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Enhanced Accounting for Item Cost Variability in AASHTOWare Project Software

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A Research Report from the National Center for Sustainable Transportation

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16. Abstract This study applies bootstrap analysis to historic transportation project item cost data to develop improved estimates of item cost confidence bounds for use in transportation project cost uncertainty analysis (a component of lifecycle analysis). Bootstrap regression results of confidence bounds will then be integrated into AASHTOWare Project Cost Estimator so that Monte Carlo procedures can estimate project-level confidence intervals for use in lifecycle project cost analysis and transportation capital planning. Data and functions contained within AASHTOWare (a cost estimation software licensed to the Departments of Transportation for over 40 states and the District of Columbia) are employed in the analyses. Coordinating with the Georgia Department of Transportation to obtain a research license for AASHTOWare took longer than expected, resulting in project delays. This report summarizes the work completed to date and describes the remaining steps required to finish the study and for the primary author to publish a final dissertation.		

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Disclaimer

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NCST

Enhanced Accounting for Item Cost Variability in AASHTOWare Project Software

A National Center for Sustainable Transportation Research Report

November 2024

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EXECUTIVE SUMMARY

The purpose of this study is to apply bootstrap analysis to historic transportation project item cost data to develop improved estimates of item cost confidence bounds for use in project cost uncertainty analysis. Bootstrap regression results of confidence bounds will then be integrated into AASHTOWare Project Cost Estimator so that Monte Carlo procedures can estimate project-level confidence intervals for use in lifecycle project cost analysis and transportation capital planning. To accomplish this, it is necessary to utilize data and functions contained within AASHTOWare. AASHTOWare is a cost estimation software licensed to the Departments of Transportation for over 40 states and the District of Columbia. Coordinating with the Georgia Department of Transportation to obtain a research license for AASHTOWare took longer than expected, resulting in project delays. This summary of the completed work states the work that has been done to date, as well as the remaining steps required to finish the study.

To date, the input data preparation process has been nearly completed, and structures have been implemented to facilitate efficient analysis of this data. Due to limitations of the AASHTOWare software, much of the data preparation must be done manually (i.e., without the aid of a computer program to automate most of the labor). As such, input data preparation will be the most time-consuming phase of this project. Subsequent analyses to assess the cost variability of items and projects involve relatively simple calculations that will not contribute greatly to project duration.

0. Project Objectives

This study expands upon previous research (Reichard, et al., 2022) in which the AASHTOWare Project Estimator appears to have employed normal distribution assumptions in establishing item cost confidence bounds that cross the zero intercept (indicating the potential for negative item costs, which is not possible). This project has applied bootstrap methods to underlying cost data to demonstrate the potential for improved estimates of item cost uncertainty within AASHTOWare and has developed Monte Carlo methods to produce mean project cost estimates and confidence bounds around total project cost, based on the variability of underlying item costs. Likewise, this study identifies the items within the Georgia Department of Transportation reference item index that are the greatest contributors to total project uncertainty, as well as assessing the inclusion of sustainable design elements within the GDOT reference item index. The overarching project goal is to support economic sustainability analysis by providing a project cost estimate range, as opposed to single dollar amount estimates, allowing decision makers to more efficiently allocate funding for projects and better understand the financial risks of a project. The objectives of this study are as follows:

1. **Develop Revised Confidence Intervals for Item Unit Costs**. AASHTOWare currently calculates 94.5% confidence intervals for the unit cost of each individual item used in a

transportation project. However, previous research indicates that these confidence intervals employed normal distribution assumptions, resulting in confidence interval bounds that fail to match historic data and/or extend below zero (which would not reflect real world conditions). Bootstrap analysis will be applied to underlying cost data to develop accurate confidence intervals for these items.

2. **Identify Items that Disproportionately Affect Project Uncertainty**. Previous research (Reichard, et al., 2022) demonstrated that a majority of total project cost uncertainty is due to the cost uncertainty of a small subset of high-use items. For example, item cost variability for concrete will have a disproportionate impact on total cost uncertainty for projects that consume a tremendous amount of concrete. Other items used in high quantities and/or have a relatively wide unit cost confidence interval often contribute the most to total project uncertainty. By examining item bid histories within the AASHTOWare database, items have been catalogued based on their potential to contribute to total project cost uncertainty as a function of their unit cost uncertainty and quantity. This will aid in future efforts to understand and reduce the sources of project cost uncertainty.
3. **Use Revised Confidence Intervals to Estimate Cumulative Project Uncertainty**. It is possible to estimate the total cost uncertainty of a transportation project using Monte Carlo simulations to generate a distribution of total project costs. This method requires the integration of accurate confidence intervals for each item cost (developed in Objective 1). The Monte Carlo simulation approach can be incorporated directly into AASHTOWare's cost estimation calculations, such that a confidence interval around the total project costs can be reported along with the median project cost.
4. **Review Database for Inclusion of Sustainable Design Elements**. The current GDOT reference item index has been reviewed to catalogue the current energy efficient items included. Sufficient inclusion of sustainable materials and items would assist decision makers in assessing the tradeoffs of cost, energy, and environmental impact. Additionally, the quality of historic bid data for these items has been compared to the quality of the broader set of reference items.
5. **Explore Applications to Life Cycle Cost Analysis**. Improving the processes used in estimating construction costs for transportation facilities allows planners and policy analysis to make informed project selection decisions and mitigate potential cost overrun risks to cash flow. However, this project also lays the foundation for future work associated with improving life cycle cost analyses. To this end, the team will explore the potential impacts of the project on maintenance and project renewal costs and will propose supplemental research designed to integrate uncertainty assessment into life cycle economic modeling.

0.1 Summary of Work Completed by Chapter

The following section contains a summary of work completed by chapter (not including executive summary, introduction, or conclusions & recommendations), as well as a summary of tasks that remain to be completed.

0.1.1 Chapter 2 – Input Data Preparation

Ultimately, this study requires access to as much historic construction bid data as available. This data is accessed through AASHTOWare, but the steps required to make use of the data are lengthy. First, each of the 4,627 GDOT reference item index pay items must be entered into a cost estimation worksheet within AASHTOWare. The software runs slower as each additional item is added to the cost estimation worksheet. After a few hundred items are added to one worksheet, it may take several minutes to enter each subsequent item. Thus, it is necessary to create multiple separate cost estimation worksheets so that items may be entered in a reasonable amount of time. Altogether, it took approximately 125 hours to enter each item into their respective cost estimation worksheets.

The next step is to have AASHTOWare calculate a bid-based unit price for each of the 4,627 items. When calculating unit prices, AASHTOWare considers a "bid history profile" for the project. The bid history profile defines the conditions for inclusion/exclusion of historic bid data in unit price calculations. Each bid history profile contains 39 parameters that can be adjusted by the user, including improvement type, terrain, and minimum number of observations, for example. Using default bid history profile settings, AASHTOWare is able to successfully calculate bid-based unit prices for 12% of the items in the GDOT reference item index. This indicates that either the AASHTOWare default bid history profile settings are too restrictive to be practical, and/or a large portion of items contained within the GDOT reference item index are rarely/never used in construction bids. Regardless, it was necessary to access more data by tweaking the bid history profile. It takes approximately three hours for AASHTOWare to calculate bid-based unit prices for each item, and every item must be recalculated when the bid history profile is adjusted. After several days of tweaks to the bis history profile, AASHTOWare was able to successfully calculate bid-based unit prices for 31% (approximately 1,300) of GDOT's reference items.

At this stage, approximately 1,300 item unit prices have been calculated for an assumed quantity of one. However, what is actually needed is the relationship between item quantity used and item unit price. For each of these 1,300 items, AASHTOWare generates a price vs. quantity analysis scatterplot containing every recorded construction bid for that item that qualifies under the conditions stipulated by the bid history profile. Typically (but not always), AASHTOWare is able to calculate a regression-based trendline that establishes a relationship between item quantity used and its unit price. AASHTOWare also visually displays 94.5% confidence intervals on each side of the trendline. From these scatterplots, it is necessary to record the number of data points (bids), the median item bid quantity, the item's unit cost at the median quantity, and the values of the upper and lower confidence interval at the median quantity. There is no easy way to determine the median item quantity other than simply counting data points visually. This is simple for items with relatively sparse bid histories, but can quickly become a cumbersome process, especially for items with thousands of historic bids. Additionally, the price vs. quantity analysis scatterplot window automatically scales to include every data point on one screen, which is problematic in the event of clear data entry error data that is several orders of magnitude off from the remainder of the data, thereby making it nearly impossible to assess the good data. There is a zoom tool, but this tool is difficult to use.

Ultimately, it takes approximately 10 minutes to assess each price vs. quantity analysis scatterplot. To date, 269 (20%) of the price vs. quantity analysis scatterplots have been assessed. The remaining 80% of the scatterplots will be assessed over the next several weeks.

To properly implement confidence interval bootstrapping, it would also be necessary to record the quantity and unit price of every historic bid for an item (the X and Y coordinate of each point on the scatterplot). There are approximately 500,000 total historic item bids contained within this dataset. If one data point was transcribed every 10 seconds, it would take approximately 1,400 hours to fully transcribe the data to a usable format. This is clearly impractical. Instead, a subset of items will be chosen for further analysis based on analysis conducted for chapters 4, 5, and 6.

Finally, to help guide analyses performed in later chapters, several item categories will be defined (e.g., asphalt & concrete, drainage, landscaping, etc.). Among other uses, these categories will be useful for gaining a better understanding of if certain types of items are contributing disproportionately to project uncertainty. The 4,627 items within the GDOT reference item index have yet to be sorted into their proper categories. This will likely require multiple days to complete.

The large majority of this chapter has already been drafted, detailing the exact methodology used to work with AASHTOWare, and also contains a more comprehensive overview of the GDOT reference item index.

0.1.2 Chapter 3 – Bootstrap Analysis for Confidence Intervals

It is notable that AASHTOWare's upper and lower 94.5% confidence intervals are always shown as being equidistant from the trendline in price vs. quantity analyses. This implies an assumption that the bid data is distributed normally, which is a dubious assumption. It is possible to derive more accurate confidence intervals through the bootstrap method of standard error. This statistical method allows for the estimation of confidence intervals for non-normally distributed data sets (Efron & Tibshirani 1986).

By far, the lengthiest portion of work required to perform confidence interval bootstrapping is the formatting of historic bid data for items. Once the data is prepared, the actual analysis will be relatively simple to perform, and can be performed entirely within spreadsheet software such as Microsoft Excel. To date, little progress has been made on completing these analyses. As mentioned previously, it is prohibitively impractical to prepare bootstrapping input data for each GDOT reference item, so a subset of items will be identified for bootstrap calculations based on analyses performed in chapters 4, 5, and 6.

0.1.3 Chapter 4 – Identification of Highly Variable Items

To gain an understanding of the underlying causes of transportation construction cost uncertainty, it is useful to analyze how each item contributes to cost uncertainty. Using the data accessed through AASHTOWare, it is possible to perform several analyses that offer insight into the nature of cost uncertainty across each GDOT reference item. These analyses are all based on calculations using an item's median bid quantity, median unit price, and/or median confidence interval values. To date, the required input data have been prepared for 20% of the items with available data. Once the remaining 80% of data is properly prepared, subsequent analyses can be performed within spreadsheet software such as Microsoft Excel. A spreadsheet has already been created that will automatically perform necessary calculations as item data is entered. Likewise, much of this chapter has already been drafted, not including the discussion section of the chapter (which can only be written after data preparation is completed).

Many of the analyses within this chapter involve using the AASHTOWare generated unit price confidence intervals in calculations. Once bootstrapping is completed, these analyses will be replicated using bootstrapped confidence intervals, and results will be compared.

