Estimating for Unit Price Escalation

NCDOT Technical Assistance 2024-07
FHWA/NC/TA2024-07
February 2024

Don Chen, Ph.D.
Yuting Chen, Ph.D.
Department of Engineering Technology and Construction Management
University of North Carolina at Charlotte

RESEARCH & DEVELOPMENT

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Don Chen, Ph.D., LEED A.P.
Yuting (Tina) Chen, Ph.D.
Wayne Goff
Claudia Garrido Martins, Ph.D., PMP

Dept. of Engineering Technology and Construction Management
University of North Carolina at Charlotte, Charlotte, NC 28223

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Final Report

To North Carolina Department of Transportation

Submitted by

Don Chen, Ph.D., LEED A.P., Professor
Department of Engineering Technology & Construction Management
The William States Lee College of Engineering
University of North Carolina at Charlotte
Phone: (704) 687-5036; Fax: (704) 687-6653; E-mail: dchen9@uncc.edu

Yuting (Tina) Chen, Ph.D., Assistant Professor
Department of Engineering Technology & Construction Management
The William States Lee College of Engineering
University of North Carolina at Charlotte
(704) 687-5040, ychen106@charlotte.edu

Wayne Goff, Professor of Practice and Program Director
Department of Engineering Technology & Construction Management
The William States Lee College of Engineering
University of North Carolina at Charlotte
(704) 687-5042, wayne.goff@charlotte.edu

Claudia Garrido Martins, Ph.D., PMP, MCP, Assistant Professor
Department of Engineering Technology & Construction Management
The William States Lee College of Engineering
University of North Carolina at Charlotte
(704) 687-5062, cgarrido@charlotte.edu

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Estimating for Unit Price Escalation		5. Report Date February 2024
		6. Performing Organization Code
7. Author(s) Don Chen, Yuting (Tina) Chen, Wayne Goff, Claudia Garrido Martins		8. Performing Organization Report No.
9. Performing Organization Name and Address Smith 274, Dept. of Engineering Technology and Construction Management University of North Carolina at Charlotte Charlotte, NC 28223-0001		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address North Carolina Department of Transportation Research and Analysis Group 1 South Wilmington Street Raleigh, North Carolina 27601		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
Supplementary Notes:		

16. Abstract

This technical assistance project was conducted to develop a construction cost estimate update method which can be used by the NCDOT STIP Unit, the Highway Divisions, and other DOT Units to better estimate construction costs for roadway and bridge projects. Data obtained from NHCCI, NCDOT CPLs, and NCDOT Bid Tabs were cleaned, grouped by funding programs, and analyzed. Findings and conclusions of analyses as well as recommendations for future studies are provided.

17. Key Words	18. Distribution Statement		
Construction Cost Estimate, Cost Escalation, Bridge, Roadway			
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 33	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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ACKNOWLEDGMENTS

This research was sponsored by the North Carolina Department of Transportation. The authors gratefully acknowledge the support and assistant from Ben Upshaw, PE, Division Project Development Engineer, Division of Highways 5th Division.

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CHAPTER 1 INTRODUCTION AND OBJECTIVES

1.1 Background, Research Needs and Significance

The North Carolina Department of Transportation (NCDOT) has traditionally employed a contingency factor approach for estimating the construction costs of its projects. Although the department mandates that these estimates be updated every two years to ensure successful project execution, recent unpredictable fluctuations in unit prices have challenged the effectiveness of this method. Notably, from 2020 Q4 to 2022 Q4, the USDOT/FHWA indicated that components such as asphalt, grading/excavation, and bridges were the main factors behind the percentage change in the National Highway Construction Cost Index (NHCCI). These fluctuations can render construction estimates significantly inaccurate within the two-year window. Such inaccuracies directly impact the balance of the Statewide Transportation Improvement Program (STIP). Consequently, pre-established project schedules of impacted projects often need re-adjustment to accommodate funding constraints. Given the volatile economic landscape and the pressing need for precise budgeting, there's a compelling need to explore a new variable rate that can be applied to NCDOT construction cost estimates to account for unit price escalation. Considering indicators such as consumer price indices, federal rates, or other local economic indices as predictors for construction cost becomes necessary. Implementing this new variable rate can enhance the adaptability and resilience of NCDOT's cost estimates amidst shifting financial conditions.

1.2 Research Objectives

To achieve the aim of this study, the following objectives are proposed:

- To Identify the optimal source for cost trend data and collect the essential data.
- To develop a method to integrate trend data into construction estimates.

1.3 Report Organization

An introduction to the research project, research needs and objectives are presented in Chapter 1. A comprehensive literature review is provided in Chapter 2. Chapter 4 summarizes the sources of research data. The research methodology is described in Chapter 4. Chapter 5 focuses on findings and conclusions. Chapter 6 provides recommendations for future research.

CHAPTER 2 LITERATURE REVIEW

2.1 Cost Overrun Factors

Escalations in contracts increase the risk of cost overrun and may lead to other problems such as conflicts and delays. Therefore, researchers and industry professionals worldwide have been trying to identify factors affecting cost overrun and explore approaches to providing accurate construction project cost estimates. In a recent study, Waugaman (2021) focused on emergency streambank protection projects of the U.S. Army Corps of Engineers Civil Works projects. Emergency streambank protection is used to protect public facilities (e.g., bridges and highways). The author concluded that Riprap placement, material and filter fabric were the major predictors of cost overrun of the analyzed projects. Welde and Dahl (2021) found that change orders made to the scope of work, contract size, duration, and urban location increased the risk and size of cost overrun. Akinradewo et al. (2021) attempted to correlate location, road project size (i.e., road length and width), median strip, pavement type, scope (i.e., new, renovation, upgrade, and replacement), and road classification (i.e., trunk, feeder, and urban) with cost overrun, and found road project scope and road classification significantly affected cost overrun.

2.2 Cost Estimation Approaches

There are two primary approaches for construction cost estimating: qualitative and quantitative (Tayefeh Hashemi et al., 2020).

The qualitative approach involves expert judgment and heuristic rules. Expert judgment relies on advice from experienced experts and peers to check the validity of the estimating results, which is intuition-based and mainly relies on unspoken yet not well documented extrapolation techniques. The heuristic rules, on the other hand, stem from intuitive judgments and relatively similar projects, oftentimes serve as “rule of thumb” to simplify the estimating process. For instance, Love et al. (2023) recommended the use of the heuristics approach (e.g., fast-and-frugal trees) to identifying cues that indicate cost uncertainty.

As the dominant approach, which has been used by 97% of the studies summarized by Tayefeh Hashemi et al. (2020), the quantitative approach includes parametric (e.g., regression based and

time-series prediction) and non-parametric methods (e.g., machine learning based). For parametric approach, Swei et al. (2017) presented a new approach to better estimating expected initial costs and associated variation for probabilistic-based life-cycle cost analysis of roadway pavement projects. Their approach combined a maximum likelihood estimator for data transformations (i.e., Box-Cox transformations) with least angle regression for dimensionality reduction in estimating the bid unit-price. In addition, their equations presented the relationships between bid quantity, location, number of bidders, and bid unit-price. Wong and Swei (2021) used time-series methods and developed four disaggregated cost indices for asphalt concrete (AC) highway construction, Portland cement concrete (PCC) highway construction, AC highway maintenance and rehabilitation (M&R), and PCC highway M&R respectively, based on the chained Fisher price index. Fisher index has been widely recommended by the International Labor Office (ILO), the World Bank, the US Bureau of Labor Statistics (BLS), and other organizations as the preferred technique to compute a price index. For non-parametric methods, one example is Tijanić et al. (2020) discovered that General Regression Neural Network can estimate the cost of roadway projects with higher accuracy, even when datasets are incomplete.

Each of the abovementioned methods has its own advantages and disadvantages. For example, a regression-based prediction approach is easy to use and transparent, and it allows engineers, estimators, and other decision makers to track factors leading to cost overrun. However, this method only works when all the risk factors are known, and most of the time, it requires that datasets should be complete. In addition, its ability to handle non-linear relationships is not satisfactory. By contrast, non-parametric approach such as neural networks have several advantages, such as their ability to detect intricate nonlinear relationships among variables and ability to discover all possible interrelations between variables. However, like any other subject, there remains some disadvantages, including the “black box” mechanism leading to discouragement in finding the origin of the results, their difficult applicability to some problems, and their need for high computational resources.

2.3 A Hybrid Approach

Considering the characteristics of qualitative and quantitative approaches reviewed above, a hybrid approach that integrates both qualitative and quantitative methods often yields superior results.

The reason is that experienced experts can help ensure the validity of the estimates obtained via quantitative approaches.

One representative research study incorporating both qualitative and quantitative approaches (Kim, 2013) was conducted to develop an excel-based hybrid estimating tool using case-based reasoning (CBR) and hybrid analytic hierarchy process (AHP) to improve the accuracy of highway project estimates in South Korea. CBR captures past experiences and matches the important features of new problem to those of the old cases that have been successfully solved. Its strength is its ability to reuse the case even if it only partially matches the current problem.

On the other hand, AHP is a Multiple-Criteria Decision-Making (MCMD) method that was originally developed by Thomas Saaty (1980). It has proven to be an effective decision-making tool for fields such as government, business, and industry. Kim (2013) used AHP method and interviewed/surveyed 18 industry professionals on cost factors of highway projects, where 24 cost factors (e.g., completed year, actual duration, type of site, length and width of highway, materials used, etc.) were identified and ranked based on the relative importance of each factor.

CHAPTER 3 RESEARCH DATA

This chapter describes the sources of data that have been collected and analyzed to develop the proposed prototype of the estimate update tool, including quarterly NHCCI components' percent changes, NCDOT Bid Tabs, and NCDOT Comprehensive Project Lists (CPLs).

3.1 Quarterly NHCCI Reports

The U.S. Department of Transportation and the Federal Highway Administration publish National Highway Construction Cost Index (NHCCI) on a quarterly basis (NHCCI Analysis and Narrative - Policy | Federal Highway Administration (dot.gov)). In 2023, two quarterly reports were published on September 12, 2023 (2023 Q1) and November 13, 2023 (2023 Q2). Both reports noted the unusual average quarterly growth of 5.2 percent in 2021 and 2022, and that these elevated changes may have been caused by "supply chain disruptions and fluctuating oil prices." To avoid potential impacts from these unforeseen factors to this research project, it was decided to focus on construction cost escalations that occurred in 2023 and use the precent changes published in NHCCI 2023 Q2 to capture cost estimate changes in the same year.

The NHCCI includes 9 components which can be divided into 2 categories: (1) for Bridge projects and (2) for Roadway projects (Table 1). These 2 types of projects are required by NCDOT to be the target project types in this research project.

Table 1. NHCCI Component Contributions to Changes from Previous Quarter (2023 Q2)

NHCCI Component	Percent Change since 2023 Q1	Category
Asphalt	1.27%	Roadway
Base Stone	0.17%	Roadway
Concrete	0.07%	Roadway
Drainage	0.07%	Roadway
Electrical	0.38%	Roadway
Grading/Excavation	0.45%	Roadway
Traffic Control	0.74%	Roadway
Utilities, erosion control, clearing, painting, and equipment	0.36%	Roadway
Bridge	0.31%	Bridge

Percent changes in column 2 of Table 1 were used to calculate a construction cost estimate adjustment factor, and categories in column 3 were used to further divide the projects into subcategories to better delineate cost groups, as described in Chapter 4.

3.2 NCDOT Bid Tabs

NCDOT publishes bid tabs through Connect NCDOT (Bid Tab Sheets (ncdot.gov)) in two formats: Excel and PDF. The Excel files are password protected, therefore, PDF files were downloaded and converted into the Excel format for further analysis. The following bid tabs for 2023 projects were downloaded from the abovementioned website and then further analyzed:

- Bid Tabs 2302 Post.pdf
- Bid Tabs 2303 Post.pdf
- Bid Tabs 2304 Post.pdf
- Bid Tabs 2305 Post.pdf
- Bid Tabs 2306 Post.pdf
- Bid Tabs 2307 Post.pdf
- Bid Tabs 2308 Post.pdf
- Bid Tabs 2309 Post.pdf
- Bid Tabs 2310 Post.pdf
- Bid Tabs 2311 Post.pdf
- Bid Tabs 2312 Post.pdf

Data mining was conducted on item descriptions and their prices in each bid tab, and then placed them under corresponding NHCCI components. This process was time consuming due to the format inconsistence issues caused by the PDF-to-Excel conversion process. For bridge projects, one NHCCI component, Bridge, was studied. For roadway projects, the following 8 NHCCI components were studied:

1. Asphalt
2. Base Stone
3. Concrete
4. Drainage
5. Electrical

6. Grading/Excavation
7. Traffic Control
8. Utilities, Erosion Control, Clearing, Painting, and Equipment

A total of 322 bids submitted in 2023 to NCDOT were studied, and Figure 1 shows the box plots of the 8-roadway related NHCCI components in terms of their percentages of the total bid prices. Summary statistics are included in Table 2.

