forecasting techniques to forecast these costs into the future. Survey responses indicating the use of these three methods may refer to the estimation of the unforecasted cost estimates required as the basis for forecasting efforts. They could also refer to use of these methods in LRTPs, whose cost estimates are not required to be presented in "year of expenditure dollars," in which case the forecasting process would not be necessary. It means that federal regulations allow for the preparation of LRTP cost estimates in current dollars, such as the estimates presented earlier in this Dissertation in Table 2-4 for the TxDOT 2040 LRTP, which are calculated in 2014 dollars. It is important to mention that regardless of the fact that LRTP cost estimates are not required to be forecasted, some STAs prepare these estimates in "year of expenditure dollars" when a tentative construction schedule is anticipated for specific capital projects considered in the LRTP. The Michigan DOT is one of those STAs, using a fixed long-range inflation rate of 4% for forecasting purposes (MDOT 2016).

Using a panel of experts to provide input during the forecasting process is a formal way to bring valuable staff experience and knowledge into this process. Usually, these panels are strategically formed on a program-by-program basis or for major capital projects, attempting to cover all knowledge areas and disciplines required by each program or project. Given that the survey showed a low use of outsourcing services associated with cost forecasting, it is safe to assume that panels of experts supporting cost forecasting efforts are mostly formed by in-house experts.

After historical bid data, risk-based estimating seems to be the second method most used by STAs in cost forecasting over long time horizons among those methods shown in Figure 2-12. "Risk-based estimates produce an expected value and a range of project costs. […] Estimators will typically use risk-based estimates during the planning, scoping, and early design phases" (Molenaar, Anderson, and Schexnayder 2011). This Dissertation will evaluate different strategies for the incorporation of risk-based techniques into the cost forecasting process, including probabilistic methods, scenario analysis, and simulation techniques.

One of the reasons that could explain why STAs stay away from new forecasting methods could be the fact that its effective implementation may require certain level of knowledge in data analytics, economics, and statistics –skills not commonly found in STAs, as showed in the survey responses illustrated in Figure 2-13. Special attention will be paid to the development of clear, straightforward guidelines on the use of forecasting techniques to facilitate their potential implementation by STAs.

A question was also included in the survey to gain an idea of the IT resources currently used by STAs to aid cost forecasting during early transportation planning stages. Figure 2-14 shows the responses received for this question, making it clear that Microsoft Excel is the software most commonly used by STAs for cost forecasting purposes, followed by in-house estimating software. AASHTOWare is a comprehensive software package divided into multiple modules intended to assist transportation agencies with planning, design, construction, and contract administration activities. Although AASHTOWare has long-range cost forecasting capabilities (AASHTO 2019), it seems to be more commonly used for mid-term forecasting; however, Figure 2-14 suggests that STAs still prefer the use of Microsoft Excel spreadsheets or their own estimating software to forecast construction costs at all planning levels. Figure 2-14 also shows that statistical software packages are rarely used by STAs, which could be explained by the lack of staff with the required skills to use this type of software, as discussed in the previous paragraph.

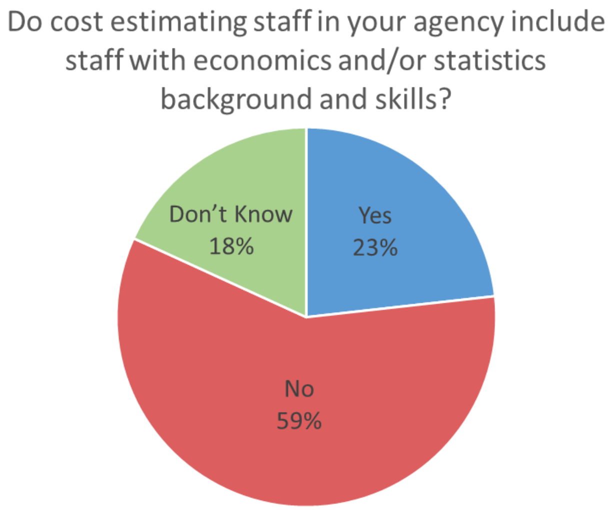

Figure 2-13 STA Staff with Economics and/or Statistics Background

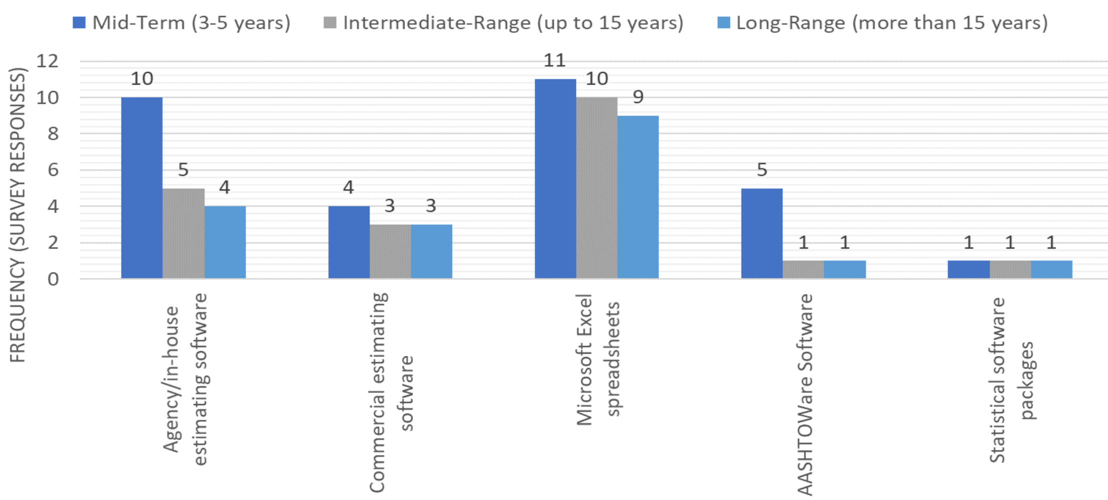

Figure 2-14 Information Technology Tools used in Cost Forecasting

2.3.3.1 Construction Cost Indexes

Although the use of a transportation related CCI is a more appropriate approach to assess inflation trends in the transportation industry, WSDOT and WisDOT are currently using an external national index to forecast construction costs, which may not accurately represent the local transportation construction market. FHWA's top recommendation for STAs and MPOs is to invest in the development of in-house CCIs with their own historical cost data for a more appropriate determination of inflation rates and more accurate cost forecasts. "Local historic cost data and experience with cost inflation are valuable data sources for use in projecting future rates" (FHWA 2017). As occurs with the use of external CCIs, a number of STAs have developed their own cost indexes, but only in a few cases they used to support forecasting efforts over long periods of time. Some of the STAs using in-house CCIs in their mid-term, intermediate, and long-range cost forecasting activities are ODOT, FDOT, SCDOT, Caltrans and Iowa DOT (ODOT 2014; FDOT 2018; SCDOT 2017; CalTrans 2018; IowaDOT 2018).

While there is great variability in the scope and configuration of programs/projects within a STA at the planning and programming phases, the set of input components an in-house CCI usually remains unchanged over time, meaning that the matching principle cannot always be met. Table 2-9 shows examples of the composition of CCIs maintained by 16 STAs. For instance, based on the component of the Colorado DOT's CCI, it can be said that this index would be more suitable for a program, project, or construction activity mainly made up by earthwork, HMA, concrete pavement, structural concrete, and reinforcing steel. Although it is possible to find some programs or projects with such scope of work, it will not be the case most times, and even if it were, the relative weight of each of the six CCI inputs should fairly represent the contribution of its respective cost element in the program or project to be forecasted, which is very unlikely. This fact makes it difficult for STAs to meet the proportionality principle.

Table 2-9 Examples of CCI Components used by STAs

Agency	Components used in the Calculation of CCI
California	Roadway excavation; aggregate base; asphalt concrete pavement; Portland cement concrete pavement; Portland cement concrete structural; bar reinforcing steel; and structural steel.
Colorado	Earthwork; hot mix asphalt; concrete pavement; structural concrete; reinforcing steel.
Florida	Surfacing; earthwork; Portland cement concrete; bituminous concrete structural; reinforcing steel; structural steel; structural concrete.
Iowa	Roadway excavation; hot mix asphalt pavement; Portland concrete cement pavement; reinforcing steel; structural steel; structural concrete.
Minnesota	Excavation; reinforcing steel; structural steel; structural concrete; concrete pavement; plant-mix bituminous.
Mississippi	Unclassified excavation; warm and hot mix asphalt pavement; concrete pavement; reinforcing steel; structural steel; class 'aa' bridge concrete.
Montana	Excavation; aggregate base; surfacing; drainage; concrete; reinforcing steel; bridge; traffic; misc. item.
Nebraska	Roadway excavation; concrete pavement; concrete for box culverts; 24" & 36" pipe, culvert; corrugated metal and plastic (cmp), reinforced; concrete for bridges; structural steel; piling, concrete and steel; asphalt concrete; asphalt cement; emulsified asphalt for track coat.
New Hampshire	Roadway excavation; crushed materials; hot mix asphalt, structural concrete, -rebar; structural steel.
Oregon	Excavation; crushed rock; Portland concrete cement; mixed asphalt; reinforcing steel; structural steel; structural concrete.
Ohio	Asphalt; aggregate base; barrier; bridge painting; curbing; drainage; earth work; erosion control; guardrail; landscaping; lightning; maintenance of traffic; pavement marking; pavement repair; Portland cement concrete pavement; removal; signalization; structures; traffic control; unclassified construction items.
South Dakota	Unclassified excavation; liquid asphalt; asphalt concrete; gravel cushion; sub-base and base; Portland cement concrete pavement; class a concrete (structures); reinforcing steel; structural steel.
Texas	Earthwork; excavation; embankment subgrade and base course -lime treated subgrade or base; cement treated subgrade or base; asphalt treated base or foundation course; flexible base surfacing; surface treatment; bituminous mixtures; concrete pavement structures; structural concrete; metal for structures; pre-structured concrete beams; foundations; drainage -riprap -retaining walls.
Utah	Roadway excavation; bituminous surface mix; bitumen; Portland cement concrete pavement; reinforcing steel; structural steel; structural concrete.
Washington	Roadway excavation; crushed surfacing; hot mix asphalt; Portland cement concrete pavement; structural concrete; steel reinforcing bar; structural steel.
West Virginia	Unclassified excavation; class 1 aggregate base course; Marshall hot-mix base course, stone; Marshall hot-mix wear course, stone, -class b concrete; reinforcing steel bars; -type 1 guardrail.

Two separate studies conducted for MnDOT (Rueda-Benavides and Gransberg 2014) and the Alabama DOT (ALDOT) (Pakalapati 2018) have demonstrated the ability of an innovative cost indexing system to overcome the limitations of traditional CCIs. This innovative system is called Multilevel Construction Cost Index (MCCI). An MCCI is designed to better meet the matching and proportionality principles described above. This system consists of a group of indexes organized in a multi-level arrangement. Thus, each cost element in a program or project can be individually forecasted by the MCCI index that best matches its scope. Costs for different programs/projects would be forecasted with different sets of indexes, offering great flexibility to customize the forecasting process to the specifics of each program or project.

Figure 2-15 illustrates the MCCI developed by Pakalapati (2018) for ALDOT. It consists of 88 cost indexes arranged across four levels. The lowest level is the Pay Item Level, which contains cost indexes for 53 pay items frequently included in ALDOTs construction contracts. This level contains the most specific indexes and would be more suitable to model cost trends and determine inflation rates at the project level. Each of the 53 indexes at this level is only intended to be used on its respective pay item. When forecasting costs for an intended project, those pay items not included in the Pay Item Level can be forecasted with one of the indexes from the other three levels –the one that best aligns with the pay item to be forecasted (the next best option).

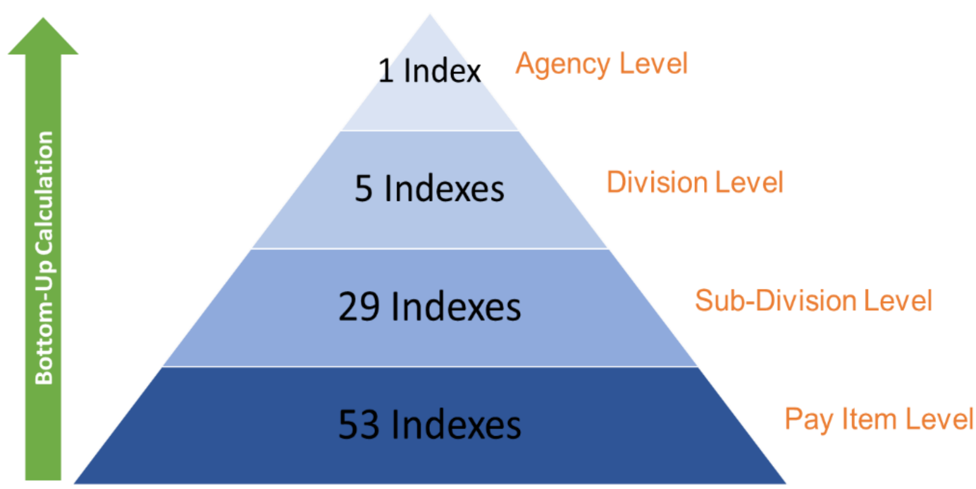

Figure 2-15 Structure of Construction Cost Indexing System

Following a bottom-up calculation approach, indexes at the Pay Item Level are then used to calculate the 29 indexes at the Sub-Division Level, which are less specific. Similarly, cost indexes at the Sub-Division Level are used to calculate five broader indexes at the Division Level, which are finally used to calculate a single general index to be used at the Agency Level. Upper indexes would be more suitable to determine inflation rates for long-range forecasts where scopes of work are less detailed. The five indexes at the Division Level correspond to following five work packages form ALDOT's work breakdown structure (2018):

- Earthwork
- Surfacing and Pavements
- Structures
- Incidental
- Traffic Control Devices and Highway Lighting

Cost indexes in the Sub-Division Level correspond to a more specific classification of work within each division. For example, the Surfacing and Pavements Division includes separate cost indexes at the Sub-Division Level for asphalt and concrete pavements. The 88 cost indexes included in Pakalapati's MCCI might not cover all classifications of work and activities required to forecast ALDOT's program costs. However, the design of this indexing system allows for the customization of the MCCI to meet the forecasting needs of the program by the incorporation of additional divisions or sub-divisions. If there is not sufficient historical data to develop a cost index for a given activity or type of work, ALDOT could still use the Agency Level Index, which is the equivalent to a traditional in-house CCI. Thus, even in the worst-case scenario, the agency would still be able to apply the traditional approach recommended by the FHWA, which has minimal expectancy.

2.4 NCHRP Report 574 – Guidance for Cost Estimation Management for Highway Projects during Planning, Programming, and Preconstruction.

An important reference for this Dissertation was the guidebook contained in the NCHRP Report 574 Guidance for Cost Estimation and Management for Highway Projects during Planning, Programming, and Preconstruction (Anderson, Molenaar, and Schexnayder 2007). This report presents the most comprehensive research project conducted at the national level on the appropriate selection of strategies, methods, and tools to improve cost forecasting over long time horizons. The project proposed a strategic approach structured around three main elements: strategies, methods, and tools. In the context of the NCHRP Report 574 these three elements are defined as follows:

- *Strategy:* A plan of action intended to address a specific factor affecting the performance of mid-term, intermediate, and long-range forecasted cost estimates.
- *Method:* A means or manner of procedures to implement the strategy. Methods are intended to support the strategies.
- *Tool*: An instrument to facilitate the actual implementation of the method.

The proposed approach provides STAs with several sets of strategies, methods, and tools to address 18 factors affecting cost forecasting (referred to in the NCHRP Report 574 as causal factors) at three different project development phases: Planning, Programing-Preliminary Design, and Final Design. These sets correspond to different combinations of 8 strategies, over 30 methods, and over 90 tools. Additional guidance is provided to STAs on how to identify the suitable set of strategies, methods, and tools recommended to address specific causal factors. Table 2-10 shows the 18 causal factors identified in the NCHRP Report 574 and classified into internal and external factors. Likewise, Table 2-11 presents and defines the eight strategies outlined in the report, while Table 2-12 defines the links between the causal factors and the strategies. For example, if a STA anticipates potential cost escalation due to changes in the scope of work, budget control efforts should be directed toward implementing management, scope/schedule, risk, and/or document quality strategies. A detailed description of the methods and tools required to implement the strategies listed in Table 2-10 can be found in Appendix A of NCHRP Report 574.

Table 2-10 Causal Factors Influencing Cost Forecasting (NCHRP Report 574)

Internal Factors	External Factors
• Bias • Delivery/Procurement Approach • Project Schedule Changes • Engineering and Construction Complexities • Scope Changes • Scope Creep • Poor Estimating • Inconsistent Application of Contingencies • Faulty Execution • Ambiguous Contract Provisions • Contract Document Conflicts	• Local Concerns and Requirements • Effects of Inflation • Scope Changes • Scope Creep • Market Conditions • Unforeseen Events • Unforeseen Conditions

Table 2-11 Planning Strategies (NCHRP Report 574)

Strategy	Definition
Management Strategy	Manage the estimate process and cost through all stages of project development
Scope/Schedule Strategy	Formulate definitive processes for controlling project scope and schedule changes
Off-Prism Strategy	Use proactive methods for engaging those external participants and conditions that can influence project costs
Risk Strategy	Identify risks, quantify their impact on cost, and take actions to mitigate their impact as the project scope is developed
Delivery and Procurement Method Strategy	Apply appropriate delivery methods to better manage cost, as project delivery influences both project risk and cost
Document Quality Strategy	Promote cost estimates accuracy and consistency through improved project documents
Estimate Quality Strategy	Use qualified personnel and uniform approaches to achieve improved estimate accuracy
Integrity Strategy	Ensure checks and balances are in place to maintain estimate accuracy and minimize the impact of outside pressures that can cause optimistic biases in estimates

Table 2-12 Link between Causal Factors and Strategies (NCHRP Report 574)

Causal Factors Influencing Cost Escalation		Strategies							
		Management	Scope/ Schedule	Off-Prism Issues	Risk	Procurement Methods	Document Quality	Estimate Quality	Integrity
Internal	Bias	X							X
Internal	Delivery/Procurement Approach	X	X		X	X			
Internal	Project Schedule Changes	X	X		X			X	
Internal	Engineering and Construction Complexities	X	X		X		X	X	
Internal	Scope Changes	X	X		X		X		
Internal	Scope Creep	X	X				X		
Internal	Poor Estimating	X	X		X		X	X	
Internal	Inconsistent Application of Contingencies				X			X	
Internal	Faulty Exclusion	X	X				X		
Internal	Ambiguous Contract Provisions						X		
Internal	Contract Document Conflicts						X		
External	Local Concern and Requirements	X	X	X	X				X
External	Effects of Inflation		X	X				X	X
External	Scope Changes	X	X		X				
External	Scope Creep		X	X					
External	Market Conditions	X		X	X	X		X	
External	Unforeseen Events				X				
External	Unforeseen Conditions				X				

In summary, an effective cost forecasting system to be used at the program level should have the flexibility to be able to handle different scopes of work along a wide range of possible forecasting time horizons –an observation.

2.5 Other Forecasting Methods

This section summarizes a wide range of cost forecasting methodologies, including approaches not currently used in the transportation construction industry. This information is summarized in Tables 2-13 to 2-15, which are actually a modified version of a table created by Chambers et al. (Chambers, Mullick, and Smith 1971) while investigating methods to facilitate sales forecasting for glass related materials. Even though that study was conducted for a different industry, these methods should be applicable to forecast construction costs in the transportation industry. Each of the methods considered by Chambers et al. is briefly described in Tables 2-13 to 2.15, including a short description of their data requirements. This table also rates the accuracy of each method for three different time horizons (short term [0-3 months]; medium term [3 months – 3 years]; long term [2 years and up]) and their ability to identify turning points (critical changes in future inflation rates). Accuracy and ability to detect critical trend changes are rated using a Likert scale ranging from "Very Poor" to "Excellent." The 17 forecasting methods presented in Table 2-13 to 2-15 are classified into three categories, as follows:

a. Qualitative Methods: These methods are mainly based on expert opinions and professional knowledge. Qualitative methods are more suitable when data is scarce. For example, when the STA needs to forecast costs for a construction activity that has never been performed in previous projects or for an activity that is rarely required by the agency.

b. Time Series Analysis and Projection: This group of forecasting methodologies uses a number of statistical techniques to model trends from historical data and to project them into the future. These data-drive methodologies are more suitable when sufficient data is available.

c. Causal Methods: These are also data-driven methodologies, but casual methods rely more on the relationship between forecasting model inputs and the output variable, which for the purposes of this study, would be the forecasted cost estimate for the intended time horizon.

Table 2-13 Basic Forecasting Techniques – Qualitative Methods

Technique	A. Qualitative Methods				
	1. Delphi Method	2. Market Research	3. Panel Consensus	4. Visionary Forecast	5. Historical Analogy
Description	A panel of experts is interrogated by a sequence of questionnaires in which the responses to one questionnaire are used to produce the next questionnaire. All experts have access to the same information for forecasting. This technique eliminates the bandwagon effect of majority opinion.	The systematic, formal, and conscious procedure for evolving and testing hypotheses about real markets.	This technique is based on the assumption that several experts can arrive at a better forecast than one person. There is no secrecy, and communication is encouraged. Forecasted values are sometimes influenced by social factors, and may not reflect a true consensus.	A prophecy that uses personal insights, judgment, and when possible, facts about different scenarios of the future. It is characterized by subjective guesswork and imagination; in general, the methods used are non-scientific.	This is a comparative analysis of similar new products that bases the forecast on similarity patterns.
Accuracy					
Short term (0-3 m)	Fair to very good	Excellent	Poor to fair	Poor	Poor
Medium term (3 m - 2 yrs.)	Fair to very good	Good	Poor to fair	Poor	Good to fair
Long term (2 years & up)	Fair to very good	Fair to good	Poor	Poor	Good to fair
Identification of turning points	Fair to good	Fair to very good	Poor to fair	Poor	Poor to fair
Data required	A coordinator issues the sequence of questionnaires, editing and consolidating the responses.	As a minimum, two sets of reports over time. One needs a considerable collection of market data from questionnaires, surveys, and time series analyses of market variables.	Information from a panel of experts is presented openly in group meetings to arrive at a consensus forecast. Again, a minimum is two sets of reports over time.	A set of possible scenarios about the future prepared by a few experts in light of past events.	Several years of history of one or more products.

Table 2-14 Basic Forecasting Techniques – Time Series Analysis & Projection

Technique	B. Time Series Analysis & Projection				
	1. Moving Average	**2. Exponential Smoothing**	**3. Box-Jenkins**	**4. X-11**	**5. Trend Projections**
Description	Each point of a moving average of a time series is the arithmetic or weighted average of a number of consecutive points of the series, where the number of data points is chosen so that the effects of seasonal or irregularity, or both, are eliminated.	Similar to the moving average, except that more recent data points are given greater weights. Descriptively, the new forecast is equal to the old one plus some proportion of the past forecasting error. Adaptive forecasting is somewhat the same except that seasonal are also computed. There are many variations of exponential smoothing.	Exponential smoothing is a special case of the Box-Jenkins technique. The time series is fitted with a mathematical model that is optimal in the sense that it assigns smaller errors to history than any other model. The type of model must be identified and the parameter then estimated.	This technique decomposes a time series into seasonal, trend cycles, and irregular elements. Primarily used for detailed time series analysis (including estimating seasonal); but its use can be extended to forecasting and tracking.	This technique fits a trend line to a mathematical equation and then projects it into the future by means of the equation. There are several variations.
Accuracy					
Short term (0-3 m)	Poor to good	Fair to very good	Very good to excellent	Very good to excellent	Very good
Medium term (3 m - 2 yrs.)	Poor	Poor to good	Poor to good	Good	Good
Long term (2 years & up)	Very poor	Very poor	Very poor	Very poor	Good
Identification of turning points	Poor	Poor	Fair	Very good	Poor
Data required	A minimum of two years of historical data, if seasonal effects are present. Otherwise, less data (of course, the more history the better). The moving average must be specified.	The same as for a moving average.	The same as for a moving average. However, in this case, more history is very advantageous in model identification.	A minimum of three years of history to start. Thereafter, the complete history.	Varies with the technique used. However, a good rule of thumb is to use a minimum of five years of annual data to start. Thereafter, the complete history.

Table 2-15 Basic Forecasting Techniques – Causal Methods

Technique	C. Causal Methods			
	1. Regression Model	**2. Econometric Model**	**4. Input-Output Model**	**5. Economic input-output model**
Description	This functionally relates the output to other economic, competitive, or internal variables and estimates an equation using the least-squares technique. Relationships are primarily analyzed statistically, although any relationship should be selected for testing on a rational ground.	An econometric model is a system of interdependent regression equations that describes some sector of economic sales or profit activity. The parameters of the regression equations are usually estimated simultaneously. As a rule, these models are relatively expensive to develop. However, due to the system of equations inherent in such models, they will better express the causalities involved than an ordinary regression equation and hence will predict turning points more accurately.	A method of analysis concerned with the interindustry of interdepartmental flow of goods or services in the economy or a company and its markets. It shows what flows of inputs must occur to obtain certain outputs. Considerable effort must be expended to use these models properly, and additional detail, not normally available, must be obtained if they are to be applied to specific businesses.	Econometric models and input-output models are sometimes combined for forecasting. The input-output model is used to provide long-term trends for econometric model; it also stabilizes the econometric model.
Accuracy				
Short term (0-3 m)	Good to very good	Good to very good	Not applicable	Not applicable
Medium term (3 m - 2 yrs)	Good to very good	Very good to excellent	Good to very good	Good to very good
Long term (2 years & up)	Poor	Good	Good to very good	Good to excellent
Identification of turning points	Very good	Excellent	Fair	Good
Data required	Several years of quarterly history to obtain good, meaningful relationships. Mathematically necessary to have two more observations than there are independent variables.	The same as for regression	Ten to fifteen years of history. Considerable amounts of information on product and service flows within a corporation (or economy) for each year for which an input output analysis is desired	The same as for a moving average and X-11

Table 2-15 Basic Forecasting Techniques – Causal Methods (Cont.)

Technique	C. Causal Methods		
	5. Diffusion Index	**6. Leading indicator**	**7. Life-cycle analysis**
Description	The percentage of a group of economic indicators that are going up or down, this percentage then becoming the index.	A time series of an economic activity whose movement in a given direction precedes the movement of some other time series in the same direction is a leading indicator.	This is an analysis and forecasting of new-product growth rates based on S-curves. The phases of product acceptance by the various groups such as innovators, early adapters, early majority, late majority, and laggards are central to the analysis.
Accuracy			
Short term (0-3 m)	Poor to Good	Poor to Good	Poor
Medium term (3 m - 2 yrs.)	Poor to Good	Poor to Good	Poor to Good
Long term (2 years & up)	Very Poor	Very Poor	Poor to Good
Identification of turning points	Good	Good	Poor to Good
Data required	The same as an intention-to-buy survey	The same as an intention-to-buy survey + 5 to 10 years of history	As a minimum, the annual sales of the product being considered or of a similar product. It is often necessary to do market surveys.

3. RESEARCH METHODOLOGY

3.1 Introduction

Case studies are in-depth investigations of subjects, groups, or phenomena on their respective real-life contexts, providing researchers with a better view of the problem at hand and facilitating the detection of issues that could have passed unnoticed with other research instruments. The unique perspective of the research problem provided by a case study allows researchers to better fill intended and unintended knowledge gaps. Case studies in this research project were conducted with the STAs of Minnesota, Colorado, and Delaware. This chapter seeks to illustrate how the present dissertation was carried out, from the moment of data collection, through all calculations, until the development of inflation rates.