0.1.4 Chapter 5 – Cumulative Cost Uncertainty

Chapter 5 estimates cumulative cost uncertainty as a function of cumulative project bids. Likewise, an estimate of cumulative quantity of items included in bids is included in this chapter. The analyses performed in this chapter rely on the exact same input data as required for chapter 4. Therefore, approximately the same amount of progress has been made. Like chapter 4, the analyses required for this chapter can easily be performed within a spreadsheet, and a Microsoft Excel spreadsheet has already been created to automate calculations as data is entered. Again, much of this chapter has already been drafted, not including the discussion section of the chapter (which can only be written after data preparation is completed).

Many of the analyses within this chapter involve using the AASHTOWare generated unit price confidence intervals in calculations. Once bootstrapping is completed, these analyses will be replicated using bootstrapped confidence intervals, and results will be compared.

0.1.5 Chapter 6 – Inclusion of Sustainable Items in Pay Item Indices

This section will contain analyses focused on sustainable design elements contained within the GDOT reference item index. The first step towards completing this process will be to identify the subset of items that quality as sustainable design elements. This has yet to be completed but will be completed simultaneously with the assignment of reference items to their item group category as described in section 0.1.2. Once the subset of sustainable design elements has been identified, analyses will be performed on the quality of existing bid history data for these items in comparison to the remainder of the reference item index Likewise, the availability of sustainable alternatives to commonly used items will be assessed. Like the chapters before, these analyses will simply require the use of spreadsheet software and will not be particularly time intensive.

0.1.6 Chapter 7 – Applications for Lifecycle Cost Analysis

AASHTOWare's bid-based item unit price estimations only capture the cost of constructing / installing the item in question. However, lifecycle cost analysis is a critical component of cost estimation. Chapter 7 will explore the applicability of this study's findings to lifecycle cost analysis. This chapter will largely rely on the conclusions drawn from the previous chapters. Thus, it has not been possible to begin work on this chapter at this time.

1. Introduction

Project cost estimation is the process of forecasting the total cost of a project. Accurate cost estimation ensures efficient allocation of resources, minimizes project delays, and facilitates effective use of taxpayer money. However, transportation infrastructure projects are notorious for going over budget. Siemiatycki (2009) reviewed existing studies on cost overruns to find that Florida DOT road construction and maintenance projects experienced increases between estimated and actual costs ranging from 8.04% to 9.36%, on average. Similarly, 55% of road construction and maintenance projects in Indiana experienced cost overruns with an average cost increase of 4.5% (Siemiatycki, 2009). In 2015, the FHWA conducted a national survey focused on cost estimation practices and procedures used by State DOTs and identified several concerns. First, 20% of state DOTs did not employ a documented cost estimation process, relying instead on informal processes and individual expertise. The report also raised concerns that state reliance on historical bid-based data might not reflect changing market conditions. For instance, following the recession of 2008, which led to increased competition and lower bids, the bids tended to be 10 to 30 percent below the State's engineer's estimate (EE), indicating that the cost estimation process was not reflective of market conditions because historic data had not caught up to market conditions. Up to 70% of State DOTs did not use a structured risk-based approach and lag in capturing market conditions in high-risk scenarios or complex projects. While 67% of states incorporated market condition adjustments in their estimations, the process of doing so varied from state to state. Only 49% of the state DOTs surveyed documented processes that clearly defined contingency and only 63% incorporated contingency amounts in their estimates. States also tended to use standardized processes for cost estimation without scaling for project type and size. As a solution to these concerns, the FHWA encourages states to use AASHTO'S "Practical Guide to Cost Estimating" as a guide to further developing their cost estimation procedures as well as a solution to the issues that existed within earlier cost estimation approaches (USDOT National Review Program, 2015).

AASHTOWare Project Estimation (AASHTOWare) is a web-based cost estimation software designed to standardize cost estimation procedure for engineering firms (AASHTO, n.d.). AASHTOWare was recently adopted by the Georgia Department of Transportation (GDOT) as an organization standard for in-house teams and consultants to estimate costs for all of their projects. AASHTOWare is also the standard cost estimation software used by other states, including New Jersey, Michigan, Connecticut, and Oregon. The software program allows estimators to input estimated material quantities for specific pay items for a project (e.g., six-inch aggregate base, measured in tons). From these pay items and quantities, AASHTOWare generates a unit cost for each item, based on historical data from bids and final costs of earlier projects within the same state and within a user-specified time frame (default 24 months).

AASHTOWare provides information on bid-history pricing that can be used to perform a rudimentary "what-if" analysis. However, none of the AASHTOWare cost estimation procedures incorporate uncertainty directly into the calculation. This can be problematic, as the distribution of potential outcomes is often more useful than the median expected outcome. An enhanced understanding of the impact of item cost variability on total transportation cost estimates can be developed by incorporating uncertainty analysis into project cost calculations. This project proposes to integrate item cost confidence bounds and employ Monte Carlo analysis to estimate a median project cost that reflects these underlying cost distributions, as well confidence bounds around the total project cost estimate.

2. Input Data Preparation

This study required an extensive review of construction cost data throughout the state of Georgia within the last decade. This section provides background information on data sources, an explanation of the data preparation and QA/QC process, and discussion of the available data.

2.1 Data Source Background Information

The two primary sources of information for this study are the Georgia Department of Transportation (GDOT) Pay Item Index, and AASHTOWare Project Cost Estimation software. Section 2.1 provides background information on these two sources.

2.1.1 Georgia Department of Transportation Reference Item Index

The Georgia Department of Transportation (GDOT) maintains an index of pay items that may be used in transportation construction projects. Each item is associated with a seven- or eight-digit reference code formatted as XXX-XXXX or A-XXX-XXX-XX respectively. Two example pay items are item 502-9000 (Timber Railing) and P-603-501-01 (P-603-5.1 – Bituminous Tack Coat, Per Gallon). The Reference Item Index is updated with the release of each new GDOT book of specifications (spec book). The most recent GDOT spec book was released in 2021. Previous spec books have been published in 2013, 2002, 2001, 1995, and 1993. The 2013 Spec Book contains 4,651 unique pay items (Georgia DOT 2013).

These 4,651 items have been broken down into numerous categories within the GDOT spec book. It will be helpful to use these categories during data analysis for broad comparison between similar items. Table 1 lists these categories.

Table 1. GDOT Spec Book 13 Item Categories

Category	Item Codes
General Provisions	001-XXXX to 150-XXXX
Auxiliary Items	151-XXXX to 158-XXXX
Construction Erosion Control	160-XXXX to 171-XXXX
Earthwork	172-XXXX to 221-XXXX
Bases And Subbases	222-XXXX to 329-XXXX
Pavements	400-XXXX to 461-XXXX
Bridges	500-XXXX to 543-XXXX
Minor Drainage Structures	544-XXXX to 577-XXXX
Incidental Items	581-XXXX to 725-XXXX
Building Installations	750-XXXX to 798-XXXX
Materials	800-XXXX to 999-XXXX

2.1.2 AASHTOWare Project Estimation

AASHTOWare Project Estimation (AASHTOWare) is a web-based cradle-to-grave estimation application designed to deliver accurate and reliable transportation construction cost estimates (AASHTO B n.d.). AASHTOWare is currently used by entities in 40 states and the District of Columbia (AASHTO, 2022). There is a specially tailored version of AASHTOWare for each state, allowing integration with state DOT reference item indices. For example, AASHTOWare licenses within the state of Georgia can interface with the GDOT Reference Item Index, and data associated with those items. Conversely, differences between state pay item indices render data from other states useless.

AASHTOWare is primarily used for bid-based cost estimation. To estimate the unit price of a particular pay item, AASHTOWare considers the bid-cost of that item in previous projects within the state. Users have the option to refine this calculation further with the inclusion of any number of optional parameters (e.g., only considering projects in rural settings, on mountainous terrain, constructed during the winter, etc.). Users also have the option to define the temporal range of data. The unit costs of pay items naturally evolve over time as markets shift and inflation occurs. A large time range leaves users vulnerable to the inclusion of data that poorly reflects current market conditions, while too small of a time range may result in inadequate sample sizes. By default, AASHTOWare considers data from the previous 24 months. From this data, AASHTOWare can predict the cost of a project based on the quantity of materials used in the project.

2.2 Preparation of Data

To analyze each item within the GDOT Reference Item Index, it was necessary to create a test AASHTOWare project containing all 4,651 reference items. The following sections detail the process of creating a project within AASHTOWare and describe the specific input parameters used in this study.

2.2.1 Preparation of Project Concept

To perform cost estimation in AASHTOWare, users must first create a “concept” to house cost estimates. Multiple cost estimates may be contained within a concept. Users are required to define certain project attributes at the concept level, which may impact cost estimate calculations. These attributes are explained below:

Spec Book (Required) – A unique identifier for a defined set of reference items associated with a given specification book (AASHTO n.d.). Users may choose to use spec books from 1993, 1995, 2001, 2002, 2013, or 2021. This project used Spec Book 13.

Unit System (Required) – The system of measurement used for item quantities, either English or Metric. Items with a Neutral unit system can be used in projects with either Metric or English unit systems (AASHTO n.d.). This project used English units.

Scope Definition (Optional) – Brief text describing the envisioned scope of the concept or project (AASHTO n.d.). This project did not include a scope definition.

Budget Class (Optional) – A classification denoting a high-level budget group to which the item belongs (AASHTO n.d.). This project did not include a budget class.

Grouping Code (Optional) – A mechanism for designing a common grouping code for entities of various types (AASHTO n.d.). This project did not use a grouping code.

Primary County ID (Required) – The reference county ID of the primary county for the concept, project, proposal, cost estimate, or contract (AASHTO n.d.). This project used Fulton County, Georgia (ID 121) as the hypothetical primary county.

Primary District ID (Required) – The reference district ID of the primary district for the concept, project, proposal, cost estimate, or contract (AASHTO n.d.). This project used TIA-3, Atlanta (ID 80003) as the hypothetical primary county.

Status Indicator (Optional) – A value depicting the relative phase of the concept (AASHTO n.d.). Users may choose either “Conceptual” or “Programed”. This project used Conceptual as its status indicator.

Construction Year (Optional) – The anticipated year of construction for a project (AASHTO n.d.). This project used 2023 as its construction year.

Letting Date (Optional) – The anticipated letting date for the concept (AASHTO n.d.). This project used April 5th, 2023, as the letting date.

Highway Type (Required) – The type of highway for the concept, project, or proposal (AASHTO n.d.). Users may choose “ASPH - Asphalt”, “COMB - Combination Asphalt & Concrete”, “CONC – Concrete”, “GRVL - Gravel”, “INTE - Interstate”, “OFF- Off System”, ”ON - On System”, or “UNDF - Undefined”. This project was listed as an Asphalt highway.

Improvement Type (Required) – A classification for the type of improvement represented by a concept, project, or proposal (AASHTO n.d.). Users may choose “AGSF- Aggregate Surface Course”, “APRT - Airport”, “BIKE - Bike Paths”, “BLDG - Building”, “BRCN - Bridge Constr”, “BRPS - Bridge Preservation”, “BRRH – Bridge Rehabilitation”, “BRRM – Bridge Removal”, “BRWD – Bridge Widening”, “BSPV – Base & Paving”, “CBGT – Curb & Gutter”, “CENG – Construction Engineering”, “CLVT – Culvert Construction”, “CMAQ – Congestion Mitigation Agreements”, “CNST – Construction”, “COE – Consultant Engineering”, “CONC – Primarily Portland Cement Concrete Work”, “DRIM – Drainage Improvements”, “ENHN – Enhancement”, “ENVR – Environmental-Misc”, “FED – Federal Project”, “GCCR – Grading And Concrete Rehab”, “GDBP – Grade/Drain/Base/Pave”, “GDDR – Guardrail”, “HOV – HOV Lanes”, “INTC – Interchange”, “INTR – Intersection Improvements”, “JTSL – Joint Sealing”, “LAND – Landscaping”, “LGHT – Highway Lighting”, “LGPA – Local Government Proj Agrmt”, “MCSF – Micro Surfacing”, “MNWD – Minor Widening”, “NON – Non-Federal Project”, “PA – Public Awareness Campaign”, “PDBR –

Pedestrian Bridge", "PENG – Preliminary Engineering", "PKRD – Park And Ride Lot Cnst", "PLMX – Plant Mix Resurfacing", "RCON – Rdwy Reconstruction", "REAL – Realignment", "RLRD – Railroad", "ROWA – Right-Of-Way", "RSTA – Rest Area", "SDWK – Sidewalk Constr", "SIGN – Signs", "SIST – Signs And Striping", "STRS – Surface Treatment", "SURV – Hwy Surveillance", "SWAL – Sound Barriers", "TCSP – Trans Community System Preservation", "TRAF – Traffic Signals, "TWSC – Truck Weigh Scales", "UTIL – Utility", "WALS – Various Walls", "WDAL – Widening Addl Lanes" – "WDN – Minor Widening", "WDRC – Widening And Reconstruction", "WDRS – Widening & Resurfacing", or "WDRV – RR Warning Devices". This project was listed as a Construction improvement type.