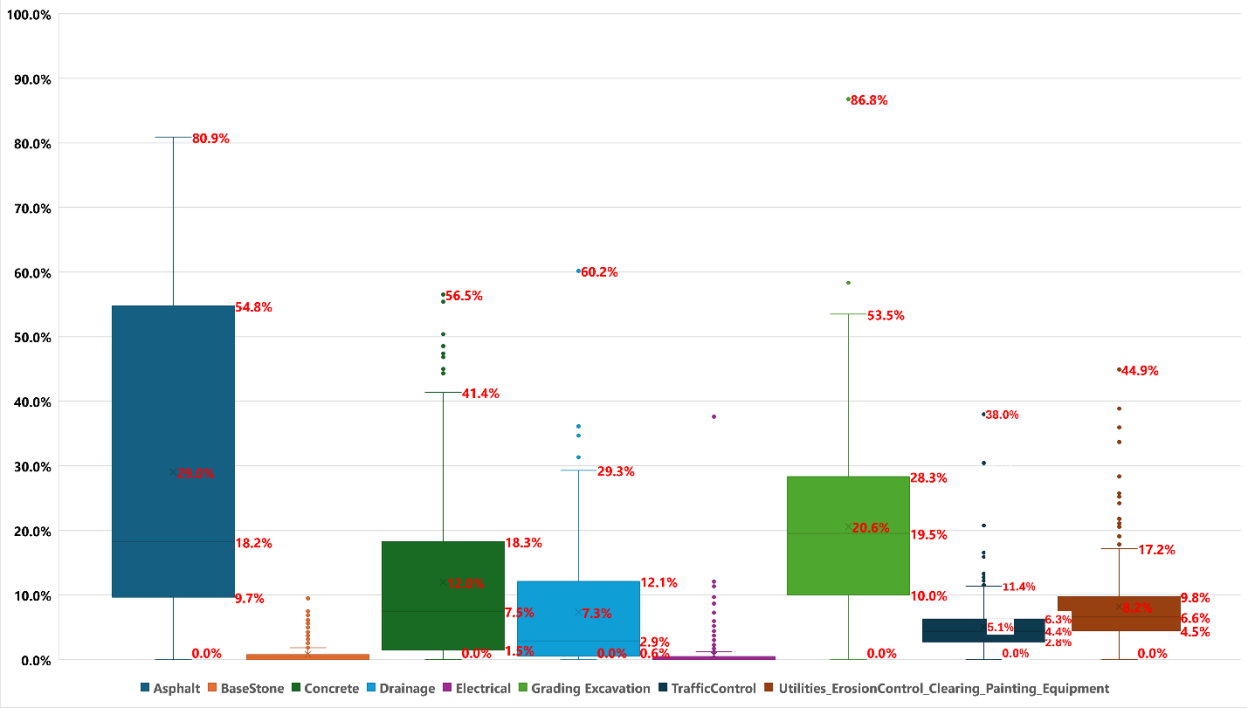


Figure 1. Box Plots of the 8 Roadway Related NHCCI Components (percent of the total bid price)

Table 2. Summary Statistics of the 8 Roadway Related NHCCI Components (percent of the total bid price)

	First quartile (Q1 or 25th percentile)	Mean	Median (Q2 or 50th percentile)	Third quartile (Q3 or 75th percentile)	Maximum (Q4 or 100th percentile)
Asphalt	9.7%	29.0%	18.2%	54.8%	80.9%
BaseStone	0.0%	0.9%	0.4%	0.8%	9.5%
Concrete	1.5%	12.0%	7.5%	18.3%	56.5%
Drainage	0.6%	7.3%	2.9%	12.1%	60.2%
Electrical	0.0%	0.7%	0.0%	0.5%	37.6%
Grading Excavation	10.0%	20.6%	19.5%	28.3%	86.8%
TrafficControl	2.8%	5.1%	4.4%	6.3%	38.0%
Utilities_ErosionControl_Clearing_Painting_Equi	4.5%	8.2%	6.6%	9.8%	44.9%

Box plots in Figure 1 allow NCDOT engineers to have an overall understanding of the construction cost structure of all 322 bids submitted to NCDOT in 2023. These bids were further divided into 7 subcategories based on each project's Funding Program, and corresponding box plots and summary statistics were provided for NCDOT engineers to review the cost structure at subcategory levels (as described in Chapter 4).

In Chapter 4, medians, as included in Table 2, were calculated for each subcategory, and then used to calculate a construction cost estimate adjustment factor. The averages, Mean values as included in Table 2, were not used because of the large number of outliers observed in Figure 1.

Another important piece of information that was obtained from NCDOT Bid Tabs is the project's final bid price, which is typically the lowest bid price among several bids. When the engineer's estimate is multiplied by the construction cost estimate adjustment factor, it is expected that the product would be as close as possible to a project's final bid price.

3.3 NCDOT Comprehensive Project Lists (CPLs)

NCDOT publishes CPLs on a weekly basis and these CPLs were available to researchers upon request. The following CPLs were provided by the NCDOT engineer:

1. Comprehensive Project List2023-01-03.xlsx
2. Comprehensive Project List2023-02-07.xlsx
3. Comprehensive Project List2023-03-07.xlsx
4. Comprehensive Project List2023-04-04.xlsx
5. Comprehensive Project List2023-05-09.xlsx
6. Comprehensive Project List2023-06-06.xlsx
7. Comprehensive Project List2023-07-04.xlsx
8. Comprehensive Project List2023-08-01.xlsx
9. Comprehensive Project List2023-09-05.xlsx
10. Comprehensive Project List2023-10-03.xlsx
11. Comprehensive Project List2023-11-07.xlsx
12. Comprehensive Project List2023-12-05.xlsx

As instructed by the NCDOT engineer, projects are no longer included in a CPL once they have let to construction. Therefore, to obtain a complete list of projects, it was necessary to combine these 12 CPLs and then use the most recent “Let Date” to remove duplicates.

It should be noted that all these projects were subcategorized using their “Funding Program”, and the first 2 CPLs on the abovementioned list do not have the “Funding Program Description” column. Consequently, the remaining 10 CPLs were combined and a total of 26,261 projects were obtained. After duplicates were removed, a total of 3,137 projects remained. The CPL data merging and duplicate removing process are shown in Figure 2 below.

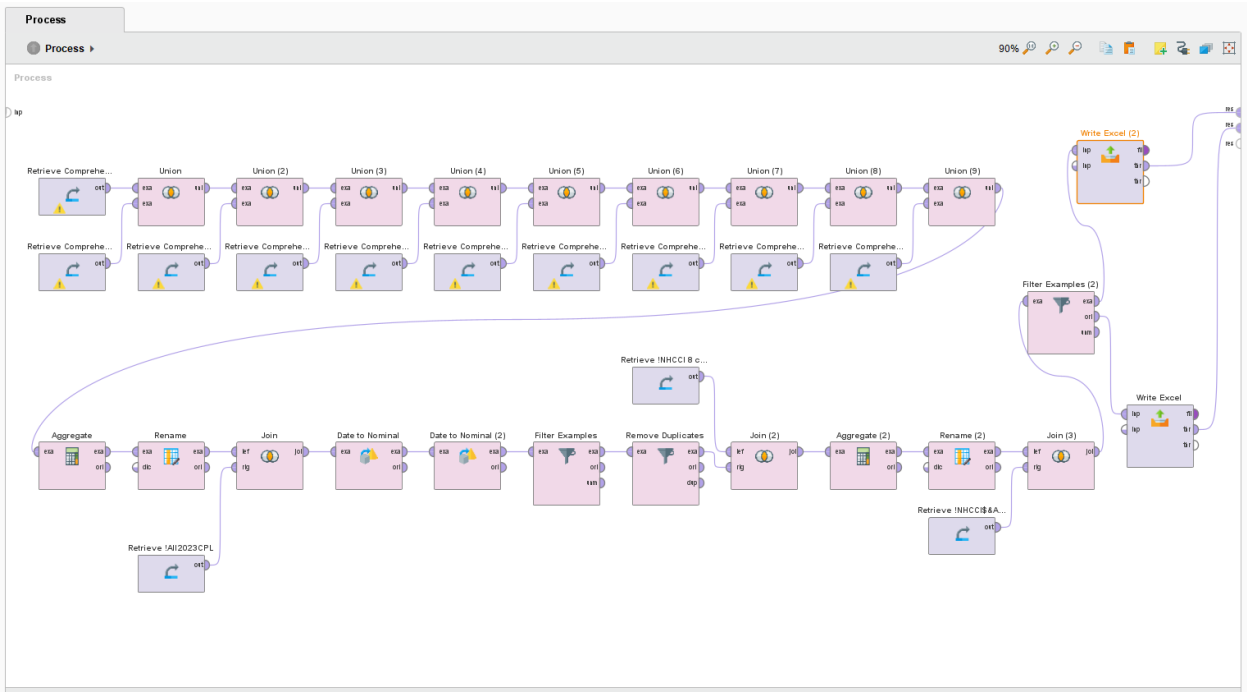


Figure 2. CPL Data Merging and Duplicate Removing Process

CHAPTER 4 RESEARCH METHODOLOGY

This chapter describes the procedures that were performed to develop the proposed prototype of the estimate update tool, including the regrouping of roadway projects and the development of the construction cost estimate adjustment factor.

4.1 Regrouping of Roadway Projects

The construction projects considered in this research project were initially divided into two categories: Bridge and Roadway. A standalone NHCCI component, Bridge, is directly related to the Bridge project category. This one-to-one relationship simplifies the prototype development process for the Bridge project category and allows researchers to be more focused on the other one-to-many relationship, which is the 8 NHCCI components relating to the Roadway project category.

A parallel coordinates plot of 322 bids (the NCDOT bid tabs data set as described in Section 3.2) was developed (Figure 3) to explore the relationships, trends, and variations of these 8 components altogether. In addition to several outliers, the most significant variations exist for Asphalt, followed by Grading/Excavation, Concrete, and Drainage. A few clusters are quite obviously visible in this plot. This indicates that one single category, Roadway, is not sufficient to represent this large cost group, and a regrouping seems to be necessary.

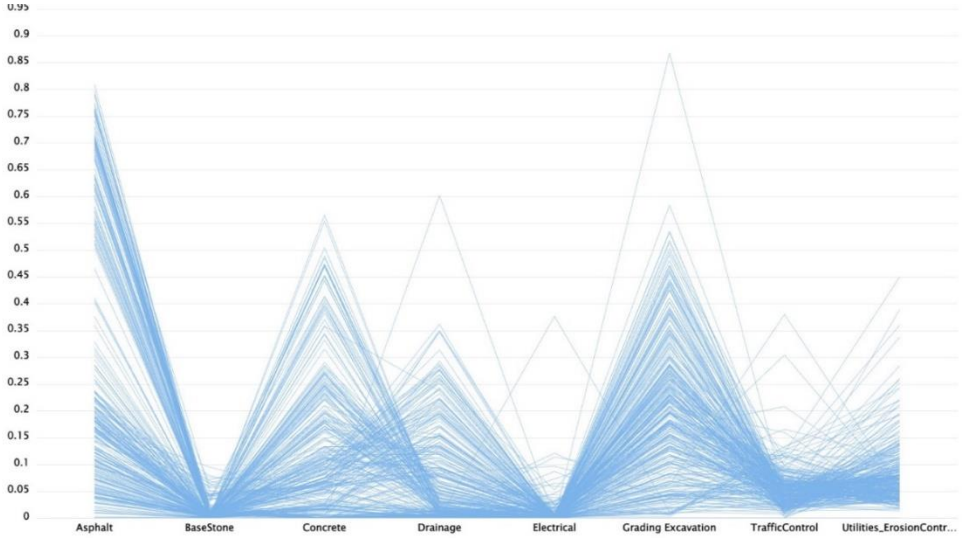


Figure 3. Parallel Coordinates Plot of 322 Bids

As an attempt to regroup these projects, another parallel coordinates plot of the same 322 bids and color-coded by project types (extracted from NCDOT Bid Tabs) is presented in Figure 4. This plot includes 322 lines (bids) in 21 different colors (project types). It can be observed that the boundaries between color groups are not distinct, which means project types are not a good factor that should be used to regroup these projects. The same conclusion can be drawn from an Andrew's plot (Figure 5) where color lines are tangled with each other, and a distinct grouping is not observed.

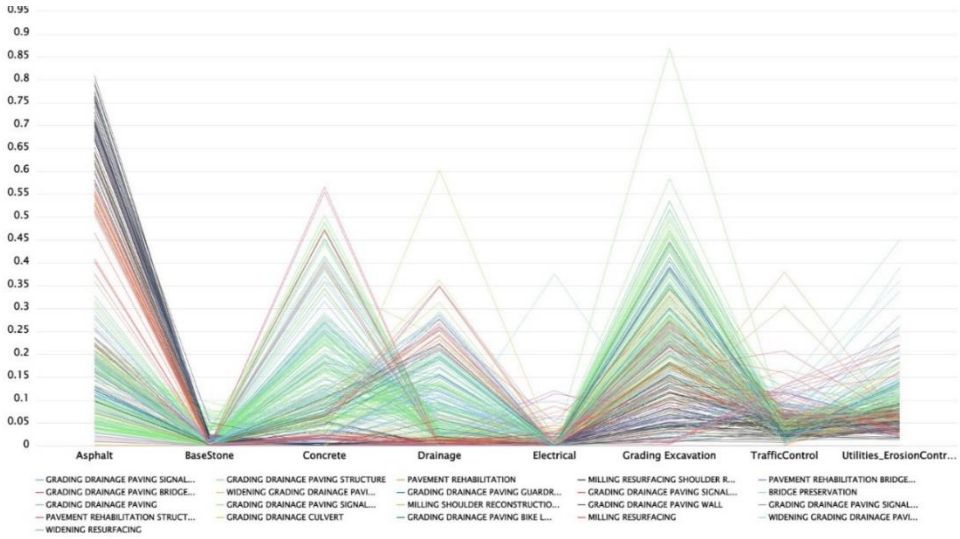


Figure 4. Parallel Coordinates Plot of 322 Bids (colored by Project Types)

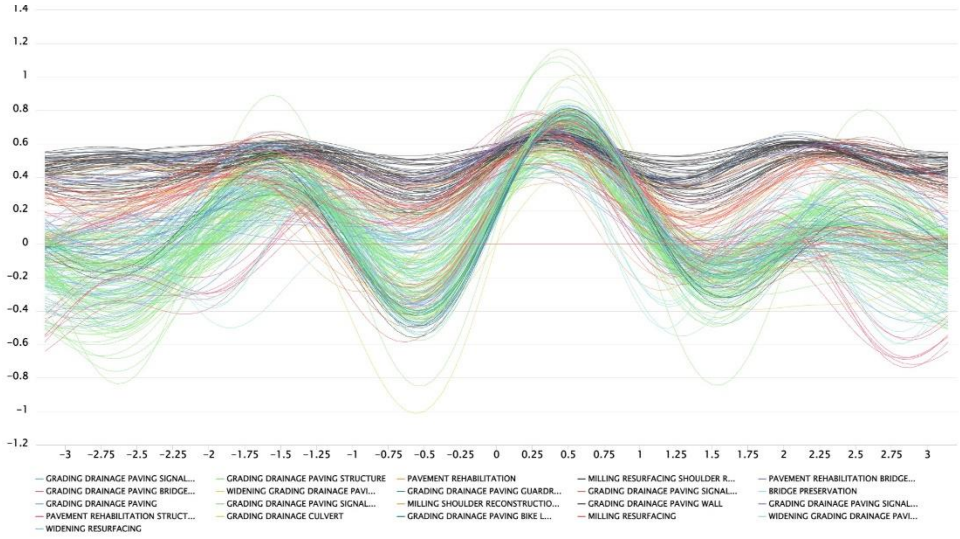


Figure 5. Andrew's Plot of 322 Bids (colored by Project Types)

An insight from the NCDOT engineer suggests that "Funding Program" could be used to regroup these projects. Another data merging process is needed as information related to the NHCCI components and "Funding Program" reside in two different data sets (Tables 3 and 4).