3.2 Research Methodology

Figure 3-1 illustrates the methodology followed by the author for each of the selected case study agencies. Each case study started with the collection and cleaning 20 years of historical bid data, which was required to perform a long-range "forecasts vs. actual outcomes" analysis. Data gathering efforts also included historical index values from five external construction cost indexes (CCIs). Those indexes are also available to the case study agencies (and to all STAs) as possible inputs to cost forecasting processes. In the case of MnDOT and CDOT, their case studies also involved in-house CCIs.

The comparative analysis in Figure 3-1 was divided into three parts. The first part consisted of a comparative suitability analysis among various cost indexing alternatives (i.e., multiple MCCI versions, external and in-house indexes). The second part was intended for the development of a protocol to develop MCCIs. Finally, the third one is intended for the assessment and comparison of different cost forecasting methods, so that a third protocol can be created. Calculations for MnDOT's case study were repeated, assuming that only the most recent ten years of data were available in an attempt to assess the implications of using a smaller amount of historical bid data.

Chapter 4 clearly explains the process that agencies must follow to carry out data collection. This is a fundamental step for the development of the present dissertation since without a cleaned and organized data set, the calculations in the following two chapters could not be carried out.

The historical bid data was used to develop different MCCI versions for each agency, served as a reference to assess the suitability of various cost indexing alternatives, and to assess the level of accuracy and reliability of the forecasting methods under consideration. The application of both parts of the comparative analysis to the three case studies allowed to refine the procedures for the suitability analysis of cost indexes and for the implementation of each cost forecasting approach.

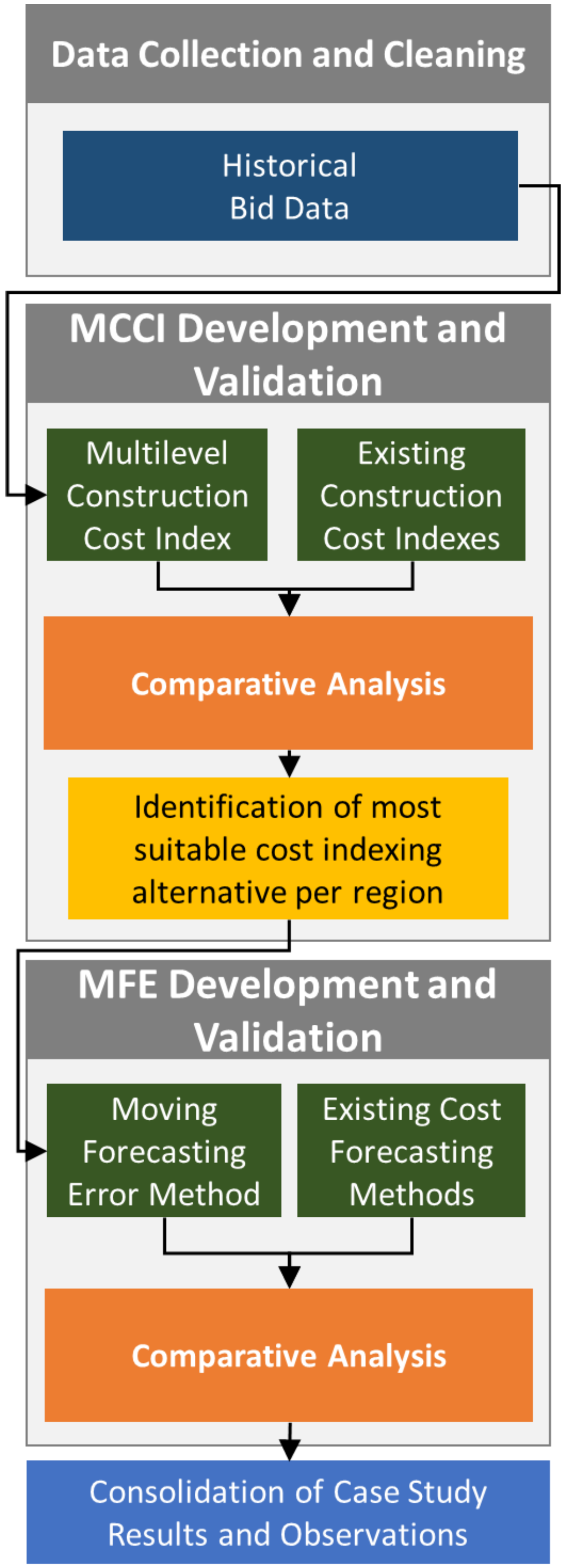

Figure 3-1 Case Study Methodology

3.2.1 Data Collection and Cleaning Protocol

Figure 3-1 represents Chapter 4 and the first step of this dissertation. This chapter explains in detail the process that was developed to collect and clean the case study data. This protocol allows other agencies that are interested in replicating this dissertation to carry out the same procedure. For each of the cases studied in this dissertation, a minimum of 20 years of historical bid data was collected. Additionally, this chapter explains the necessary methodology to clean the data through the removal of outliers. Two methodologies were used for the detection and removal of outliers, the Modified Z-score (see Title 4.2.1.1) and the 4.2.1.2 Robust Regression and Outlier Removal (ROUT) method (see Title 4.2.1.2).

At the end of this chapter, the findings are summarized, showing the findings of the data analysis process of the three case studies. Also, Table 4-3 shows the Existing Construction Cost Indexes, which were used in Chapter 5 to compare against the developed MCCIs.

3.2.2 Protocol to Develop Scope-Based MCCIs

Next step on Figure 3-1 is the MCCI development and validation represented on Chapter 5. This title describes a protocol that shows how to create MCCIs using the historical bid data cleaned on the previous chapter. This dissertation uses a flexible cost indexing methodology developed by two separate studies conducted for MnDOT (Gransberg and Rueda 2014) and the Alabama Department of Transportation (ALDOT) (Pakalapati and Rueda 2018). This methodology was improved and tested for the first time for a forecasting application on this dissertation. Chapter 5 describes in detail how to calculate the indexes from the pay item level until the Agency level, showing the formulas used and some examples. It should be noted that this dissertation also proposes use of this methodology for the project and program level. Various MCCI versions were developed for each agency in an attempt to identify the most effective one at representing the regional construction market. The difference between versions lies in their geographic scope (statewide and regional) and their type of price input: awarded unit prices (submitted by the selected contractors); average unit prices per project; median unit prices per project; and all unit prices received from both successful and unsuccessful contractors. At the end, this different MCCIs were compared with the existing construction indexes collected by the author and the most suitable per region was found.

3.2.3 Protocol to Develop Scope-Based Inflation Rates

Chapter 6 introduces the idea of creating inflation rates using all data collected, cleaned and analyzed through this dissertation. Using the local data, the author intended to represent the local construction market. Thus, this chapter proposes the use of the Moving Forecasting Error as a methodology to accomplish this goal. The MFE is fully explain in the first part of this chapter, and a 6-step-by-step process describes the ideal way to calculate an Inflation Rate.

3.2.4 Consolidation of Case Study Results and Observations

The final step on Figure 3-1 represent the las chapter of this document. The conclusions, recommendations, and limitations of the major contributions found during the development of this dissertation are summarized and explain in detail.

4. DATA COLLECTION AND CLEANING PROTOCOL

4.1 Introduction

This chapter summarizes the entire process needed to collect, clean, and organize the information so that other STAs can replicate this study. Before beginning this process, all historical bid data must be in a digital format in which EXCEL can carry out calculations and operations. In order to do so, it is important that each unit of information is divided into separate cells, which may require extra effort on the part of the agency.

4.2 Historical Bid Data Collection and Cleaning

If the intended MCCI is anticipated to be used for long-range forecasting purposes, the STA should make efforts to collect and clean, at least, 20 years of historical bid data since that is the recommended look-back period for long-range forecasts. To the maximum extent possible and practical, efforts should be made to collect data from all unit price projects awarded during that period of time. That would facilitate a considerable amount of data to better identify the basket pay items discussed in the next section. Table 4-1 summarizes the amount of historical bid data collected from each case study agency in terms of the number of years of data and the number of projects that provided that data. Considerable data collection efforts were required to gather 20 years of bid data from each agency. That amount of data was required to effectively assess the performance of the cost forecasting practices over long periods of time. Appendix A summarizes a number of attributes from the dataset collected from each STA.

Table 4-1 Summary of Collected Historical Bid Data per Agency

Agency	Years of Bid Data	Number of Projects
MnDOT	1999 – 2018 (20 years)	4,299
CDOT	1993 – 2017 (25 years)	3,108
DelDOT	1999 – 2018 (20 years)	1,533

All collected data should then be formatted into a tidy format, merging all projects into a single dataset. Figure 4-1 shows a screen capture of a small portion of the tidy dataset created for MnDOT. This was one of the case studies conducted for this Dissertation. "Tidy datasets are easy to manipulate, model and visualize, and have a specific structure: each variable is a column, each observation is a row, and each type of observational unit is a table" (Wickham 2014). There is only one observational unit in this Dissertation: pay items included in the collected projects. Thus, there is only one table, with each row referring to a single pay item used in a given project. The columns show all the available information associated with each pay item and its respective contract. Information provided for each pay item on each row includes, but is not limited to, item identification number, item description, awarded quantity, unit of measurement, contract identification number, project location (e.g., county, district), and unit price submitted by each bidder.

J	K	L	M	N	O	P	Q	R	S
S.P. Number	Job Description	Line Number	Item Number	Description	Unit	Quantity	Eng P	Bidder 1 UP	Bidder 2 UP
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	10	2021501/00010	MOBILIZATION	LS	1	120000	223800	222000
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	20	2051501/00010	MAINT AND RESTORATION OF HAUL ROADS	LS	1	1	1	1
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	30	2102502/00010	PAVEMENT MARKING REMOVAL	L F	2800	3	1	1
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	40	2104501/00010	REMOVE PIPE CULVERTS	L F	40	14	22	17
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	50	2104501/00042	REMOVE GUARDRAIL-PLATE BEAM	L F	1763	5	3	3
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	55	2104505/00122	REMOVE BITUMINOUS SHOULDER PAVEMENT	S Y	51701	2	3.07	2.75
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	60	2104509/00013	REMOVE PIPE APRON	EACH	4	200	192	229
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	70	2104509/00355	REMOVE LIGHTING SYSTEM	EACH	1	5000	18000	18000
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	80	2105523/00030	COMMON BORROW (CV)	C Y	1032	20	26	21
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	90	2105602/00016	CONSTRUCT EMERGENCY PULLOUTS	EACH	4	10000	3300	7465
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	100	2105603/00010	MINOR GRADING	L F	2126	10	12	16
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	110	2118501/00010	AGGREGATE SURFACING CLASS 1	TON	2247	18	18	17
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	120	2232603/00025	MILLED RUMBLE STRIPS	L F	76850	0.2	0.15	0.15
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	130	2302602/00020	DOWEL BAR	EACH	496	12	8	8
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	140	2302602/00030	DRILL & GROUT REINF BAR (EPOXY COATED)	EACH	100	15	15	15
6780-107	LOCATED ON TH 90 W.B. FROM TH 75 TO ROCK/NOBLES COUNTY LI	150	2302603/11000	JOINT REPAIR (TYPE A1)	L F	71	10	5	5

Figure 4-1 Example of Tidy Dataset MnDOT

Any efforts to create a tidy dataset would be greatly rewarded with easier and more expedite data manipulation and processing procedures. Although some of the information included in the tidy dataset will not be immediately used for the development of the MCCI, it could be required for future market or financial analysis, or to optimize MCCIs by modeling additional cost influencing factors.

4.2.1 Outlier Detection and Removal

Data cleaning efforts should also include the identification and removal of outliers, which would also be considerably easier with a tidy dataset. "Usually, the presence of an outlier indicates some sort of problem. This can be a case that does not fit the model under study, or an error in measurement" (Cho, Youn, and Martinez 2010). The guidebook recommends the use of two outlier detection filters strategically selected and applied to serve different purposes. The first filter is the modified Z-score method (Iglewicz and Hoaglin 1993), which is applied at the pay item level (to each row) in order to identify outliers among the unit prices received for the same item under the same contract. While some of those errors could correspond to typographical mistakes or the misinterpretation of the scope contained within the unit price, a number of them are the result of unbalanced bids (Rueda Benavides 2016). "A bid is considered unbalanced if the unit rates are substantially higher or lower, in relation to the estimate and the rates quoted by other bidders" (JICA 2010). There are three main reasons that could lead a contractor to unbalance a bid: 1) to protect its intended profit or fixed cost which could be partially lost if actual quantities of work are less than the bid quantities; 2) to maximize profits by taking advantage of errors in the quantities of work listed in the solicitation documents; or 3) to inflate prices for early activities to reduce financial costs (the cost of borrowing money) (FHWA 1988). Regardless of the ethical implications usually associated with unbalanced bids, this is a common practice among construction contractors and could mislead STAs when tracking market changes over time.

4.2.1.1 Modified Z-score

The modified Z-score method is applied using Equation 4.1. The reason behind the use of this method is that outliers are identified using the sample median ($\tilde{x}$) and the median absolute deviation (MAD), making it more suitable for small samples. Since this method is used on bids submitted by different contractors under the same contract, it is applied to relatively small samples. The average number of bids received by some agencies for a single contract is between three and four. Other more commonly used outlier detection methods rely on the sample mean and standard deviation to identify outliers. However, these two statistics are more sensitive to extreme values in small samples, increasing the risk of not detecting outliers that should be discarded (Iglewicz and Hoaglin 1993). Based on Iglewicz and Hoaglin guidelines, all unit prices with absolute modified Z-score greater than 3.5 ($|M_i|>3.5$) were removed from the dataset.

$$M_i = \frac{0.6745(X_i - \tilde{x})}{MAD} \tag{4.1}$$

Where: $M_i = Modified\ ZScore\ for\ Observation\ i$
$MAD = \ Median\ Absolute\ Deviation = \ \{|x_i - Median|\}$
$x_i = \ Value\ of\ Observation\ i$
$\tilde{x} = \ Median\ of\ All\ Observations$

Since the modified Z-score method compares unit prices for the same item under a given contract, it may find no outliers if all bidders are forced to submit unit prices substantially higher (or lower) than those typically paid by the agency for the same pay item in other projects. Table 4-2 shows an example of the Modified Z-score method applied on a CDOT Asphalt paving project. This specific contract has four different items offered by five different bidders. In all cases, one of the bids had to be removed from the data since the magnitude of the numbers indicated in Table 4-2 exceeds 3.5. Therefore, these bids were considered outliers. This procedure was replicated for all contracts in each of the three agencies.

Table 4-2 Example Modified Z-score CDOT Sample Project

ITEM ID	DESCRIPTION	UNIT	Quantity	Unit Price	Mean	Median	MAD	Z-score
403-00720	Hot Bituminous Pavement (Patching) (Asphalt)	TON	100	100	89.6	72	28	1.26
403-00720	Hot Bituminous Pavement (Patching) (Asphalt)	TON	100	69	89.6	72	3	0.13
403-00720	Hot Bituminous Pavement (Patching) (Asphalt)	TON	100	72	89.6	72	0	0.00
403-00720	Hot Bituminous Pavement (Patching) (Asphalt)	TON	100	150	89.6	72	78	**3.51**
403-00720	Hot Bituminous Pavement (Patching) (Asphalt)	TON	100	57	89.6	72	15	0.67
411-10255	Emulsified Asphalt (Slow-Setting)	GAL	3294	0.5	0.816	0.7	0.2	0.79
411-10255	Emulsified Asphalt (Slow-Setting)	GAL	3294	1.6	0.816	0.7	0.9	**3.57**
411-10255	Emulsified Asphalt (Slow-Setting)	GAL	3294	0.75	0.816	0.7	0.05	0.20
411-10255	Emulsified Asphalt (Slow-Setting)	GAL	3294	0.53	0.816	0.7	0.17	0.67
411-10255	Emulsified Asphalt (Slow-Setting)	GAL	3294	0.7	0.816	0.7	0	0.00
207-00205	Topsoil	CY	279	15	27.98	30	15	**5.06**
207-00205	Topsoil	CY	279	28.4	27.98	30	1.6	0.54
207-00205	Topsoil	CY	279	32	27.98	30	2	0.67
207-00205	Topsoil	CY	279	30	27.98	30	0	0.00
207-00205	Topsoil	CY	279	34.5	27.98	30	4.5	1.52
202-00035	Removal of Pipe	LF	11	300	95.6	35	265	**7.45**
202-00035	Removal of Pipe	LF	11	11	95.6	35	24	0.67
202-00035	Removal of Pipe	LF	11	32	95.6	35	3	0.08
202-00035	Removal of Pipe	LF	11	100	95.6	35	65	1.83
202-00035	Removal of Pipe	LF	11	35	95.6	35	0	0.00

4.2.1.2 Robust Regression and Outlier Removal (ROUT)

The second recommended outlier detection approach is used as a secondary filter to remove outliers overlooked by the modified Z-score method. The missed outliers could have resulted from unusual project requirements that may have forced all contractors to bid outside the typical unit price ranges. Since the modified Z-score method compares unit prices for the same item under a given contract, it may find no outliers if all bidders are forced to submit unit prices substantially higher (or lower) than those typically paid by the agency for the same pay item in other projects. The Robust Regression and Outlier Removal method (ROUT) (Motulsky and Brown 2006) is a suitable second detection filter. This method combines robust regression and non-linear regression techniques to identify values that could be significantly apart from the regression equation.

The ROUT method can be applied using GraphPad Prims 7, a statistical software equipped with a ROUT function that can be activated during the development of non-linear regression models. Figure 4-2 shows an example of the output yielded by this software. All red data points are outliers detected by the ROUT method and excluded from the regression analysis.

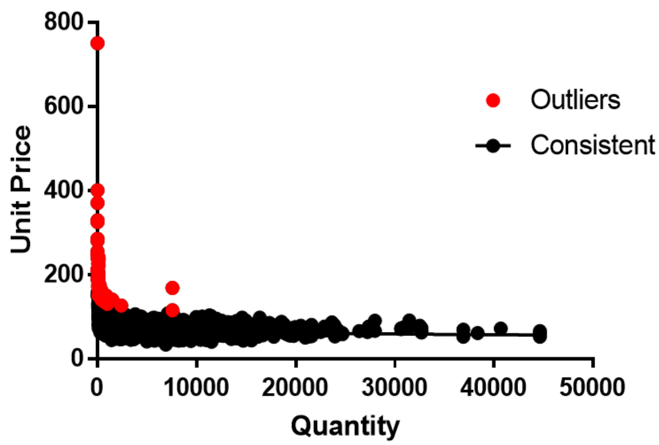

Figure 4-2 GraphPad Prims 7 Output – Example

4.3 Results of the Data Cleaning Process

Figures 4-3 to 4-5 summarize the results of the data cleaning process of the three case study agencies. Each of the spheres represents the number of contracts of the agency after each step of the data cleaning process. The last level of each one is represented by the lightest color, which shows the number of contracts used when choosing the most representative items of each agency. This process will be explained in detail in the next chapter. Each of the case studies presented different limitations in this process. In the case of MnDOT, between the years 1999 and 2015, some items were duplicated and with units in different metric systems, Imperial and Metric.

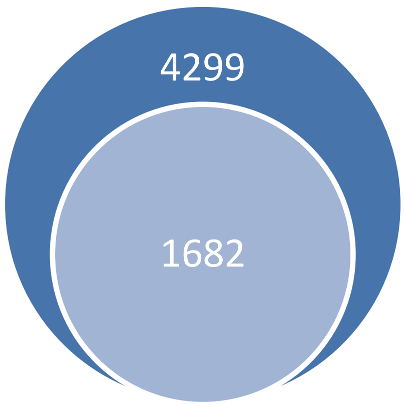

Figure 4-3 MnDOT data cleaning process

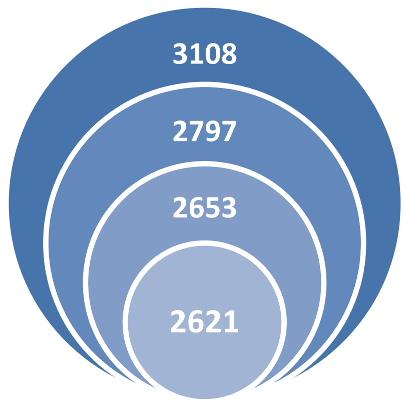

Figure 4-4 CDOT data cleaning process

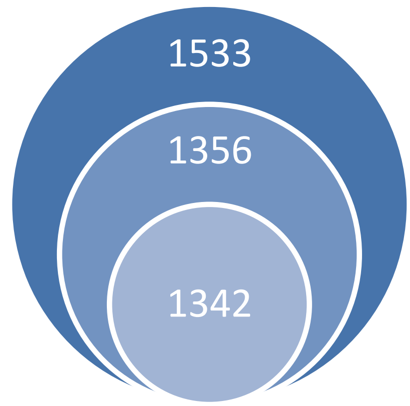

Figure 4-5 DelDOT data cleaning process

In the case of CDOT, the author initially collected information from 3108 contracts. The information each contract was divided into different files, which caused that the information of 311 contracts was incomplete. At the end of this first cleaning process, the data was distributed between the years 1993 and 2017 (25 years), but very few were between the years 1993 to 1994 and 2013 to 2017. Therefore, the author used 2,653 contracts awarded between 1994 and 2013 (20 years). For DelDOT, 177 contracts were not taken into consideration since they did not contract with the information necessary to differentiate the region in which they were executed. As previously mentioned, the last step of the three figures represents the contracts after the Modified Z-score and ROUT process has been completed.

4.4 Existing Cost Indexing Alternatives

In addition to the different MCCI versions developed by the author for each case study, the cost indexing alternatives considered in this Dissertation included five external and two in-house CCIs. These indexes are options being used by the agencies and other indexes found by the author on the exploratory process. Table 4-3 summarizes the information about the existing cost indexing alternatives. Three of those indexes, including the in-house CCIs, are classified as highway construction indexes, one is a building/vertical construction index, and two are macroeconomic indexes. It should be noted that MnDOT's and CDOT's in-house cost indexes were only used with their respective case studies. The five existing indexes include the national and the regional versions of the RSMeans CCI. Although RSMeans cost indexes are mainly intended for the vertical and commercial construction industry, this study found that RSMeans CCIs are an option considered by some STAs.

Table 4-3 Existing Construction Cost Indexes

Index	Components	Applicability	Frequency
Highway Construction			
Federal Highway Administration: **National Highway Construction Cost Index (NHCCI)**	• Bid data from highway construction contracts executed by STAs	National	Quarterly
Minnesota Department of Transportation: **Construction Composite Cost Index (CCI)**	• Excavation Index - Excavation • Structures Index - Reinforcing Steel - Structural Steel - Structural Concrete • Surfacing Index - Bituminous Pavement - Concrete Pavement	Minnesota	Quarterly &Annual
Colorado Department of Transportation: **Colorado Construction Cost Index (CCI)**	• Earthwork • Hot Mix Asphalt • Concrete Pavement • Structural Concrete • Reinforcing Still	Colorado	Quarterly
Building Construction			
RSMeans Construction Cost Index (CCI)	• 9 types of buildings - 66 construction materials - Wage rates for 21 different trades - 6 types of construction equipment	National & Regional	Annual
Macroeconomic Indexes			
Bureau of Labor Statistics (BLS): **Consumer Price Index (CPI)**	• 80,000 items in a market basket of goods and services purchased by urban consumers.	National	Monthly
Bureau of Economic Analysis (BEA): **Personal Consumption Expenditures (PCE) Price Index**	• Actual and imputed expenditures of households, including data pertaining to durable and non-durable goods and services	National	Quarterly

5. PROTOCOL TO DEVELOP SCOPE-BASED MCCIS

5.1 Introduction

An MCCI consists of a group of indexes organized in a multi-level arrangement. Thus, each cost element in a program or project can be individually represented by its closest matching MCCI index. After selecting the most relevant group of MCCI indexes for the scope of work under consideration, they are mathematically combined into a single scope-based CCI, which is then used to generate annual inflation rates. Costs for different programs/projects are forecasted with different sets of indexes, offering great flexibility to customize the forecasting process to the specifics of each program or project. The rest of this section provides additional information about this alternative cost indexing approach and details the MCCI development process.

5.2 Defining Basket of Pay Items for MCCI

The "basket of pay items" in the title of this section refers to the set of contract pay items used to create an MCCI. In an ideal world, an STA would be able to easily track the prices of all its contract pay items. However, most items are not frequently used, making it difficult to track their pricing variability over time. Likewise, some pay items with a low frequency of use and low impact on total project costs may not be worth monitoring. The author performed the following steps to find the largest possible group of significant repetitive pay items to build the MCCIs for the case study agencies:

1. *Discard those items whose units do not consistently refer to the same set of specifications or amounts work (e.g., each, lump sum), and keep those units that are comparable between projects (e.g., linear feet, cubic yards, tons)*. Pay items measured on an "each" or "lump sum" basis are usually not comparable between projects. Therefore, it is not appropriate to track their price changes using historical unit prices.
2. *Identify those pay items frequently used by the agency, ideally but not necessarily, at least once in the first and second halves of each year*. Although items used on a semi-annual frequency are preferred, that should not be a strict requirement since that could lead to the dismissal of relevant items whose frequency of use could skip a few periods. MCCI systems are able to handle missing values.
3. *Discard those items that show no apparent correlation between their unit prices and their respective quantities of work*. That would be a violation of the economies of scale principle, which could mean that unit prices for those items are not comparable between projects. The MCCI methodology has the capacity to consider economies of scale in the calculation of index values.

Appendix B shows the final basket of pay items developed for each agency. A total of 61, 40, and 37 representative pay items remained for MnDOT, CDOT, and DelDOT, respectively, after following the three steps listed above. The number of items is less than 1% of the entire list of pay items used by those agencies. However, they could represent over 25% of their annual construction budgets.

5.3 MCCI Configuration and Calculation

Historical bid data from the selected basket of pay items is then used to develop several cost indexes organized in a multilevel arrangement like the one shown in Figure 5-1. This figure illustrates the five-level arrangement with the 96 cost indexes developed for the Colorado Department of Transportation (CDOT), another of the case studies agencies involved in this study. The 96 indexes shown in Figure 3.5 were developed with a basket of 40 pay items. The lowest level in the MCCI is the Pay Item Level, which contains one cost index for each of those 40 pay items. This level has the most specific cost indexes. Each of the 40 cost indexes at this level is only intended to be used on its respective pay item.

Following a bottom-up calculation approach, CDOT's indexes at the Pay Item Level were used to calculate the 28 indexes at Sub-Division Level 1, which are less specific. Similarly, the indexes at Sub-Division Level 1 were used to calculate 22 broader indexes at Sub-Division Level 2, and so on, until reaching the top level where a single general index was calculated at the Agency Level.