Season (Optional) – The name used to identify the season (AASHTO n.d.). Users may choose either "FALL – Autumn", "SPRI – Spring", "SUMM – Summer", or "WINT – Winter". This project was listed as a Spring project.

Terrain (Required) – The type of terrain or natural land features for the concept, project, or proposal (AASHTO n.d.). Users may choose either level, mountainous, or rolling. This project was listed as level terrain.

Urban/Rural (Required) – Indicates the population density in the area where work is to be performed for a concept, project, or proposal (AASHTO n.d.). Users may choose either "RURL – Rural", "S – Suburban", or "URBN – Urban". This project was listed as an Urban project.

Work Type (Required) – A work type classification used to calculate bid-based prices (AASHTO n.d.). Users may choose either "ASGF – Aggregate Surface Course", "ASEW – Asphalt and Earthwork", "ASPH – Asphalt", "BGPT – Building Painting", "BRHB – Bridge Rehabilitation", "BRPS – Bridge Preservation", "CONC – Concrete", "CRIB – Crib", "CURB – Curb And Gutter", "DBLD – Design/Build", "DRNG – Drainage", "ENHN – Enhancement", "EROC – Erosion Controls", "ERTH – Earthwork", "GDBP – Grading, Drainage, Base Pavement", "GDRL – Guardrail", "GENC – General Construction", "INTC – Inter Connect Cable", "INTR – Intersection", "ITS – ITS***", "JNTS – Joints Bridge Seals", "LSCP – Landscaping", "LTNG – Lighting", "MISC – Miscellaneous Construction", "PENG – Preliminary Engineering", "PMIX – Plant Mix", "PVMK – Pavement Markings", "RCON – Reconstruction", "ROWA – Right Of Way", "SGNL – Signals", "SIGN – Signing", "SRFP – Surface Preparation", "SRFT – SRFT", "STRL – Structures – Bridges", "STRS – Structures", "UTIL – Utilities", or "WDRC – Widening Drainage Reconstruction". This project work type was listed as General Construction.

Locations (Optional) – The location of the project. Uses may include the latitude and longitude of the project. No location was included in this project.

The AASHTOWare software runs progressively slower as more items are added to a concept or cost estimate. To allow for efficient analysis of data, the project was split into three separate concepts. Each concept used identical input parameters. Concept 1 contained pay item index items with item codes between 000-0000 and 500-9999, as well as items A-000-000-00 to T-999-999-99. Concept 2 contained pay item index items with item codes between 501-0000 and 656-9999. Concept 3 contained pay item index items with item codes between 657-0000 and

999-9999. Table 2 contains a summary of input parameters used to create each project concept.

Table 2. Project Concept Input Parameters

Spec Book	**13 – 2013 SPEC YEAR**
Unit System	English
Scope Definition	<blank>
Budget Class	<blank>
Grouping Code	<blank>
Primary County ID	121 – Fulton
Primary District ID	80003 – TIA-3, Atlanta
Status Indicator	Conceptual- Conceptual
Construction Year	2023
Letting Date	04/05/2023
Highway Type	ASPH - ASPHALT
Improvement Type	CNST - CONSTRUCTION
Season	SPRI – Spring
Terrain	Level – Level
Urban/Rural	URBN- URBAN
Work Type	GENC- General Construction
Locations	<blank>

2.2.2 Preparation of Cost Estimates

Within a concept, users may create one or more cost estimates. These cost estimates allow users to estimate the costs of pay items. Users are required to define certain project attributes at the cost estimation level, which may impact cost estimate calculations. These attributes are explained below:

Estimate Phase (Required) – The phase of the estimate (AASHTO n.d.). Users may choose "1-PE - Planners Estimate", "2-DE - Designers Estimate", "3-EE - Engineers Estimate", or "4-CBA - CBA Estimate". This project was listed as being in phase 2, Designers Estimate.

Estimated By (Optional) – An identifier for the person performing the cost estimate (AASHTO n.d.). This was left blank for this project.

Design Build (Optional) – Indicates whether the cost estimate is for a design build improvement (AASHTO n.d.). This checkbox was left unchecked in this project.

Budget Class (Optional) – A classification denoting a high-level budget group to which the item belongs (AASHTO n.d.). No budget class was identified for this project.

Lanemiles (Optional) – The number of lanemiles/kilometers in the cost estimate (AASHTO n.d.). This was left blank for this project.

Estimate Type (Optional) – A classification that describes the type of cost estimate (AASHTO n.d.). Users may choose either “BRDG – Bridge”, “RDWY – Roadway”, or “UTIl – Utilities”. This project was listed as a Roadway estimate type.

The AASHTOWare software runs progressively slower as more items are added to a concept or cost estimate. To allow for efficient analysis of data, the project was split into fifteen separate cost estimates. Each cost estimate used identical input parameters. Table 3 contains a summary of input parameters used to create each project cost estimate. Table 4 contains a list of the item codes contained within each project cost estimate.

Table 3. Project Cost Estimate Input Parameters

Estimate Phase	**2-DE – Designers Estimate**
Estimated By	<blank>
Design Build	No
Budget Class	<blank>
Lanemiles	<blank>
Estimate Type	RDWY - Roadway

Table 4. Project Cost Estimates by Associated Item Codes

Concept	**Cost Estimate**	**Item Codes**	**Number of Items**
1	1	000-0000 to 500-9999, A-000-000-00 to T-999-999-99	925
2	2	501-0000 to 549-9999	313
2	3	550-0000 to 599-9999	266
2	4	600-0000 to 643-9999	613
2	5	644-0000 to 652-9999	252
2	6	653-0000 to 656-9999	231
3	7	657-0000 to 659-9999	210
3	8	660-0000 to 669-9999	278
3	9	670-0000 to 679-9999	210
3	10	680-0000 to 682-9999	301
3	11	683-0000 to 702-1999	150
3	12	702-2000 to 702-9999	342
3	13	703-0000 to 936-9999	247
3	14	937-0000 to 950-9999	174
3	15	951-0000 to 999-9999	195

2.2.3 Entering of Pay Items

The final required step before entering items is to define one or more item categories within the cost estimate. Users must choose one of 78 pre-defined category types and must include a text description of the category. This project used category 0100 – Roadway for every pay item. A full list of cost estimate item categories is contained in Table 5.

Table 5. Cost Estimate Item Categories

Category Code	Category Title
0100	Roadway
0110	Pavement
0200	Drainage
0210	Temporary Drainage
0300	Temporary Erosion Control
0400	Permanent Erosion Control
0500	MS4
0600	Signing
0610	Pavement Marking
0700	Signals
0801 - 0820	Bridge 1 - 20
0901 - 0936	Wall 1 - 36
1000	Lighting
1100	Utilities
1200	ITS
1300	Landscaping
2000 - 2003	Bid Alternate 1A – 1D
2010 - 2013	Bid Alternate 2A – 2D

Each of the 4,651 items were entered using the Item Pricing Worksheet page contained within the cost estimate. Users are required to input a pay item code, as well as the category ID and quantity of the item. Each item was given a placeholder quantity of 1.000 units. In some cases, items also required the entering of a supplemental description. These items were given a supplemental description of “test”. Upon entering these fields, AASHTOWare automatically fills in the item pricing worksheet with a line index, item description, and unit. A sample row of the item pricing worksheet is shown in Table 6.

Table 6. Item Pricing Worksheet Sample Row

Cat ID	Line	Item	Descr	Unit	Quantity	Unit Price	Ext Amt	Supp Descr	Supp Descr Req
0100-Roadway	0230	507-0010	PSC CAPS	EA	1.000	42,625.26692	42,625.27		No

Items were entered into each item pricing worksheet sequentially by item code until the AASHTOWare software became too slow to facilitate efficient data entry (after approximately 250 entries, it can take over 45 seconds for AASHTOWare to process each new item entry, leading to extreme inefficiency). Once this point was reached, a new cost estimate with identical input parameters was created, and the next items in the sequence were added to the item pricing worksheet associated with the new cost estimate. Once each item pricing worksheet was sufficiently populated with items, unit prices were calculated using the "Calculate Bid Based Prices" function contained within the cost estimate Tasks menu. On average, the calculation of bid-based prices took between 10–120 minutes to complete per cost estimate, depending on the number of items contained within the cost estimate, as well as the scope of data contained within the bid history profile (see Section 2.2.4 for information on the preparation of a Bid History Profile).

After the calculation of bid-based prices was completed for all 15 cost estimates, each estimate was exported to an .xml file using the "Export Concept Cost Estimates" function contained within the concept Tasks menu. This allowed the separate cost estimates to be combined into one Microsoft Excel spreadsheet and facilitated additional data analysis. At this stage, QA/QC was performed on the data to remove any inadvertent double entries, as well as to check for any items that were inadvertently omitted. The exporting of concept cost estimates took approximately 30-60 seconds per concept.

2.2.4 Bid History Profile

To calculate bid based prices for items, users must associate a bid history profile with each cost estimate. A bid history profile is a collection of settings used to gather historical bid data for cost estimation purposes. When a bid history profile is selected during cost estimation, this collection of settings determines which historical bid data is included (AASHTO n.d.).

By default, users can choose one of three bid history profiles contained within AASHTOWare: BHP-ALL (Statewide – 24 months), BHP-Asphalt (BHP with Asphalt Market Area), or BHP District (BHP profile with District Market area). This study will focus on BHP ALL (which will be referred to as the default bid history profile), as it is the most comprehensive bid history profile. Each bid history profile contains several input parameters that can be adjusted within a cost estimate. Each input parameter is explained below:

Start Letting Date – A data selection attribute to designate the starting point in time over which the bid history profile will collect data to be used in bid-based price calculations (AASHTO n.d.). This is left blank by default.

End Letting Date – A data selection attribute to designate the ending point in time over which the bid history profile will collect data to be used in bid-based price calculations (AASHTO n.d.). This is left blank by default.

Number of Months – The number of months to include in a bid history profile that uses rolling dates (AASHTO n.d.). By default, AASHTOWare considers data within the previous 24 months.

Use Only – A data selection attribute for the status of proposals that will be used in bid-based price calculations (AASHTO n.d.). Users may choose either “Awarded and Rejected Proposals” or “Awarded Proposals Only”. By default, AASHTOWare considers Awarded Proposals Only.