Table 3. NCDOT Bid Tab Data Structure

Project ID	Asphalt	BaseStone	Concrete	Drainage	Electrical	Grading Excavation	Traffic Control	Utilities_ErosionControl_Clearing_Painting_Equipment	Bid Price
Project 1									
Project 2									
Project 3									
...									

Table 4. NCDOT CPL Data Structure

Project ID	Let Date	Funding Program Description	CON $	CON Estimate Date
Project i				
Project i+1				
Project i+2				
...				

After merging these two data sets using Project ID as the key attribute, the final data set has 213 bids which belong to 48 projects (each project can include up to 5 bids). A bar chart (Figure 6) and box plots developed using these 213 bids are shown below (Figures 7-14).

A total of 6 different funding programs are included in the CPL data sets. They are:

1. Highway – Bridge
2. Highway - Interstate Maintenance
3. Highway - Locally Selected
4. Highway – Safety
5. Highway - STI (Prioritization)
6. Rail - STI (Prioritization)

Some projects were not assigned a funding program, and their corresponding funding programs were categorized as Unknown. As shown in Figure 6, the funding program "Highway – STI (Prioritization)" has funded the largest number of projects, which is 19 (87 bids), and the funding program "Rail – STI' has funded the least number of projects, which is one (2 bids). Box plots of 8 NHCCI components (Figures 7-14) display summary statistics, including the min., max., mean, median, and other quartiles, that enable the NCDOT engineers to quickly understand the important point values across all funding programs. It should be noted that bridge projects funded by the

Highway – Bridge funding program have their own NHCCI percent change rate, and their appearance in Figures 7-14 is for reference purposes only.

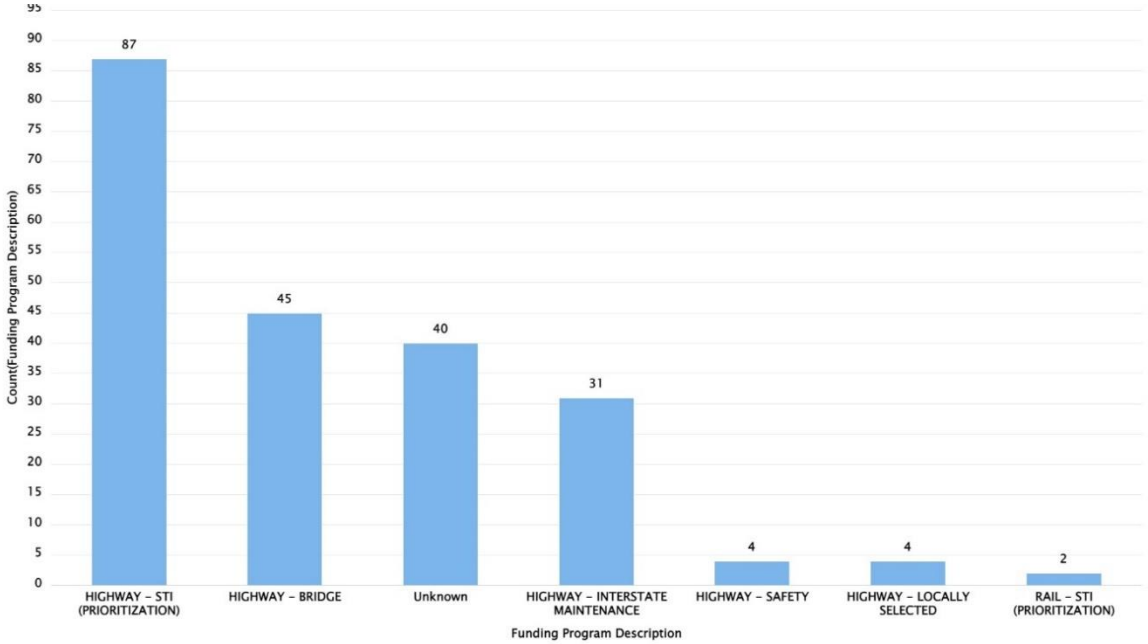


Figure 6. Numbers of Bids by Funding Program

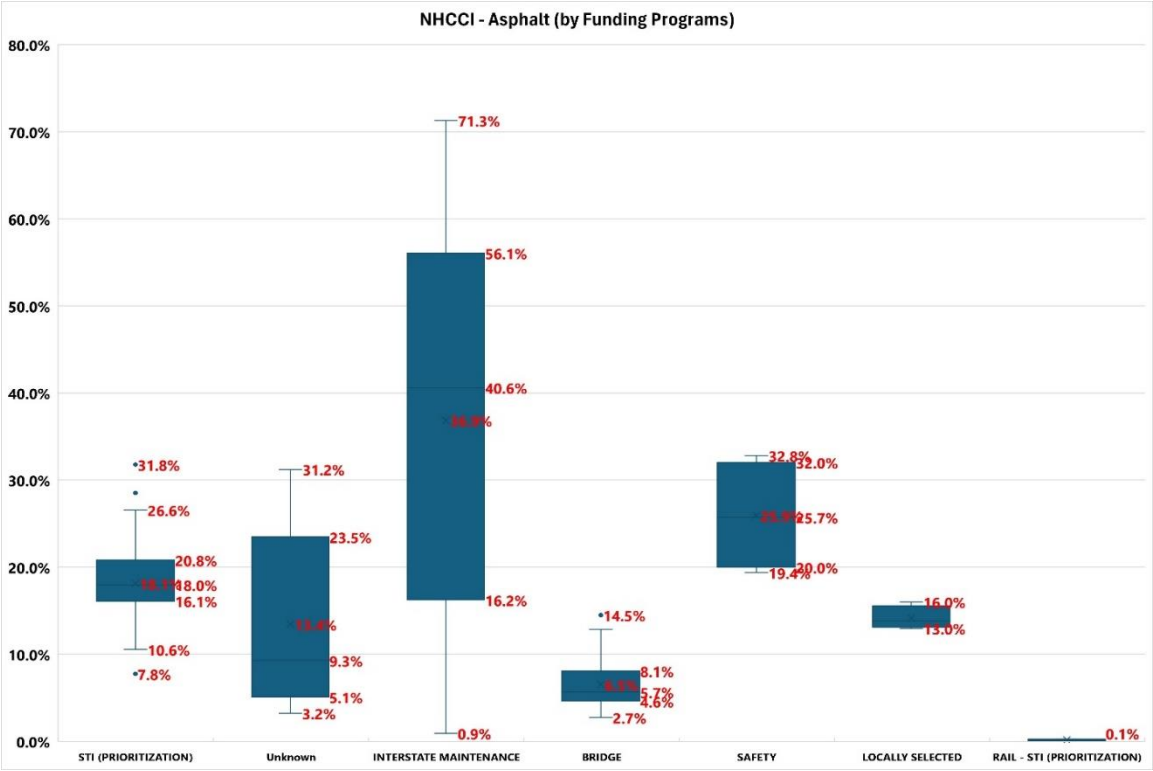


Figure 7. Box Plots of the NHCCI Component - Asphalt (by Funding Programs)

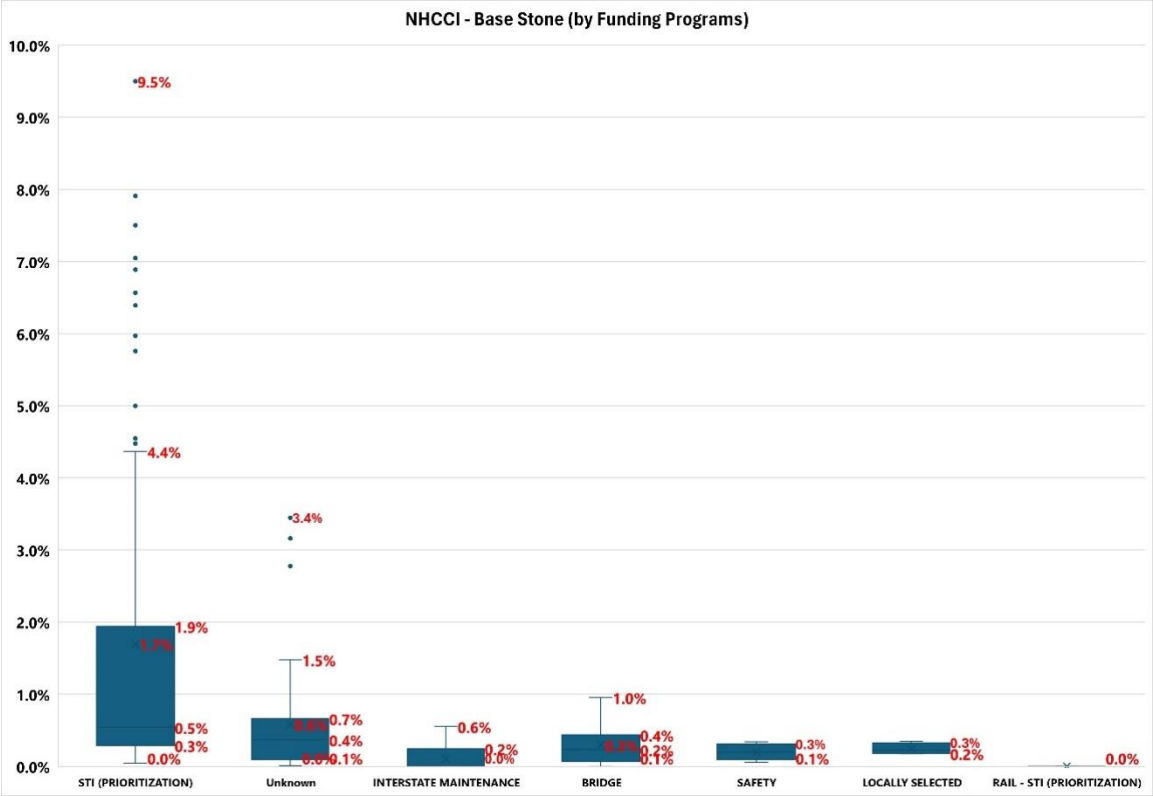


Figure 8. Box Plots of the NHCCI Component – Base Stone (by Funding Programs)

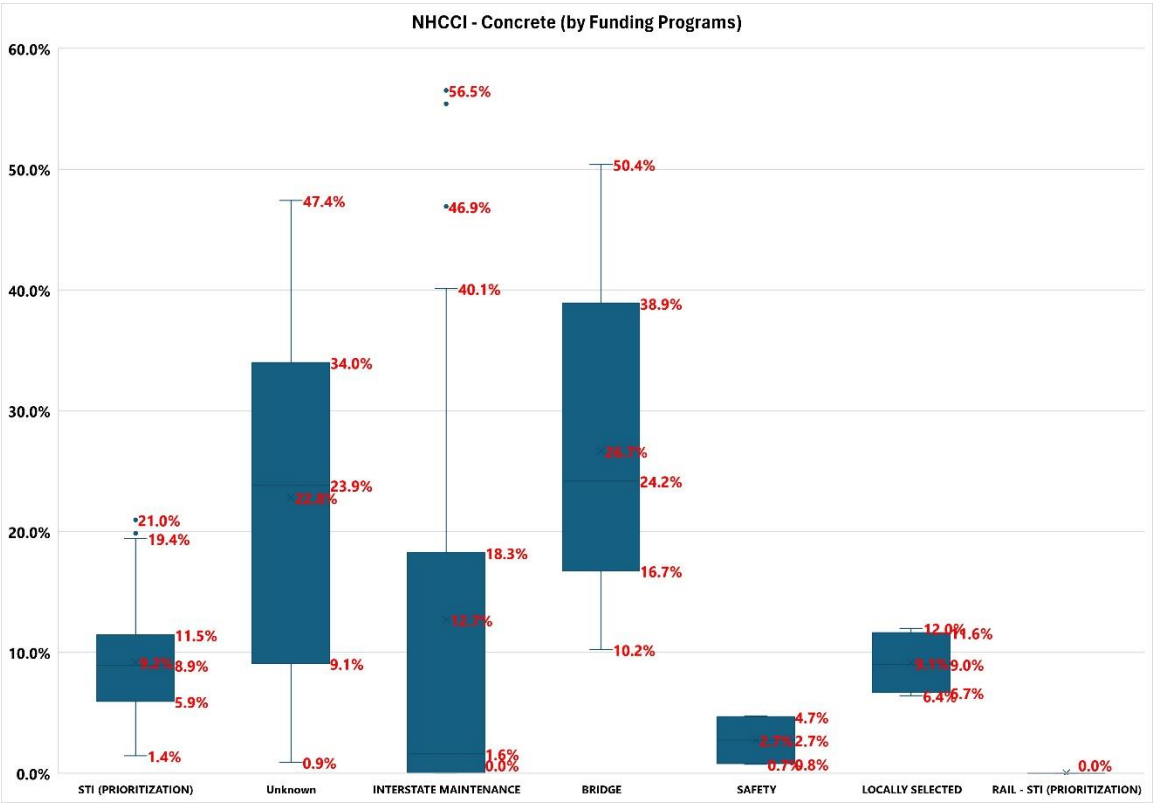


Figure 9. Box Plots of the NHCCI Component – Concrete (by Funding Programs)