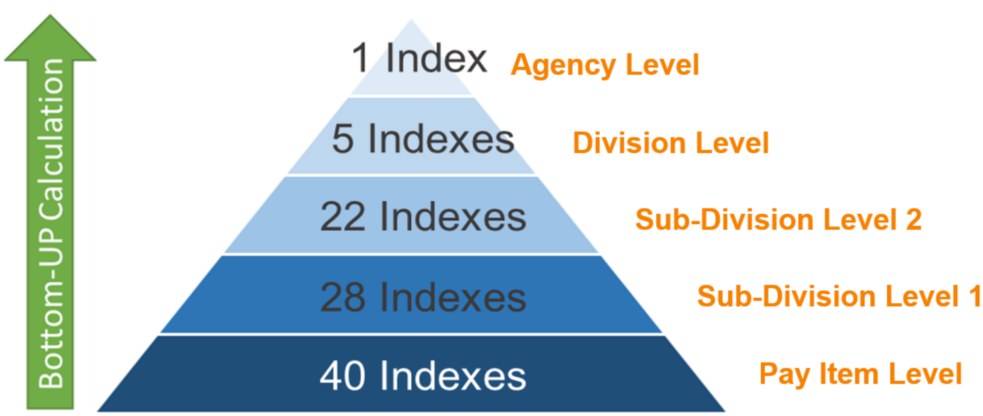

Figure 5-1 Example of MCCI Configuration – CDOT MCCI

All indexes were developed with a semi-annual updating frequency, once on June 30, and again on December 31. A semi-annual recalculation approach was selected in this study because an exploratory data analysis anticipated an inconsistent quarterly supply of data for some of the chosen pay items. Likewise, a semi-annual updating frequency was preferred over annual updates because shorter periods can better reflect the volatility of the construction market (Molenaar, Anderson, and Schexnayder 2011).

Even though STAs execute hundreds of contracts per year, it is not possible to ensure that every item in a representative group of cost items will be used during each index period, which could result in missing index values. Unlike traditional CCIs, the multi-level arrangement of MCCIs facilitates a mechanism to avoid missing index values by allowing the use of corresponding upper indexes to fill the gaps.

Calculations to develop MCCIs are divided into two major steps: 1) calculation of indexes at the Pay Item Level and 2) bottom-up calculation of indexes at upper levels.

Step 1: Calculation of Indexes at the Pay Item Level

The first step is the calculation of all indexes at the Pay Item Level. Since those are single-component indexes (calculated with a single pay item), there is no need to deal with the challenges associated with the combination of different types of index inputs. Nevertheless, to effectively track unit price fluctuations at the pay item level, it is necessary to consider the economies of scale principle, which is done by tracking the average movements of the regression curve that define the quantity-unit price relationship. “Economies of scale refers to a reduction in total cost per unit as output increases” (Betts 2007). The higher the quantities of work, the lower the unit price (Zhang and Sun 2007; Akintoye 2000).

Figure 5-2 uses MnDOT’s Common Excavation pay item to illustrate the concept of economies of scale. This figure shows awarded unit prices for that pay item during a 5-year period. As shown in this figure, the quantity-unit price relationship for this excavation activity can be modeled using a non-linear regression model. More specifically, Figure 5-2 shows a power regression curve, which is a regression approach commonly used to explain the reduction in unit prices as the quantities of work increase (Rueda 2016; Pakalapti 2018). Power regression functions were used to model unit prices for all items at the pay item level.

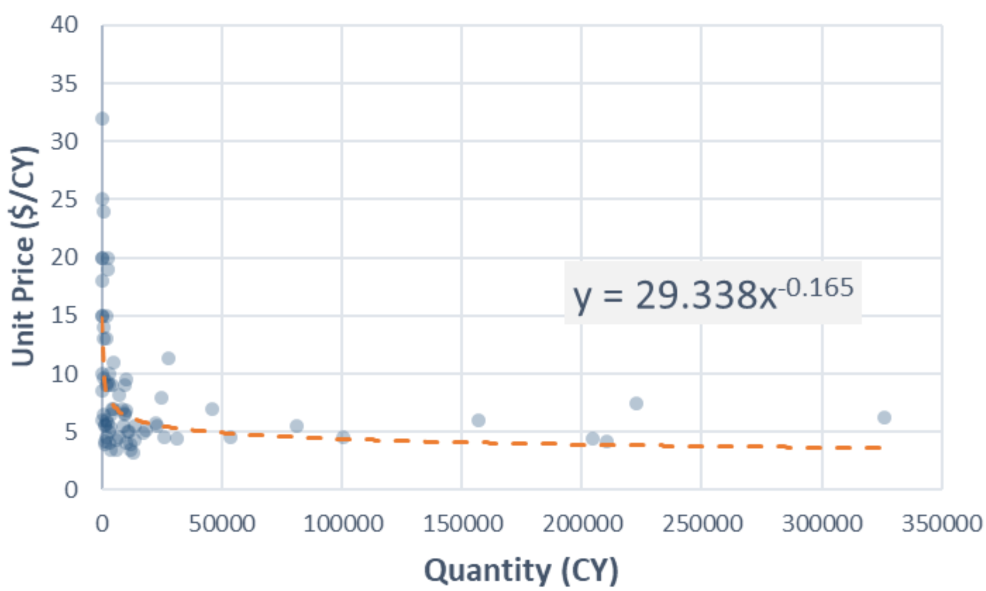

Figure 5-2 Unit Price Model for Common Excavation 2008-2012 – MnDOT

Traditional cost indexing approaches have a limited capacity to consider the economies of scale principle. For example, a traditional indexing approach could indicate a reduction in the price of excavation if the unit price paid last year for 10,000 cubic yards of common excavation is compared against the price paid today for 200,000 cubic yards. However, the price difference could actually be due to the significant difference in the amount of excavation delivered under each contract. To address this problem, the two previous studies using the MCCI approach (Gransberg and Rueda 2014; Pakalapati and Rueda 2018) defined a number of quantity ranges for each pay item. Assuming that quantities of work within each range have comparable unit prices, they proceeded to track price changes for each quantity range. A single price change measure for each item was then estimated as a weighted average of all quantity ranges.

Although the use of quantity ranges proved to be an effective approach, it required considerable quantitative efforts to establish quantity ranges, track price changes within each range, and combine measures from all quantity ranges into a single measure of change. This study has proposed an improvement to that approach by tracking the average movements of the power regression curve. For instance, if a curve for a given item moves up 10%, the index for that pay item is increased by 10%.

Step 2: Bottom-Up Calculation of Indexes at Upper Levels

The second major step in the development of an MCCI refers to bottom-up calculations to define indexes at the upper levels. To calculate the indexes on the Sub-Division Level 1, indexes at the pay item level are grouped based on similar characteristics and aggregated to produce a single overall cost index per group. It means that, for CDOT's MCCI in Figure 5-1, 28 groups were formed out of the 40 pay item cost indexes, resulting in the 28 indexes at Sub-Division Level 1. In a similar way, these 28 indexes were divided into 22 groups to produce the 22 indexes at Sub-Division Level 2, and so on until calculating a single Agency Level index with the 5 indexes from the Division Level. The combination of similar indexes into a higher-level index is just the weighted average of the grouped items at the lower level. Weights for this calculation are proportional to the dollar amounts spent on the items under consideration during each indexing period.

Indexes at all levels are grouped according to the coding scheme used by each STA to classify its pay items. Pay item identification numbers could communicate information about the scope, materials, and/or activities associated with each item. Thus, pay items with similar identification numbers can be assumed to be closely related. STAs' pay item coding schemes, which usually align with their standard specification books, are also used in this study to label each of the cost indexes in the MCCI.

Table 5-1 shows how some of the indexes were grouped and labeled across all CDOT's MCCI versions. This table only shows identification labels for indexes across the bottom-up pathways of the 13 pay item indexes under Division 2. Divisions 3 to 5 also have downward ramifications, but those are not shown in Table 5-1.

The MCCIs developed for MnDOT and DelDOT have slightly different configurations than the one shown in Table 5-1, but those are also five-level MCCIs and the bottom-up calculation process and upward ramifications follow the same general principles. A complete version of Table 5-1, as well as the corresponding tables for MnDOT and DelDOT can be found in Appendix B. Each STA's MCCI configuration should be adjusted according to its unique pay item classification system. Table 5-2 shows the number of cost indexes developed at each MCCI level for each agency.

Table 5-1 CDOT's MCCI Levels and Configuration

<table>
<tr><th>Pay Item Level</th><th>Sub-Division Level 1</th><th>Sub-Division Level 2</th><th>Division Level</th><th>Agency Level</th></tr>
<tr><td>202-00035</td><td>202-000</td><td rowspan="5">202</td><td rowspan="13">2</td><td rowspan="16">1</td></tr>
<tr><td>202-00210</td><td rowspan="4">202-002</td></tr>
<tr><td>202-00220</td></tr>
<tr><td>202-00240</td></tr>
<tr><td>202-00250</td></tr>
<tr><td>203-00010</td><td rowspan="2">203-000</td><td rowspan="3">203</td></tr>
<tr><td>203-00060</td></tr>
<tr><td>203-00100</td><td>203-001</td></tr>
<tr><td>206-00000</td><td rowspan="2">206-000</td><td rowspan="4">206</td></tr>
<tr><td>206-00065</td></tr>
<tr><td>206-00100</td><td>206-001</td></tr>
<tr><td>206-00360</td><td>206-003</td></tr>
<tr><td>207-00205</td><td>207-002</td><td>207</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>3</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>4</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>5</td></tr>
</table>

Table 5-2 Number of Cost Indexes per Level per Case Study Agency

Agency	MnDOT	CDOT	DelDOT
Agency Level	1	1	1
Division Level	12	5	7
Sub-Division Level 2	21	22	14
Sub-Division Level 1	28	28	21
Pay Item Level	61	40	37
Total No. of Cost Indexes	**123**	**96**	**80**

As moving from the Pay Item Level to the Agency Level, the number of digits used to identify the MCCI indexes is reduced, meaning that now the index represents a broader scope of work. In other words, the degree of detail of an index is given by its MCCI level, with the scope becoming increasingly broader at upper levels. For example, cost indexes 203-00010 and 203-00060 in Table 5-1 only represent these two specific pay items. Bid data from these two indexes was then used to calculate cost index 203-000 at Sub-Division Level 1, which is intended to represent all items that start with 203-000. In the same way, index 203 represents all pay items that start with 203 and index 2 represents all pay items starting with 2. The Division Level corresponds to the actual construction divisions from the STA's standard specification book. All the construction divisions in CDOT Standard Specification Book are listed below (CDOT 2019). Thus, in the case of CDOT, index 2 represents the overall market behavior of earthwork activities, comprising all pay items starting with 2.

- Division 2 – Earthwork
- Division 3 – Bases
- Division 4 – Pavements
- Division 5 – Structures

The bottom-up process to produce higher-level indexes is just a weighted average calculation of the grouped items at the lower levels, as shown in Figure 5-3. This figure shows how two of CDOT's pay item indexes (203-0010 and 203-0060) are combined to generate their corresponding index at Sub-Division Level 1 (230-000). Weights for this calculation are proportional to the dollar amounts awarded on the items under consideration during each indexing period within the group. It means that during index Period 1, 203-00010 contributed with 25% of the combined awarded amount between and 203-00010 and 203-00060, and the latter contributed to the remaining 75%.

203-000					
Period	1	2	3	4	5
Index	100	126.11	128.93	130.13	126.02

$$I_{Com_i} = \sum_{i=0}^{n} I_{ji} * W_{ji}$$

203-00010					
Period	1	2	3	4	5
Index	100	98.57	95.92	85.36	85.65
Weight	0.25	0.34	0.32	0.1	0.3

203-00060					
Period	1	2	3	4	5
Index	100	140.34	144.10	134.99	143.70
Weight	0.75	0.66	0.68	0.90	0.70

Note: I_{comi} $= Combined\ index\ value\ at\ index\ period\ i$
I_{ji} $= Index\ Value\ for\ Item\ j\ at\ index\ period\ j$
W_{ji} $= Weight\ for\ Item\ j\ at\ index\ period\ j$

Figure 5-3 MCCI Bottom-Up Calculation Approach

5.4 MCCI Configuration and Calculation

As mentioned before in this Dissertation, one of the most important benefits offered by MCCIs is the ability to customize the cost forecasting process to meet the specifics of each project or program through the use of scope based CCIs. This section presents the process to generate scope based CCIs from an MCCI at both the project and program level.

5.4.1 Project-Specific Cost Indexes

The process of generating a project specific CCI is illustrated with the asphalt paving project shown in Table 5-3. This is an actual project awarded by MnDOT. In summary, a project-specific cost index is developed by combining individual relevant MCCI indexes; one MCCI index for each anticipated pay item. Each pay item is paired with the MCCI index that best represents its scope, as indicated by its item identification number. The final project specific CCI is just the weighted average of the selected MCCI indexes. The weight for each pay item is proportional to its contribution to the total estimated project cost. Weights are calculated using engineering estimates since actual awarded prices would not be known until awarding the project. Likewise, engineering estimates are calculated based on current prices observed at the moment of developing the project specific CCI. It should be noted that, at this point of the process, the relative relevance of each item is more important than predicting the actual prices to be submitted by the successful contractor at the letting date.

Table 5-3 shows the weight and MCCI index selected for each item. The latter refers to the index identification labels in the last column of the table (see the configuration of MnDOT's MCCI in Appendix B). Those labels are equivalent to the labels shown in Table 5-1 for CDOT. For example, item 2580606/00010 - Interim Pavement Marking in Table 5-3 has its own index at the pay item level. On the other hand, item 2582502/41104 - 4\" Solid Line White-Epoxy had to move up to the MCCI Division Level to find its best matching index. It should be noted that cost indexes at MnDOT's Division Level are identified with three-digit labels (e.g., 258). Likewise, the identification number for all MnDOT's pay items always start with 2; therefore, that is the single-digit label for the Agency Level index (see Appendix B).

Table 5-3 Asphalt Paving Project – MnDOT Sample Project

Item Number	Description	Units	Weight	MCCI Index
2021501/00010	Mobilization	LS	2.3781%	2
2051501/00010	Maintenance and Restoration of Haul Roads	LS	0.0001%	2
2104509/00055	Remove Twisted End Treatment	EACH	0.1203%	2104
2104521/00220	Salvage Guard Rail-Plate Beam	L F	0.1077%	2104521/00220
2104601/01011	Haul Salvaged Material	LS	0.0595%	2104
2105501/00010	Common Excavation	C Y	0.0773%	2105501/00010
2221501/00010	Aggregate Shouldering Class 1	TON	1.9326%	2
2221604/00010	Aggregate Shouldering	S Y	0.1231%	2
2232501/00040	Mill Bituminous Surface (1.5\")	S Y	0.3325%	2232501/00040
2232602/00010	Milled Rumble Strips	EACH	0.3266%	2232602/00010
2357606/00010	Bituminous Material for Shoulder Tack	GAL	0.0195%	2357606/00010
2360501/22200	Type SP 12.5 Wearing Course Mixture (2,b)	TON	82.7320%	2360501/22200
2411507/00060	Concrete End Post	EACH	1.5658%	2411
2540602/00150	Mail Box Support	EACH	0.1359%	2
2554501/00001	Traffic Barrier Design Special	L F	0.6992%	2554501
2554501/02007	Traffic Barrier Design B8307	L F	0.3703%	2554501/02007
2554501/02038	Traffic Barrier Design B8338	L F	0.6268%	2554501/02038
2554521/00020	Anchorage Assembly-Plate Beam	EACH	0.1364%	2554
2554523/00028	End Treatment-Tangent Terminal	EACH	0.2610%	2554
2563601/00010	Traffic Control	LS	4.1618%	2
2580603/00010	Interim Pavement Marking	L F	0.5916%	2580603/00010
2582501/03008	Pavement Message (Stop Ahead) Epoxy	EACH	0.1567%	258
2582502/41104	4\" Solid Line White-Epoxy	L F	2.4801%	258
2582502/41524	24\" Stop Line White-Epoxy	L F	0.0266%	258
2582502/42104	4\" Solid Line Yellow-Epoxy	L F	0.3017%	258
2582502/42204	4\" Broken Line Yellow-Epoxy	L F	0.2770%	258
		TOTAL	100.00%	

The weighted sum for the combination of the selected MCCI indexes is a simple process. It is exactly the same as the bottom-up calculation process explained in the previous section for the development of indexes at upper levels. Table 5-4 and Figure 5-4 show an example of a project specific CCI generated for the asphalt paving project in Table 5-3 using one of the MCCI versions developed for MnDOT. All project- and program-specific CCIs developed with the proposed methodology are set to start with an index value of 100. Index values in the order of hundreds are commonly used in CCIs (Gransberg and Rueda 2014).

Table 5-4 CCI Development for a MnDOT Sample Asphalt Paving Project

Date	Index	Date	Index	Date	Index	Date	Index
P1-1999	100.00	P1-2004	98.33	P1-2009	167.73	P1-2014	206.80
P2-1999	95.56	P2-2004	107.63	P2-2009	154.21	P2-2014	234.74
P1-2000	104.65	P1-2005	111.53	P1-2010	180.67	P1-2015	232.07
P2-2000	102.32	P2-2005	129.98	P2-2010	211.10	P2-2015	208.51
P1-2001	103.47	P1-2006	137.55	P1-2011	176.54	P1-2016	250.10
P2-2001	119.04	P2- 2006	160.08	P2-2011	135.62	P2-2016	174.95
P1-2002	114.94	P1-2007	146.38	P1-2012	202.39	P1-2017	223.16
P2-2002	100.77	P2-2007	170.48	P2-2012	168.01	P2-2017	236.04
P1-2003	100.13	P1-2008	158.46	P1-2013	205.13	P1-2018	245.06
P2-2003	104.46	P2-2008	162.91	P2-2013	224.80	P2-2018	278.82

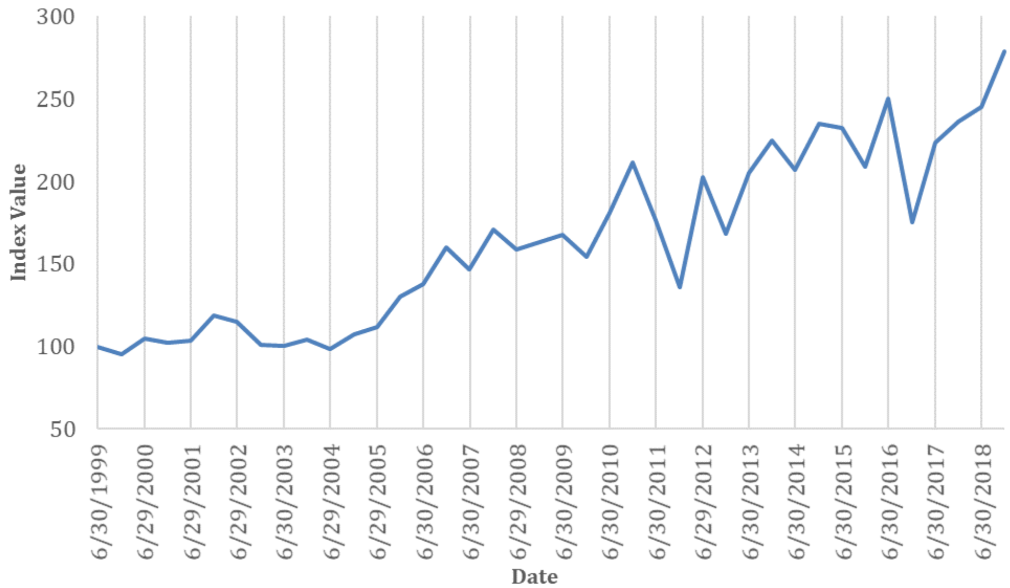

Figure 5-4 CCI Development for a MnDOT Sample Asphalt Paving Project

5.4.2 Program-Specific Cost Indexes

The first step in the creation of program-specific cost indexes is to understand the composition of the scope of work associated with the program. Some programs, such as Bridge or Pavement Management Programs, are aimed to plan construction activities for a specific type of work. In those cases, the program-specific cost index could be a project-specific index for a carefully selected sample project intended to represent the scope of the intended program. For example, the asphalt paving project in Table 5-3 was originally identified as a good representative of MnDOT's typical asphalt paving activities. Thus, a planning program focused only on asphalt paving could use the index shown in Table 5-4 and Figure 5-4 to determine a program-specific inflation rate.

The process to develop program-specific indexes for programs that involve various types of work (such as LRTPs) has a few additional steps, but it is still a simple four-step process:

1. Identify the different types of work contained in the program.
2. Approximate the percentage of the total program that corresponds to each type of work. These percentages will be used as weights in Step 4.
3. Identify a sample project that reasonably represents each type of work and develop project specific CCIs for those projects. This step may not always be required since the agency could create and maintain a library of generic cost indexes for typical types of work.
4. Combine all project-specific indexes through a weighted average calculation using the weights defined at Step 2.

The simplicity of this methodology also facilitates sensitivity analyses to evaluate multiple scenarios or to quantify the risk of having drastic changes in the anticipated distribution of work within the program. For example, Figure 5-5 shows three possible program-specific indexes that could be developed by MnDOT for a statewide pavement program that combines asphalt paving (AP) and concrete paving (CP) activities.

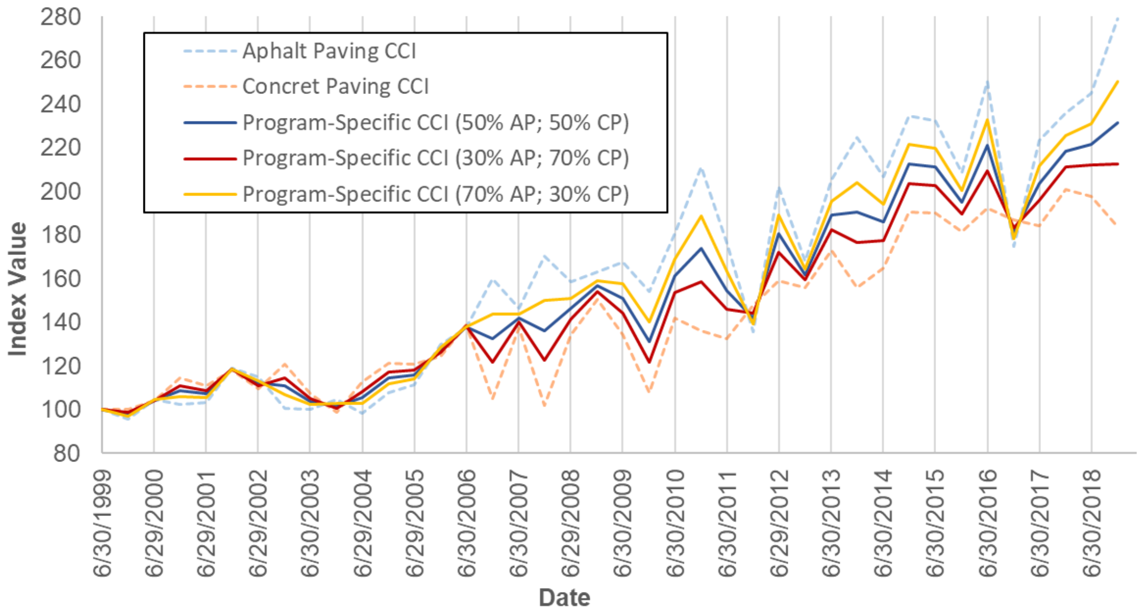

Figure 5-5 Program-Specific CCI – MnDOT Sample Paving Program

The three program-specific indexes in Figure 5-5 correspond to three different distributions of the amounts of work associated with each pavement material (50%/50%; 30%/70%; and 70%/30%). These hybrid indexes are the result of a weighted average calculation between an Asphalt Paving and a Concrete Paving CCI. The Asphalt Paving CCI is the same project specific CCI shown in Figure 5-4, which is assumed to represent all asphalt paving activities. Similarly, the Concrete Paving CCI in Figure 5-5 is a project specific CCI for a representative concrete paving project. All the examples of project- and program-specific CCIs presented in this chapter were developed with one of the 20 MCCI versions developed for MnDOT: a statewide MCCI calculated with all unit prices submitted by both successful and unsuccessful contractors. The following section provides more information about all the MCCI versions developed for each of the three case study agencies.

5.4.3 MCCI Versions under Consideration

As mentioned before, various MCCI versions were developed for each agency in an attempt to identify the most effective one at representing the regional construction market. All MCCI versions for each agency follow the configurations in Appendix B. The difference between versions lies in their geographic scope (statewide and regional) and their type of price input: awarded unit prices (submitted by the selected contractors); average unit prices per project; median unit prices per project; and all unit prices received from both successful and unsuccessful contractors. Tables 5-5 to 5-7 outline the different MCCI versions developed for each agency.

Table 5-5 DelDOT - Multilevel Construction Cost Index Classification

<table>
<tr><th>Geographic Classification</th><th colspan="2">Description</th></tr>
<tr><td rowspan="4">Statewide Multilevel Construction Cost Indexes</td><td colspan="2">Statewide MCCI with Awarded Unit Prices</td></tr>
<tr><td colspan="2">Statewide MCCI with Average Unit Prices per Project</td></tr>
<tr><td colspan="2">Statewide MCCI with Median of Unit Prices per Project</td></tr>
<tr><td colspan="2">Statewide MCCI with All Unit Prices</td></tr>
<tr><td rowspan="13">Regional Multilevel Construction Cost Indexes</td><td>Region</td><td>Description</td></tr>
<tr><td rowspan="4">North</td><td>North MCCI with Awarded Unit Prices</td></tr>
<tr><td>North MCCI with Average Unit Prices per Project</td></tr>
<tr><td>North MCCI with Median of Unit Prices per Project</td></tr>
<tr><td>North MCCI with All Unit Prices</td></tr>
<tr><td rowspan="4">Central</td><td>Central MCCI with Awarded Unit Prices</td></tr>
<tr><td>Central MCCI with Average Unit Prices per Project</td></tr>
<tr><td>Central MCCI with Median of Unit Prices per Project</td></tr>
<tr><td>Central MCCI with All Unit Prices</td></tr>
<tr><td rowspan="4">South</td><td>South MCCI with Awarded Unit Prices</td></tr>
<tr><td>South MCCI with Average Unit Prices per Project</td></tr>
<tr><td>South MCCI with Median of Unit Prices per Project</td></tr>
<tr><td>South MCCI with All Unit Prices</td></tr>
</table>

Table 5-6 MnDOT - Multilevel Construction Cost Index Classification

Geographic Classification	Region	Description
Statewide Multilevel Construction Cost Indexes		Statewide MCCI with Awarded Unit Prices
		Statewide MCCI with Average Unit Prices per Project
		Statewide MCCI with Median of Unit Prices per Project
		Statewide MCCI with All Unit Prices
Regional Multilevel Construction Cost Indexes	**North**	North MCCI with Awarded Unit Prices
		North MCCI with Average Unit Prices per Project
		North MCCI with Median of Unit Prices per Project
		North MCCI with All Unit Prices
	North Central	North Central MCCI with Awarded Unit Prices
		North Central MCCI with Average Unit Prices per Project
		North Central MCCI with Median of Unit Prices per Project
		North Central MCCI with All Unit Prices
	South Central	South Central MCCI with Awarded Unit Prices
		South Central MCCI with Average Unit Prices per Project
		South Central MCCI with Median of Unit Prices per Project
		South Central MCCI with All Unit Prices
	South	South MCCI with Awarded Unit Prices
		South MCCI with Average Unit Prices per Project
		South MCCI with Median of Unit Prices per Project
		South MCCI with All Unit Prices

Table 5-7 CDOT - Multilevel Construction Cost Index Classification

Geographic Classification	Region	Description
Statewide Multilevel Construction Cost Indexes		Statewide MCCI with Awarded Unit Prices
		Statewide MCCI with Average Unit Prices per Project
		Statewide MCCI with Median of Unit Prices per Project
		Statewide MCCI with All Unit Prices
Regional Multilevel Construction Cost Indexes	**Northwest**	Northwest MCCI with Awarded Unit Prices
		Northwest MCCI with Average Unit Prices per Project
		Northwest MCCI with Median of Unit Prices per Project
		Northwest MCCI with All Unit Prices
	Northeast	Northeast MCCI with Awarded Unit Prices
		Northeast MCCI with Average Unit Prices per Project
		Northeast MCCI with Median of Unit Prices per Project
		Northeast MCCI with All Unit Prices
	Southwest	Southwest MCCI with Awarded Unit Prices
		Southwest MCCI with Average Unit Prices per Project
		Southwest MCCI with Median of Unit Prices per Project
		Southwest MCCI with All Unit Prices
	Southeast	Southeast MCCI with Awarded Unit Prices
		Southeast MCCI with Average Unit Prices per Project
		Southeast MCCI with Median of Unit Prices per Project
		Southeast MCCI with All Unit Prices

The evaluation of the different MCCI versions outlined in Tables 5-5 to 5-7 was intended to determine if different geographic conditions could result in different inflationary trends in the construction industry, as well as to determine what index input would more effectively represent the local construction market. Different geographic conditions bring different challenges and requirements at the program and project level. Therefore, different prices could be obtained for the same type of work or commodity in different locations. Price variability across the country or state depends on multiple factors including: the local climate and geological conditions; the availability of qualified local labor, suppliers, subcontractors, and general contractors; and the local applicable regulations (Akanni, Oke, and Akpomiemie 2015; Cuervo and Pheng 2005; Kaming et al. 1997).