Improvement Type – A classification for the type of improvement represented by a concept, project, or proposal (AASHTO n.d.). Users may choose one or more of the following: “AGSF- Aggregate Surface Course”, “APRT - Airport”, “BIKE - Bike Paths”, “BLDG - Building”, “BRCN - Bridge Constr”, “BRPS - Bridge Preservation”, “BRRH – Bridge Rehabilitation”, “BRRM – Bridge Removal”, “BRWD – Bridge Widening”, “BSPV – Base & Paving”, “CBGT – Curb & Gutter”, “CENG – Construction Engineering”, “CLVT – Culvert Construction”, “CMAQ – Congestion Mitigation Agreements”, “CNST – Construction”, “COE – Consultant Engineering”, “CONC – Primarily Portland Cement Concrete Work”, “DRIM – Drainage Improvements”, “ENHN – Enhancement”, “ENVR – Environmental-Misc”, “FED – Federal Project”, “GCCR – Grading And Concrete Rehab”, “GDBP – Grade/Drain/Base/Pave”, “GDDR – Guardrail”, “HOV – HOV Lanes”, “INTC – Interchange”, “INTR – Intersection Improvements”, “JTSL – Joint Sealing”, “LAND – Landscaping”, “LGHT – Highway Lighting”, “LGPA – Local Government Proj Agrmt”, “MCSF – Micro Surfacing”, “MNWD – Minor Widening”, “NON – Non-Federal Project”, “PA – Public Awareness Campaign”, “PDBR – Pedestrian Bridge”, “PENG – Preliminary Engineering”, “PKRD – Park And Ride Lot Cnst”, “PLMX – Plant Mix Resurfacing”, “RCON – Rdwy Reconstruction”, “REAL – Realignment”, “RLRD – Railroad”, “ROWA – Right-Of-Way”, “RSTA – Rest Area”, “SDWK – Sidewalk Constr”, “SIGN – Signs”, “SIST – Signs And Striping”, “STRS – Surface Treatment”, “SURV – Hwy Surveillance”, “SWAL – Sound Barriers”, “TCSP – Trans Community System Preservation”, “TRAF – Traffic Signals, “TWSC – Truck Weigh Scales”, “UTIL – Utility”, “WALS – Various Walls”, “WDAL – Widening Addl Lanes” – “WDN – Minor Widening”, “WDRC – Widening And Reconstruction”, “WDRS – Widening & Resurfacing”, and/or “WDRV – RR Warning Devices”. This is left blank by default.

Work Type – A work type classification used to calculate bid-based prices (AASHTO n.d.). Users may choose one or more of the following: “ASGF – Aggregate Surface Course”, “ASEW – Asphalt and Earthwork”, “ASPH – Asphalt”, “BGPT – Building Painting”, “BRHB – Bridge Rehabilitation”, “BRPS – Bridge Preservation”, “CONC – Concrete”, “CRIB – Crib”, “CURB – Curb And Gutter”, “DBLD – Design/Build”, “DRNG – Drainage”, “ENHN – Enhancement”, “EROC – Erosion Controls”, “ERTH – Earthwork”, “GDBP – Grading, Drainage, Base Pavement”, “GDRL – Guardrail”, “GENC – General Construction”, “INTC – Inter Connect Cable”, “INTR – Intersection”, “ITS – ITS***”, “JNTS – Joints Bridge Seals”, “LSCP – Landscaping”, “LTNG – Lighting”, “MISC – Miscellaneous Construction”, “PENG – Preliminary Engineering”, “PMIX – Plant Mix”, “PVMK – Pavement Markings”, “RCON – Reconstruction”, “ROWA – Right Of Way”, “SGNL – Signals”, “SIGN – Signing”, “SRFP – Surface Preparation”, “SRFT – SRFT”, “STRL – Structures – Bridges”, “STRS – Structures”, “UTIL – Utilities”, or “WDRC – Widening Drainage Reconstruction”. This is left blank by default.

Spec Book – A unique identifier for a defined set of reference items associated with a given specification book (AASHTO n.d.). Users may choose to use spec books from 1993, 1995, 2001, 2002, 2013, and/or 2021. This is left blank by default.

Source of Item Prices – A basic parameter that indicates the source of the bids to be included in estimation calculations (AASHTO n.d.). Users may choose either “Estimate”, “Exclude High/Low Bids”, “Low Bids”, “Select Bidder”, or “Winning Bids”. AASHTOWare uses Low Bids as the default source of item prices.

Number of Low Bidders Per Proposal – A basic parameter that indicates the number of low bids (based on bid rank) per proposal to include in the calculations. This parameter is required if the Source of Item Prices field is set to Low Bids (AASHTO n.d.). By default, AASHTOWare includes three low bidders per proposal.

Market Area – A basic parameter that indicates the geographical definition for areas that will be used in the analysis for cost estimation (AASHTO n.d.). Users may choose either “Asphalt Market Area” or “District Market Area”. This is left blank by default.

Date to Use for Item Prices – A basic parameter that indicates the type of date to use for item prices (AASHTO n.d.). Users may choose either “Awarded Date”, “Letting Date”, “Letting Date + Adjustment”, “Notice to Proceed Date”, “Proposal Status Date”, or “Work Began Date”. By default, AASHTOWare uses the Letting Date for item prices.

Letting Date Adjustment – The adjustment to be applied to the letting date, in days (AASHTO n.d.). By default, AASHTOWare uses a 60-day letting date adjustment.

Minimum Number of Bids Before Excluding – A basic parameter that indicates the minimum number of bids received on a proposal before excluding the high/low bidders. This parameter is required if the Source of Item Prices field is set to Exclude High/Low Bids (AASHTO n.d.). By default, AASHTOWare requires at least 5 bids before excluding low/high bids.

Vendor Number – A basic parameter to indicate which vendor bids will be included in the bid history calculations. This parameter is required if the Source of Item Prices field is set to Selected Bidder (AASHTO n.d.). This is left blank by default.

Item Group Set – A profile containing groups of items that are analyzed collectively for bid-based pricing (AASHTO n.d.). This is left blank by default.

Convert Opposite Units – A basic parameter that indicates whether to convert bid data that uses a different unit system (English or Metric) than the unit system indicated by the cost estimate being priced (AASHTO n.d.). AASHTOWare excludes data with the opposite unit system by default.

Date Rule when date is not available – A basic parameter that indicates which date to apply when the selected Date to use for item prices is not available (AASHTO n.d.). Users may choose either “Exclude Proposal Item” or “Use Letting Date + Adjustment”. By default, AASHTOWare uses the Letting Date + Adjustment.

Highway Type – An advanced parameter that indicates whether Highway Type is included as a variable in the calculation of regressions and averages (AASHTO n.d.). By default, AASHTOWare does not consider Highway Type in these calculations.

Improvement Type – An advanced parameter that indicates whether Improvement Type is included as a variable in the calculation of regressions and averages (AASHTO n.d.). By default, AASHTOWare does not consider Improvement Type in these calculations.

Market Area – An advanced parameter that indicates whether Market Area is included as a variable in the calculation of regressions and averages (AASHTO n.d.). By default, AASHTOWare does not consider Market Area in these calculations.

Season – An advanced parameter that indicates whether Season is included as a variable in the calculation of regressions and averages (AASHTO n.d.). By default, AASHTOWare does not consider Season in these calculations.

Terrain – An advanced parameter that indicates whether Terrain is included as a variable in the calculation of regressions and averages (AASHTO n.d.). By default, AASHTOWare does not consider Terrain in these calculations.

Urban/Rural – An advanced parameter that indicates whether the Urban/Rural attribute is included as a variable in the calculation of regressions and averages (AASHTO n.d.). By default, AASHTOWare does not consider the Urban/Rural attribute in these calculations.

Work Type – An advanced parameter that indicates whether Work Type is included as a variable in the calculation of regressions and averages (AASHTO n.d.). By default, AASHTOWare does not consider Work Type in these calculations.

Generate Averages – An advanced parameter that indicates whether average bid prices will be calculated (AASHTO n.d.). AASHTOWare generates averages by default.

Minimum Number of Observations – An advanced parameter that indicates the number of observations needed to calculate an average bid price. This parameter is required when the Generate Averages check box is selected (AASHTO n.d.). By default, AASHTOWare requires at least 10 observations for the calculation of averages.

Percent of Date Range to select – An advanced parameter to indicate what percentage of the total selected date range will be used in the calculation of average bid prices. This allows the date range for averages to be shorter than the date range for regressions (AASHTO n.d.). By default, AASHTOWare considers 100% of the date range for the calculation of averages.

Percent of Quantity Outliers to exclude – An advanced parameter to indicate the percentage of quantity outliers to exclude when generating average bid prices (AASHTO n.d.). By default, AASHTOWare excludes 10% of quantity outliers when generating averages.

Percent of Price Outliers to exclude – An advanced parameter to indicate the percentage of price outliers to exclude when generating average bid prices (AASHTO n.d.). By default, AASHTOWare excludes 10% of price outliers when generating averages.

Generate Regressions – An advanced parameter that indicates whether regression bid prices will be calculated (AASHTO n.d.). AASHTOWare calculates regression bid prices by default.

Minimum Number of Observations – An advanced parameter that indicates the number of observations needed to calculate a regression bid price. This parameter is required when the Generate Regressions check box is selected (AASHTO n.d.). By default, AASHTOWare requires at least 20 observations for the calculation of regressions.

Exclude Models that are out of range compared to the average – An advanced parameter that indicates whether the regression calculation should exclude models that are out of range when compared to the average price (AASHTO n.d.). This option is turned on by default.

Include date variable in analysis – An advanced parameter that indicates whether estimation calculations will consider the date parameters when generating the regression. Selection of this parameter causes the system to include a calculation of how the prices change over time based on the selected data (AASHTO n.d.). This option is turned on by default.

Percent of regression model outliers to exclude – An advanced parameter to indicate the percentage of model outliers to exclude when generating regression bid prices (AASHTO n.d.). By default, AASHTOWare excludes 10% of model outliers when generating regression bid prices.

Level of improvement to add – An advanced parameter setting that indicates the level of improvement required to add a regression parameter to the model (AASHTO n.d.). This field is set to 0.20 by default.

Exclude regressions with positive quantity coefficients – An advanced parameter to indicate the exclusion of regression models with positive quantity coefficients (inverse relationship between quantity and price) (AASHTO n.d.). This option is turned on by default.

Minimum month range of history needed – An advanced parameter to indicate the minimum range of months of historical data needed to consider the date variable in the regression price calculation. This parameter is required if the Date Variable in Analysis check box is selected (AASHTO n.d.). By default, AASHTOWare requires at least 16 months of bid history to include the date variable in regression price calculation.

Minimum number of Observations – The minimum number of observations required to utilize the date parameters in the regression calculations (AASHTO n.d.). By default, AASHTOWare requires at least 20 observations to utilize the date parameters in regression calculations.

Maximum inflation/deflation rate allowed – An advanced parameter to allow exclusion of the date as a parameter in the regression analysis based upon the inflation/deflation rate. A value of 10 includes the date in the regression if the annual inflation/deflation rate is between plus or minus 10 percent (AASHTO n.d.). This value is set to 10 by default.

Using the default (BHP ALL) bid history profile with the concept and cost estimate input parameters described in Section 2.2.1 and Section 2.2.2 respectively, AASHTOWare was able to calculate cost estimates for a mere 12.2% of items (567 of 4651). One potential contributing factor to this low success rate is the supply chain disruptions associated with the Covid-19 global pandemic, resulting in project delays within the previous 24 months. To increase the calculation success rate, several tweaks were made to the default bid history profile. These adjustments are summarized in Table 7.

Table 7. Adjusted Bid History Profile Parameters*

Bid History Profile Parameter	Default Bid History Profile	Adjusted Bid History Profile
Number of Months	24	36, 48, 60, 72, 84, 96, & 108
Minimum Number of Observations (averages)	10	2
Minimum Number of Observations (regressions)	20	6
Minimum month range of history needed (date parameters)	16	2
Minimum number of observations (date parameters)	20	6

*Default settings were used for all unlisted bid history profile parameters

Figure 1 depicts the rate of successful calculations by bid history profile, by number of months. After relaxing the minimum number of required observations and including data from rejected proposals, the calculation success rate can be increased by roughly 3% per every additional 12 months of included data. This trend continues until approximately 96 months, at which point the success rate begins to plateau. With the concept parameters outlined in Section 2.2.1, cost estimate parameters outlined in Section 2.2.2, and bid history profile adjustments outlined in Table 7, the highest achievable item cost calculation success rate within AASHTOWare is 31%.