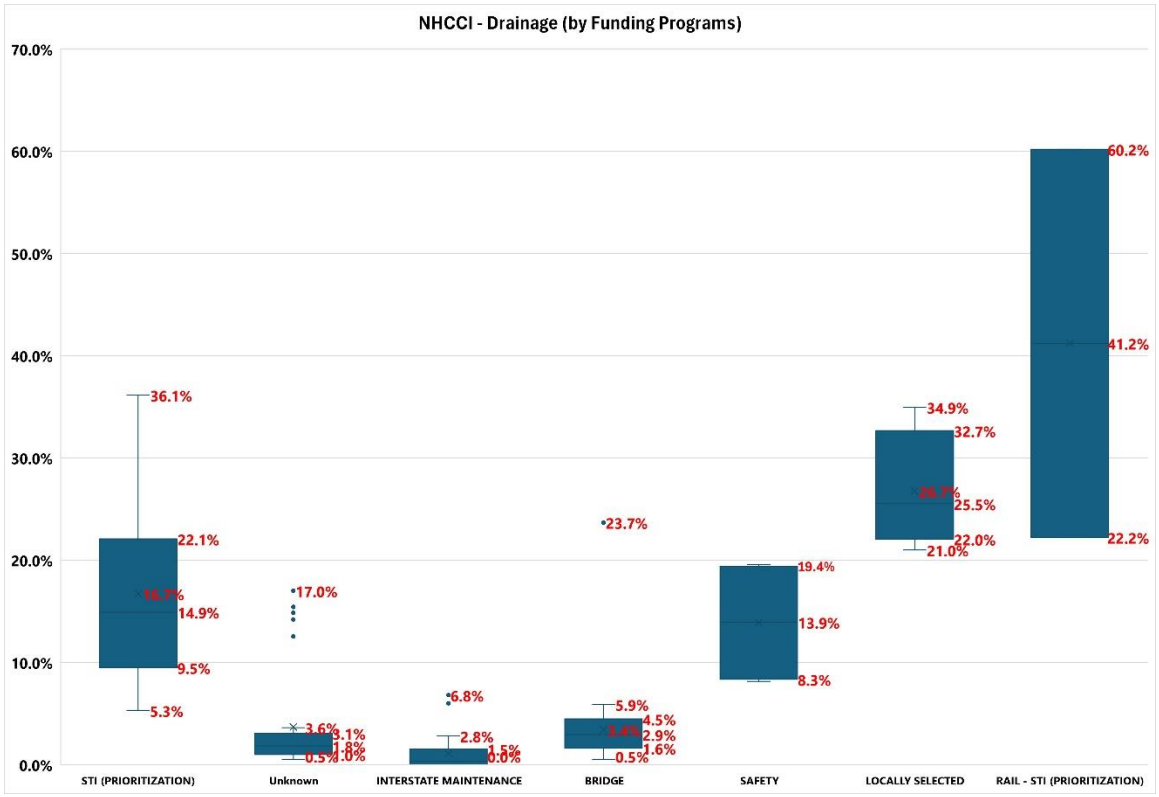


Figure 10. Box Plots of the NHCCI Component – Drainage (by Funding Programs)

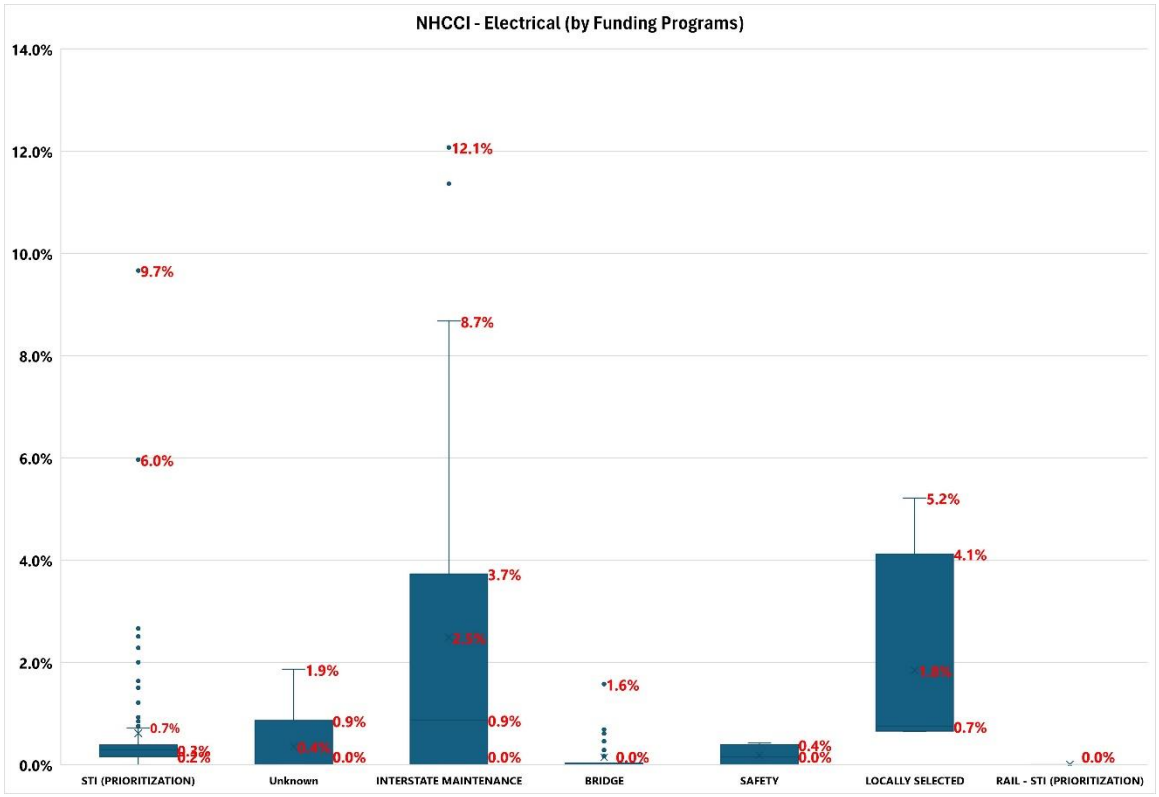
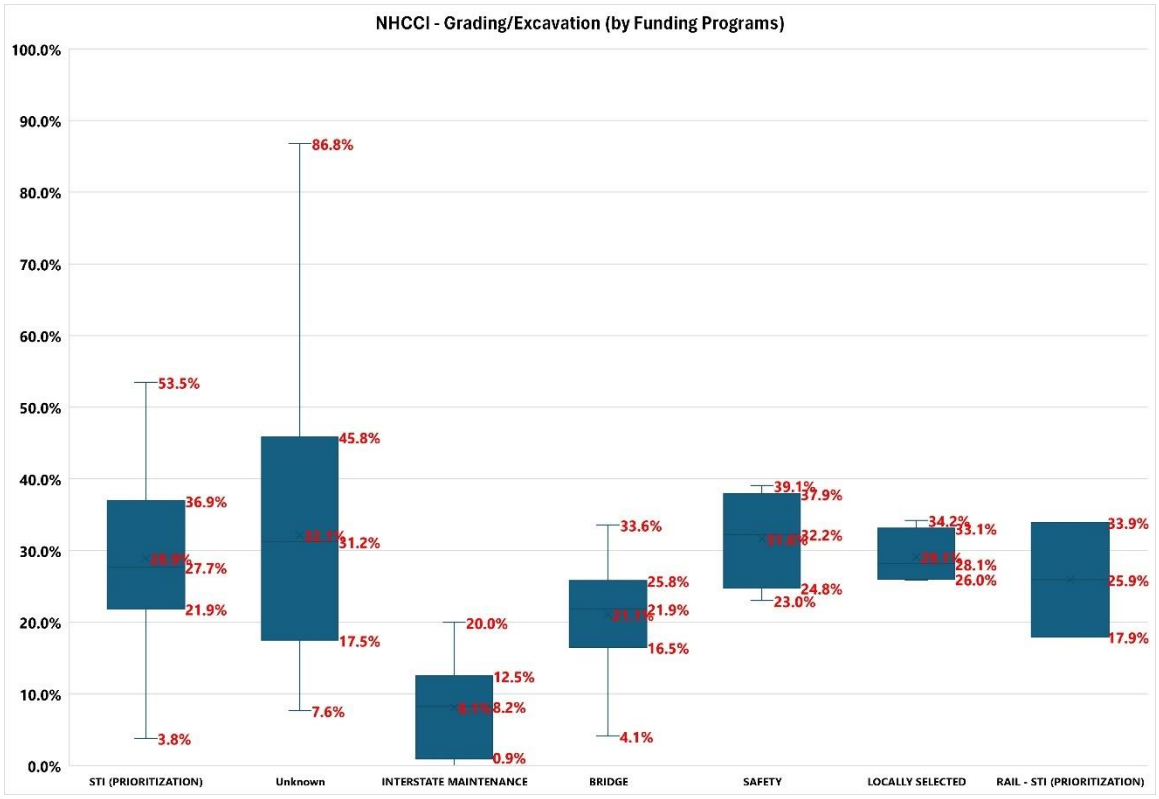


Figure 11. Box Plots of the NHCCI Component – Electrical (by Funding Programs)



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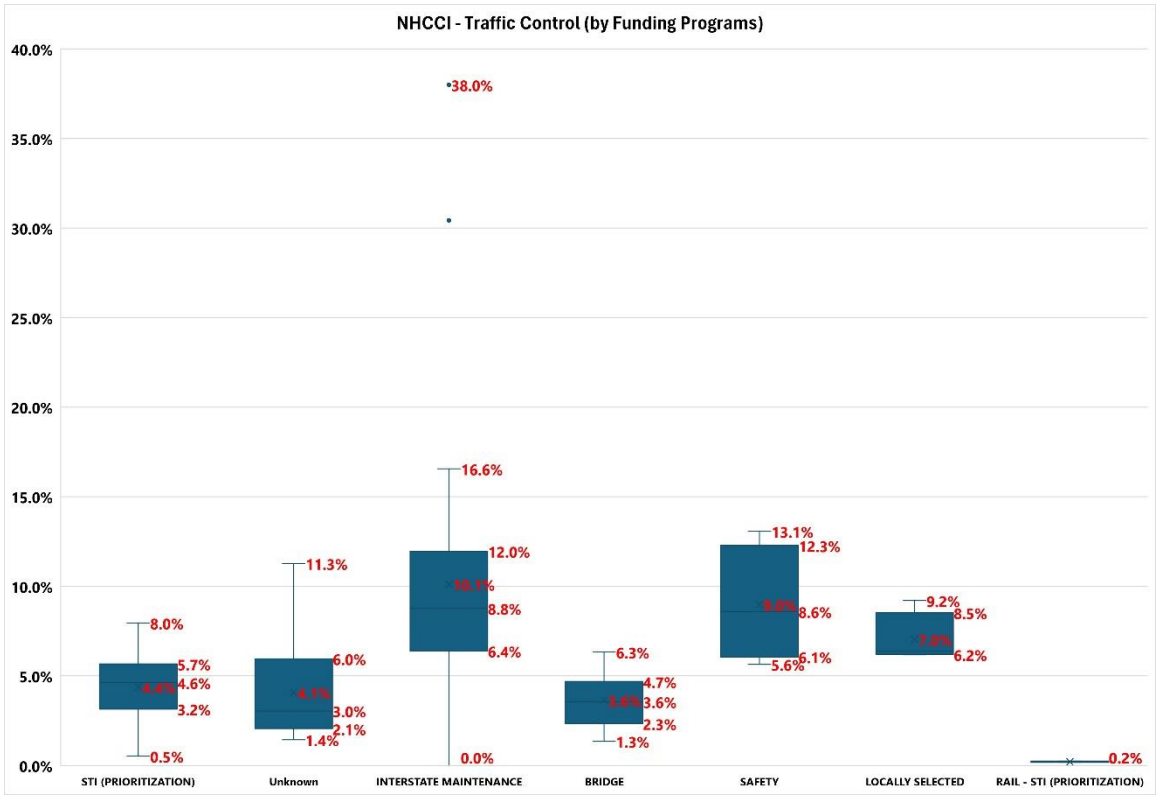
287 *Figure 12. Box Plots of the NHCCI Component – Grading/Excavation (by Funding Programs)*



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289 *Figure 13. Box Plots of the NHCCI Component – Traffic Control (by Funding Programs)*