Extensive research has been performed to investigate the factors that make current construction prices at Location A higher than those at Location B. However, little has been done to investigate if construction prices at Location A grow at higher/lower rate than those at Location B. There is a knowledge gap on how different geographic considerations affect inflation rates in the construction sector. In an attempt to address this gap, the author developed separate MCCIs for the different geographic regions shown in Figures 5-6 to 5-8.

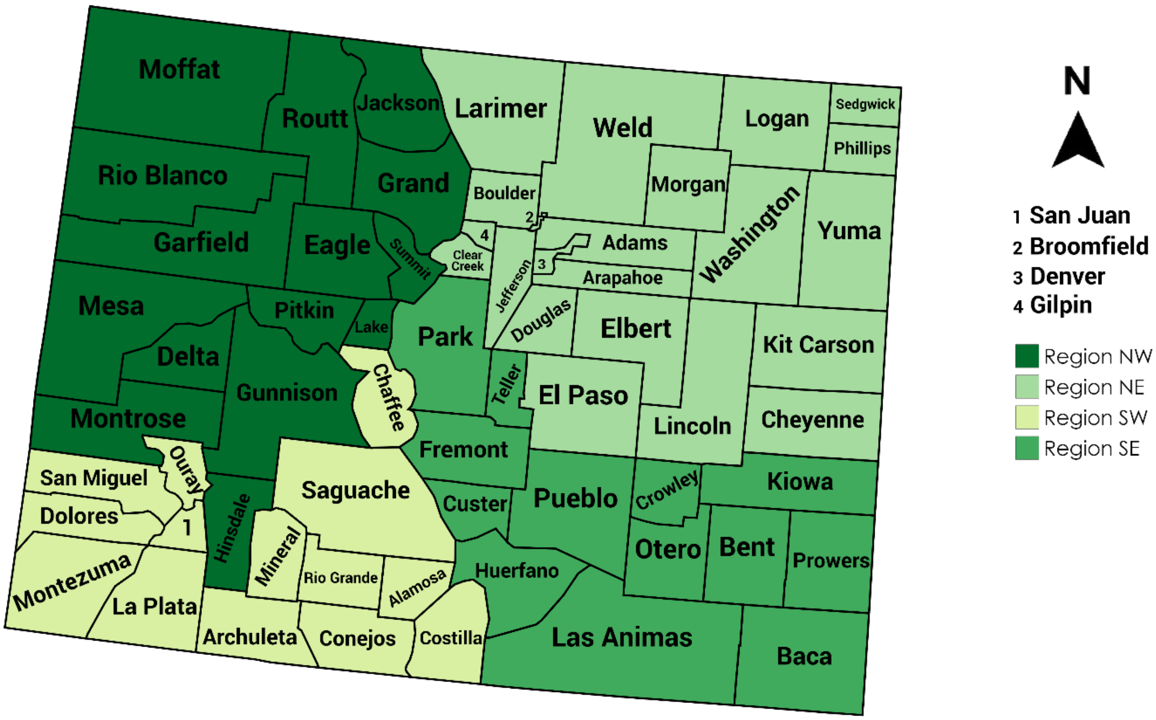

Figure 5-6 CDOT Geographic Regions

Figure 5-7 DelDOT Geographic Regions

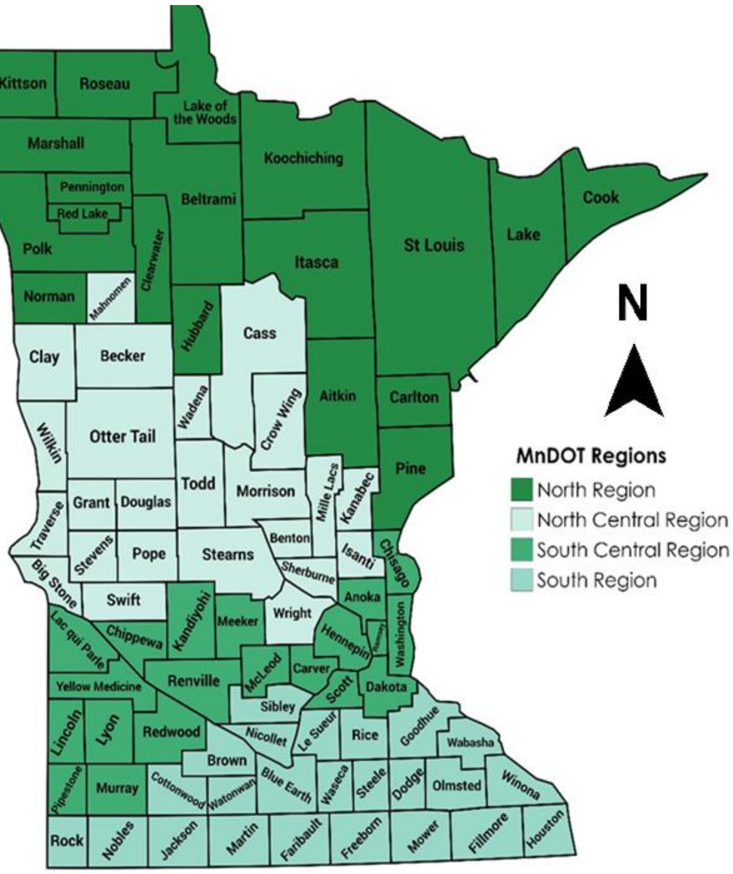

Figure 5-8 MnDOT Geographic Regions

The geographic classification of indexes is just an additional partition to the available data in an attempt to analyze price volatility at the regional level. Thus, DelDOT's "Statewide MCCI with Awarded Unit Prices" was developed with historical data from all available projects across the state and using only unit prices submitted by the awarded contractors. On the other hand, DelDOT's "North MCCI with Awarded Unit Prices" was also built with low-bid proposals, but only with bid data from Sussex County. Therefore, this MCCI and any findings from this data are only applicable to that region.

The regional classification done for each agency was intended to produce regions large enough to provide a constant stream of bid data, but at the same time, not too large to keep them relevant geographic-wise. The regional classification also tried to meet the apparent criteria followed by the selected agencies for the designation of their operational districts/regions. For example, each geographic region in Figure 5-8 is a combination of two of MnDOT's operational districts. Each region in Figure 5-6 is associated with a given regional office, except for the Northeast region, which combines CDOT's Regions 1 and 4. On the other hand, having only three counties, DelDOT treats each county as a separate district.

Although regional MCCIs were not the best option for most regions, as shown on Table 5-9, it was found that different statewide MCCI versions were more suitable for different regions within the same state, which still allowed the study to conclude that construction activities in different geographic regions could be affected by different inflation patterns. In other words, it would be reasonable to consider the use of different inflation rates for different regions across the state. Those different regional inflation rates would be the result of using a different construction cost index in each region. In other to optimize implementation efforts, STAs could evaluate only statewide MCCIs, considering regional versions only for those parts of the state consuming considerable portions of the construction budget. Implementation efforts could be further optimized by considering only MCCIs developed with awarded unit prices and with all the unit prices received by the agencies. The most suitable MCCIs for ten of the eleven regions evaluated through the case studies were built with those two price inputs.

5.5 Identification of Suitable Construction Cost Index

The proposed protocol is not aimed to find the best possible CCI. It is instead intended to facilitate a comparative analysis to identify the most suitable alternative among a set of available options, even if all options are traditional CCIs affected by the limitations discussed in this Dissertation. This means that the protocol can still be used by STAs that decide not to implement MCCIs.

It should be noted that the proposed protocol for the assessment of cost indexes is not intended to evaluate their cost forecasting capabilities. The protocol is instead aimed to identify the indexing alternative that most closely resembles the observed behavior of the construction market, which should be the most suitable source of historical pricing data for the intended cost forecasting process. Figure 5-9 illustrates the proposed comparative suitability analysis protocol. Each step in this protocol is discussed in the following sections.

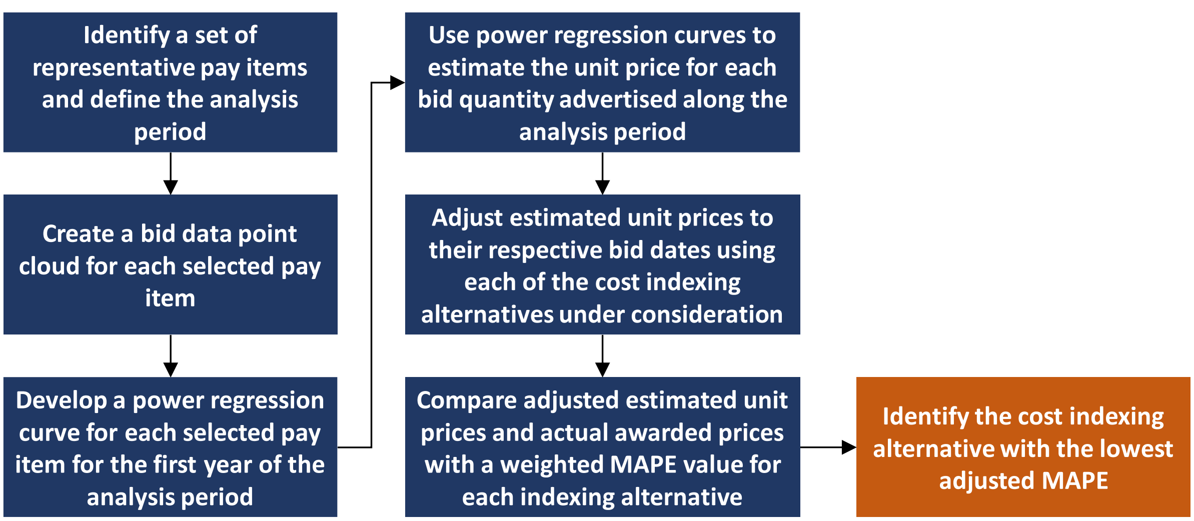

Figure 5-9 Cons Indexing Comparative Suitability Analysis Protocol

5.5.1 Representative Pay Items and Analysis Period

The pay items used for the comparative analysis of cost indexing alternatives do not necessarily need to include all the MCCI pay items referenced in Chapter 4. Due to time and resource constraints, this dissertation only considered between three to five of the case study agencies' most relevant pay items to apply the proposed protocol. The selected pay items for each agency are listed in Table 5-8. Further research is required to determine the optimal number of relevant pay items for this analysis. However, a simple computation algorithm would make it easy to consider any number of pay items.

Table 5-8 Selected Relevant Items for Comparison Analysis

Agency	Item ID	Description	Relative Weight
MnDOT	2106507/00010	Excavation - Common	17%
	2301507/00010	Structural Concrete	33%
	2360509/23200	Type SP 12.5 Wearing Course Mixture (3,B)	21%
	2360509/23300	Type SP 12.5 Wearing Course Mixture (3,C)	19%
	2360509/24500	Type SP 12.5 Wearing Course Mixture (4,E)	10%
CDOT	412-00600	Concrete Pavement (6 Inch)	33%
	403-00720	Hot Mix Asphalt (Patching) (Asphalt)	56%
	203-00010	Unclassified Excavation (Complete In Place)	11%
DelDOT	202000	Excavation and Embankment	24%
	406001	Hot-Mix Patching	54%
	503001	Patching C.C.C. Pavement,1.8 m to 6 m, Type A	22%

Likewise, the analysis period used for the identification of the most suitable cost indexing alternative does not need to be the same 20-year period suggested for the development of MCCIs. The analysis period for the proposed protocol should be long enough to include a good amount of cost indexing data, but not too long, so that the indexing alternatives are still evaluated on their suitability to the current construction industry. If a given cost index shows the best effectiveness at tracking price fluctuations over the last 20 years, but a different one is found to be more effective over the last 10 years, preference should be given to the latter. Thus, an analysis period of about 10 years is recommended.

5.5.2 Bid Data Point Clouds

"Accuracy" is an abstract concept in construction cost estimating. The market price for a given construction activity cannot be defined by a single "accurate" value. Different contractors competing for the same project commonly submit different sets of prices in their bids. This does not necessarily mean that some of those prices are wrong or inaccurate. There is some natural price variability resulting from the combination of several factors, including the construction means and methods adopted by each contractor, differences in overhead and profit markups, the use of different suppliers and subcontractors, each bidder's unique perception of risk, and bargaining power of each contractor. Thus, the historical bid data for a given pay item forms a cloud of points fluctuating over time, which represents each item's unavoidable cost variability.

The proposed protocol uses three-dimensional bid data point clouds. The three parameters that give the location of each point in the cloud are: 1) letting data; 2) bid quantity; and 3) and recorded awarded unit price. The following steps are aimed to identify the indexing alternative that most closely determines the middle of those data point clouds.

5.5.3 Base Power Regression Curves and Base Unit Price Estimates

The base power regression curves used in the comparative analysis of cost indexing alternatives are similar to those used to develop MCCI in Section 5.3, but they are built with bid data from projects awarded during the first year of the analysis period. Table 5-10 shows an example of the base power regression curve for the Hot Mix Asphalt (Patching) item during the year 1994 on the CDOT. In the case of MnDOT's case study, one power regression curve was developed for each of the items listed in Table 5-8. The analysis period for that case study started in January 2007 and ended in December 2018; therefore, base power regression curves were created with historical bid data from 2007.

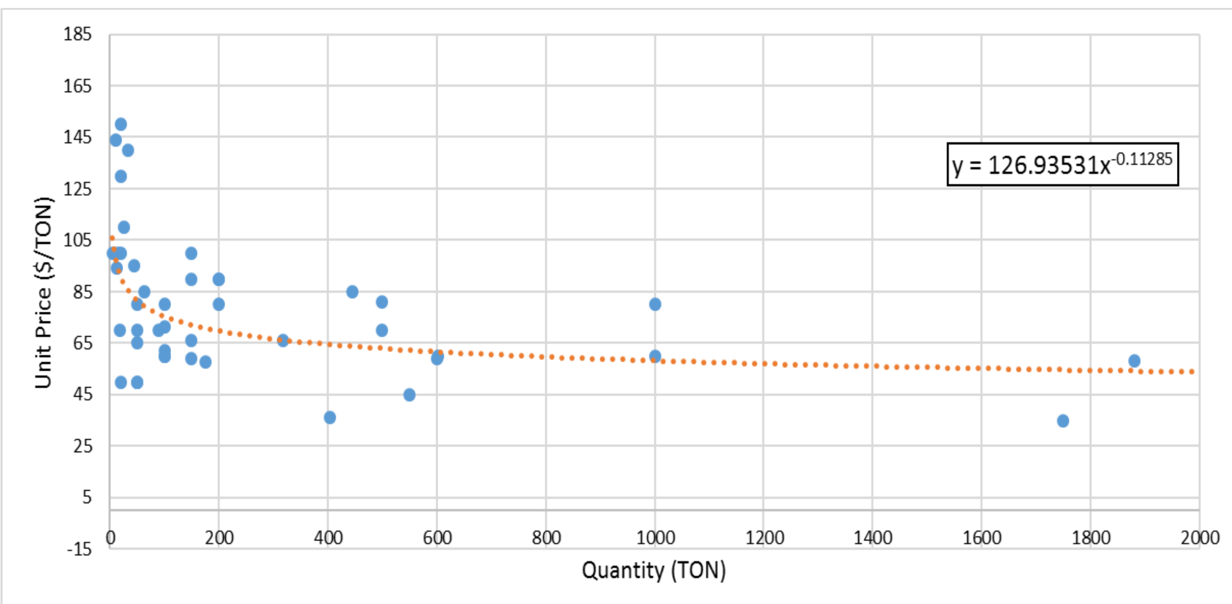

Figure 5-10 Base Power Regression Curve for Hot Mix Asphalt (Patching) 1994 – CDOT

Those curves are then used to estimate base unit prices for all bid quantities awarded for each of the selected pay items along the analysis period. Since the regression curves were developed with data from the first year of the analysis period, all unit price estimates produced with those curves are assumed to yield average unit prices in the middle of that year. Thus, MnDOT's base power regression curve for Structural Concrete (second item in Table 5-8) was used to estimate a unit price for a quantity awarded in 2018, but the output corresponded to the average price for that amount of structural concrete in mid-2007.

5.5.4 Index-Based Data Point Clouds

All base unit price estimates from the previous step are then adjusted to their respective letting dates, creating another data point cloud for each pay item –called index-based data point cloud. Each cost indexing alternative under consideration is used to create a separate set of index-based data point clouds. Each point in the index-based data point clouds has a corresponding point in the original bid data point clouds created with the actual historical bid data. The following steps are intended to measure the average distance between corresponding points provided by each cost indexing option. The shorter the average distance, the larger the overlapping between the bid data and the index-based data point clouds, and the more suitable the cost indexing alternative.

5.5.5 Average Distance between Bid Data and Index-Based Data Point Clouds and Identification of the Most Suitable Cost Indexing Alternative

The average distances between the bid data and the index-based data point clouds were quantified in the form of Mean Absolute Percentage Error (MAPE) values. One MAPE value per pay item. MAPE values are commonly used in the cost estimating literature to measure and compare accuracy between cost estimating approaches (Gardner 2015), but in this study, those values are aimed to indicate the degree of overlap between data point clouds for each selected pay item. For instance, for the case study with the Delaware Department of Transportation (DelDOT), three MAPE values (one per pay item listed in Table 5-8) were calculated with each of the 21 cost indexing alternatives considered for that case study. MAPE values were calculated as shown in Equation 3.4.

$$MAPE_{ij} = \frac{100\%}{n} \sum_{k=1}^{n} \left| \frac{P_{aki} - P_{eij}}{P_{aki}} \right| \quad (5.1)$$

Where: $MAPE_{ij} = Mean\ Absolute\ Percentage\ Error\ fo\ Item\ i\ with\ Index\ j$
$P_{aki} = Awarded\ Unit\ Price\ for\ Observation\ k\ for\ Item\ i$
$P_{eij} = Index\ Based\ Unit\ Price\ for\ Observation\ k\ for\ Item\ i\ with\ Index\ j$
$n = Number\ of\ Observations\ for\ Item\ i$

The MAPE values associated with each cost indexing approach are then combined into a single overall MAPE taking into consideration the relative importance of each pay item (relative weight in Table 5-8). The result of this combination is a weighted MAPE, which is determined by the weighted average of the pay item MAPE values. The relative weights shown in Table 5-8 were used to calculate the weighted MAPEs for the three case studies. Likewise, the comparative analysis protocol was conducted at the regional level in order to identify the most suitable cost indexing alternative for each of the regions shown in Figures 5-6 to 5-8. Table 5-9 shows the results of this process for the MnDOT.

Table 5-9 Comparative Analysis MAP Results MnDOT

Region	ITEM	Statewide Multilevel Construction Cost Indexes - MAPEs				Regional Multilevel Construction Cost Indexes - MAPES			
		Awarded Unit Price	Average	Median	All Unit Prices	Awarded Unit Price	Average	Median	All Unit Prices
North	2106507/00010	35.24%	44.77%	42.54%	35.28%	35.68%	40.96%	40.49%	36.98%
	2301507/00010	17.54%	17.57%	17.84%	18.21%	17.01%	21.68%	17.79%	20.24%
	2360509/23200	18.70%	19.99%	20.10%	19.37%	19.15%	21.57%	20.69%	20.22%
	2360509/23300	16.37%	18.39%	19.40%	20.24%	19.68%	18.69%	18.03%	18.60%
	2360509/24500	17.79%	21.15%	20.47%	21.57%	22.04%	18.38%	19.82%	22.50%
	Weighted MAPE	**20.60%**	**23.24%**	**23.09%**	**22.10%**	**21.67%**	**24.03%**	**22.52%**	**23.01%**
North Central	2106507/00010	36.80%	52.98%	49.92%	40.90%	28.83%	33.03%	31.72%	29.52%
	2301507/00010	13.73%	15.28%	14.19%	16.01%	16.27%	18.00%	17.86%	17.41%
	2360509/23200	17.28%	19.97%	19.79%	17.81%	17.83%	17.36%	17.86%	17.23%
	2360509/23300	15.72%	18.79%	19.50%	19.67%	18.65%	29.19%	29.87%	26.42%
	2360509/24500	21.56%	20.61%	20.91%	21.83%	33.26%	29.66%	29.66%	27.15%
	Weighted MAPE	**19.59%**	**23.90%**	**23.15%**	**21.93%**	**20.96%**	**23.78%**	**23.74%**	**22.17%**
South Central	2106507/00010	37.85%	40.81%	40.21%	38.31%	41.63%	47.38%	47.17%	41.42%
	2301507/00010	26.01%	21.93%	22.12%	22.57%	25.15%	23.23%	21.60%	22.05%
	2360509/23200	18.69%	19.44%	19.27%	18.72%	20.06%	23.75%	23.30%	22.92%
	2360509/23300	18.76%	20.42%	20.84%	20.21%	19.21%	27.47%	28.25%	28.61%
	2360509/24500	17.27%	15.22%	15.11%	15.69%	28.21%	23.04%	23.90%	24.51%
	Weighted MAPE	**24.22%**	**23.64%**	**23.64%**	**23.29%**	**26.09%**	**28.24%**	**27.82%**	**27.04%**
South	2106507/00010	36.52%	46.87%	44.51%	36.98%	41.52%	49.20%	37.99%	49.28%
	2301507/00010	19.27%	18.75%	18.86%	19.15%	32.99%	21.95%	19.71%	22.07%
	2360509/23200	14.89%	15.91%	15.74%	14.53%	14.50%	14.10%	14.18%	13.74%
	2360509/23300	15.40%	15.45%	16.32%	15.47%	21.94%	18.99%	19.33%	18.72%
	2360509/24500	16.29%	14.55%	14.96%	14.76%	13.81%	14.81%	14.86%	13.53%
	Weighted MAPE	**20.26%**	**21.89%**	**21.70%**	**20.07%**	**26.51%**	**23.66%**	**21.10%**	**23.45%**

Table 5-9 highlights the most accurate MCCI per region for the MnDOT case study. It shows that the Statewide MCCI with Awarded Unit Prices is the most suitable alternative for the northern regions, while price fluctuations in the southern regions are better represented by the Statewide MCCI with All Unit Prices. A possible reason to explain why statewide indexes outperformed regional MCCIs could be that the larger datasets used at state level allowed for a more accurate representation construction market changes in Minnesota. Although the efforts to develop regional MCCIs did not yielded positive results, there is still an important finding from these results: MnDOT's construction activities in the southern and northern regions are affected by different inflation patterns.

The two suitable statewide MCCIs were then compared with the weighted MAPE values of the existing cost indexes. Initially, this comparison was performed over a shorter period of time, from 2007 to 2014, since MnDOT could not calculate index values after 2014 due to lack of data. To ensure an "apples to apples" comparison, the analysis period was reduced to all cost indexes. Table 5-10 and Appendix D show the results of this comparison for this case study.

The results in Table 5-10 show that, when compared against the selected existing cost indexes, the Awarded Unit Price and All Unit Prices MCCIs are still the best options for the northern and southern regions, respectively for this example. On the other hand, if MnDOT decides not to invest in the development and implementation of MCCIs, the second best alternatives would be its in-house CCI in the northern regions, the PCE in the South Central Regions, and the RSMeans National CCI in the South Region.

Table 5-10 Comparative Analysis Results MCCIs vs Existing Indexes MnDOT

Region	ITEM	Statewide MCCIs		RSMeans CCI		NHCCI	CPI	PCE	MnDOT CCI
		Awarded Unit Price	All Unit Prices	National	Regional				
North	2106507/00010	33.33%	30.50%	65.60%	65.89%	69.66%	66.94%	67.32%	62.56%
	2301507/00010	20.05%	19.33%	26.20%	26.75%	32.40%	28.46%	29.49%	22.03%
	2360509/23200	18.58%	19.45%	20.66%	20.92%	27.25%	22.43%	23.03%	18.47%
	2360509/23300	16.51%	21.01%	24.99%	24.30%	16.84%	21.55%	20.81%	32.42%
	2360509/24500	17.58%	21.11%	15.22%	15.50%	13.51%	13.78%	12.75%	17.77%
	Weighted MAPE	**21.08%**	**21.77%**	**30.39%**	**30.57%**	**32.74%**	**30.92%**	**31.20%**	**29.74%**
North Central	2106507/00010	35.66%	41.06%	54.89%	55.22%	60.50%	56.77%	57.38%	51.32%
	2301507/00010	16.82%	19.31%	23.62%	23.98%	33.18%	26.37%	26.90%	19.36%
	2360509/23200	14.13%	15.90%	13.71%	13.78%	20.95%	15.08%	15.59%	13.27%
	2360509/23300	16.96%	22.75%	31.57%	30.77%	18.89%	26.49%	25.65%	41.25%
	2360509/24500	21.31%	22.06%	18.40%	18.53%	21.96%	19.29%	19.46%	18.68%
	Weighted MAPE	**19.97%**	**23.26%**	**27.87%**	**27.92%**	**31.41%**	**28.50%**	**28.74%**	**27.65%**
South Central	2106507/00010	491.63%	501.92%	498.23%	500.18%	518.91%	503.32%	504.72%	498.57%
	2301507/00010	30.21%	26.49%	30.47%	30.93%	36.62%	32.34%	32.70%	26.94%
	2360509/23200	17.38%	16.94%	15.24%	15.28%	18.60%	15.59%	15.68%	16.09%
	2360509/23300	12.26%	14.16%	17.68%	16.56%	10.81%	14.36%	13.33%	26.76%
	2360509/24500	16.44%	14.82%	14.52%	14.33%	13.54%	13.06%	12.88%	18.43%
	Weighted MAPE	**23.99%**	**23.01%**	**24.55%**	**24.50%**	**26.12%**	**24.52%**	**24.46%**	**25.72%**
South	2106507/00010	36.85%	36.64%	33.11%	33.03%	30.86%	32.71%	32.81%	34.76%
	2301507/00010	23.22%	22.98%	28.38%	28.95%	36.00%	30.72%	31.63%	24.52%
	2360509/23200	13.89%	13.59%	14.69%	14.79%	20.50%	16.02%	16.48%	14.37%
	2360509/23300	15.93%	15.81%	20.50%	20.25%	16.68%	17.76%	17.83%	26.71%
	2360509/24500	15.59%	14.97%	13.61%	13.81%	17.10%	14.00%	14.08%	15.65%
	Weighted MAPE	**21.42%**	**21.16%**	**23.31%**	**23.47%**	**26.26%**	**23.80%**	**24.23%**	**23.65%**

The same steps were used to compare the MCCIs described on tables 5-5 to 5-7 for each case study and the existing cost indexes on table 4-3. Table 5-11 and Appendix D summarize the top three cost indexing alternatives identified for each region of the three case studies.