To maximize the amount of data available for analysis, the 108-Month Adjusted Bid History Profile will be used for the remainder of this study.

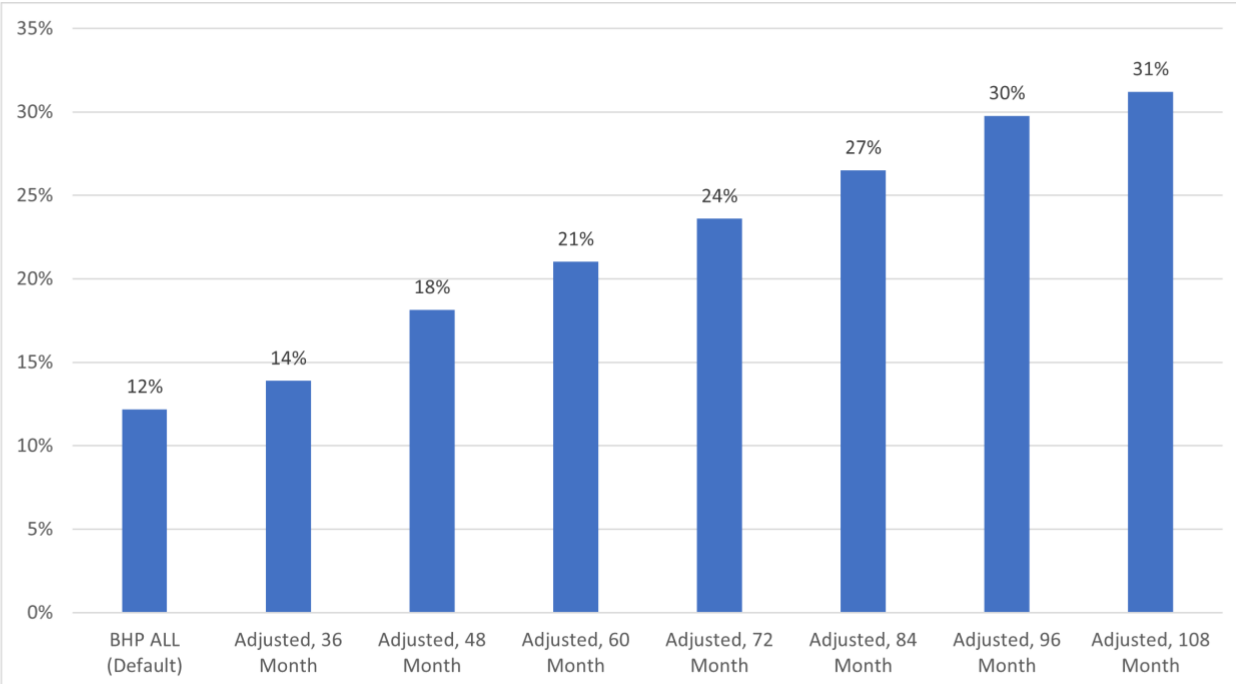

Figure 1. Successful Calculations by Bid History Profile

2.2.4 Regression-Based Trendlines

For each successfully calculated pay item, AASHTOWare attempts to calculate a regression-based cost estimate based on previous bid data. In theory, as the quantity of an item used in a project increases, the cost per unit should be expected to decrease due to bulk discounts, economies of scale, and/or diminished influence of fixed costs that are baked into the item cost (such as the cost of operating equipment associated with an item). In addition to a regression-based trendline, AASHTOWare also calculates a 94.5% confidence interval. An example of an AASHTOWare generated price vs quantity analysis is shown in Figure 2.

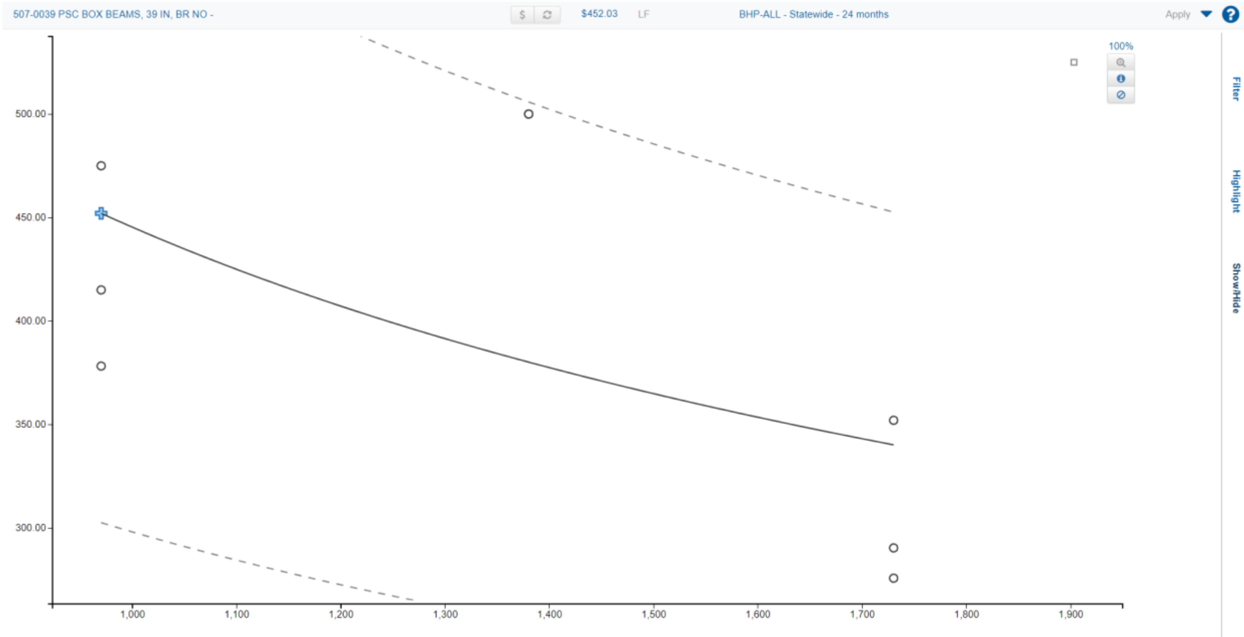

Figure 2. Price vs. Quantity Analysis - Item 507-0039: PSC BOX BEAMS, 39 IN, BR NO-

In Figure 2, the quantity of item used is displayed on the X-axis, and the unit price of the item is displayed on the Y-axis. The regression-based trendline is shown in black, and the 94.5% confidence intervals are shown as dashed lines. Each historic data point is shown as a hollow circle. In this case, the user requested a cost estimate for a quantity of 1, as denoted by the blue plus symbol. AASHTOWare reports an estimated unit cost of $452.03.

AASHTOWare can fail to generate a regression-based trendline under four conditions. Most commonly, the sample size is too small to generate a regression-based trendline. By default, AASHTOWare requires 20 observations before calculating a regression-based trendline, but that threshold has been reduced to six for this study. In these cases, AASHTOWare simply calculates the average item price from historic data without attempting to derive a price vs. quantity relationship. An example of this is shown in Figure 3.

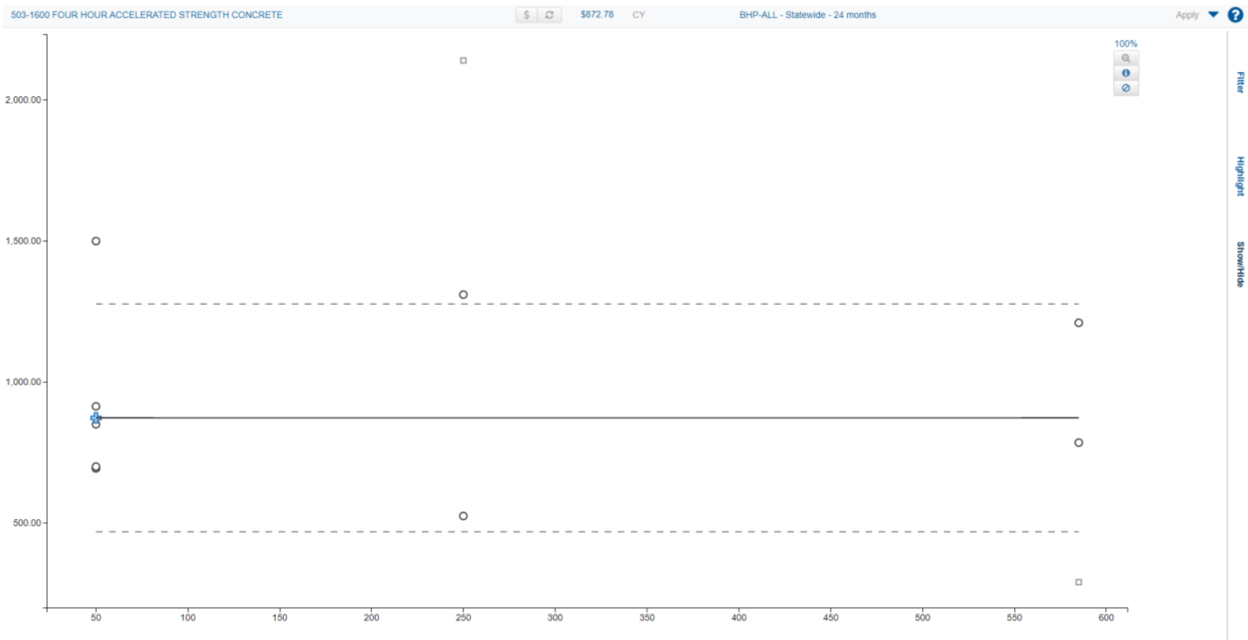

Figure 3. Price vs. Quantity Analysis - Item 503-1600: FOUR HOUR ACCELERATED STRENGTH CONCRETE

Likewise, there are several instances in which AASHTOWare is unable to generate a trendline of any kind due to the same quantity being recorded across all observations, as shown in Figure 4. In this example, there have been 75 recorded bids to construct exactly one type 3 field engineers office, with no bids to construct any other quantity of type 3 field engineer offices in a project. Thus, it is impossible to derive a relationship between price and quantity. Unfortunately, when AASHTOWare is unable to report a price vs quantity trendline, there is also no way to access the 94.5% confidence intervals for that item. Thus, there currently is no way to measure uncertainty associated with items that have not been used in at least two separate quantities across different projects.