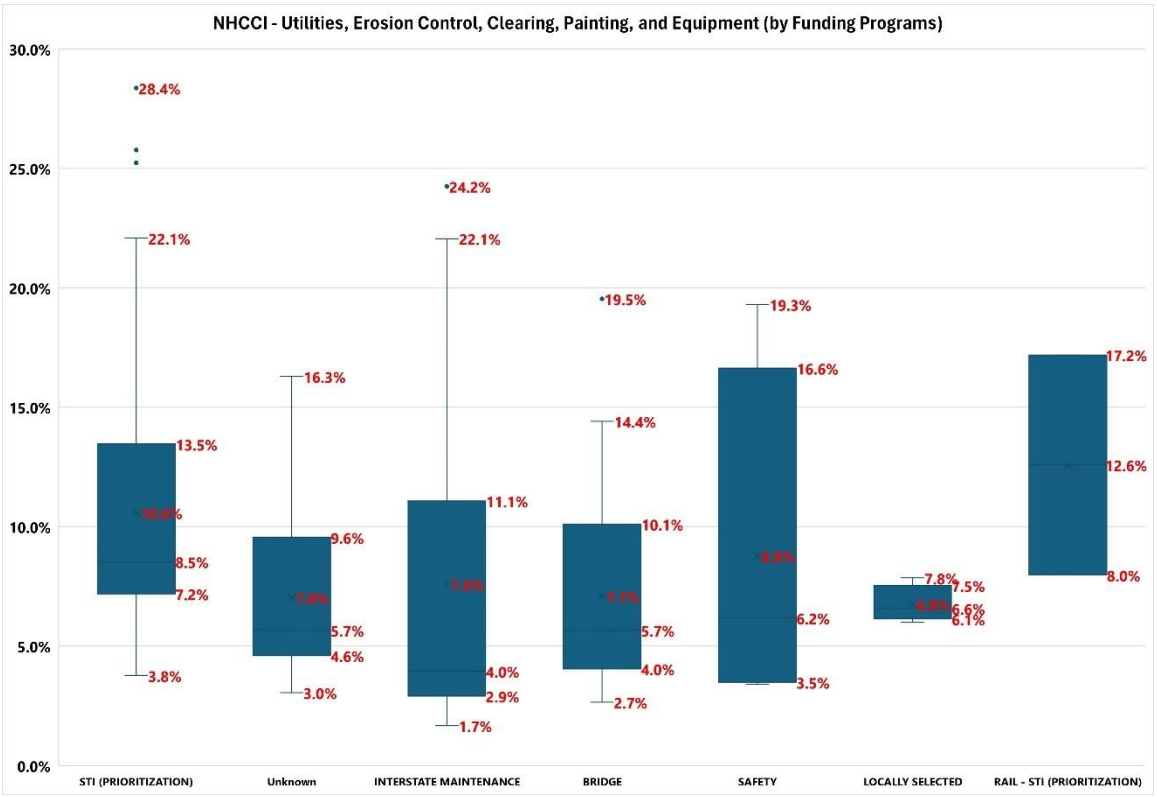

Figure 14. Box Plots of the NHCCI Component – Utilities, etc. (by Funding Programs)

To check the regrouping results using Funding Program as the indicator, a parallel coordinates plot is presented in Figure 15. This plot includes 213 lines (bids) in 7 different colors (Funding Programs). It can be observed that the boundaries between color groups are distinct, which means Funding Programs are a good factor that should be used to regroup these projects. The same conclusion can be drawn from an Andrew's plot (Figure 16) where clusters of color lines are visibly separate from each other, and a distinct grouping is observed.

With this conclusion, the next step would be to calculate a construction cost estimate adjustment factor for each Funding Program. The procedure is described in Section 4.2.

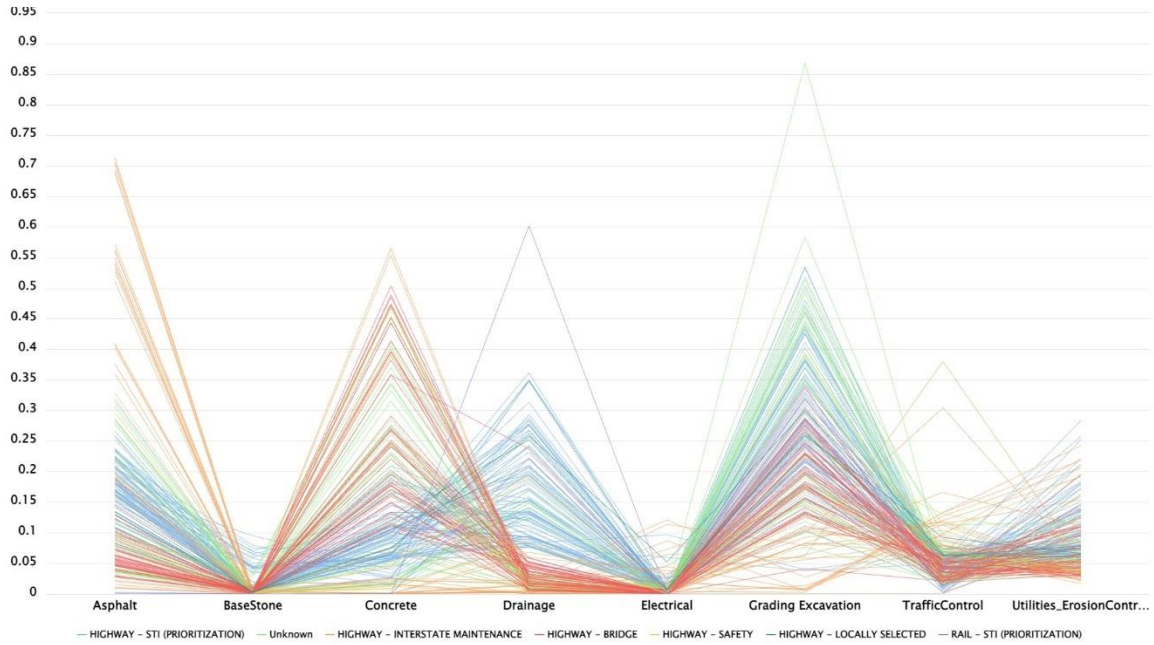

Figure 15. Parallel Coordinates Plot of 213 Bids (colored by Funding Programs)

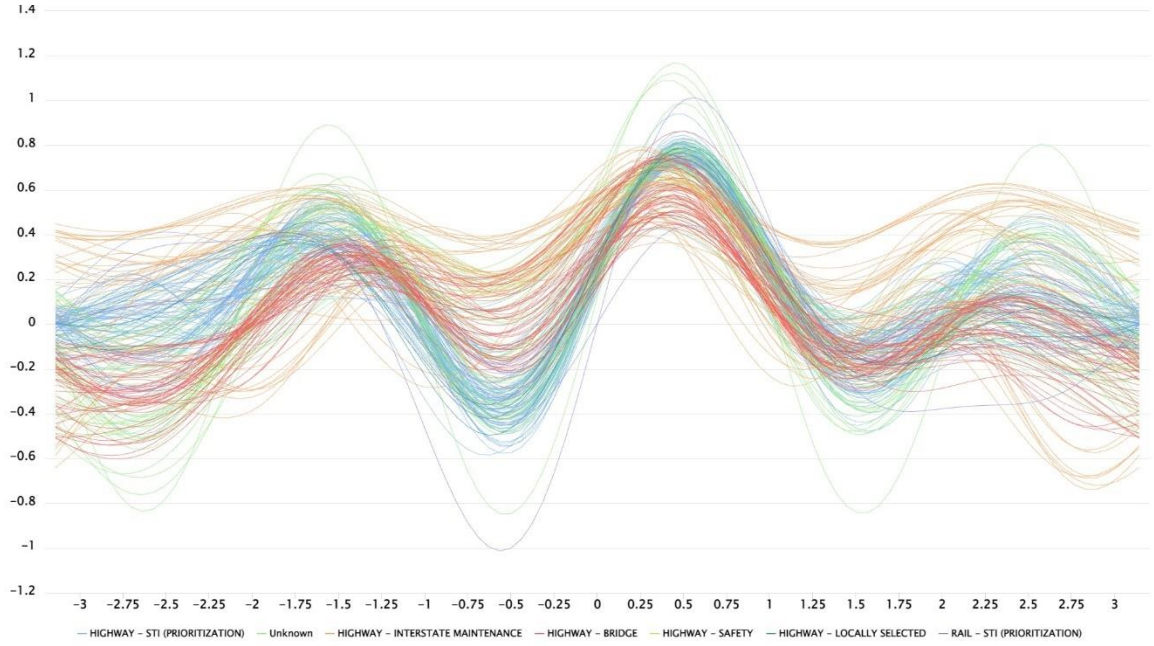

Figure 16. Andrew's Plot of 213 Bids (colored by Funding Programs)

4.2 Construction Cost Estimate Adjustment Factors

Construction cost estimate adjustment factors for 6 funding programs are calculated using Equation (1):

$$\text{Construction Cost Estimate Adjustment Factor}_i = Weighted\ Composite\ Index_i \times Scaling\ Factor_i = \left(1 + \sum_{i=1}^{5}\sum_{j=1}^{8}\left(NHCCI_j \times Median_{i,j}\right)\right) \times \left(\frac{1}{\sum_{j=1}^{8} Median_j}\right) \quad (1)$$

where,

i: Funding Programs. When the Funding Program is Highway – Bridge, the Weighted Composite Index is a constant, 1.0031. Other 5 Funding Programs are: Highway – Interstate Maintenance, Highway – Locally Selected, Highway – Safety, Highway – STI (Prioritization), and Rail – STI (Prioritization).

j: NHCCI components. *j* is from 1 to 8, including Asphalt, Base Stone, Concrete, Drainage, Electrical, Grading/Excavation, Traffic Control, and Utilities, Erosion Control, Clearing, Painting, and Equipment

Scaling Factor: An adjustment factor that is used to extrapolate a portion of a bid to represent the whole bid. For each bid, the sum of median percentages of 8 NHCCI components is less than 100%, and the remaining percentage does not belong to any one of the 8 components. Thus, the sum of median percentages (the portion) should be scaled up to represent the whole bid (the whole entity).

Median: Median percentages of 8 NHCCI components.

Estimated construction costs for 6 funding programs are calculated using Equation (2):

$$\text{Estimated Construction Cost}_i = CON\ \$_i \times \text{Construction Cost Estimate Adjustment Factor}_i \quad (2)$$

where,

i: Funding Programs. When the Funding Program is Highway – Bridge, the Weighted Composite Index is a constant, 1.0031. Other 5 Funding Programs are: Highway – Interstate Maintenance, Highway – Locally Selected, Highway – Safety, Highway – STI (Prioritization), and Rail – STI (Prioritization).

CON $: NCDOT engineers' construction cost estimates, which is included in NCDOT CPLs. CON $ includes the total construction cost, Contract administration, and contingency, and the latter two are estimated to be approximately 15% of the total construction cost. Therefore, to make a valid comparison, the bid prices are adjusted by multiplying an 115% factor.

Construction cost estimate adjustment factors and estimated construction costs were calculated for each funding program, and the results are presented in Tables 5-10 and Figures 17-22.

Table 5. The Construction Cost Estimate Adjustment Factor for Funding Program: Highway – Bridge

NHCCI Components	Asphalt	Base Stone	Concrete	Drainage	Electrical	Grading / Excavation	Traffic Control	Utilities / Erosion Control / Clearing / Painting / Equipment
Median	5.66%	0.23%	24.20%	2.93%	0.00%	21.87%	3.57%	5.67%
NHCCI Components (percent change)	1.27%	0.17%	0.07%	0.07%	0.38%	0.45%	0.74%	0.36%
Weighted Composite Index	1.0031							
Scaling Factor	1.5593							
Construction Cost Estimate Adjustment Factor	1.2036							

Table 6. The Construction Cost Estimate Adjustment Factor for Funding Program: Highway – Interstate Maintenance

NHCCI Components	Asphalt	Base Stone	Concrete	Drainage	Electrical	Grading / Excavation	Traffic Control	Utilities / Erosion Control / Clearing / Painting / Equipment
Median	40.60%	0.00%	1.61%	0.34%	0.87%	8.22%	8.77%	3.95%
NHCCI Components (percent change)	1.27%	0.17%	0.07%	0.07%	0.38%	0.45%	0.74%	0.36%
Weighted Composite Index	1.0064							
Scaling Factor	1.5536							
Construction Cost Estimate Adjustment Factor	1.5635							

Table 7. The Construction Cost Estimate Adjustment Factor for Funding Program: Highway – Locally Selected

NHCCI Components	Asphalt	Base Stone	Concrete	Drainage	Electrical	Grading / Excavation	Traffic Control	Utilities / Erosion Control / Clearing / Painting / Equipment
Median	13.80%	0.23%	9.02%	25.51%	0.75%	28.14%	6.38%	6.58%
NHCCI Components (percent change)	1.27%	0.17%	0.07%	0.07%	0.38%	0.45%	0.74%	0.36%
Weighted Composite Index	1.0040							
Scaling Factor	1.1061							
Construction Cost Estimate Adjustment Factor	1.1105							

Table 8. The Construction Cost Estimate Adjustment Factor for Funding Program: Highway – Safety

NHCCI Components	Asphalt	Base Stone	Concrete	Drainage	Electrical	Grading / Excavation	Traffic Control	Utilities / Erosion Control / Clearing / Painting / Equipment
Median	20.61%	0.12%	4.63%	19.23%	0.36%	36.75%	6.48%	3.57%
NHCCI Components (percent change)	1.27%	0.17%	0.07%	0.07%	0.38%	0.45%	0.74%	0.36%
Weighted Composite Index	1.0051							
Scaling Factor	1.0898							
Construction Cost Estimate Adjustment Factor	1.0953							