Table 5-11 Case Study Results - Top Three Cost Indexing Alternatives per Region

<table>
<tr><th>Agency</th><th>Region</th><th>Top-Three Indexing Alternatives</th></tr>
<tr><td rowspan="5">MnDOT</td><td>North</td><td rowspan="2">1. Statewide MCCI with Awarded Unit Prices
2. North MCCI with Awarded Unit Prices
3. Statewide MCCI with All Unit Prices</td></tr>
<tr><td>North Central</td></tr>
<tr><td>South Central</td><td>1. Statewide MCCI with All Unit Prices
2. Statewide MCCI with Median of Unit Prices per Project
3. Statewide MCCI with Average Unit Prices per Project</td></tr>
<tr><td>South</td><td>2. Statewide MCCI with All Unit Prices
3. Statewide MCCI with Awarded Unit Prices
4. South MCCI with Median of Unit Prices per Project</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="4">CDOT</td><td>Northwest</td><td>1. Statewide MCCI with All Unit Prices
2. Northwest MCCI with Awarded Unit Prices
3. Statewide MCCI with Median of Unit Prices per Project</td></tr>
<tr><td>Northeast</td><td>1. Northeast MCCI with All Unit Prices
2. Statewide MCCI with Median of Unit Prices per Project
3. Northeast MCCI with Awarded Unit Prices</td></tr>
<tr><td>Southwest</td><td rowspan="2">1. Statewide MCCI with Awarded Unit Prices
2. Statewide MCCI with Median of Unit Prices per Project
3. Statewide MCCI with All Unit Prices</td></tr>
<tr><td>Southeast</td></tr>
<tr><td rowspan="3">DelDOT</td><td>North</td><td>1. Statewide MCCI with Median of Unit Prices per Project
2. Statewide MCCI with All Unit Prices
3. North MCCI with All Unit Prices</td></tr>
<tr><td>Central</td><td>1. Statewide MCCI with Awarded Unit Prices
2. Statewide MCCI with All Unit Prices
3. Statewide MCCI with Median of Unit Prices per Project</td></tr>
<tr><td>South</td><td>1. Statewide MCCI with All Unit Prices
2. Statewide MCCI with Median of Unit Prices per Project
3. Statewide MCCI with Awarded Unit Prices</td></tr>
</table>

6. PROTOCOL TO DEVELOP SCOPE-BASED INFLATION RATES

6.1 Introduction

The protocol proposed in Chapter 5 for the comparative analysis of cost indexing alternatives is only intended to identify the index that most effectively represents the local construction market. After successfully applying the protocol to identify the most suitable cost indexing alternative, the agency still has to face the challenge of selecting an appropriate method to generate an inflation rate from that index. This chapter aims to assist STAs with that challenge. The chapter summarizes the process and findings associated with the assessment a cost forecasting approach. That assessment facilitated a better understanding of their forecasting performance and allowed to formulate guidelines and recommendations to maximize their effectiveness.

Recognizing that there is some variability in the level of effort and resources that different STAs would invest towards the improvement of their cost forecasting practices, this Dissertation considered an advanced data-driven procedure called Moving Forecasting Error (MFE). This innovative method was first used in this study to evaluate other approaches, but its results were later used to generate inflation rates and risk-based forecasting time horizons.

6.2 Moving Forecasting Error

The Moving Forecasting Error (MFE) methodology is a novel cost forecasting. It proved to be effective in generating scope-based inflation rates and in quantifying cost forecasting uncertainty in the form of risk-based forecasting outputs. This is an iterative process designed to maximize the value of the available data.

For instance, an STA with only 20 years of historical bid data to produce long-range forecasts would be forced to rely on this single 20-year dataset to predict the market behavior during the next 20 years. It seems to be common knowledge that not all 20-years periods would show the same market trends. Thus, in an ideal world, the agency would have access to multiple 20-year periods to consider multiple possible scenarios. Unfortunately, that is not the case for most STAs. The MFE method recognizes that there are a number of 3, 5, 10, and 15-year periods within the available data and takes advantage of those smaller data partitions to better infer future market conditions in the long-range.

Figure 6-1 illustrates the use of the MFE methodology to evaluate the use of standard annual inflation rates. This method uses real data from previous index values to show what would have happened if MnDOT would have actually used a given cost forecasting methodology along a given period of time in the past. This process starts by assuming that the individual performing the cost forecast is at the date that corresponds to the first known index value in available data (the oldest value). In the case of MnDOT and DelDOT, that date is January 1, 1999. It is then assumed that this person used the method under consideration at that point in time to project predict future price fluctuations until reaching that right-end of the time series (December 31, 2018). Since the actual index values along this period of time are known, it is possible to determine how good or bad were the predictions made by this individual. After calculating all forecasting errors along the time horizon, then this person is moved forward one index period, where he/she applies the same forecasting, the forecasting errors are estimated, and the person moves again to the next period.

This process continues and measures of estimating accuracy are collected until this person reaches the end of the time series. Figure 6-1 corresponds to the first application of MFE with a simple annual inflation rate of 3% on the asphalt paving MCCI index for the North Region of the MnDOT.

Further analysis of the MFE results from the previous section revealed that they are a great source of information to map forecasting accuracy and reliability trends across all forecasting time horizons. These trends were used to make inferences on the levels of accuracy and reliability of long-range forecasts, for which fewer observations were available. The plotting of these trends results in the creation of risk-based forecasting timelines like the one shown in Figure 6-2. This risk-based chart must not be confused with results from a regression. A regression model is obtained from a single pass along the time series, while this figure is the results of a most exhaustive analysis that considered all possible time horizons contained in the available data. Thus, trends in the first 10 years are the result of analyzing all possible 10-year periods in the asphalt paving MCCI, including the most recent 10 years. The risk-based forecasting timeline in Figure 6-2 is actually placed in the future over a 20-year time horizon and the vertical axis corresponds to index values assuming a current index value of 100.

Figure 6-1 Moving Forecasting Error

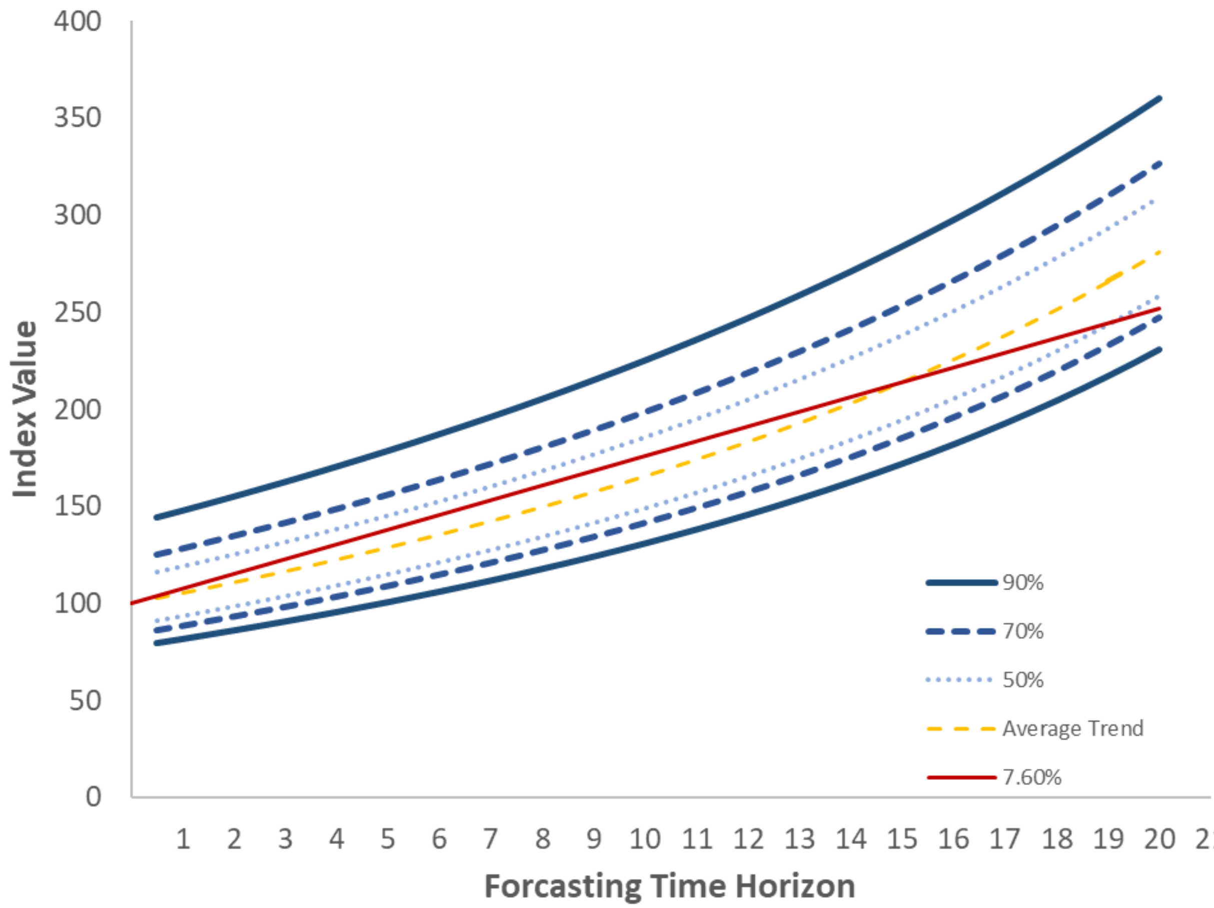

Figure 6-2 Risk-Based Forecasting Timeline with a 7.6% Simple inflation

Assuming that the target inflation rate is assumed to match the average projection in Figure 6-2 to reach a breakpoint where the budget risk is balanced, it would not be possible to achieve this target with a simple inflation rate due to the different shapes of the average trend and the linear projects obtained with simple annual rates. Figure 6-2 shows a 7.6% annual simple inflation rate unsuccessfully attempting to match the average trends. Different simple inflation rates intersect with the average projection at different times along the time horizons. As shown in Figure 6-3, a 5.3% compounded annual inflation rate would better match the average trend producing the same risk-balanced estimate ranges highlighted in Table 6-3 for all time horizons.

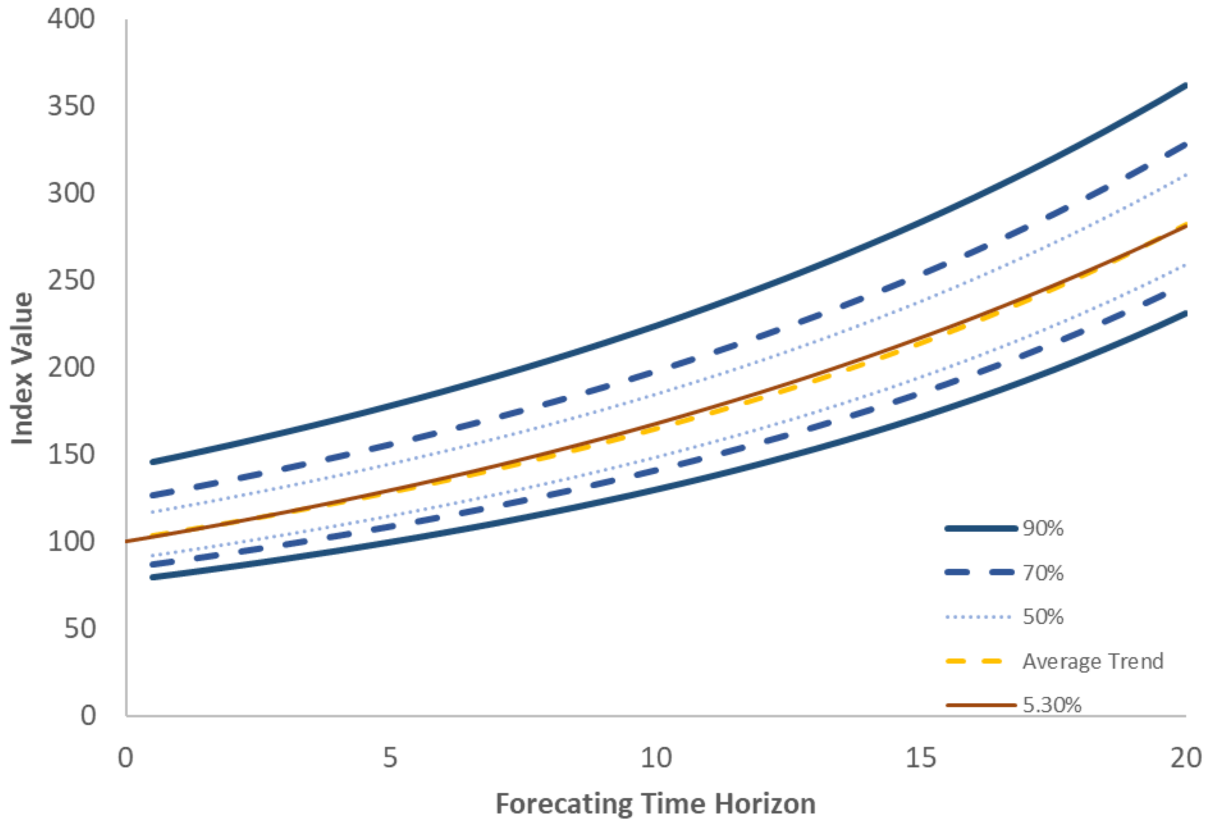

Figure 6-3 Risk-Based Forecasting Timeline with a 5.3% Compounded inflation

6.3 Calculation of the MFE

The proposed MFE methodology is applied to any cost index through the following 6-step process described on this chapter:

6.3.1 MFE Step 1

Apply the protocol for the comparative suitability analysis of cost indexing alternatives explained in Chapter 3 to identify the most suitable cost index for the region under consideration. That index would be assumed to effectively represent its respective local construction market. It should be noted that if a better market representative were found for that region, that would become the most suitable index.

6.3.2 MFE Step 2

Project the first index value into the future using a 4% annual compounded inflation rate. This step is forecasting an index value rather than a cost estimate in dollars. For each forecasting period along the available data, in six-month increments, calculate and record the percentage difference between the forecasted index value and the actual index value. Each of those differences is a forecasting error measure. At the end of this process, a 20-year dataset would produce 39 forecasting error measures for different forecasting periods (i.e., 0.5; 1; 1.5; 2; […] 18.5; 19; 19.5 years). Since the first known index value is calculated after the first six months of data (at 0.5 years), a 20-year dataset would not allow the calculation of a forecasting error for a 20-year forecast. The longest possible forecast would be over 19.5 years. The forecasting error at each forecasting period would be calculated as follows:

$$FE_t = \frac{I_t - I_0 \times (1+i)^t}{I_0 \times (1+i)^t} \times 100\% \tag{6.1}$$

Where:
$FE_t = Forecasting\ Error\ over\ t\ years$
$I_0 = First\ Known\ Index\ Value$
$I_t = Known\ Index\ Value\ at\ Time\ t$
$i = Compounded\ Inflation\ Rate$

6.3.3 MFE Step 3

Repeat Step 2, but this time forecasting the second known index value (at 1 year). This second iteration would generate 38 forecasting errors with a 20-year dataset (on less than at Step 1), with a maximum forecasting time horizon of 19 years. Continue repeating this process, in six-month intervals, until forecasting the second last known index value, always calculating and recording forecasting errors for the different forecasting periods.

6.3.4 MFE Step 4

At the end of Step 3, the STA would have several forecasting error measures for different forecasting periods. With a 20-year dataset, the agency would have 39, 38, 37, (…) 3, 2, and 1 forecasting error for a 0.5, 1, 1.5, (…) 18.5, 19, and 19.5-year forecast, respectively. The number of recorded forecasting errors decreases as the forecasting time horizon increases. With a single measured error for a 19.5-year forecast, it is not possible to make reliable conclusions about potential market scenarios associated with long-range forecasts.

Instead of relying on this single long-range forecasting error, the proposed MFE method takes advantage of the more reliable assessments conducted for shorter forecasting periods, identifies trends, and extrapolate those trends to the long-range forecasting zone. This is done by first calculating an average forecasting error for each forecasting time horizon (e.g., the average of the 39 recorded forecasting errors for 0.5 years), and then plotting all average forecasting errors as shown in Figure 6-4. This figure illustrates the average forecasting errors obtained when applying the MFE method on a scope-based asphalt paving CCI developed for the Colorado Department of Transportation (CDOT). Each point in this figure corresponds to the average forecasting error calculated for each forecasting period from 0.5 to 19.5 years. The negative sign in the average forecasting errors means that actual market values tend to be lower than those obtained with the inflation rate under consideration.

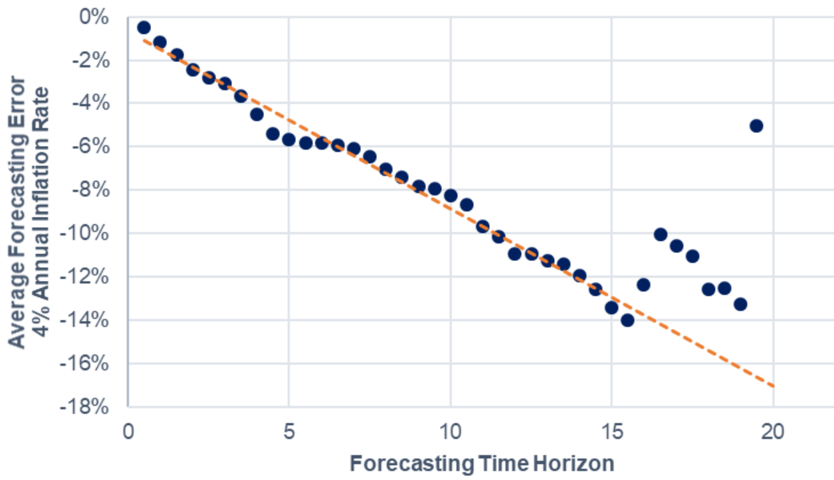

Figure 6-4 Example of MFE Output – Average Forecasting Errors for DelDOT's Asphalt Paving Activities with a 4% Compounded Annual Inflation Rate

Figure 6-4 shows how the more reliable average errors for shorter forecasting periods define a strong trend that can be projected to long-range periods. Similar outputs were obtained from the application of the MFE method in 11 case study regions. In most cases, with a 20-year dataset, points tend to start falling off the trend after about 15 years, when average values start to be calculated with less than ten observed forecasting errors. Based on that observation, the proposed MFE method ignores all values calculated with less than ten observations and uses regression analysis to project the remaining values into the future to estimate expected errors for long-range forecasts. That is how the linear projection in Figure 6-4 was created.

6.3.5 MFE Step 5

The MFE method not only facilitates a better assessment of average forecasting errors, but also allowed the projection of percentiles around average values to establish error ranges at 50%, 70%, and 90% confidence levels. Figure 6-5 shows the same linear trend of average errors from Figure 6-4, but this time with its respective confidence intervals. Based on this figure, DelDOT could reasonably assume, with a 90% confidence level, that any 15-year asphalt paving cost forecast estimated in this region with a 4% compounded inflation rate would offer a forecasting error between +12% and -27%.

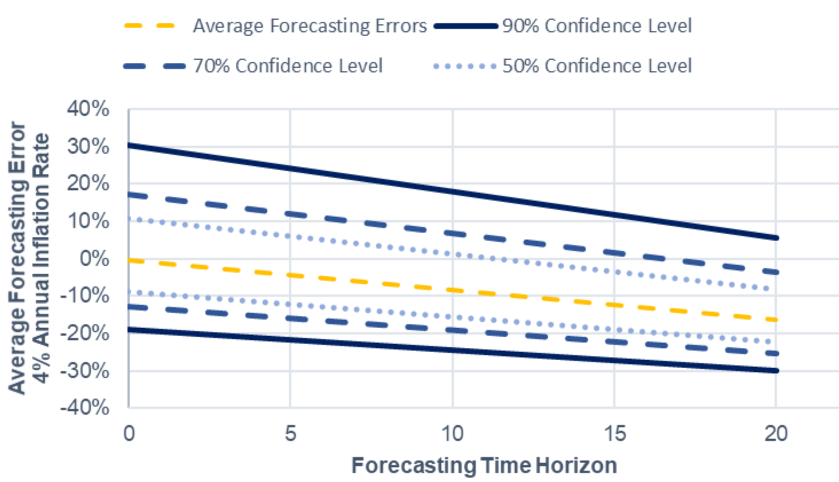

Figure 6-5 Example of MFE Output – Average Forecasting Errors with Confidence Intervals for DelDOT's Asphalt Paving Activities with a 4% Compounded Annual Inflation Rate

Confidence levels are defined by assuming that forecasting errors at each forecasting period follow a normal distribution. Thus, the confidence bands in Figure 6-5 are calculated from 50%, 70%, and 90% confidence intervals from those normal distributions at each forecasting time horizon. For example, the upper 90% limit in Figure 6-5 is the result of a regression model developed with the upper 90% confidence intervals of all forecasting time periods from 0.5 to 15 years. Averages errors calculated with less than observations are also discarded.

6.3.6 MFE Step 6

MFE cost forecasting errors, like those shown in Figure 6-5, can now be used to create a risk-based forecasting timeline of forecasting factors. Forecasting factors are unitless values that form a generic risk-based forecasting timeline that can be used to estimate the intended inflation rate. Those generic outputs can also be translated into dollars to easily obtain a risk-based forecasting timeline for any current-dollar estimate. Figure 6-6 shows the risk-based forecasting timeline for the forecasting factors estimated from the forecasting errors in Figure 6-5. Figure 6-6 also shows the 4% compounded projection, which was actually used as a reference to develop the risk-based output. Table 6-4 details the process to calculate the forecasting factors for the first 5 years in Figure 6-6 by applying the forecasting errors in Figure 6-5 to the 4% annually compounded projection of a forecasting factor of 1.

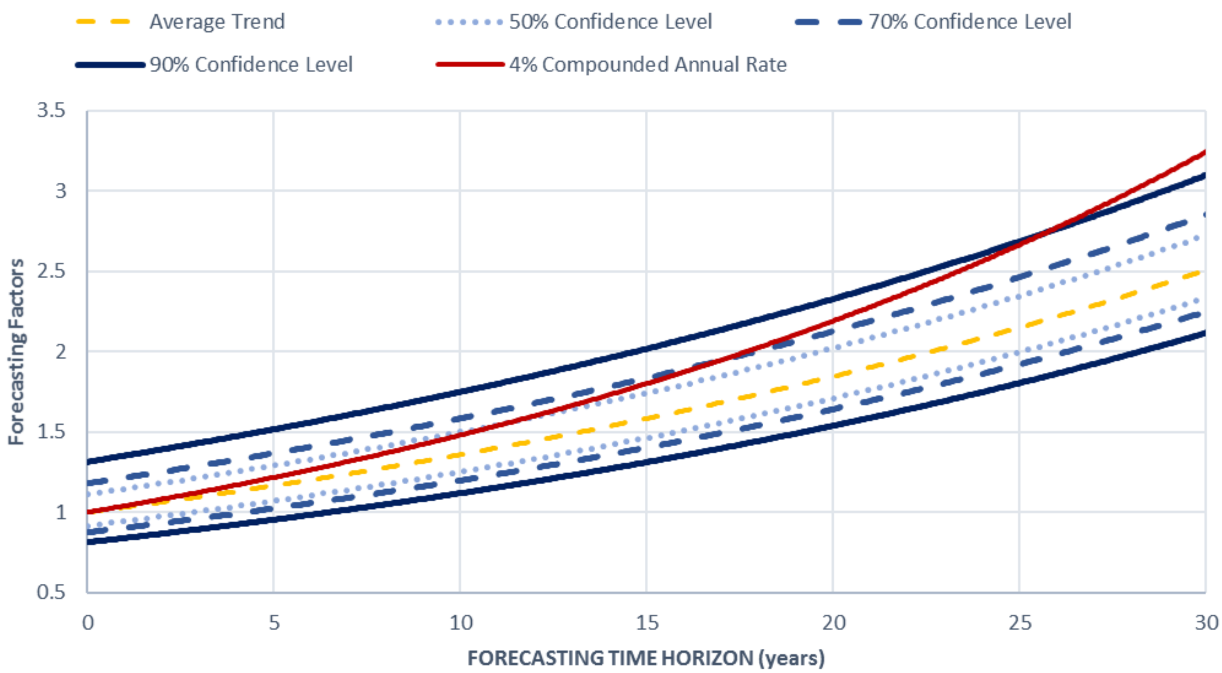

Figure 6-6 Example of Risk-Based Forecasting Timeline with 4% Compounded Projection

Table 6-1 Example of Forecasting Factors Calculation

Row	Year (A)		0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
A	Forecast of FF =1 4% CAIR (B=1.04^A)		1.02	1.04	1.06	1.08	1.1	1.12	1.15	1.17	1.19	1.22
B	Average FE		0%	-1%	-1%	-2%	-2%	-3%	-3%	-4%	-4%	-4%
C	Average FF (B*[1+C])		1.02	1.03	1.05	1.06	1.08	1.09	1.11	1.13	1.14	1.16
D	50% CL FE	25th PCTL	-9%	-9%	-10%	-10%	-10%	-11%	-11%	-11%	-12%	-12%
E		75th PCTL	11%	10%	10%	9%	8%	8%	7%	7%	6%	6%
F	70% CL FE	15th PCTL	-13%	-13%	-14%	-14%	-14%	-15%	-15%	-15%	-16%	-16%
G		85th PCTL	17%	17%	16%	15%	15%	14%	14%	13%	12%	12%
H	90% CL FE	5th PCTL	-19%	-19%	-20%	-20%	-20%	-21%	-21%	-21%	-21%	-22%
I		95th PCTL	31%	30%	29%	28%	28%	27%	26%	25%	25%	24%
J	50% CL FF	25th PCTL (B*[1+D])	0.93	0.94	0.96	0.97	0.99	1	1.02	1.04	1.05	1.07
K		75th PCTL (B*[1+E])	1.13	1.14	1.16	1.18	1.2	1.21	1.23	1.25	1.27	1.29
L	70% CL FF	15th PCTL (B*[1+F])	0.89	0.9	0.92	0.93	0.95	0.96	0.97	0.99	1.01	1.02
M		85th PCTL (B*[1+G])	1.2	1.21	1.23	1.25	1.27	1.29	1.3	1.32	1.34	1.36
N	90% CL FF	5th PCTL (B*[1+H])	0.83	0.84	0.85	0.87	0.88	0.89	0.91	0.92	0.94	0.95
O		95th PCTL (B*[1+I])	1.33	1.35	1.37	1.39	1.41	1.43	1.45	1.47	1.49	1.51

Note: FF = Forecasting Factor; FE = Forecasting Error; CAIR = Compounded Annual Inflation Rate; CL = Confidence Level; = PCTL = Percentile.