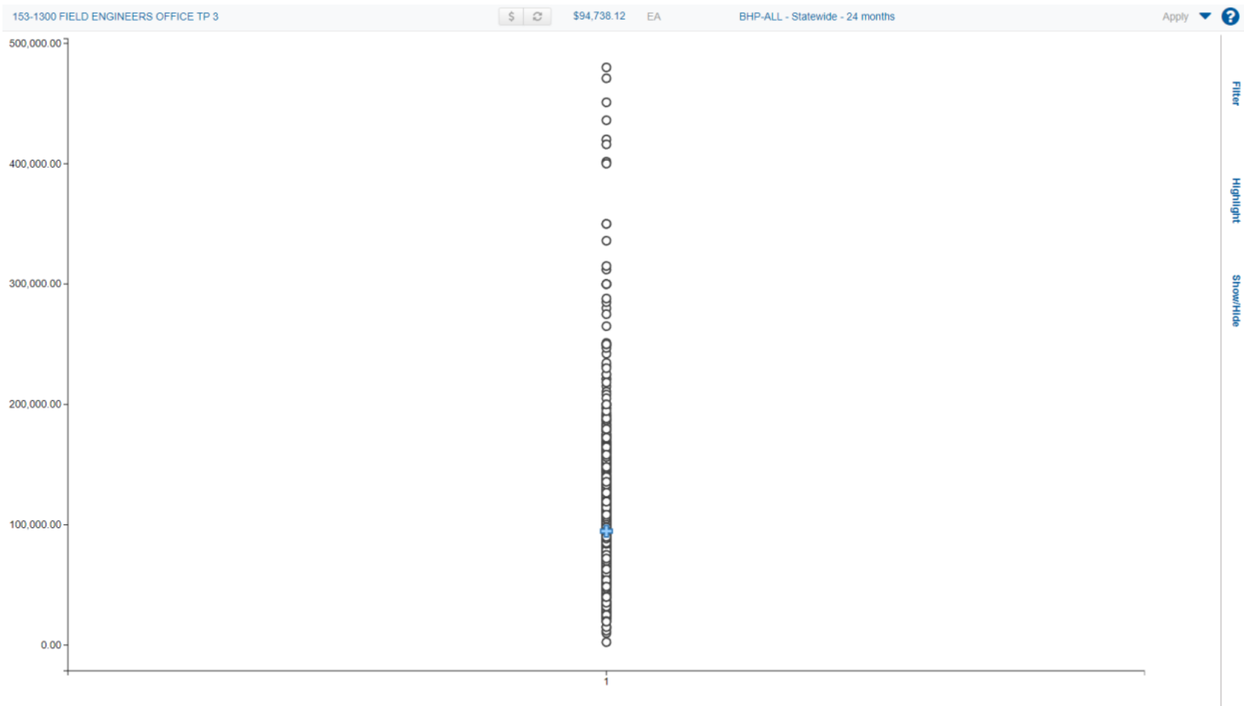

Figure 4. Price vs. Quantity Analysis - Item 153-1300: FIELD ENGINEERS OFFICE TP 3

in some rare cases, AASHTOWare detects an inverted correlation between quantity and unit cost (as quantity increases, unit cost increases). By default, AASHTOWare opts to not calculate a regression-based estimate in these situations, opting instead for a simple average calculation. An example of this is shown in Figure 5.

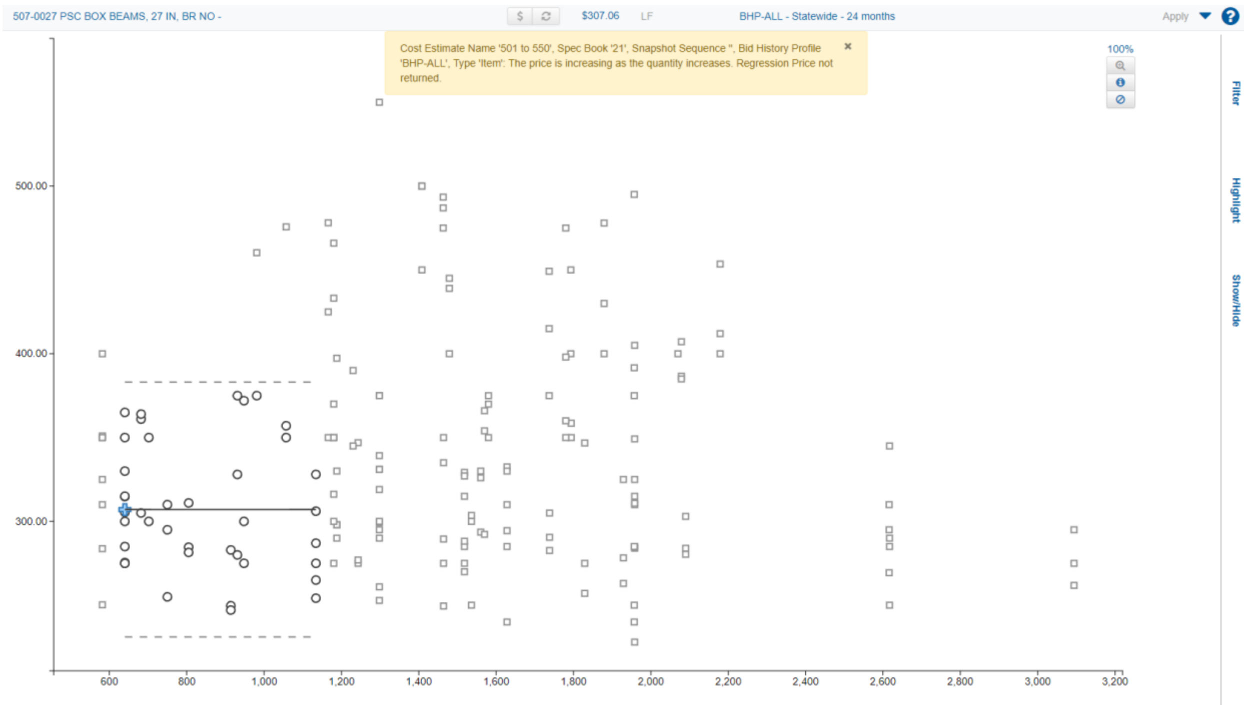

Figure 5. Price vs. Quantity Analysis - Item 507-0027: PSC BOX BEAMS, 27 IN, BR NO-

Finally, even if there are enough observations, those observations are distributed across multiple quantities, and AASHTOWare does not detect an inverted price-quantity correlation, a regression-based trendline still will not be generated unless it provides a sufficient improvement over simply taking the average of existing observations. By default, AASHTOWare requires a 20% improvement to report a regression based trendline. An example of an item that meets all other criteria but fails to experience at least a 20% improvement from a regression based trendline is shown in Figure 6.

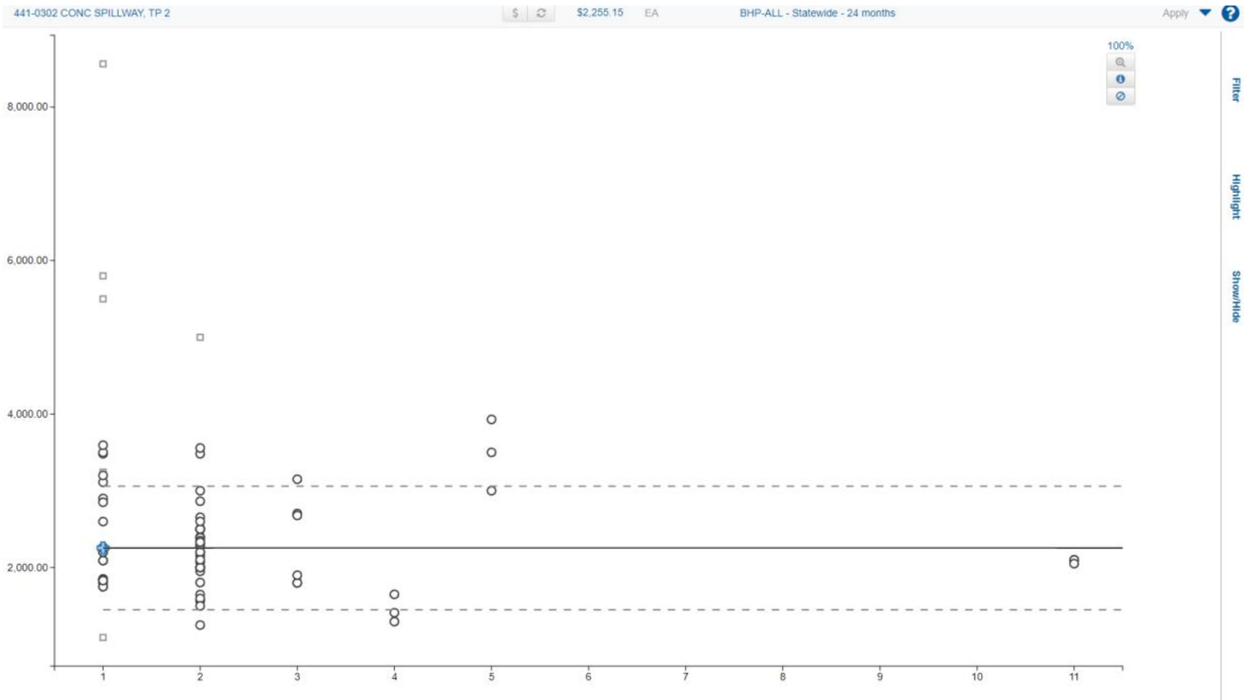

Figure 6. Price vs. Quantity Analysis - Item 441-0302: CONC SPILLWAY, TP 2

Ultimately, AASHTOWare can generate a regression-based trendline for approximately half of the items for which it is able to successfully calculate a bid-based unit price. The most common reason for failure is too few observations. Table 8 contains information on regression-based trendline calculation rates and the reasons for calculation failures. Likewise, Table 9 contains regression-based trendline calculation rates and failure types by item category.

Table 8. Regression-Based Trendline Calculation Rate & Failure Distribution

Number of successfully calculated bid-based prices	1,450 (31.1%)
Number of successfully generated regression-based trendlines	621 (13.4%)
Failure Type 1 – Too few bids (no estimate returned)	3201 (68.8%)
Failure Type 2 – Only one quantity (no confidence intervals returned)	344 (7.4%)
Failure Type 3 – Inverted correlation (no regression based trendline returned)	77 (1.7%)
Failure Type 4 – Insufficient improvement (no regression based trendline returned)	408 (8.8%)

Table 9. Regression-Based Trendline Calculation Rate & Failure Distribution by Item Category

Item Category	Successful Regressions	Type 1 Failures	Type 2 Failures	Type 3 Failures	Type 4 Failures
General Provisions	1	263	3	0	1
Auxiliary Items	0	5	3	0	0
Construction Erosion Control	34	16	5	2	16
Earthwork	15	31	1	0	3
Bases And Subbases	7	86	1	0	7
Pavements	67	302	6	1	11
Bridges	59	50	31	10	51
Minor Drainage Structures	41	148	23	6	43
Incidental Items	335	1,889	205	45	255
Building Installations	0	28	0	0	2
Materials	40	379	73	11	54

2.2.5 Working with Price vs. Quantity Analyses

Using the AASHTOWare price vs. quantity tool, it is possible to collect nearly all the data required for the analyses performed in this study. Namely, it is possible to record the number of bids in which each item has been present, the median quantity of items used in bids, the median bid-based unit price of an item, and the 94.5% confidence intervals for the bid-based unit price. This section details the specific methods used to gather that information.

Bid Observations by Item – It is possible to quickly note the number of bids in which an item has been included by using the show/hide tool within the price vs. quantity analysis scatterplot, as shown in Figure 7. This tool shows the number of data points in the data set, and if they have been included/excluded from consideration when calculating the bid-based unit price of the item.

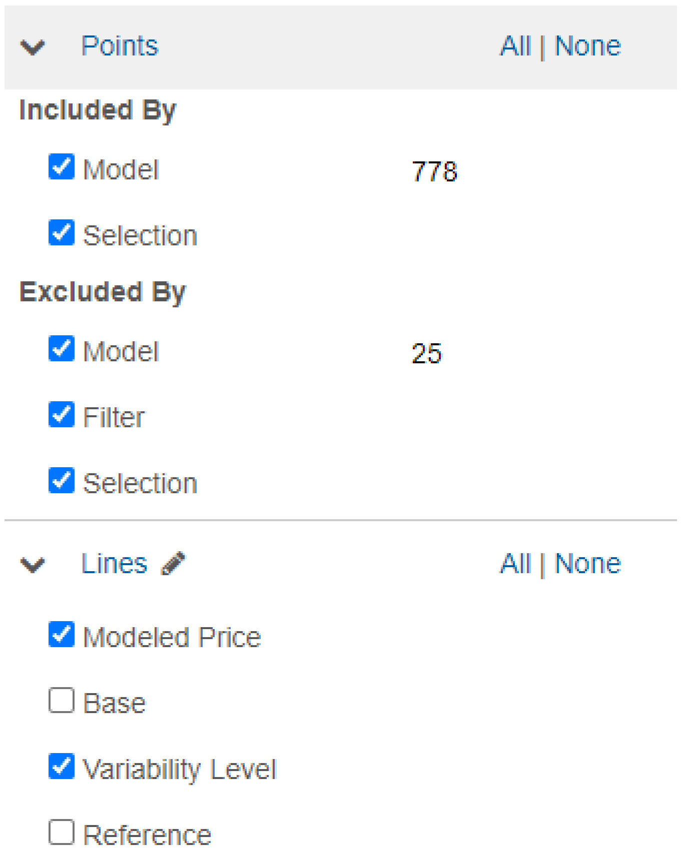

Figure 7. Price vs. Quantity Show/Hide Tool Page

Table 10 contains a list of the items most included in project bids in the state of Georgia between 2014 and 2023. Generally, the most frequently included items have been related to pavement and/or landscaping. Table 11 contains the item most included in bids by item category.