Table 9. The Construction Cost Estimate Adjustment Factor for Funding Program: Highway – STI (Prioritization)

NHCCI Components	Asphalt	Base Stone	Concrete	Drainage	Electrical	Grading / Excavation	Traffic Control	Utilities / Erosion Control / Clearing / Painting / Equipment
Median	17.97%	0.54%	8.94%	14.90%	0.29%	27.66%	4.62%	8.53%
NHCCI Components (percent change)	1.27%	0.17%	0.07%	0.07%	0.38%	0.45%	0.74%	0.36%
Weighted Composite Index	1.0044							
Scaling Factor	1.1984							
Construction Cost Estimate Adjustment Factor	1.2036							

Table 10. The Construction Cost Estimate Adjustment Factor for Funding Program: Rail – STI (Prioritization)

NHCCI Components	Asphalt	Base Stone	Concrete	Drainage	Electrical	Grading / Excavation	Traffic Control	Utilities / Erosion Control / Clearing / Painting / Equipment
Median	0.16%	0.00%	0.00%	41.20%	0.00%	25.93%	0.21%	12.58%
NHCCI Components (percent change)	1.27%	0.17%	0.07%	0.07%	0.38%	0.45%	0.74%	0.36%
Weighted Composite Index	1.8027							
Scaling Factor	1.2488							
Construction Cost Estimate Adjustment Factor	2.2512							

Table 11. The Construction Cost Estimate Adjustment Factor for Funding Program: Unknown

NHCCI Components	Asphalt	Base Stone	Concrete	Drainage	Electrical	Grading / Excavation	Traffic Control	Utilities / Erosion Control / Clearing / Painting / Equipment
Median	9.28%	0.37%	23.85%	1.81%	0.00%	31.23%	3.05%	5.67%
NHCCI Components (percent change)	1.27%	0.17%	0.07%	0.07%	0.38%	0.45%	0.74%	0.36%
Weighted Composite Index	1.0032							
Scaling Factor	1.3287							
Construction Cost Estimate Adjustment Factor	1.3330							

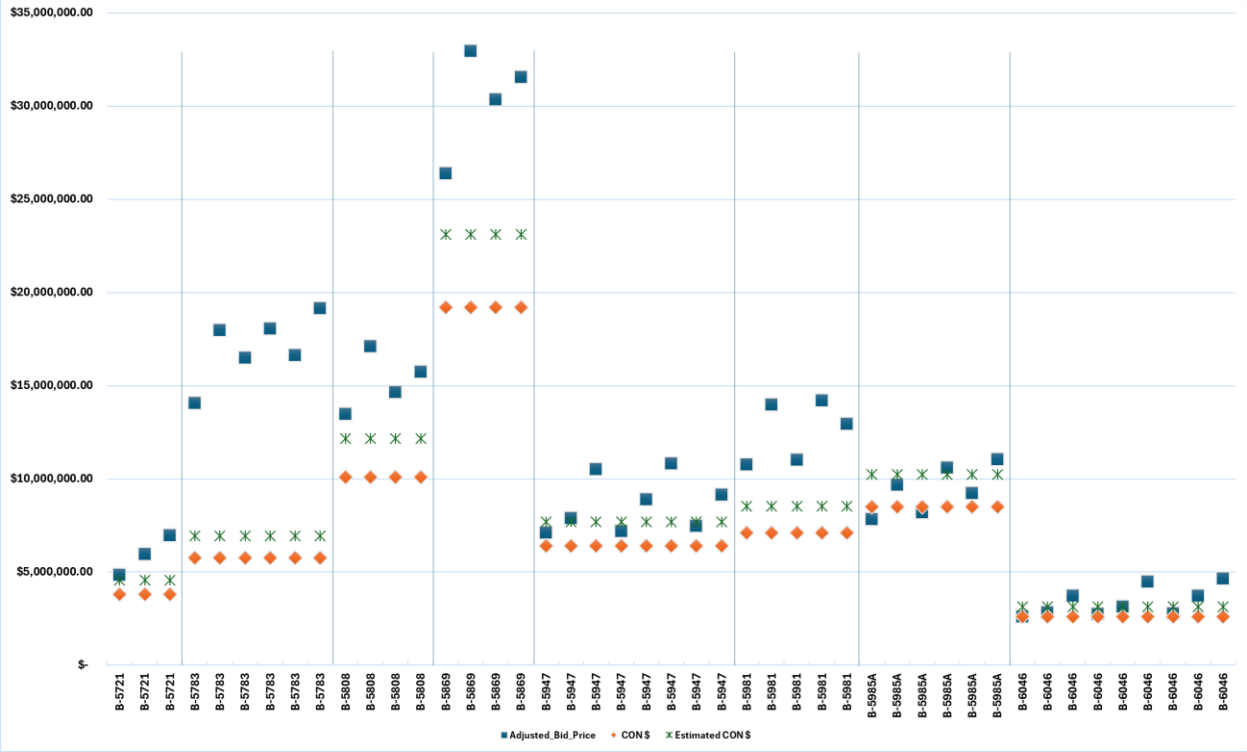

Figure 17. Dot Plot of Adjusted Bid Price, CON $, and Estimated CON $ (Funding Program: Highway – Bridge)

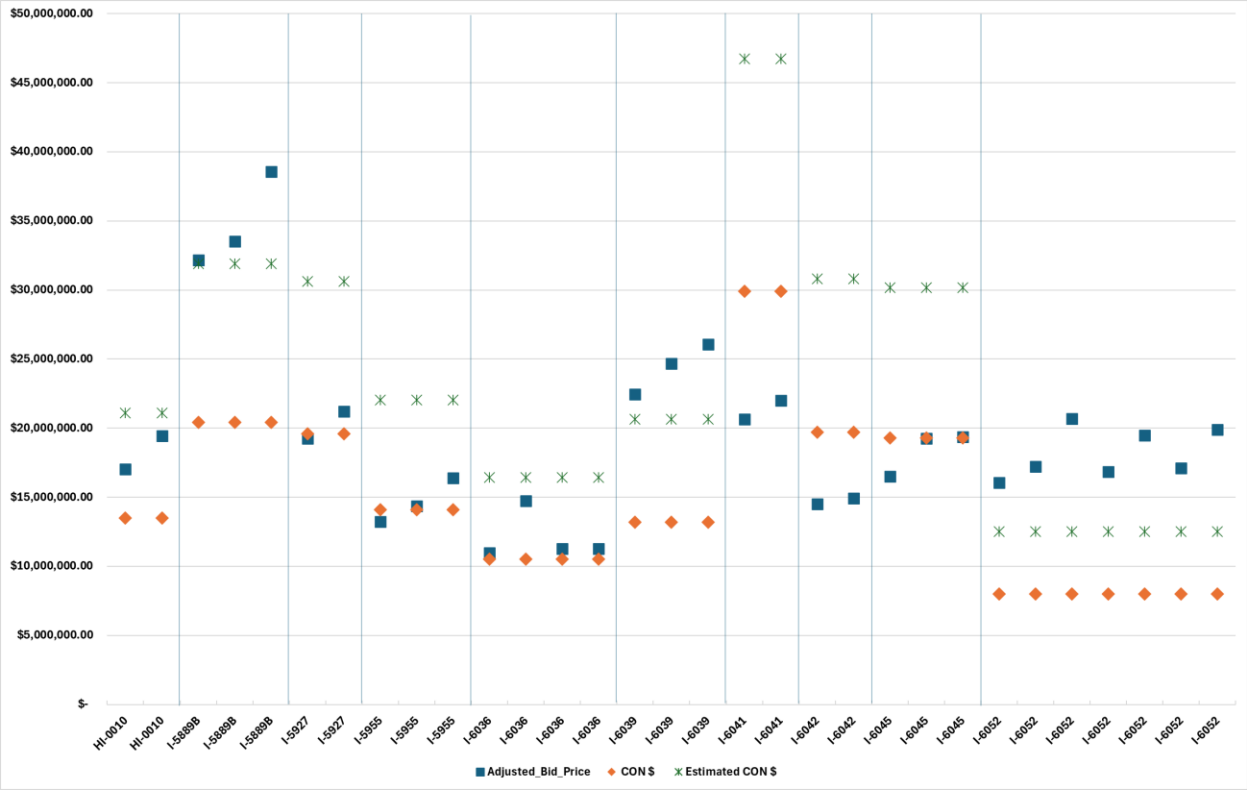

Figure 18. Dot Plot of Adjusted Bid Price, CON $, and Estimated CON $ (Funding Program: Highway – Interstate Maintenance)

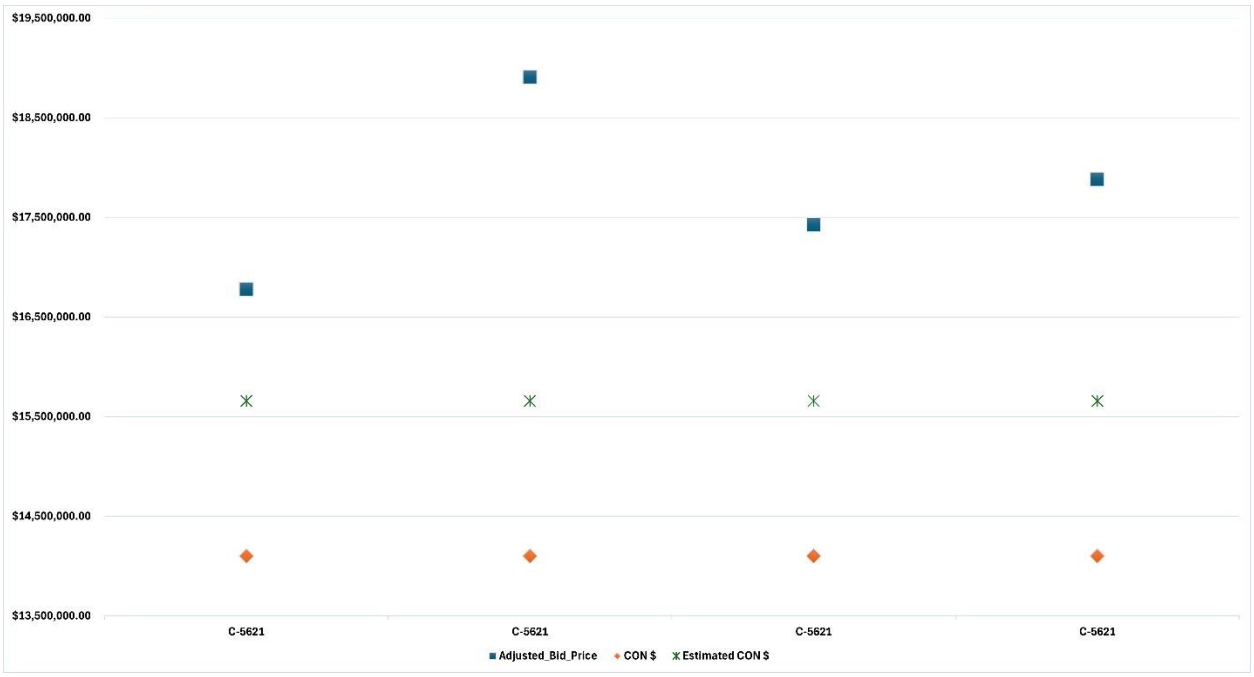

Figure 19. Dot Plot of Adjusted Bid Price, CON $, and Estimated CON $ (Funding Program: Highway – Locally Selected)

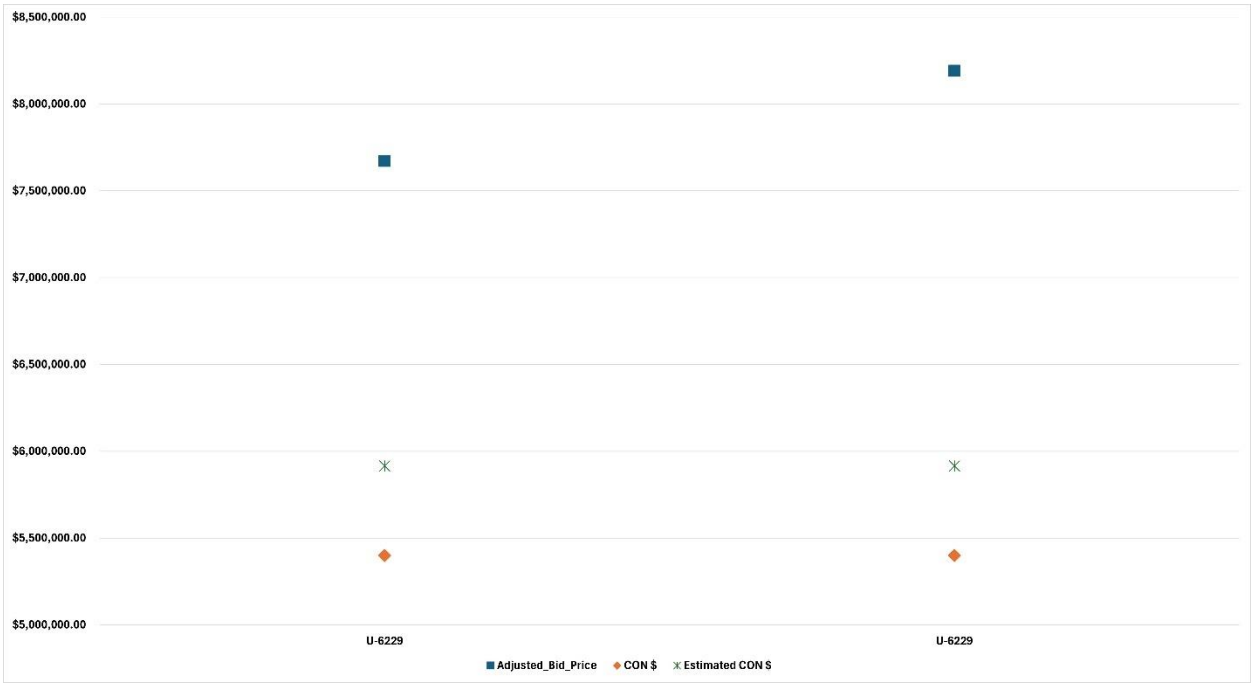

Figure 20. Dot Plot of Adjusted Bid Price, CON $, and Estimated CON $ (Funding Program: Highway – Safety)