The risk-based forecasting timeline in Figure 6-6 is the result of plotting and connecting the data points from rows C and J-O in Table 6-4. The unitless values in this figure can be easily transformed into dollar values to generate a risk-based forecasting output just by multiplying all forecasting factors by the given current-dollar estimate. For example, if the current-dollar estimate for a given asphalt paving program in Colorado is $10 million, the multiplication of this value by each of the forecasting factors in Figure 6-4 would generate the risk-based forecasting timeline shown in Figure 6-6. This figure is actually a scaled version of Figure 6-5. With Figure 6-7, CDOT could conclude that the expected average value for this program in 15 years would be around $15.8 million. With a 70% confidence level, CDOT could expect this value to be between $14 and $18 million, approximately.

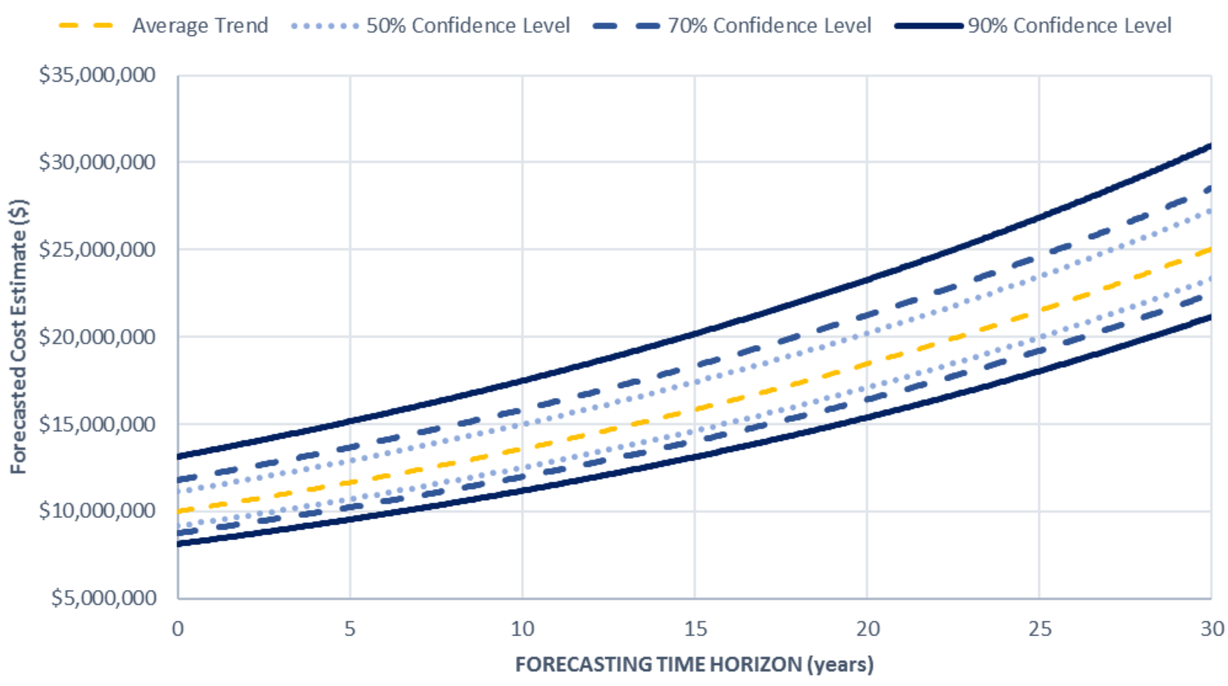

Figure 6-7 Example of MFE Output – Risk Based Forecasting Timeline for $10 M Program

Instead of directly producing risk-based forecasting timelines from the calculated forecasting factors, CDOT could also use Figure 6-5 to estimate an annual inflation for asphalt paving activities in the region under consideration. This inflation rate could be shared with other estimators across the region to facilitate cost forecasts without the need of sharing a spreadsheet with all forecasting factors. Assuming that the target inflation rate is intended to match the average trend in Figure 6-5, CDOT could perform a simple statistical to find that the average trend in Figure 6-5 would be matched by a 3.1% annual compounded inflation rate, as shown in Figure 6-8.

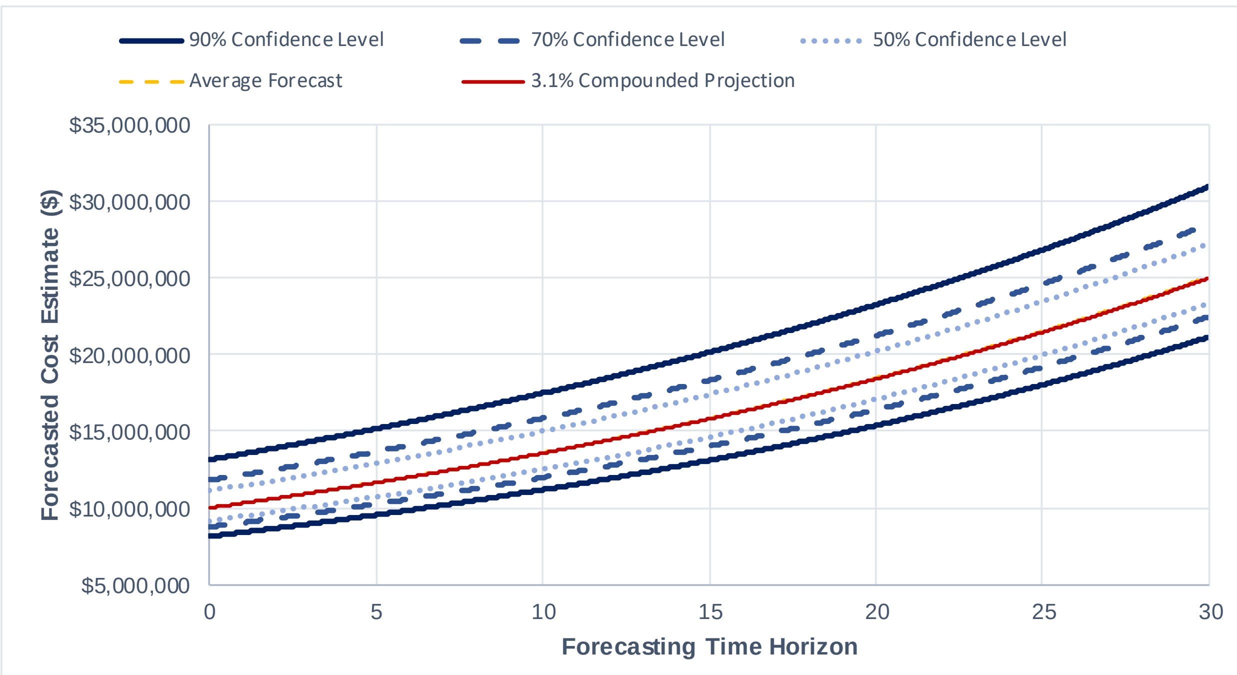

Figure 6-8 Example of Risk-Based Forecasting Timeline with 3.1% Compounded Projection

All case study results presented in this section to illustrate the use of the proposed MFE methodology were obtained by using an arbitrary 4% compounded annual inflation rate as a point of reference. In a perfect world, any arbitrary inflation rate (even simple inflation rates) would yield the same results shown in Figure 6-5 and 6-6, but that is not the case. The use of regression analysis to approximate market average error trends makes outputs from different inflation rates slightly different. Research results suggest that the use of reasonable inflation rates as a point of reference produces more accurate results, and that is the reason that motivated the selection of the suggested rate (4%). However, future research efforts will further investigate this matter, in order to determine if a different input would offer better forecasting effectiveness.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions and Major Contributions

The first objective of this dissertation was achieved through the analysis of information collected during the course of a comprehensive literature review (previous studies, policy documents, manuals, and standard procedures), an online survey developed and administrated to STAs, and feedback provided by the AASHTO Technical Committee on Cost Estimating (TCCE). Efforts were made to collect relevant policy documents from all other STAs in order to facilitate a better understanding of current transportation planning and cost forecasting practices. Manuals and standard procedures from all 50 STAs were reviewed in this study, including documents from STAs that also completed the survey. This dissertation found that the construction prices have been growing following an upward trend over the intermediate and long-range time horizons with most short-term deflation situations or market corrections lasting less than five years. Transportation construction prices in all case study regions, and for both asphalt and concrete paving, have been increasing on an overall exponential rate during the last 20 years. This dissertation was intended to generate such type of impact by improving agencies' practice in terms of forecasting procedures. More specifically, this dissertation presented the research efforts that led to the development of a Cost Forecasting Approach, able to give flexibility to the STAs to improve their cost forecasting practices, proposing an advanced data-driven procedure called Moving Forecasting Error (MFE) used to generate inflation rates and risk-based forecasting time horizons.

Although the state-of-practice showed that some agencies in the country use External Cost Indexes, this dissertation developed an MCCI in each of the case studies in an attempt to identify the most effective one at representing the regional construction market. This dissertation used 20 years of historical bid data from the Colorado Department of Transportation (1999-2018), Delaware Department of Transportation (1994-2013), and Minnesota Department of Transportation (1999 - 2018). Even though regional MCCIs were not the best option for most regions (as seen in Table 5-11), the fact that different statewide indexes are more suitable for different regions in the same state allows concluding that construction activities in different locations could be affected by different inflation patterns. In other words, it would be reasonable to consider the use of different inflation rates for different regions across the state. Those regional inflation rates would be the result of using a different construction cost index in each region.

To satisfy the second objective of this dissertation, and address all the needs founded, this Dissertation developed scope-based MCCIs for each of the case studies. This process was required in order to find a scope-based inflation rate and achieve the proposed forecasting process. After comparing Statewide and Regional MCCIs, it was found that in most of the cases the Statewide MCCI represent in a more accurate way the regional market behavior. Likewise, this Dissertation found that Statewide Indexes with different data input (Lowest bid or All Unit prices) modelled most of the regions in that case studies.

In all case studies and geographic regions, the three alternatives with the lowest weighted MAPEs were three MCCIs. Moreover, it was found that the top MCCI always statistically significantly outperformed the most suitable existing CCI (with a 95% confidence level). The author believes that the ability of MCCIs to meet the matching and proportionality principles discussed is what makes this alternative cost indexing system more effective at tracing construction price fluctuations than the traditional alternatives.

In order to find scope-based inflation rates, this dissertation proposed the use of the Moving Forecasting Error, which is an iterative process designed to maximize the value of available data. This methodology allows DOTs to develop a risk-based output, different to the deterministic that is being used.

In comparison with regression analysis, MFE could be described as a more conservative or risk-averse approach since its output is the result of the assessment of several forecasting scenarios created within the available data, while regression analysis relies on a single pass along the available data. However, the study found that regression techniques are more suitable to model the anticipated continuation of short-term market corrections. In those cases, MFE calculations could yield a more conservative output assuming a more normal pricing behavior.

7.2 Recommendations and Limitations

This dissertation found that cost forecasting processes with short look-back periods are more susceptible to market corrections, with the risk of anticipating unlikely future market scenarios. A ten-year case study conducted in Minnesota showed that an agency with only ten years of available historical bid data to implement the data-driven forecasting procedures proposed in this dissertation could expect a 40% reduction in forecasting effectiveness with respect to the performance offered by a 20-year dataset. However, this statement was the result of a single reduced case study. Future research efforts should be aimed to validate this statement by replicating this analysis among other STAs. To minimize this risk, the study recommends the use of at least ten years of historical cost data for mid-term and intermediate-range forecasts, and, ideally, 20 years look-back periods in long-range forecasting procedures.

The main challenge faced by the author was associated with considerable data analysis efforts to be conducted for the quantitative analysis of cost forecasting practices. The author made significant efforts to collect at least 20 years of historical cost data from each case study agency in order to effectively assess the performance of cost forecasting practices over long-range time horizons. In some cases, this task was quite challenging due to the way agencies store and maintained the record of historical information. In many cases, the author had to convert scanned files in PDF format to excel files.

In addition to the efforts required to collect and clean that amount of data, some of the forecasting practices to be evaluated in this study involved advanced quantitative processes that could be difficult to apply at such a large scale. Experience and preparation are required to deal with these challenges, given the amounts of data to develop similar cost estimating models.

The replication study is limited by funding and schedule constraints. Depending on the amount of information and the technological resources that the agency has, sources of funding and recruitment must be taken into account.

Future research could be aimed to replicate these research efforts for other paid items and other state transportation agencies. Likewise, the selection of the basket of items should be according to agency needs and other provisions. Having direct contact with a professional in the estimating department of the case study agency would improve the understanding of the circumstances of each specific project. Thus, further studies could identify external causes on the variations of the prices. Also, better understanding of the individual needs on each agency is needed to develop better project based MCCIs, not only using materials but also scope of the contracts.

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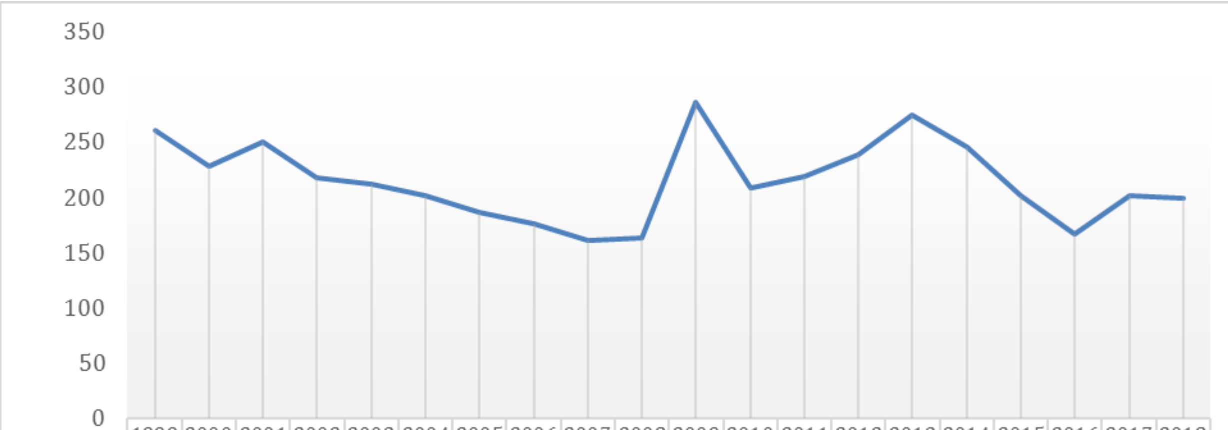
APPENDIX A - HISTORICAL BID DATA SUMMARY

MnDOT SUMMARY:

Historical bid data collected from the Minnesota Department of Transportation (MnDOT) came from 4,334 projects awarded between January 1999 and December 2018. On average, MnDOT average of 215 contracts per year along this period of time, as shown on Figure A.1.



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
MnDOT	261	228	250	218	212	202	186	176	161	163	286	209	219	239	275	246	201	167	201	199

Figure A.1 Annual Number of Contracts MnDOT from 1999 – 2018

As seen in Figure A.2, 73% of the contracts were awarded in the first period of each year (see Figure A.2), with 43% being awarded during the second quarter (see Figure A.3). Figure A.4 shows that the MnDOT's Metro District (DM) is the one with the largest number of projects awarded.

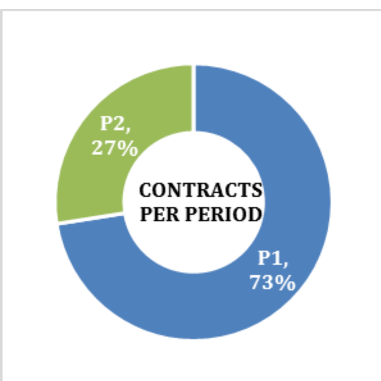


Figure A.2 Distribution of contracts per period MnDOT from 1999 - 2018

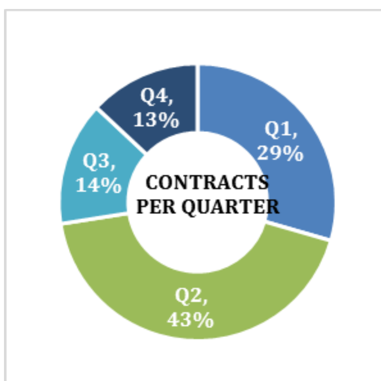


Figure A.3 Distribution of contracts per quarter MnDOT from 1999 - 2018

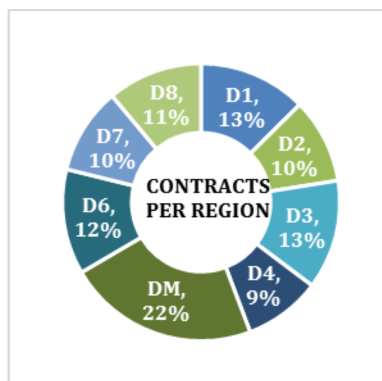


Figure A.4 Distribution of contracts per region MnDOT from 1999 – 2018

Figure A.5 shows a seasonal trend in the distribution of contracts during the first and second part of the year. The number of contracts awarded by MnDOT during the first period of each year is significantly higher than the number of contracts awarded during the second period. This seasonal behavior is typical in northern states. Winter temperatures limit the ability of contractors to perform work during the second period of the year.

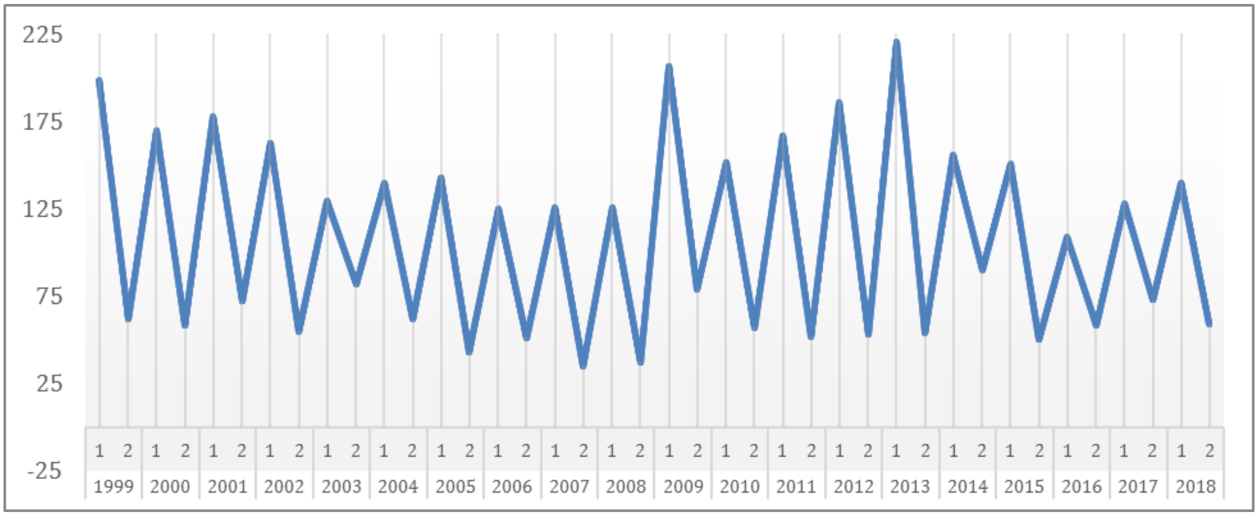


Figure A.5 Contracts awarded per period MnDOT from 1999 – 2018

CDOT SUMMARY:

Throughout the data collection process of the Colorado Department of Transportation, twenty-four years of information on the contracts attached by this agency were found, equivalent to 3108 projects, as shown in Figure A.6.

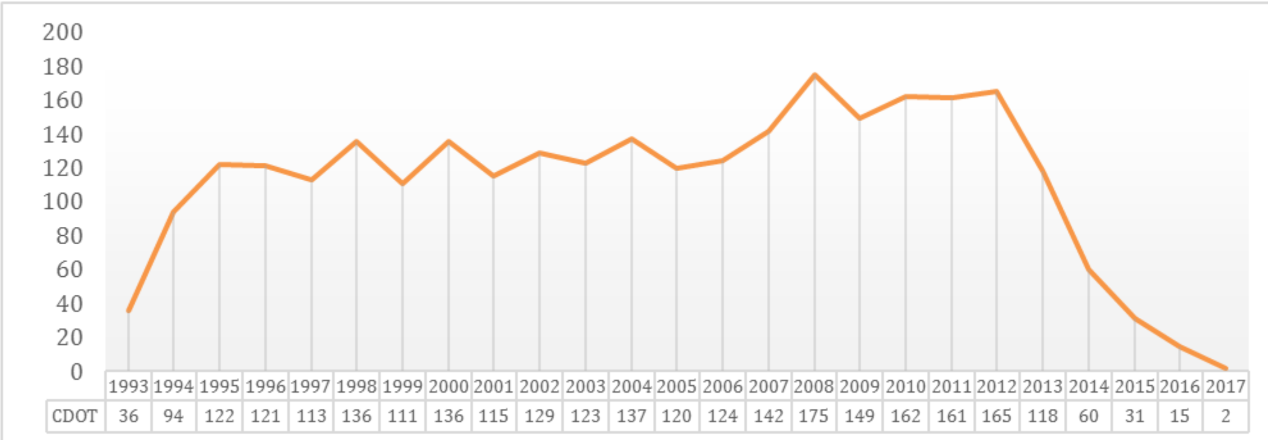


Figure A.6 Annual Number of Contracts CDOT from 1993 – 2017

Through the process of data cleaning and data analysis, two significant difficulties were encountered. First, some of the contracts did not have the information corresponding to the date of publication or award. Although the author tried hard to find the corresponding information on the agency's website, this was not possible. Besides, the data collected from 1993 and between 2013 and 2017 was not enough to carry out a representative analysis. For these reasons, the author used only twenty years of data between 1994 and 2013, corresponding to 2653 projects distributed, as shown in Figure A.7.

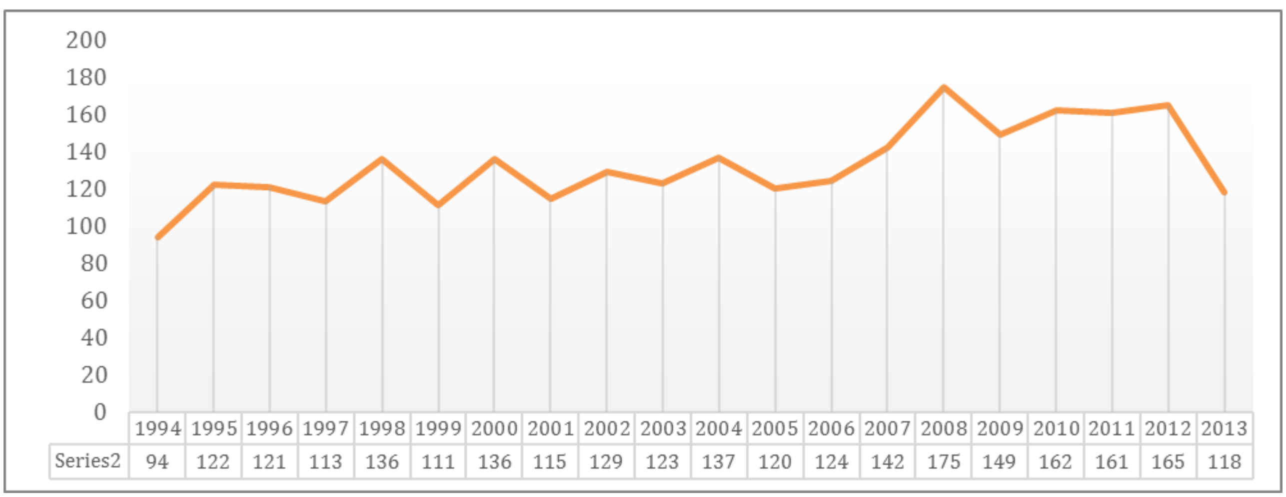


Figure A.7 Annual Number of Contracts CDOT from 1994 – 2013

On average, the Colorado Department of Transportation awards 132 contracts annually, of which 61% are awarded in the first period of the year, as shown in Figure A.8. Of this 61%, 29% are awarded in the first three months of the year and 32% between April and June, as shown in Figure A.9. Regarding the geographical distribution of the contracts, they are distributed in the six different regions, almost similar, as shown in Figure A.10. The project division is between 10% and 21%. These six regions will later become only four based on the analysis of this project.

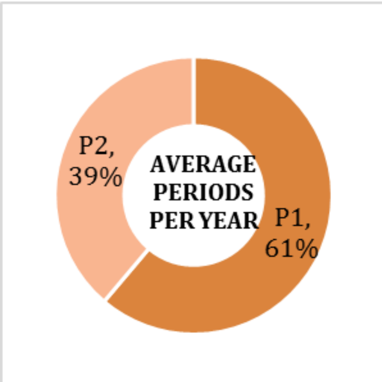


Figure A.8 Distribution of contracts per period CDOT from 1994 - 2013

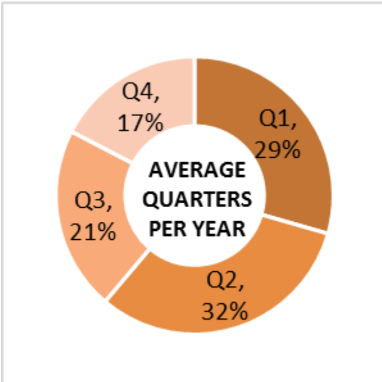


Figure A.9 Distribution of contracts per quarter CDOT from 1994 - 2013

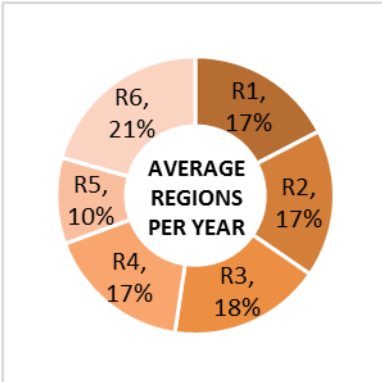


Figure A.10 Distribution of contracts per region CDOT from 1994 – 2013

Same as mentioned in the description in Figure A.8, Figure A.11 shows the number of contracts awarded in each period of the year. Same as in the previous agency, a cyclical behavior is observed in which the highest number of settlements is allocated within the first six months of the year. This trend is evidenced by a more significant difference from the year 2001, where more pronounced peaks are seen. For the case of 2013, the number of contracts awarded in the second period of the year that the author managed to collect was very little, so Figure A.11 shows a drastic decrease at the end of it.

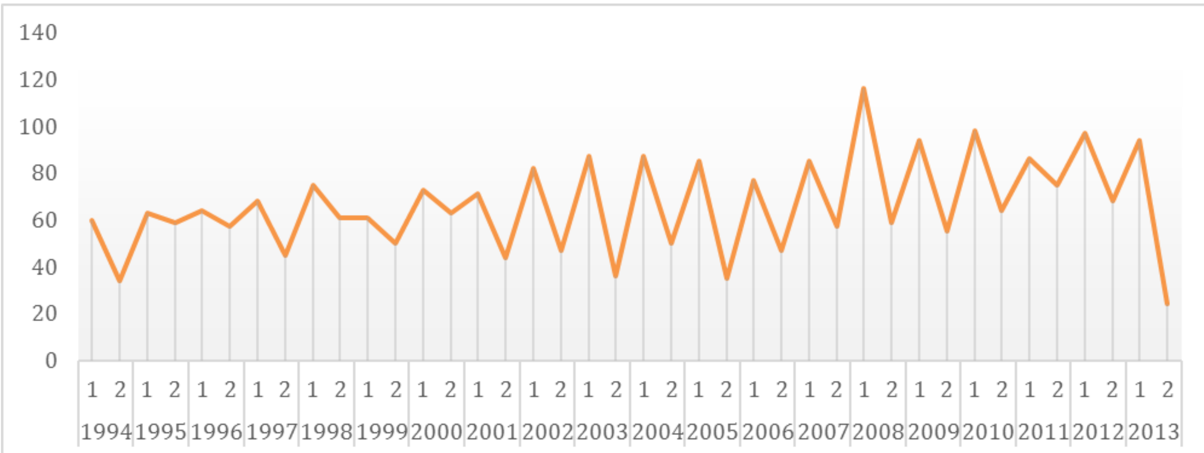


Figure A.11 Contracts awarded per period CDOT from 1994 - 2013

DelDOT SUMMARY:

The State of Delaware is much smaller compared to the previous two case studies. This can be evidenced in the number of contracts executed between 1999 and 2018, shown in Figure A.12. While in this agency, the highest number of contracts awarded was 97 in 2001, in the Minnesota and Colorado agencies, the years with the highest number of contracts were 286 in 2009 and 175 in 2008, respectively.