Table 10. Items Most Commonly Included in Bids (2014-2023)

Rank	Item Code	Item Title	Number of Bids
1	654-1001	RAISED PVMT MARKERS TP 1	4,700
2	413-0750	TACK COAT	4,319
3	653-1704	THERMOPLASTIC SOLID TRAF STRIPE, 24 IN, WHITE	4,172
4	654-1003	RAISED PVMT MARKERS TP 3	3,927
5	653-0120	THERMOPLASTIC PVMT MARKING, ARROW, TP 2	3,563
6	700-7000	AGRICULTURAL LIME	3,385
7	700-8000	FERTILIZER MIXED GRADE	3,381
8	700-8100	FERTILIZER NITROGEN CONTENT	3,373
9	700-6910	PERMANENT GRASSING	3,313
10	653-6004	THERMOPLASTIC TRAF STRIPING, WHITE	3,310

Table 11. Maximum Item Bid Quantities by Item Category

Item Category	Item Code	Item Title	Number of Bids
General Provisions	150-5010	TRAFFIC CONTROL, PORTABLE IMPACT ATTENUATOR	835
Auxiliary Items	153-1300	FIELD ENGINEERS OFFICE TP 3	75
Construction Erosion Control	163-0232	TEMPORARY GRASSING	3,158
Earthwork	207-0203	FOUND BKFILL MATL, TP II	973
Bases And Subbases	231-1250	MISCELLANEOUS CONSTRUCTION, UNPAVED ROADS, STREETS AND DRIVEWAYS	1,587
Pavements	413-0750	TACK COAT	4,319
Bridges	511-1000	BAR REINF STEEL	1,950
Minor Drainage Structures	550-2180	SIDE DRAIN PIPE, 18 IN, H 1-10	958
Incidental Items	654-1001	RAISED PVMT MARKERS TP 1	4,700
Building Installations	754-5000	BENCH	10
Materials	999-5200	DETECTABLE WARNING SURFACE	294

Median Item Quantity – Within AASHTOWare, it is possible to view an item's bid history in tabular format. However, it is not possible to export this data to a .csv file, nor is it possible to easily work with the data in its AASHTOWare format. Thus, the easiest way to find the median item quantity is by using the selection tool to manually select half of the data points and noting the quantity at which the division occurs, as shown in Figure 8. This can be time consuming, particularly for items that have hundreds of data points.

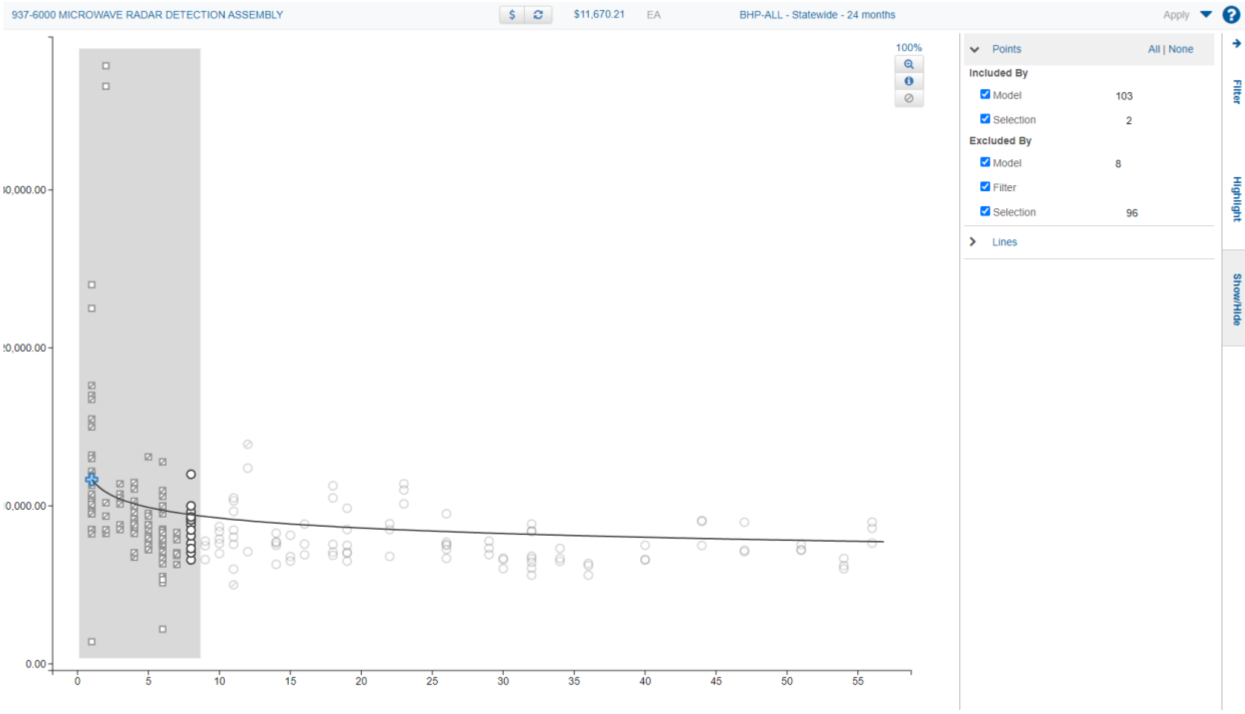

Figure 8. Locating Median Item Quantity Using the Select Tool & Show/Hide Tool

Table 12 contains a list of the items with the highest median quantities used in project bids in the state of Georgia between 2014 and 2023. Table 13 contains a list of items with the highest median quantities used in project bids over the same time period by item category.

Table 12. Items with Highest Median Quantities Used in Bids (2014-2023)

Rank	Item Code	Item Title	Median Quantity Used	Unit	Number of Bids
1	001-9996	TRANSPORTATION ENHANCEMENT ACTIVITY – LIMITED PARTICIPATION	1,189,250	*$*	345
2	208-0100	IN PLACE EMBANKMENT	383,100	CY	53
3	225-4340	SOIL-LIME TREATED ROADBED, CL C, 8 IN	380,895	SY	12
4	430-0185	PLAIN PC CONC PVMT, CL 1 CONC, 8 ½ IN THK	321,805	SY	2
5	461-1000	RESEALING ROADWAY JOINTS AND CRACKS, TP-	303,000	LF	80
6	225-4840	SOIL-LIME TREATED SUBBASE, CL B, 8 IN	290,482	SY	3
7	206-0002	BORROW EXCAV, INCL MATL	199,850	CY	117
8	205-0001	UNCLASS EXCAV	196,569	CY	165
9	420-0300	BITUMNOUS SCRUB SEAL TYPE C	172,521	SY	26
10	424-5107	SINGLE SURFACE TRTMT, STN SIZE 7, GP 2 ONLY	164,296	SY	340

Table 13. Items with Highest Median Quantities Used in Bids by Category (2014-2023)

Item Category	Item Code	Item Title	Median Quantity Used	Unit	Number of Bids
General Provisions	001-9996	TRANSPORTATION ENHANCEMENT ACTIVITY – LIMITED PARTICIPATION	1,189,250	*$*	345
Auxiliary Items	158-1000	TRAINING HOURS	9,500	HR	16
Construction Erosion Control	171-0030	TEMPORARY SILT FENCE, TYPE C	4,205	LF	2,074
Earthwork	208-0100	IN PLACE EMBANKMENT	383,100	CY	53
Bases And Subbases	225-4340	SOIL-LIME TREATED ROADBED, CL C, 8 IN	380,895	SY	12
Pavements	430-0185	PLAIN PC CONC PVMT, CL 1 CONC, 8 ½ IN THK	321,805	SY	2
Bridges	511-3000	SUPERSTR REINF STEEL, BR NO -	48,306	LB	1,930
Minor Drainage Structures	573-2006	UNDDR PIPE INCL DRAINAGE AGGR, 6 IN	900	LF	330
Incidental Items	653-6210	AUDIBLE PROFILED THERMOPLASTIC SOLID TRAF STRIPE W/OMNI RPM, 5 IN, (125MM) (WHITE)	109,402	LF	31
Building Installations	754-5000	BENCH	9	EA	10
Materials	935-1119	OUTSIDE PLANT FIBER OPTIC CABLE, LOOSE TUBE, SINGLE MODE, 288 FIBER	70,600	LF	3

Median Bid-Based Unit Price – The median bid-based unit price of an item can be observed by noting the value of the bid-based trendline at the median quantity. This is trivial in cases such as Figure 3 or Figure 6 when a regression-based trendline has not been generated, thereby resulting in the trendline returning the same unit cost at all quantities. In cases such as Figure 2 when a regression-based trendline has been generated, it is possible to observe the bid-based unit price at the median quantity by hovering the mouse cursor over the trendline at the point in which it crosses the median.

Median 94.5% Confidence Intervals – The median 94.5% confidence intervals are found using similar methods as the median bid-based unit price. Users may observe the values of the lower or higher confidence interval bound at any quantity by hovering the cursor over the confidence interval line at that point.

There are two possible sets of circumstances that render this process impossible. First, as discussed previously, AASHTOWare is unable to generate a price vs. quantity trendline if every recorded bid observation for that item is of the same quantity. Without a trendline, AASHTOWare also does not calculate confidence intervals for its bid-based price calculation. These items have not been considered for further analysis. Second, there are occasions in which one or both confidence intervals are plotted out of view of the scatterplot. Currently, AASHTOWare lacks the functionality to zoom out beyond the initial scale of the scatterplot. In cases where one of the two bounds is visible, it is possible to calculate the location of the missing bound by accounting for the fact that each bound is the same distance from the trendline. In cases where neither bound is visible, the locations of the upper bound was assumed to be 5% larger than the highest visible unit price on the price vs. quantity analysis, and the lower bound was estimated by calculating the difference between the assumed upper bound and the trendline.

2.3 Summary of Work Completed to Date and Next Steps

At this stage, approximately 1,300 item unit prices have been calculated for an assumed quantity of one. However, what is actually needed is the relationship between item quantity used and item unit price. For each of these 1,300 items, AASHTOWare generates a price vs. quantity analysis scatterplot containing every recorded construction bid for that item that qualifies under the conditions stipulated by the bid history profile. Typically (but not always), AASHTOWare is able to calculate a regression-based trendline that establishes a relationship between item quantity used and its unit price. AASHTOWare also visually displays 94.5% confidence intervals on each side of the trendline. From these scatterplots, it is necessary to record the number of data points (bids), the median item bid quantity, the item's unit cost at the median quantity, and the values of the upper and lower confidence interval at the median quantity. There is no easy way to determine the median item quantity other than simply counting data points visually. This is simple for items with relatively sparse bid histories, but can quickly become a cumbersome process, especially for items with thousands of historic bids. Additionally, the price vs. quantity analysis scatterplot window automatically scales to include every data point on one screen, which is problematic in the event of clear data entry error data that is several orders of magnitude off from the remainder of the data, thereby making it nearly impossible to assess the good data. There is a zoom tool, but this tool is difficult to use. Ultimately, it takes approximately 10 minutes to assess each price vs. quantity analysis scatterplot. To date, 269 (20%) of the price vs. quantity analysis scatterplots have been assessed. The remaining 80% of the scatterplots will be assessed over the next several weeks.