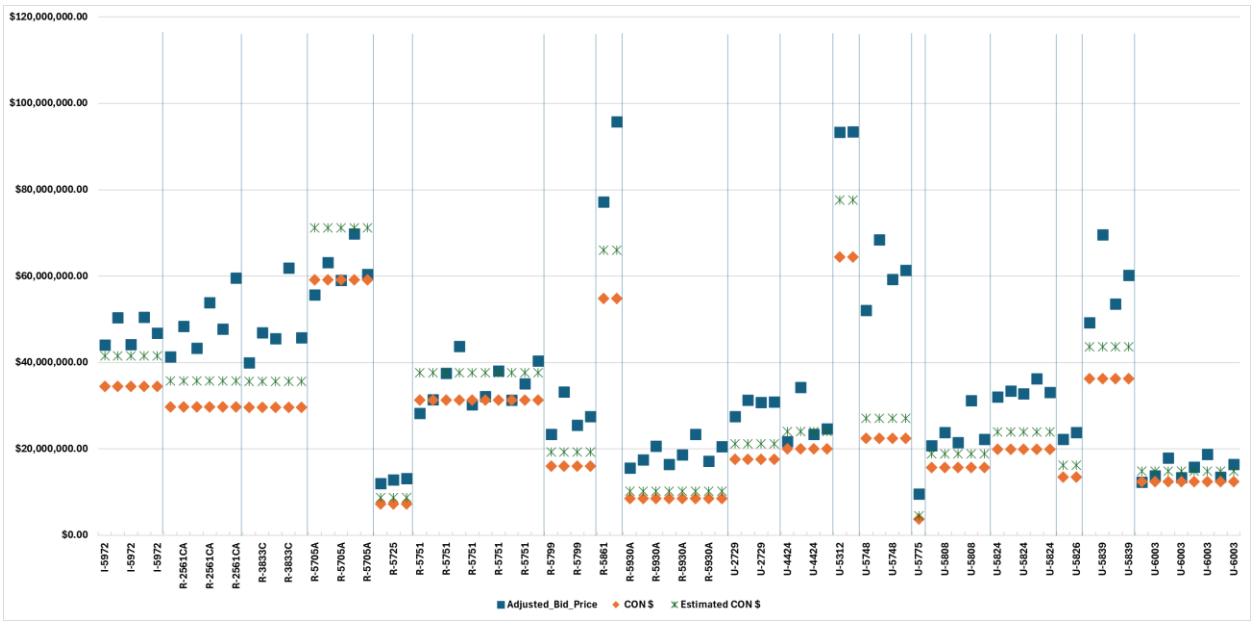

Figure 21. Dot Plot of Adjusted Bid Price, CON $, and Estimated CON $ (Funding Program: Highway – STI (Prioritization))

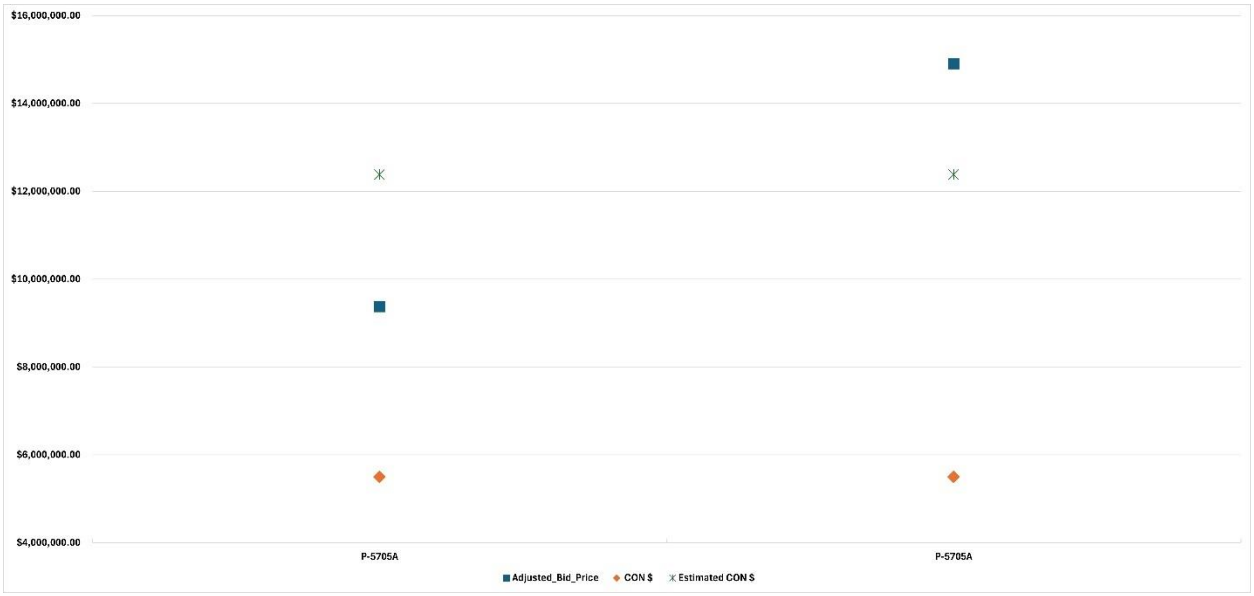

Figure 22. Dot Plot of Adjusted Bid Price, CON $, and Estimated CON $ (Funding Program: Rail – STI (Prioritization))

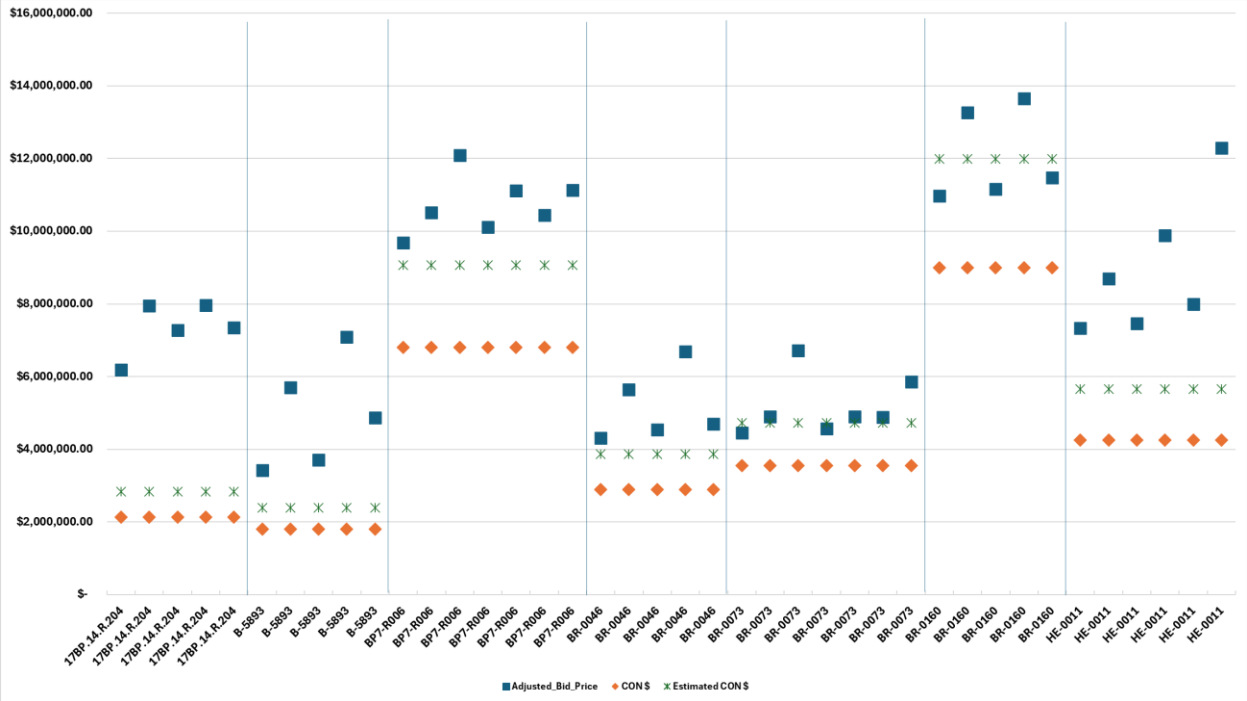

Figure 23. Dot Plot of Adjusted Bid Price, CON $, and Estimated CON $ (Funding Program: Unknown)

CHAPTER 5 FINDINGS AND CONCLUSIONS

This technical assistance project was conducted to develop a construction cost estimate method which can be used by the NCDOT engineers to better estimate construction costs for bridge and roadway projects. Findings and conclusions upon the completion of this project are presented below.

5.1 Research Data

As described in Chapter 3, NCDOT engineers provided two out of three types of data that were used to conduct data analyses for this research project. Researchers observed that two data sets obtained from NCDOT are complete and of high quality. The flowchart below (Figure 24) illustrates how key information was used in this project.

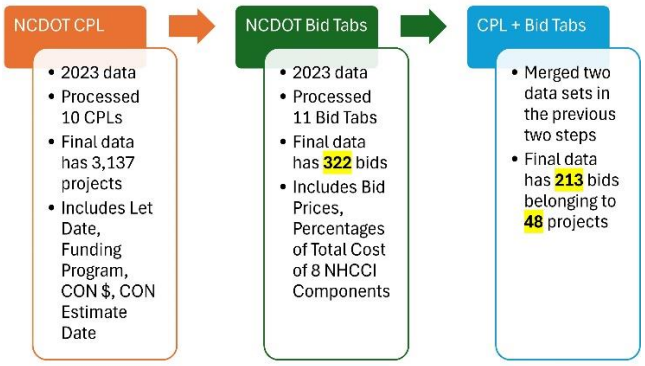

Figure 24. Key Information of NCDOT Data Sets

As shown in the final step of this workflow, information of 48 projects was extracted and the numbers of these projects supported by following funding programs are:

- Highway – Bridge: 8
- Highway – Interstate Maintenance: 10
- Highway – Locally Selected: 1
- Highway – Safety: 2
- Highway – STI (Prioritization): 19
- Rail – STI (Prioritization): 1
- Unknown: 7

5.2 Summary Statistics of NHCCI Components

Summary statistics of the following information are included in Table 12:

- A total of 322 bids (as shown in Figure 24)
- Percentage of the total bid prices of 8 NHCCI components
- By 7 Funding Programs

Figure 25 presents a heatmap generated using the median values of 8 NHCCI components. Since the final merged data in this project shows that three funding programs, Highway – Locally Selected, Highway – Safety, and Rail – STI (Prioritization), each supported only one or two projects in 2023, their representations in Figure 25 are not the focus of this heatmap. For the Highway – Interstate Maintenance program, most of the funding went to Asphalt, followed by Grading/Excavation and Traffic. For the Highway – STI (Prioritization) program, a large percentage of funding went to Grading/Excavation, followed by Asphalt, Drainage, and Concrete. For projects supported by the Unknown funding program, a large percentage of funding went to Concrete, followed by Grading/Excavation. This funding allocation makes sense since most of the projects in this category seem to be bridge projects (Figure 23). Similarly, funding has been reasonably allocated for the Interstate Maintenance and STI (Prioritization) program.

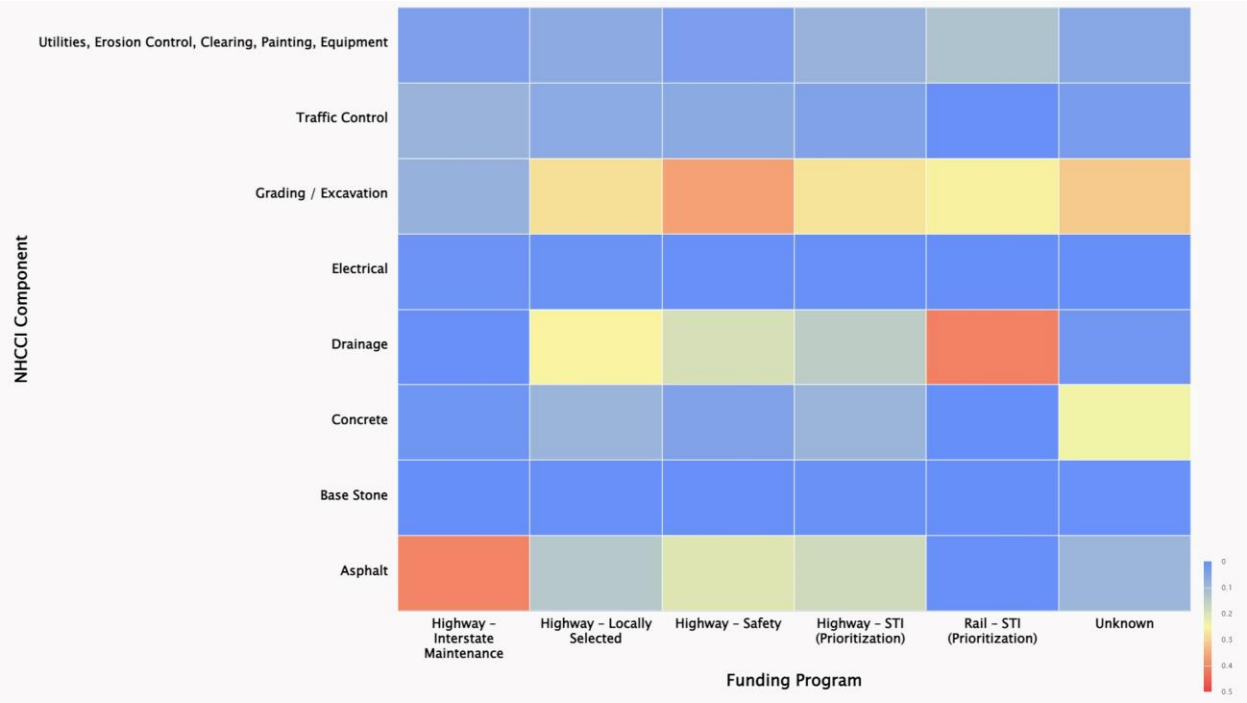

Figure 25. Heatmap of Summary Statistics

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Table 12. The Construction Cost Estimate Adjustment Factor for Funding Program: Unknown