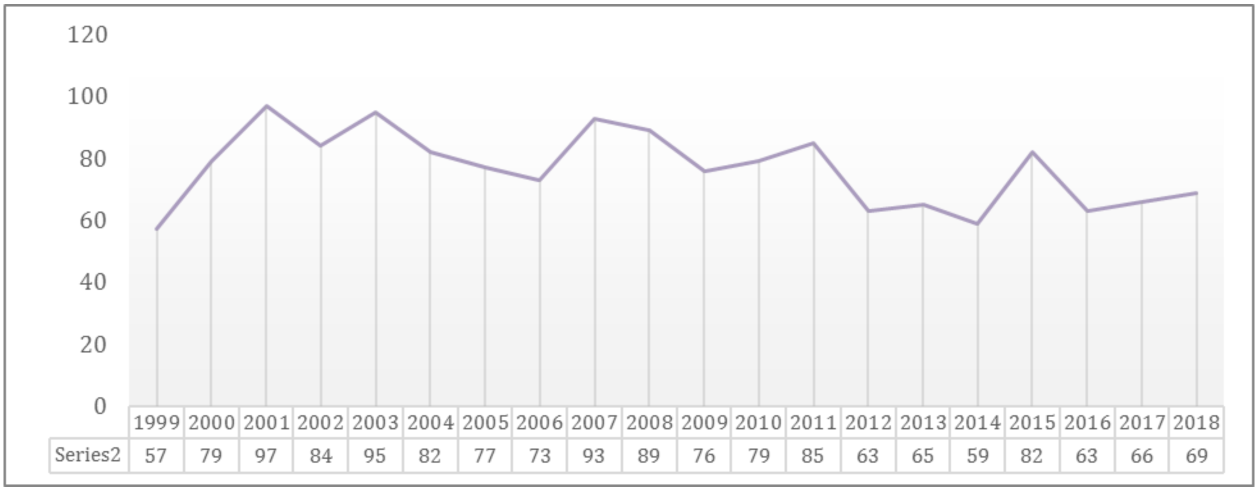


Figure A.12 Annual Number of Contracts DelDOT from 1999 – 2018

On average, the number of contracts awarded in the first and second periods of the year is very similar. As Figure A.13 shows, 53% of the contracts were executed in the first period of the year, compared with 47% in the second. Although the average shows an almost even division of contracts by period, Figure A.15 shows the detailed quarterly distribution between 1999 and 2018 for the Delaware Department of Transportation. This indicates differences within the years between the number of contracts of the first and second periods.

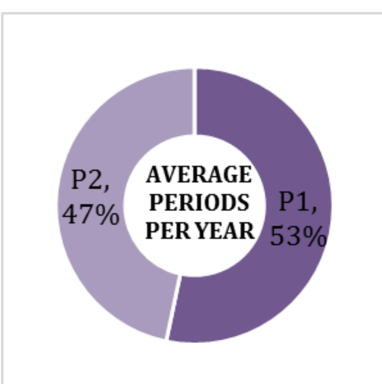


Figure A.13 Distribution of contracts per period DelDOT from 1999 - 2018

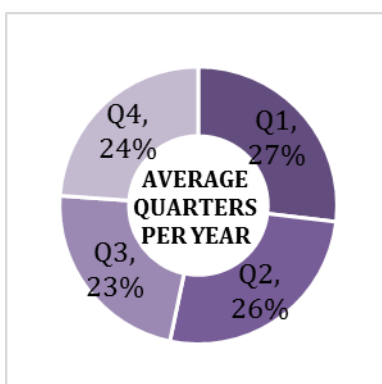


Figure A.14 Distribution of contracts per quarter DelDOT from 1999 - 2018

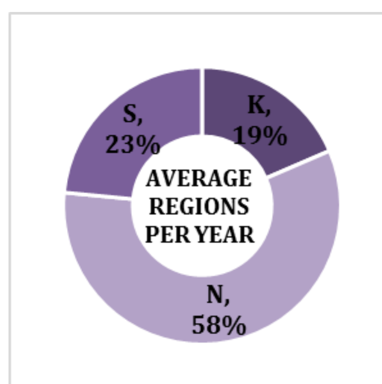


Figure A.15 Distribution of contracts per region DelDOT from 1999 – 2018

On the other hand, Figure A.15 shows the distribution of contracts from 1999 to 2018. Given the geographical conditions of this State, the location of its central city, and the proximity to the city of Philadelphia, it can be seen that 58 % of the contracts were awarded in New Castle County. The distribution by quarters is almost homogeneous, as shown in Figure A.14, the contracts are distributed in 27%, 26%, 23%, and 24%, respectively. The big difference is shown in Figure A.16, which shows that 58% of the contracts were awarded in New Castle County, which is the one that is farther north and closer to the city of Philadelphia.

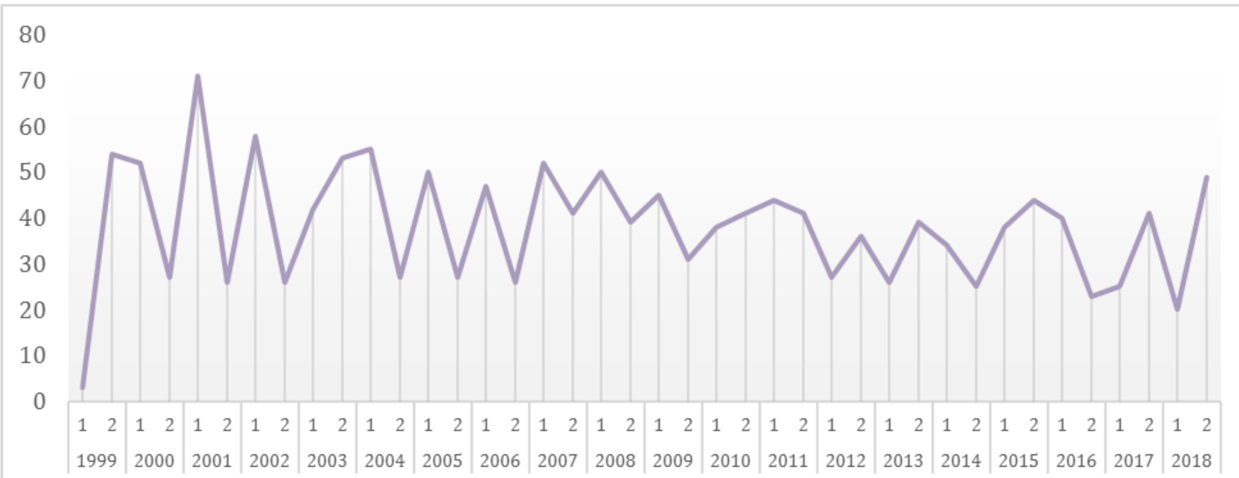


Figure A.16 Contracts awarded per period CDOT from 1994 - 2013

APPENDIX B – CONFIGURATION OF MULTILEVEL CONSTRUCTION COST INDEXES

MnDOT Multilevel Construction Cost Index:

Table B.1 MnDOT Multilevel Construction Cost Index – Basket of Pay Items

No.	Item ID	Description	No.	Item ID	Description
1	2104503/00255	Remove Pipe Culverts	32	2360509/24500	Type SP 12.5 Wearing Course Mixture (4,E)
2	2104503/00285	Remove Sewer Pipe (Storm)	33	2401501/01143	Structural Concrete (1A43)
3	2104503/00315	Remove Curb and Gutter	34	2401501/03643	Structural Concrete (3Y43)
4	2104503/00450	Remove Cable Guardrail	35	2401508/00010	Reinforcement Bars
5	2104503/00460	Remove Guardrail-Plate Beam	36	2401508/00011	Reinforcement Bars (Epoxy Coated)
6	2104503/00195	Sawing Concrete Pavement (Full Depth)	37	2402503/00280	Expansion Joint Devices Type 4
7	2104503/00205	Sawing Bituminous Pavement (Full Depth)	38	2404518/00010	Concrete Wearing Course (3U17A)
8	2104503/01560	Salvage Guardrail-Plate Beam	39	2406504/00010	Bridge Approach Panels
9	2104504/00070	Remove Pavement	40	2501503/12018	18\" CS Pipe Culvert
10	2104504/00090	Remove Concrete Pavement	41	2501503/13242	24\" RC Pipe Culvert
11	2104504/00120	Remove Bituminous Pavement	42	2501503/13302	30\" RC Pipe Culvert
12	2104504/00140	Remove Bituminous Shoulder Pavement	43	2501503/13362	36\" RC Pipe Culvert
13	2105504/00035	Geotextile Fabric Type 5	44	2501603/25080	Clean Pipe Culvert
14	2105507/00015	Common Excavation	45	2503503/19122	12\" RC Pipe Sewer Design 3006
15	2105507/00290	Select Granular Borrow (CV)	46	2503503/19182	18\" RC Pipe Sewer Design 3006
16	2106507/00010	Excavation - Common	47	2506503/00012	Construct Drainage Structure Design A or F
17	2106507/00130	Common Embankment (CV)	48	2506503/00032	Construct Drainage Structure Design C or G
18	2211507/00170	Aggregate Base (CV) Class 5	49	2506503/00080	Construct Drainage Structure Design H
19	2211507/00210	Aggregate Base (CV) Class 6	50	2506503/03020	Construct Drainage Structure Design 60-4020
20	2232504/00040	Mill Bituminous Surface (1.5\")	51	2506503/02420	Construct Drainage Structure Design 48-4020
21	2232504/00060	Mill Bituminous Surface (2.0\")	52	2511507/00013	Random Riprap Class II
22	2232504/00120	Mill Bituminous Surface (3.0\")	53	2511507/00014	Random Riprap Class III
23	2232603/00025	Milled Rumble Strips	54	2511507/00015	Random Riprap Class IV
24	2232603/00030	Milled Rumble Strips-Intermittent	55	2511515/00014	Geotextile Filter Type IV
25	2301507/00010	Structural Concrete	56	2521518/00040	4\" Concrete Walk
26	2355506/00010	Bituminous Material for Fog Seal	57	2554503/02007	Traffic Barrier Design B8307
27	2357606/00020	Bituminous Material for Shoulder Tack	58	2554503/02038	Traffic Barrier Design B8338
28	2360509/22200	Type SP 12.5 Wearing Course Mixture (2,B)	59	2580503/00010	Interim Pavement Marking
29	2360509/23200	Type SP 12.5 Wearing Course Mixture (3,B)	60	2581501/00010	Removable Preformed Plastic Marking
30	2360509/23300	Type SP 12.5 Wearing Course Mixture (3,C)	61	2581603/00020	Removable Preformed Plastic Mask (Black)
31	2360509/24200	Type SP 12.5 Wearing Course Mixture (4,B)	-	-	-

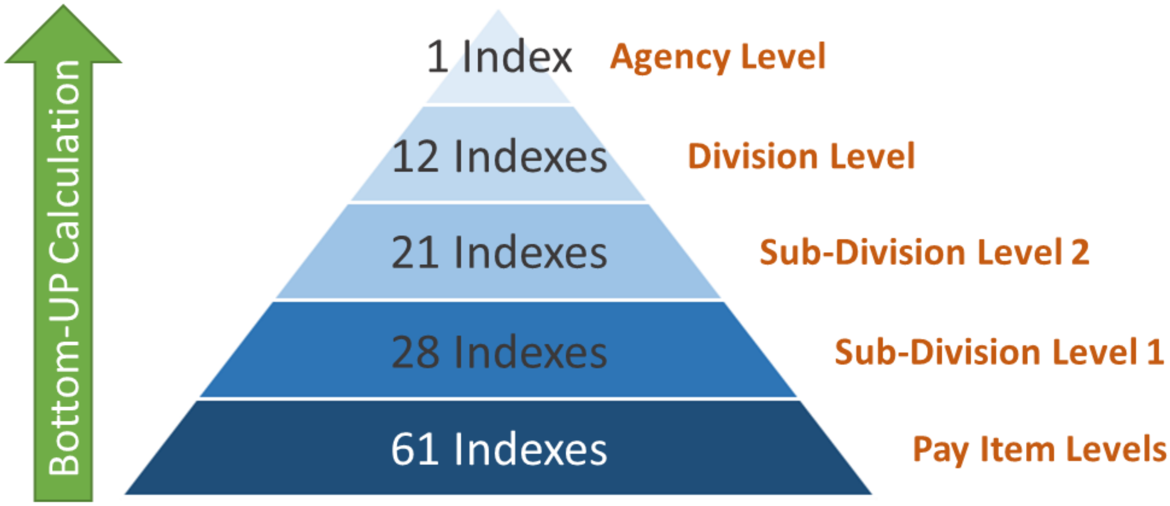


Figure B.1 MnDOT Multilevel Construction Cost Index – General Configuration

Table B.2 MnDOT Multilevel Construction Cost Index – Configuration and Labels

Level 1		Level 2		Level 3		Level 4		Level 5
1	2104503/00255	1	2104503	1	2104	1	210	2
2	2104503/00285							
3	2104503/00315							
4	2104503/00450							
5	2104503/00460							
6	2104503/00195							
7	2104503/00205							
8	2104503/01560							
9	2104504/00070	2	2104504					
10	2104504/00090							
11	2104504/00120							
12	2104504/00140							
13	2105504/00035	3	2105504	2	2105			
14	2105507/00015	4	2105507					
15	2105507/00290							
16	2106507/00010	5	2106507	3	2106			
17	2106507/00130							
18	2211507/00170	6	2211507	4	2211	2	221	
19	2211507/00210							
20	2232504/00040	7	2232504	5	2232	3	223	
21	2232504/00060							
22	2232504/00120							
23	2232603/00025	8	2232603					
24	2232603/00030							

Table B.2 MnDOT Multilevel Construction Cost Index – Configuration and Labels (Cont.)

Level 1		Level 2		Level 3		Level 4		Level 5
25	2301507/00010	9	2301507	6	2301	4	230	2
26	2355506/00010	10	2355506	7	2355	5	235	
27	2357606/00020	11	2357606	8	2357			
28	2360509/22200	12	2360509	9	2360	6	236	
29	2360509/23200							
30	2360509/23300							
31	2360509/24200							
32	2360509/24500							
33	2401501/01143	13	2401501	10	2401	7	240	
34	2401501/03643							
35	2401508/00010	14	2401508					
36	2401508/00011							
37	2402503/00280	15	2402503	11	2402			
38	2404518/00010	16	2404518	12	2404			
39	2406504/00010	17	2406504	13	2406			
40	2501503/12018	18	2501503	14	2501	8	250	
41	2501503/13242							
42	2501503/13302							
43	2501503/13362							
44	2501603/25080	19	2501603					
45	2503503/19122	20	2503503	15	2503			
46	2503503/19182							
47	2506503/00012	21	2506503	16	2506			
48	2506503/00032							
49	2506503/00080							
50	2506503/03020							
51	2506503/02420							
52	2511507/00013	22	2511507	17	2511	9	251	
53	2511507/00014							
54	2511507/00015							
55	2511515/00014	23	2511515					
56	2521518/00040	24	2521518	18	2521	10	252	
57	2554503/02007	25	2554503	19	2554	11	255	
58	2554503/02038							
59	2580503/00010	26	2580503	20	2580	12	258	
60	2581501/00010	27	2581501	21	2581			
61	2581603/00020	28	2581603					

CDOT Multilevel Construction Cost Index:

Table B.3 CDOT Multilevel Construction Cost Index – Basket of Pay Items

No.	Item ID	Description	No.	Item ID	Description
1	202-00035	Removal of Pipe	21	506-00218	Riprap (18 Inch)
2	202-00210	Removal of Concrete Pavement	22	506-00224	Riprap (24 Inch)
3	202-00220	Removal of Asphalt Mat	23	509-00000	Structural Steel
4	202-00240	Removal of Asphalt Mat (Planing)	24	515-00120	Waterproofing (Membrane)
5	202-00250	Removal of Pavement Marking	25	601-03030	Concrete Class D (Box Culvert)
6	203-00010	Unclassified Excavation (Complete In Place)	26	601-03040	Concrete Class D (Bridge)
7	203-00060	Embankment Material (Complete In Place)	27	601-03050	Concrete Class D (Wall)
8	203-00100	Muck Excavation	28	602-00000	Reinforcing Steel
9	206-00000	Structure Excavation	29	602-00020	Reinforcing Steel (Epoxy Coated)
10	206-00065	Structure Backfill (Flow-Fill)	30	606-00301	Guardrail Type 3 (6-3 Post Spacing)
11	206-00100	Structure Backfill (Class 1)	31	606-00710	Guardrail Type 7 (Style CA)
12	206-00360	Mechanical Reinforcement of Soil	32	608-00000	Concrete Sidewalk
13	207-00205	Topsoil	33	609-21010	Curb and Gutter Type 2 (Section I-B)
14	304-06000	Aggregate Base Course (Class 6)	34	610-00020	Median Cover Material (Patterned Concrete)
15	304-06007	Aggregate Base Course (Class 6)	35	613-00200	2 Inch Electrical Conduit
16	403-00720	Hot Mix Asphalt (Patching) (Asphalt)	36	613-01200	2 Inch Electrical Conduit (Plastic)
17	411-10255	Emulsified Asphalt (Slow-Setting)	37	614-00012	Sign Panel (Class II)
18	412-00600	Concrete Pavement (6 Inch)	38	621-00450	Detour Pavement
19	503-00036	Drilled Caisson (36 Inch)	39	627-00001	Pavement Marking Paint
20	506-00212	Riprap (12 Inch)	40	627-00005	Epoxy Pavement Marking

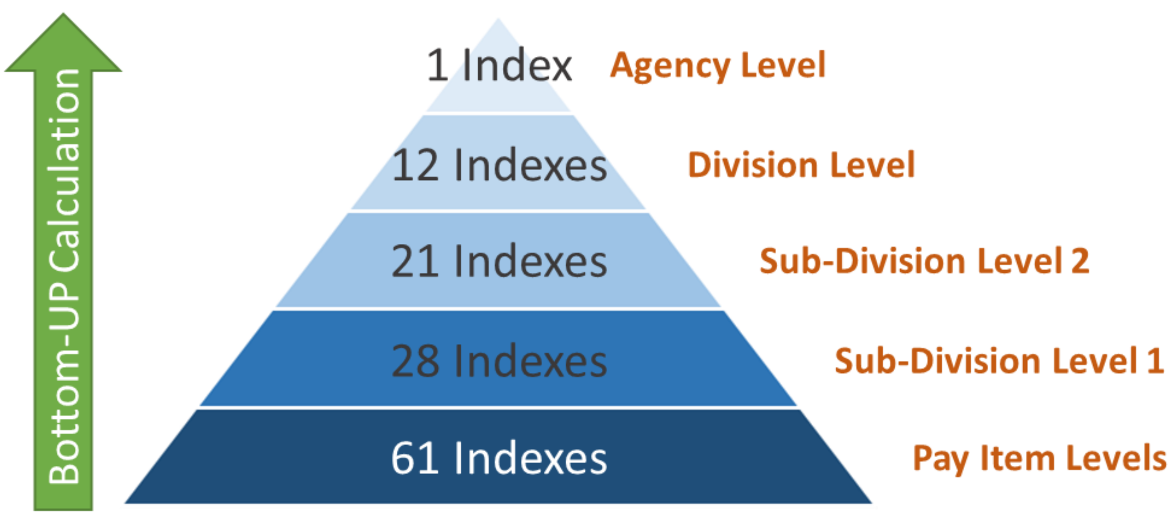


Figure B.2 CDOT Multilevel Construction Cost Index – General Configuration

Table B.4 CDOT Multilevel Construction Cost Index – Configuration and Labels

Level 1		Level 2		Level 3		Level 4		Level 5
1	202-00035	1	202-000	1	202	1	2	1
2	202-00210	2	202-002					
3	202-00220							
4	202-00240							
5	202-00250							
6	203-00010	3	203-000	2	203			
7	203-00060							
8	203-00100	4	203-001					
9	206-00000	5	206-000	3	206			
10	206-00065							
11	206-00100	6	206-001					
12	206-00360	7	206-003					
13	207-00205	8	207-002	4	207			
14	304-06000	9	304-060	5	304	2	3	
15	304-06007							
16	403-00720	10	403-007	6	403	3	4	
17	411-10255	11	411-102	7	411			
18	412-00600	12	412-006	8	412			
19	503-00036	13	503-000	9	503	4	5	
20	506-00212	14	506-002	10	506			
21	506-00218							
22	506-00224							
23	509-00000	15	509-000	11	509			
24	515-00120	16	515-001	12	515			
25	601-03030	17	601-030	13	601	5	6	
26	601-03040							
27	601-03050							
28	602-00000	18	602-000	14	602			
29	602-00020							
30	606-00301	19	606-003	15	606			
31	606-00710	20	606-007					
32	608-00000	21	608-000	16	608			
33	609-21010	22	609-210	17	609			
34	610-00020	23	610-000	18	610			
35	613-00200	24	613-002	19	613			
36	613-01200	25	613-012					
37	614-00012	26	614-000	20	614			
38	621-00450	27	621-004	21	621			
39	627-00001	28	627-000	22	627			
40	627-00005							

DelDOT Multilevel Construction Cost Index:

Table B.5 DelDOT Multilevel Construction Cost Index – Basket of Pay Items

No.	Item ID	Description	No.	Item ID	Description
1	202000	Excavation and embankment	20	701020	Integral Portland cement concrete curb and gutter, type 1
2	207000	Excavation and backfill for structures	21	701021	Integral Portland cement concrete curb and gutter, type 2
3	208000	Excavation and backfill for pipe trenches	22	701022	Integral Portland cement concrete curb and gutter, type 3
4	209001	Borrow, type a	23	705001	P.C.C. sidewalk, 4"
5	209002	Borrow, type b	24	705002	P.C.C. sidewalk, 6"
6	209003	Borrow, type c	25	705007	Sidewalk surface detectable warning system
7	209006	Borrow, type f	26	712005	Riprap, r-4
8	210000	Furnishing borrow type "c" for pipe, utility trench, and structure backfill	27	712021	Riprap, r-5
9	212000	Undercut excavation	28	713003	Geotextiles, riprap
10	302005	Graded aggregate base course, type b	29	720050	Galvanized steel beam guardrail, type 1
11	302008	Graded aggregate base course, type b, patching	30	748015	Permanent pavement striping, symbol/legend alkyd-thermoplastic
12	302011	Delaware no. 3 stone	31	748019	Temporary markings, paint, 4"
13	402000	Hot-mix bituminous concrete and/or cold-laid bituminous concrete	32	748026	Temporary markings, paint symbol/legend
14	406001	Hot-mix patching	33	748530	Removal of pavement striping
15	503001	Patching P.C.C. pavement, 6' to 15', type a	34	758000	Removal of existing Portland cement concrete pavement, curb, sidewalk, etc.
16	604000	Bar reinforcement, epoxy coated	35	762001	Saw cutting, bituminous concrete, full depth
17	612021	Reinforced concrete pipe, 15", class iv	36	762002	Saw cutting, concrete, full depth
18	701010	Portland cement concrete curb, type 1	37	908001	Topsoil
19	701011	Portland cement concrete curb, type 2	-	-	-

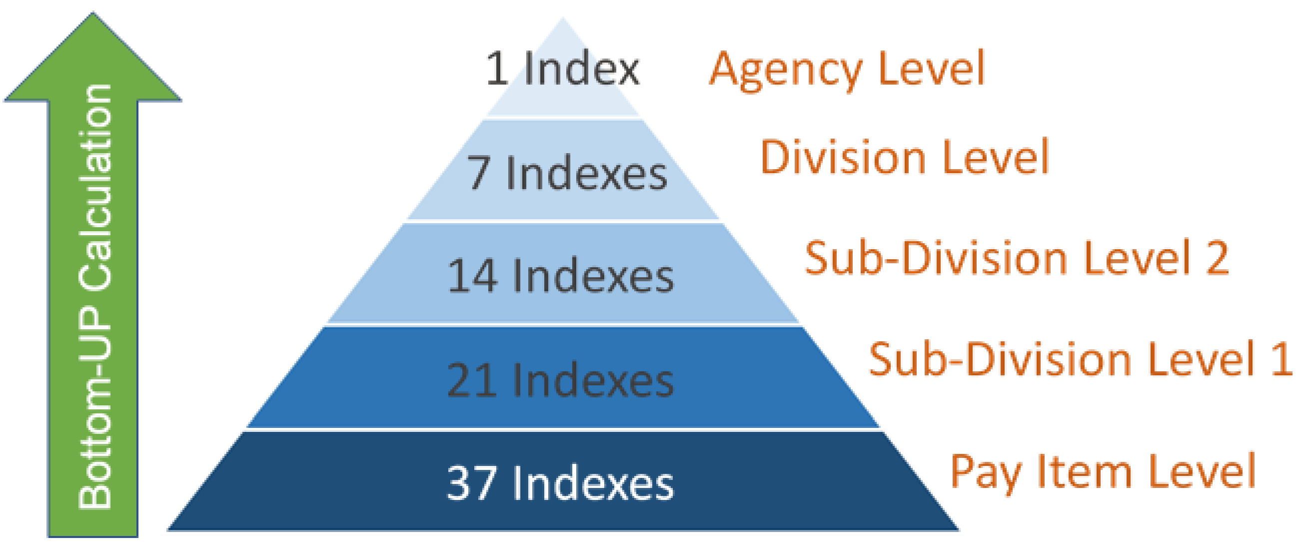


Figure B.3 DelDOT Multilevel Construction Cost Index – General Configuration

Table B.6 DelDOT Multilevel Construction Cost Index – Configuration and Labels

Level 1		Level 2		Level 3		Level 4		Level 5
1	202000	1	202	1	20	1	2	1
2	207000	2	207					
3	208000	3	208					
4	209001	4	209					
5	209002							
6	209003							
7	209006							
8	210000	5	210	2	21			
9	212000	6	212					
10	302005	7	302	3	30	2	3	
11	302008							
12	302011							
13	402000	8	402	4	40	3	4	
14	406001	9	406					
15	503001	10	503	5	50	4	5	
16	604000	11	604	6	60	5	6	
17	612021	12	612	7	61			
18	701010	13	701	8	70	6	7	
19	701011							
20	701020							
21	701021							
22	701022							
23	705001	14	705					
24	705002							
25	705007							
26	712005	15	712	9	71			
27	712021							
28	713003	16	713					
29	720050	17	720	10	72			
30	748015	18	748	11	74			
31	748019							
32	748026							
33	748530							
34	758000	19	758	12	75			
35	762001	20	762	13	76			
36	762002							
37	908001	21	908	14	90	7	9	

APPENDIX C. INDEX SUMMARY

Table C.1 RSMeans Construction Cost Index

RSMEANS CONSTRUCTION COST INDEX				
Date	National	Duluth-1,2	Minneapolis-3	Rochester-4
1/1/1998	113.60	117.70	124.60	115.50
1/1/1999	116.60	120.30	126.50	117.10
1/1/2000	118.90	124.10	131.10	120.10
1/1/2001	122.20	131.40	136.10	124.90
1/1/2002	126.70	131.90	139.50	130.00
1/1/2003	129.70	136.70	146.50	134.50
1/1/2004	132.80	139.10	150.10	137.00
1/1/2005	146.70	157.30	164.60	152.80
1/1/2006	156.20	166.20	173.90	161.90
1/1/2007	165.00	174.20	184.50	171.40
1/1/2008	171.00	177.40	190.60	175.00
1/1/2009	182.50	191.80	203.10	188.00
1/1/2010	181.60	193.10	203.80	188.90
1/1/2011	185.70	195.70	208.10	193.80
1/1/2012	194.00	203.10	214.70	199.70
1/1/2013	196.90	205.10	216.30	201.40
1/1/2014	203.00	211.10	220.70	207.50
1/1/2015	204.00	212.90	222.00	209.10
1/1/2016	207.70	217.60	227.20	212.40
1/1/2017	209.40	212.10	221.20	207.60
1/1/2018	215.80	214.20	223.40	209.70

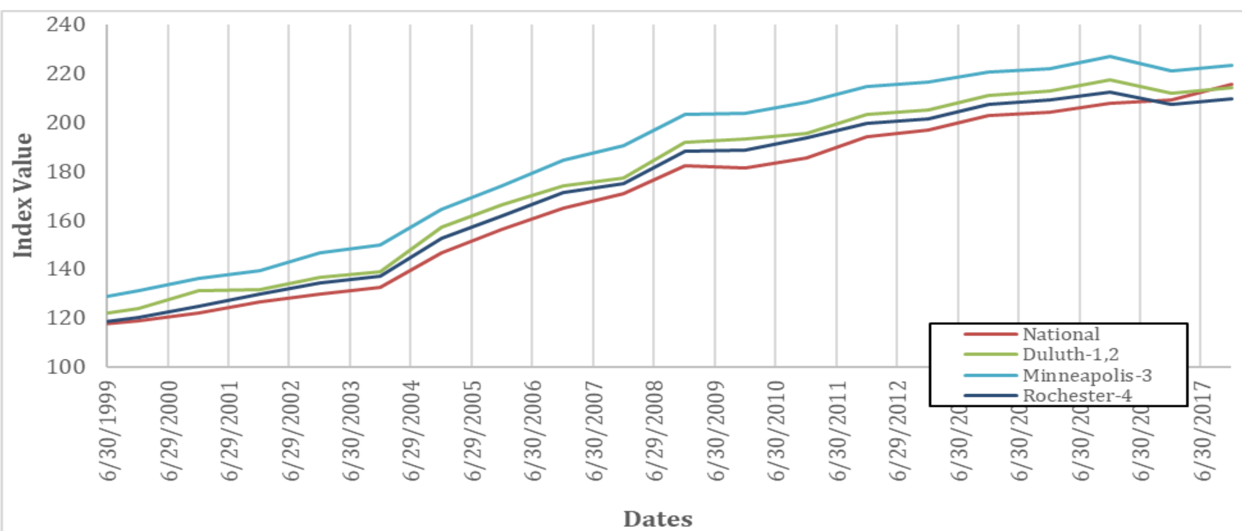


Figure C.1 RSMeans Construction Cost Index

Table C.2 National Highway Construction Cost

NATIONAL HIGHWAY CONSTRUCTION COST							
Date	Index	Date	Index	Date	Index	Date	Index
3/31/2003	1	3/31/2007	1.5636	3/31/2011	1.4568	42094	1.7198
6/30/2003	1.0096	6/30/2007	1.5612	6/30/2011	1.5006	42185	1.7048
9/30/2003	1.024	9/30/2007	1.5375	9/30/2011	1.5412	42277	1.7063
12/31/2003	1.0216	12/31/2007	1.5143	12/31/2011	1.5411	42369	1.6627
3/31/2004	1.0459	3/31/2008	1.5686	3/31/2012	1.5769	42460	1.6311
6/30/2004	1.1009	6/30/2008	1.6441	6/30/2012	1.627	42551	1.6779
9/30/2004	1.1431	9/30/2008	1.7848	9/30/2012	1.5955	42643	1.6798
12/31/2004	1.1492	12/31/2008	1.6267	12/31/2012	1.6071	42735	1.6534
3/31/2005	1.2409	3/31/2009	1.5	3/31/2013	1.5908	42825	1.6172
6/30/2005	1.2814	6/30/2009	1.4398	6/30/2013	1.6235	42916	1.6846
9/30/2005	1.3718	9/30/2009	1.4292	9/30/2013	1.6448	43008	1.7343
12/31/2005	1.4125	12/31/2009	1.4026	12/31/2013	1.5931	43100	1.6619
3/31/2006	1.4486	3/31/2010	1.4419	3/31/2014	1.6278	43190	1.6747
6/30/2006	1.5213	6/30/2010	1.4384	6/30/2014	1.6699	43281	1.7521
9/30/2006	1.6184	9/30/2010	1.4465	9/30/2014	1.7351	43373	1.8447
12/31/2006	1.5527	12/31/2010	1.43	12/31/2014	1.6938	43465	1.8727

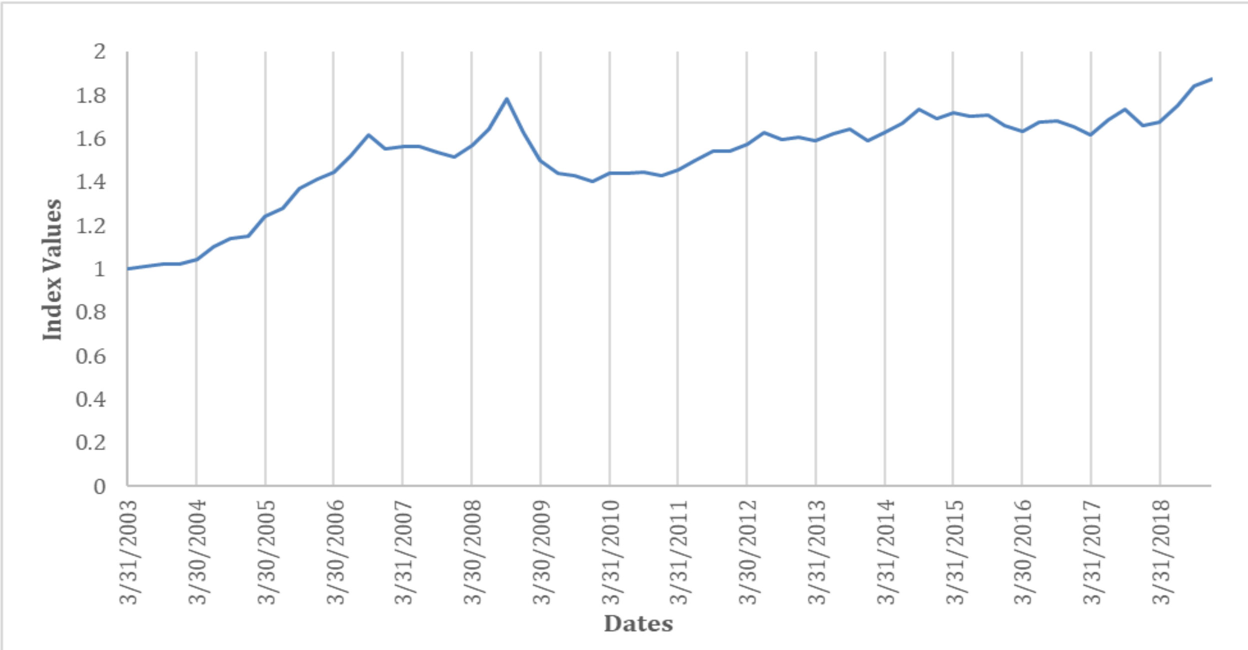


Figure C.2 National Highway Construction Cost

Table C.3 Minnesota Department of Transportation Construction Cost Index

MINNESOTA DEPARTMENT OF TRANSPORTATION CONSTRUCTION COST INDEX	
Date	Index
12/31/1998	123.58
12/31/1999	126.75
12/31/2000	133.91
12/31/2001	141.61
12/31/2002	140.73
12/31/2003	151.6
12/31/2004	149.61
12/31/2005	140.73
12/31/2006	197.1
12/31/2007	212.88
12/31/2008	234.22
12/31/2009	225.32
12/31/2010	229.17
12/31/2011	245.95
12/31/2012	256.94
12/31/2014	283.58

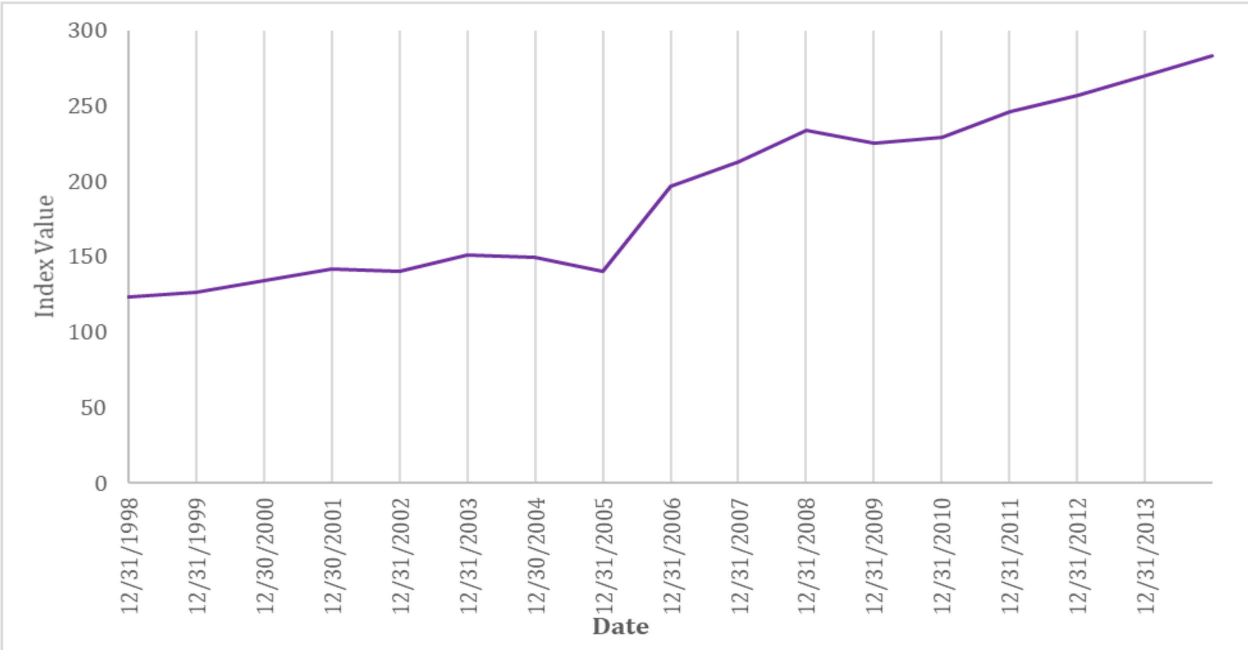


Figure C.3 Minnesota Department of Transportation Construction Cost Index

Table C.4 Bureau of Labor Statistics Consumer Price Index

BUREAU OF LABOR STATISTICS CONSUMER PRICE INDEX	
Date	Index
12/31/2006	202.6
12/31/2007	208.976
12/31/2008	216.177
12/31/2009	215.935
12/31/2010	218.576
12/31/2011	226.28
12/31/2012	230.338
12/31/2013	233.548
12/31/2014	237.088
12/31/2015	237.769
12/31/2016	241.237
12/31/2017	246.163
12/31/2018	252.125

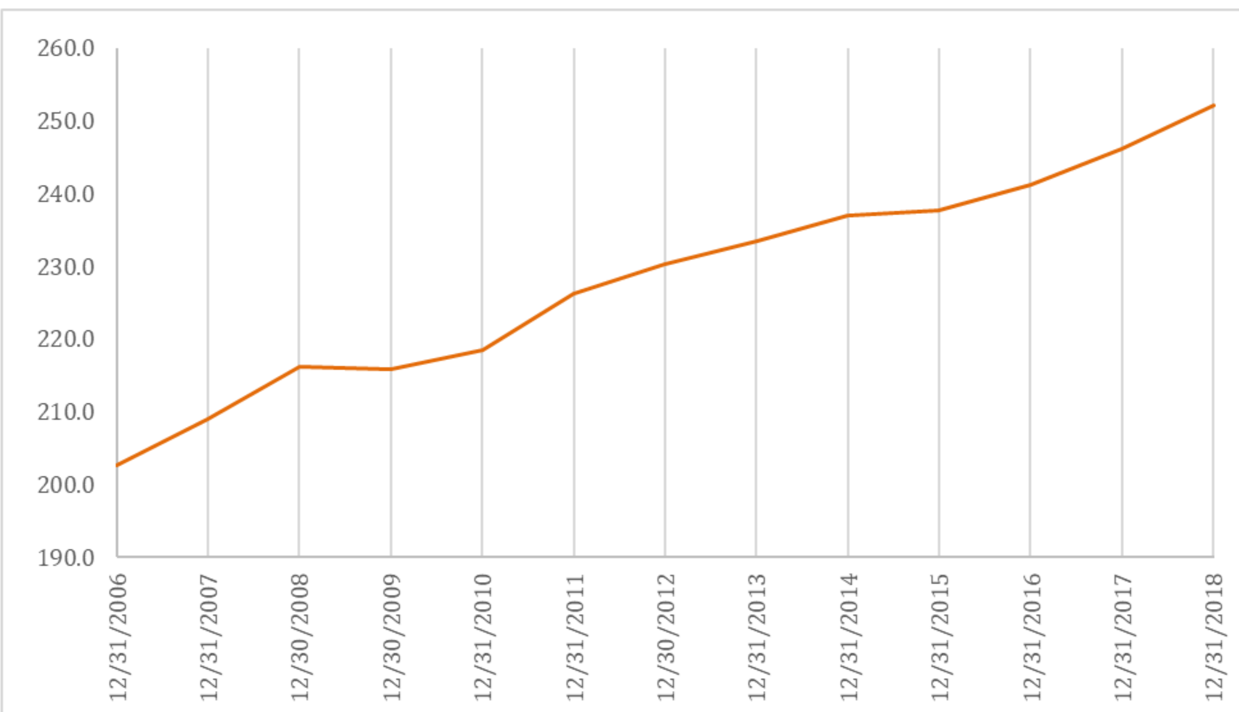


Figure C.4 Bureau of Labor Statistics Consumer Price Index

Table C.5 Bureau of Economic Analysis Personal Consumption Expenditures

BUREAU OF ECONOMIC ANALYSIS PERSONAL CONSUMPTION EXPENDITURES							
Date	Index	Date	Index	Date	Index	Date	Index
1/1/2002	80.154	4/1/2006	89.282	7/1/2010	95.753	41913	102.847
4/1/2002	80.651	7/1/2006	89.677	10/1/2010	96.163	42005	102.479
7/1/2002	80.91	10/1/2006	89.443	1/1/2011	96.953	42095	103.264
10/1/2002	81.441	1/1/2007	90.362	4/1/2011	98.281	42186	103.51
1/1/2003	82.032	4/1/2007	91.369	7/1/2011	98.691	42278	103.25
4/1/2003	82.13	7/1/2007	91.622	10/1/2011	98.597	42370	103.284
7/1/2003	82.415	10/1/2007	92.398	1/1/2012	99.388	42461	104.217
10/1/2003	82.854	1/1/2008	93.243	4/1/2012	99.985	42552	104.674
1/1/2004	83.574	4/1/2008	94.517	7/1/2012	100.182	42644	104.763
4/1/2004	84.322	7/1/2008	95.253	10/1/2012	100.445	42736	105.438
7/1/2004	84.541	10/1/2008	93.707	1/1/2013	100.891	42826	105.912
10/1/2004	85.209	1/1/2009	93.181	4/1/2013	101.293	42917	106.265
1/1/2005	85.665	4/1/2009	93.864	7/1/2013	101.59	43009	106.679
4/1/2005	86.508	7/1/2009	94.383	10/1/2013	101.611	43101	107.485
7/1/2005	87.278	10/1/2009	94.949	1/1/2014	102.224	43191	108.322
10/1/2005	87.798	1/1/2010	95.223	4/1/2014	103.091	43282	108.636
1/1/2006	88.295	4/1/2010	95.679	7/1/2014	103.311	43374	108.706

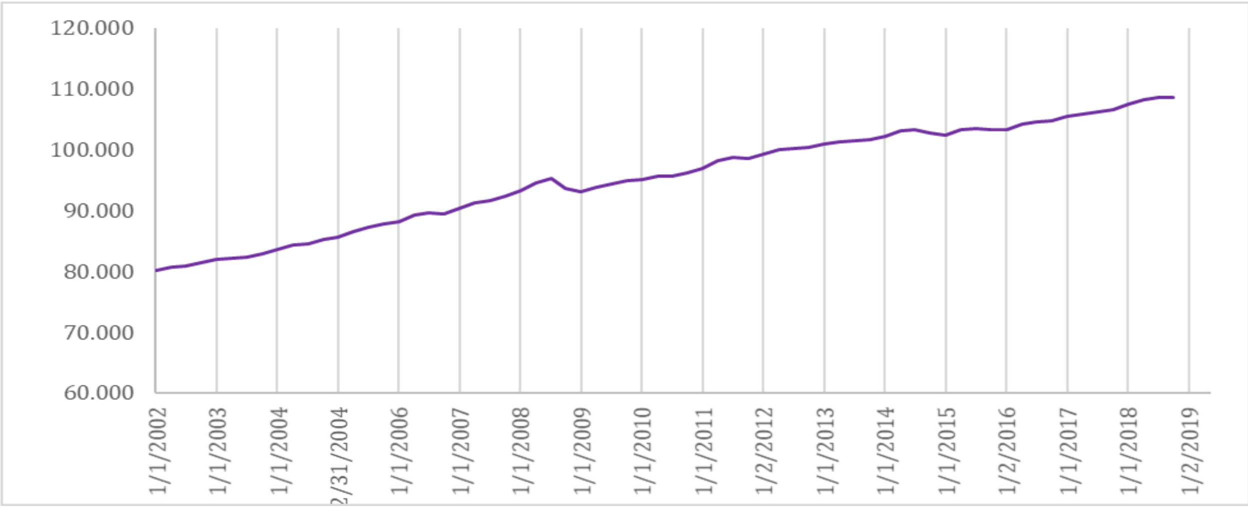


Figure C.5 Bureau of Economic Analysis Personal Consumption Expenditures

APPENDIX D. MEAN ABSOLUTE PERCENTAGE ERROR (MAPE) VALUES

Table D.1 Comparative Analysis MAP Results CDOT

Region	ITEM	Statewide Multilevel Construction Cost Indexes - MAPEs				Regional Multilevel Construction Cost Indexes - MAPES			
		Awarded Unit Price	**Average**	**Median**	**All Unit Prices**	**Awarded Unit Price**	**Average**	**Median**	**All Unit Prices**
Northwest	412-00600	18.92%	20.44%	10.17%	2.33%	3.84%	9.34%	10.08%	24.45%
	403-00720	18.53%	23.35%	17.67%	18.55%	21.51%	24.14%	28.48%	25.88%
	203-00010	4.34%	7.27%	6.58%	5.15%	6.48%	6.86%	7.25%	5.96%
	Weighted MAPE	**41.79%**	**51.07%**	**34.42%**	**26.03%**	**31.84%**	**40.34%**	**45.80%**	**56.29%**
Northeast	412-00600	19.10%	22.94%	15.17%	15.85%	20.47%	31.21%	27.34%	13.03%
	403-00720	27.88%	35.88%	21.32%	27.67%	24.76%	30.97%	30.56%	24.17%
	203-00010	4.57%	9.90%	9.27%	6.60%	4.88%	7.28%	6.64%	5.63%
	Weighted MAPE	**51.55%**	**68.71%**	**45.76%**	**50.12%**	**50.12%**	**69.46%**	**64.54%**	**42.83%**
Southeast	412-00600	11.17%	12.79%	9.67%	12.12%	13.06%	14.44%	14.70%	11.31%
	403-00720	20.20%	18.48%	18.64%	18.78%	25.03%	28.31%	33.93%	25.05%
	203-00010	9.88%	14.83%	13.80%	11.80%	7.89%	23.33%	13.43%	12.09%
	Weighted MAPE	**41.25%**	**46.10%**	**42.11%**	**42.71%**	**45.98%**	**66.08%**	**62.05%**	**48.45%**
Southwest	412-00600	10.33%	16.20%	10.65%	12.65%	13.16%	16.65%	13.58%	14.59%
	403-00720	28.06%	37.51%	23.45%	28.63%	34.41%	43.39%	41.22%	33.84%
	203-00010	6.38%	14.83%	14.29%	9.97%	12.46%	20.18%	19.17%	12.26%
	Weighted MAPE	**44.77%**	**68.54%**	**48.39%**	**51.24%**	**60.03%**	**80.22%**	**73.97%**	**60.69%**

Table D.2 Comparative Analysis Results MCCIs vs Existing Indexes CDOT

Region	ITEM	Statewide MCCIs		Regional MCCIs	RSMeans CCI		NHCCI	CPI	PCE	CDOT CCI
		Awarded Unit Price	All Unit Prices	All Unit Prices	National	Regional				
Northwest	412-00600	18.92%	2.33%	24.45%	23.44%	23.44%	24.73%	18.05%	16.65%	31.07%
	403-00720	18.53%	18.55%	25.88%	21.20%	21.20%	23.34%	18.84%	18.54%	30.58%
	203-00010	4.34%	5.15%	5.96%	9.74%	9.74%	11.03%	8.38%	8.10%	13.01%
	Weighted MAPE	**41.79%**	**26.03%**	**56.29%**	**54.38%**	**54.38%**	**59.10%**	**45.27%**	**43.28%**	**74.66%**
Northeast	412-00600	19.10%	15.85%	13.03%	20.86%	20.22%	25.67%	18.48%	18.37%	31.62%
	403-00720	27.88%	27.67%	24.17%	31.12%	29.93%	36.79%	26.51%	25.77%	46.50%
	203-00010	4.57%	6.60%	5.63%	12.86%	12.47%	14.40%	11.29%	11.02%	16.61%
	Weighted MAPE	**51.55%**	**50.12%**	**42.83%**	**64.84%**	**62.62%**	**76.87%**	**56.28%**	**55.16%**	**94.73%**
Southeast	412-00600	11.17%	12.12%	11.31%	16.79%	16.41%	22.82%	14.12%	13.62%	27.70%
	403-00720	20.20%	18.78%	25.05%	34.32%	33.56%	38.05%	28.91%	27.97%	47.61%
	203-00010	9.88%	11.80%	12.09%	19.86%	19.56%	22.03%	17.49%	17.13%	25.32%
	Weighted MAPE	**41.25%**	**42.71%**	**48.45%**	**70.97%**	**69.53%**	**82.90%**	**60.52%**	**58.73%**	**100.63 %**
Southwest	412-00600	10.33%	12.65%	14.59%	8.43%	8.43%	12.09%	8.87%	9.03%	16.73%
	403-00720	28.06%	28.63%	33.84%	18.03%	18.03%	17.52%	17.47%	17.44%	20.43%
	203-00010	6.38%	9.97%	12.26%	17.10%	17.10%	19.72%	15.57%	15.33%	21.09%
	Weighted MAPE	**44.77%**	**51.24%**	**60.69%**	**43.55%**	**43.55%**	**49.33%**	**41.92%**	**41.80%**	**58.25%**

Table D.3 Comparative Analysis MAP Results DelDOT

Region	ITEM	Statewide Multilevel Construction Cost Indexes - MAPEs				Regional Multilevel Construction Cost Indexes - MAPES			
		Awarded Unit Price	Average	Median	All Unit Prices	Awarded Unit Price	Average	Median	All Unit Prices
Central	202000	23.73%	33.23%	30.76%	27.63%	32.20%	92.67%	83.50%	97.29%
	406001	74.51%	84.48%	79.21%	77.78%	3.09E+02	8.64E+12	3.45E+15	76.09%
	503001	4.94%	6.45%	6.01%	5.72%	1946.76%	1.41E+05	3.13E+06	10.09%
	Weighted MAPE	**103.18%**	**124.16%**	**115.98%**	**111.13%**	**3.28E+02**	**8.64E+12**	**3.45E+15**	**183.47%**
North	202000	19.34%	25.34%	23.39%	20.35%	19.94%	29.86%	27.09%	27.00%
	406001	107.48%	108.82%	96.06%	100.54%	95.26%	101.92%	98.14%	93.92%
	503001	9.19%	14.89%	13.80%	12.56%	38.72%	18.30%	18.23%	12.58%
	Weighted MAPE	**136.01%**	**149.05%**	**133.25%**	**133.45%**	**153.91%**	**150.08%**	**143.46%**	**133.51%**
South	202000	14.67%	18.64%	17.35%	15.83%	17.02%	17.70%	17.05%	12.89%
	406001	100.96%	103.49%	94.28%	93.57%	136.49%	135.05%	126.35%	113.28%
	503001	4.90%	8.04%	7.49%	6.26%	6.46%	8.63%	9.65%	8.90%
	Weighted MAPE	**120.53%**	**130.17%**	**119.13%**	**115.66%**	**159.97%**	**161.38%**	**153.06%**	**135.08%**

Table D.4 Comparative Analysis Results MCCIs vs Existing Indexes DelDOT

Region	ITEM	Statewide MCCIs			RSMeans CCI		NHCCI	CPI	PCE
		Awarded Unit Price	Median Unit Prices	All Unit Prices	National	Regional			
Central	202000	23.73%	30.76%	27.63%	48.50%	49.93%	43.00%	44.27%	43.78%
	406001	74.51%	79.21%	77.78%	100.88%	104.07%	92.47%	92.45%	91.28%
	503001	4.94%	6.01%	5.72%	8.84%	9.24%	7.70%	7.50%	7.26%
	Weighted MAPE	**103.18%**	**115.98%**	**111.13%**	**158.22%**	**163.24%**	**143.17%**	**144.22%**	**142.33%**
North	202000	19.34%	23.39%	20.35%	29.75%	30.70%	27.88%	27.07%	26.83%
	406001	107.48%	96.06%	100.54%	146.98%	151.29%	131.30%	134.91%	132.94%
	503001	9.19%	13.80%	12.56%	18.47%	19.17%	16.53%	16.20%	15.88%
	Weighted MAPE	**136.01%**	**133.25%**	**133.45%**	**195.21%**	**201.17%**	**175.71%**	**178.18%**	**175.65%**
South	202000	14.67%	17.35%	15.83%	27.76%	28.77%	23.95%	24.55%	23.99%
	406001	100.96%	94.28%	93.57%	118.60%	121.96%	105.32%	108.22%	106.49%
	503001	4.90%	7.49%	6.26%	11.05%	11.79%	9.15%	9.11%	8.86%
	Weighted MAPE	**120.53%**	**119.13%**	**115.66%**	**157.41%**	**162.52%**	**138.41%**	**141.88%**	**139.34%**