Funding Program	NHCCI Component	First quartile (Q1 or 25th percentile)	Mean	Median (Q2 or 50th percentile)	Third quartile (Q3 or 75th percentile)	Maximum (Q4 or 100th percentile)
Highway – Interstate Maintenance	Asphalt	16.2%	36.9%	40.6%	56.1%	71.3%
	Base Stone	0.0%	0.1%	0.0%	0.2%	0.6%
	Concrete	0.0%	12.7%	1.6%	18.3%	56.5%
	Drainage	0.0%	1.1%	0.3%	1.5%	6.8%
	Electrical	0.0%	2.5%	0.9%	3.7%	12.1%
	Grading / Excavation	0.9%	8.1%	8.2%	12.5%	20.0%
	Traffic Control	6.4%	10.1%	8.8%	12.0%	38.0%
	Utilities, Erosion Control, Clearing, Painting, Equipment	2.9%	7.6%	4.0%	11.1%	24.2%
Highway – Locally Selected	Asphalt	13.1%	14.2%	13.8%	15.6%	16.0%
	Base Stone	0.2%	0.2%	0.2%	0.3%	0.3%
	Concrete	6.7%	9.1%	9.0%	11.6%	12.0%
	Drainage	22.0%	26.7%	25.5%	32.7%	34.9%
	Electrical	0.7%	1.8%	0.7%	4.1%	5.2%
	Grading / Excavation	26.0%	29.1%	28.1%	33.1%	34.2%
	Traffic Control	6.2%	7.0%	6.4%	8.5%	9.2%
	Utilities, Erosion Control, Clearing, Painting, Equipment	6.1%	6.8%	6.6%	7.5%	7.8%
Highway – Safety	Asphalt		20.6%	20.6%		21.9%
	Base Stone		0.1%	0.1%		0.2%
	Concrete		4.6%	4.6%		4.7%
	Drainage		19.2%	19.2%		19.5%
	Electrical		0.4%	0.4%		0.4%
	Grading / Excavation		36.8%	36.8%		39.1%
	Traffic Control		6.5%	6.5%		7.3%
	Utilities, Erosion Control, Clearing, Painting, Equipment		3.6%	3.6%		3.7%
Highway – STI (Prioritization)	Asphalt	16.1%	18.1%	18.0%	20.8%	31.8%
	Base Stone	0.3%	1.7%	0.5%	1.9%	9.5%
	Concrete	5.9%	9.2%	8.9%	11.5%	21.0%
	Drainage	9.5%	16.7%	14.9%	22.1%	36.1%
	Electrical	0.2%	0.6%	0.3%	0.4%	9.7%
	Grading / Excavation	21.9%	28.9%	27.7%	36.9%	53.5%
	Traffic Control	3.2%	4.4%	4.6%	5.7%	8.0%
	Utilities, Erosion Control, Clearing, Painting, Equipment	7.2%	10.6%	8.5%	13.5%	28.4%
Rail – STI (Prioritization)	Asphalt		0.2%	0.2%		0.2%
	Base Stone		0.0%	0.0%		0.0%
	Concrete		0.0%	0.0%		0.0%
	Drainage		41.2%	41.2%		60.2%
	Electrical		0.0%	0.0%		0.0%
	Grading / Excavation		25.9%	25.9%		33.9%
	Traffic Control		0.2%	0.2%		0.2%
	Utilities, Erosion Control, Clearing, Painting, Equipment		12.6%	12.6%		17.2%
Unknown	Asphalt	5.1%	13.4%	9.3%	23.5%	31.2%
	Base Stone	0.1%	0.6%	0.4%	0.7%	3.4%
	Concrete	9.1%	22.8%	23.9%	34.0%	47.4%
	Drainage	1.0%	3.7%	1.8%	3.1%	17.0%
	Electrical	0.0%	0.4%	0.0%	0.9%	1.9%
	Grading / Excavation	17.5%	32.1%	31.2%	45.8%	86.8%
	Traffic Control	2.1%	4.1%	3.0%	6.0%	11.3%
	Utilities, Erosion Control, Clearing, Painting, Equipment	4.6%	7.0%	5.7%	9.6%	16.3%

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This table allows NCDOT engineers to review cost distributions among NHCCI components at the funding program level. It should be noted that missing values in some cells indicate that the corresponding statistics cannot be calculated due to data scarcity.

5.3 Accuracy of the Construction Cost Estimate Adjustment Factor

As described in Section 4.2, a construction cost estimate adjustment factor was calculated for each funding program. Then an estimated construction cost was calculated using this factor. Due to the time constraint, new bid prices in 2024 are not used to validate the accuracy of this factor. Rather, a comparison between a project's final bid price (the lowest bid price) and its estimated construction cost was conducted to check the performance of the factor. The equation for the percentage error is:

$$Percentage\ Error = \left(\frac{Adjusted\ Bid\ Price - Estimated\ CON\ \$}{Adjusted\ Bid\ Price}\right) \times 100\% \quad (3)$$

A box plot of percentage errors shows the following:

- The Bridge program has the highest accuracy (a median of 7.8%), followed by STI (Prioritization) (14.4%), Unknown (16.5%), and Interstate Maintenance (-54.3%). Percentage errors from the other three programs, Locally Selected, Safety, and Rail – STI, are not representative due to their very small sample sizes.
- For the Bridge, STI (Prioritization), and Unknown programs, most projects' adjusted bid prices are higher than the estimated construction costs. This means that the magnitude of the construction cost estimate adjustment factor developed in this research is small.
    - This research project considered one quarterly percent rate published by NHCCI and can use two quarterly rates. The reason is that NCDOT is interested in evaluating construction cost adjustments on projects with estimates 6 months old or more. The compound effect of two quarterly rates, mostly likely having positive values, can increase the magnitude of the construction cost estimate adjustment factor and improve the accuracy.
- For the Interstate Maintenance program, most projects' adjusted bid prices are lower than the estimated construction costs. This means that the magnitude of the construction cost estimate adjustment factor developed in this research is large.

- This indicates that there is a need to further look into the bid price data to identify anomalies.

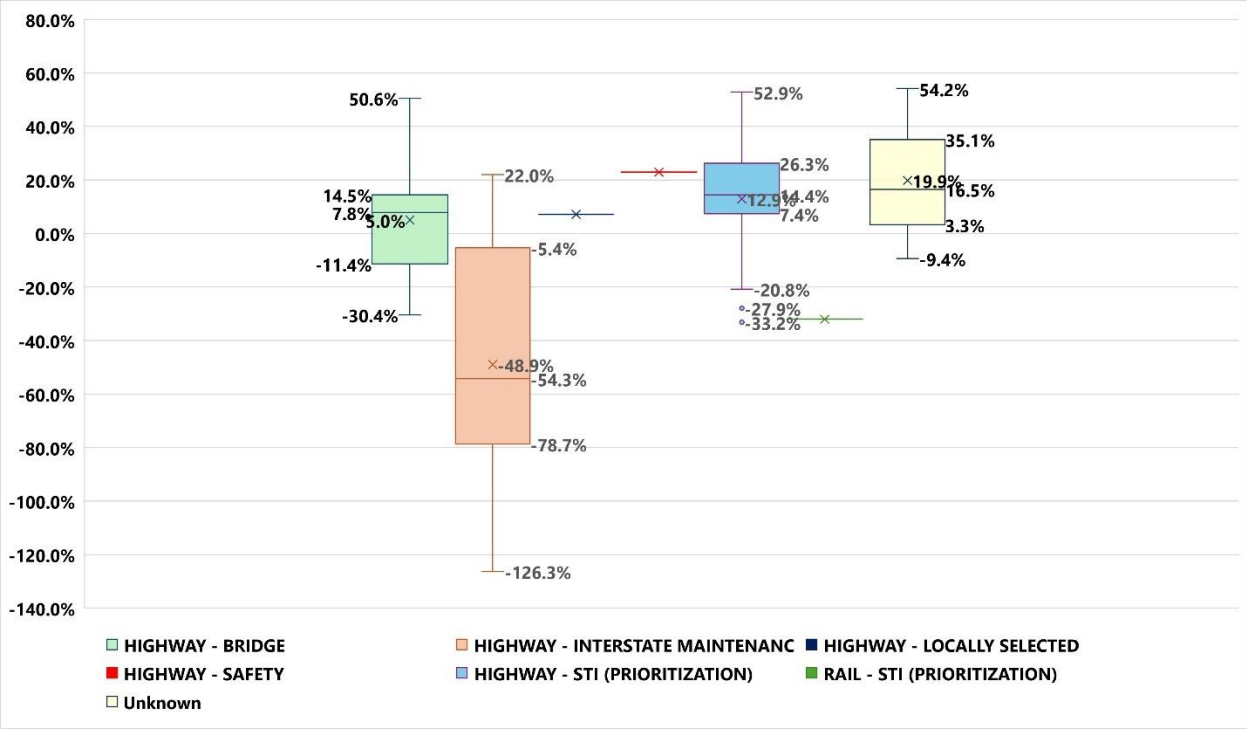

Figure 26. Box Plot of Percentage Error by Funding Programs

CHAPTER 6 RECOMMENDATIONS

Upon the completion of this technical assistance research project, researchers would like to make the following recommendations for future studies:

1. More bridge and roadway project data should be collected for future studies. This study used the data that was collected in the most recent and available year, 2023, in order to avoid negative impacts from unforeseen factors such as "supply chain disruptions and fluctuating oil prices" that occurred in 2021 and 2022. After the data cleansing process was completed, only 48 projects were left and the distribution of these projects of 7 funding programs is quite unbalanced (Figure 27). It was challenging to draw meaningful conclusions from three programs, Safety, Locally Selected, and Rail, due to their very small sample sizes. The largest sample size is 19, which is not sufficient to be used to make unbiased conclusions. For future studies, it is recommended that data from at least 30 projects, meaning data from multiple years, in each funding program should be collected.

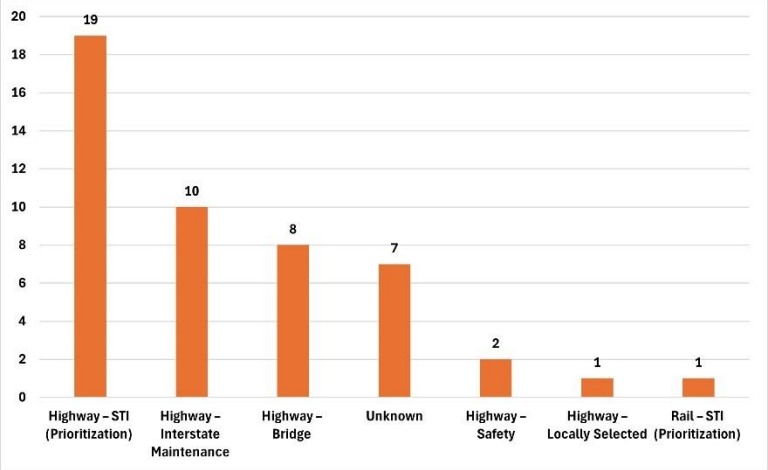

Figure 27. Number of Projects Available for Study by Funding Programs

2. Multiple NHCCI quarterly rates should be used. NCDOT is interested in evaluating construction cost adjustments on projects with estimates 6 months old or more. This means at least two NHCCI quarterly rates can be used for this type of research project. The compound effect of at least two quarterly rates, mostly likely having positive values, can increase the magnitude of the construction cost estimate adjustment factor and improve the

accuracy. NHCCI published only two NHCCI quarterly rates in 2023. One rate was published in September 2023, and the other one in November 2023. Any project that has its CON $ estimate date before June 2023 and its let date after September 2023 can take two NHCCI quarterly rates into consideration. Researchers decided not to proceed because only 12 out of 48 projects meet this requirement. More published NHCCI quarterly rates along with information collected from more projects in 2024, however, can support this method.

3. The construction cost estimate adjustment factor for the Highway – Interstate Maintenance funding program should be further studied due to the factor's poor performance in this study. One possible reason could be its relatively small sample size of 10. High variations of its NHCCI components could be another reason. The implementation of recommendations 1 and 2 can be helpful in finding a solution to improve the accuracy of the factor.
4. Bid tabs in Excel format should be obtained and used for future projects. Bid tabs provide real-world cost distributions that are used to calculate construction cost estimate adjustment factors for each funding program. Therefore, being able to extract information easily from bid tabs is an important condition to develop a cost estimate prototype tool in Excel. Due to security reasons, bid tabs in Excel format are password protected. Researchers had to convert PDF files into Excel for information retrieval. This process was time-consuming and error-prone, mainly because of the inconsistent format of converted Excel files. Custom-built equations that work in one Excel file would fail to run in the next Excel file. It is strongly recommended that NCDOT would grant access to bid tabs for future studies.

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