To properly implement confidence interval bootstrapping, it would also be necessary to record the quantity and unit price of every historic bid for an item (the X and Y coordinate of each point on the scatterplot). There are approximately 500,000 total historic item bids contained within this dataset. If one data point was transcribed every 10 seconds, it would take approximately 1,400 hours to fully transcribe the data to a usable format. This is clearly impractical. Instead, a subset of items will be chosen for further analysis based on analysis conducted for chapters 4, 5, and 6.

Finally, to help guide analyses performed in later chapters, several item categories will be defined (e.g., asphalt and concrete, drainage, landscaping, etc.). Among other uses, these categories will be useful for gaining a better understanding of if certain types of items are contributing disproportionately to project uncertainty. The 4,627 items within the GDOT reference item index have yet to be sorted into their proper categories. This will likely require multiple days to complete.

3. Bootstrap Analysis for Improved Confidence Intervals

It is notable that AASHTOWare's upper and lower 94.5% confidence intervals are always shown as being equidistant from the trendline in price vs. quantity analyses. This implies an assumption that the bid data is distributed normally. However, this is likely an erroneous assumption. Within AASHTOWare, it is relatively common for the lower bound of the confidence interval to go below zero, as seen in Figure 9. This implies that the material supplier would be paying a contractor to take supplies off their hands (Reichard et. Al., 2022). This is an extremely dubious assertion and is evidence that the process of deriving these confidence intervals is flawed. Similarly, it is relatively common for the majority of historic data to not be contained within the 94.5% confidence interval, which again suggests flaws in the confidence interval calculation process.

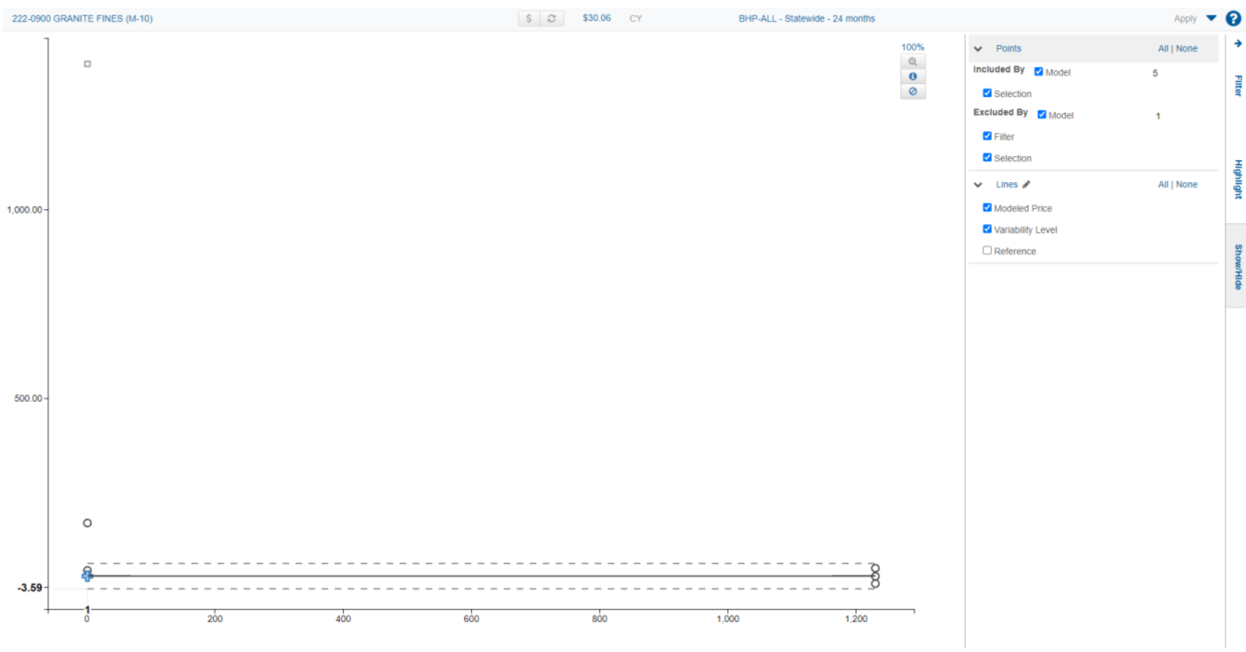

Figure 9. Price vs. Quantity Analysis - Item 222-0900: GRANITE FINES (M-10)

It is possible to derive more accurate confidence intervals through the bootstrap method of standard error. This statistical method allows for the estimation of confidence intervals for non-normally distributed data sets (Efron and Tibshirani 1986). The following section describes the use of bootstrapping to derive improved item confidence intervals.

3.1 Methodology

The following subsection details the methods used to select and prepare data for bootstrap analysis, as well as the actual process of performing the bootstrap analysis.

3.1.1 Data Selection and Preparation

To perform a bootstrap analysis for an item, it is first necessary to have access to the existing bid history data for that item. While AASHTOWare does allow users to view item bid histories, there is no current functionality allowing users to export this data to a .csv file for analysis. Thus, each data point must be transcribed manually. To do this for every item in the GDOT reference item index would constitute the manual transcription of over 250,000 data points, which is impractical. Instead, bootstrap analysis will be performed on a subset of approximately 50 items that have proven to be notable throughout analyses in subsequent chapters. These items are contained in the following tables, and a full list of these items can be found in Appendix A. Items Used for Bootstrap Analysis

- Table 12. Items with Highest Median Quantities Used in Bids (2014-2023)
- Table 13. Items with Highest Median Quantities Used in Bids by Category (2014-2023)
- Table 14. Items with the Highest Range Ratios
- Table 15. Items with the Lowest Range Ratios
- Table 17. Items with the Highest Leverage
- Table 18. Average Item Leverage by Item Category
- Table 19. Items with the Highest Cumulative Cost Uncertainty (2014-2023)
- 20 Additional Randomly Selected Items

For items with relatively few bids, the easiest way to transcribe item bid history data is by using the price vs. quantity analysis tool to visually observe the coordinates of each data point. Users may determine the precise quantity and unit price of each data point by hovering their mouse cursor over that data point. As the number of bids increases, it becomes increasingly impractical to use this process, but it is still possible to access item bid history data in a tabular format within AASHTOWare. This process is slower but ensures that all data points are accounted for.

3.2 Summary of Work Completed and Next Steps

By far, the lengthiest portion of work required to perform confidence interval bootstrapping is the formatting of historic bid data for items. Once the data is prepared, the actual analysis will be relatively simple to perform, and can be performed entirely within spreadsheet software such as Microsoft Excel. To date, little progress has been made on completing these analyses. As mentioned previously, it is prohibitively impractical to prepare bootstrapping input data for each GDOT reference item, so a subset of items will be identified for bootstrap calculations based on analyses performed in chapters 4, 5, and 6.

4. Identification of Highly Variable Items

To gain an understanding of the underlying causes of transportation construction cost uncertainty, it is useful to analyze how each item contributes to cost uncertainty. Using the data accessed through AASHTOWare, it is possible to perform several analyses that offer insight into the nature of cost uncertainty across each GDOT reference item. The following chapter assesses the range, range ratio, and leverage of each item, which measure the per-unit cost uncertainty, uniformity of observed data, and per-project cost uncertainty of each item, respectively.

4.1 Methodology

The following section details the methods used to calculate range, range ratio, and leverage, which are three metrics that can be used to help identify highly variable items.

4.1.1 Range and Range Ratio

One simple way to gain an understanding of cost uncertainty associated with a particular pay item is to calculate the difference between the upper and lower 94.5% confidence interval bounds. This calculation, which will be referred to as the range, shows the potential for per-unit item cost uncertainty. For items with regression-based trendlines, the range will be calculated for the median quantity.

Equation 1 $$\boldsymbol{Range = Upper\ CI - Lower\ CI}$$

Range, on its own, is useful when analyzing individual items, but it is less useful when comparing items to each other because it omits important context about the item's bid history. An item with a median bid-based unit cost of $105 and a range of 100 likely introduces more uncertainty than an item with a median bid-based unit cost of $10,000 and a range of 200, despite having a smaller range. One way to normalize an item's range is to divide it by its average bid-based unit price. This is called the range ratio. The range ratio is helpful in observing the quality of data associated with an item. An item with a high range ratio has a high degree of uncertainty relative to its average cost, whereas an item with a low range ratio has very low uncertainty relative to its unit cost.

Equation 2 $$\boldsymbol{Range\ Ratio = \frac{Range}{Average\ Bid{-}Based\ Unit\ Price}}$$

4.1.2 Leverage

Using the price vs. quantity analyses generated by AASHTOWare, it is possible to derive the potential for cost variation associated with every item in the GDOT Reference Item Index (Reichard et. Al., 2022). This potential for unit cost variation will be referred to as "Leverage" throughout this study. Leverage is a function of quantity used and range.

Equation 3 $$\boldsymbol{Leverage = Median\ Quantity\ x\ Range}$$

For example, in the example displayed in Figure 3, the value of the upper confidence interval is $1,276.37, and the value of the lower confidence interval is $469.19. According to

AASHTOWare, there is a 94.5% chance that the true unit cost of Four Hour Accelerated Strength Concrete is within the $807.18 range between the two confidence intervals. In other words, there is $807.18 worth of price uncertainty per cubic yard of Four Hour Accelerated Strength Concrete used in a project. In this example, the median quantity used is 250 cubic yards. Thus, Four Hour Accelerated Strength Concrete's leverage can be calculated as follows:

$$\boldsymbol{Leverage_{Item\ 503-1600} = 250cy\ x\ (\$1,276.37 - \$469.19) = \$201,795}$$

In other words, the inclusion of Four Hour Accelerated Strength Concrete in a project, on average, will result in $201,795 of cost uncertainty. An item with high leverage is likely to contribute a greater proportion of project cost uncertainty, whereas items with low leverage are unlikely to contribute a substantial portion of total project cost uncertainty.

4.2 Results

The items with the highest and lowest range ratios are shown in Table 14 and Table 15 respectively. Table 16 contains the average range ratio by item category.

Table 14. Items with the Highest Range Ratios

Rank	Item Code	Item Title	Average Bid-Based Unit Cost	Range	Range Ratio
1	509-0005	PRESTRESSING CAST-IN-PLACE CONC, BR NO. -	$553.70	$109,897.31	198.48
2	520-4173	LOAD TEST, STEEL H, HP 14 X 102	$14.16	$431.89	30.50
3	999-0060*	BIORETENTION AREA	$351.54	$9,107.00	25.91
4	520-4179	LOAD TEST, STEEL H, HP 14 X 117	$316.23	$8,140.96	25.74
5	725-0010	WEED CONTROL	$0.15	$1.08	7.20
6	664-0610	REMOVAL OF UNDERGROUND ELECTRIC DISTRIBUTION (SECONDARY SERVICE) 600 V OR LESS	$97.23	5.28	5.28
7	660-1120	TEMPORARY BYPASS PUMPING	$44.48	$228.52	5.14
8	610-2401	REM WOVEN WIRE FENCE, INCL POSTS	$17.68	$87.56	4.95
9	527-0050	CABLE STAY PROTECTIVE TAPE REPAIR	$66.08	$315.74	4.78
10	514-1000	EPOXY COATED SUPERSTR REINF STEEL, BR NO. -	$5.04	$21.80	4.33

*The calculations for this item are very clearly being thrown off by a data entry error. Once this error is corrected, the range ratio drops to 3.29.

Table 15. Items with the Lowest Range Ratios

Rank	Item Code	Item Title	Average Bid-Based Unit Cost	Range	Range Ratio
1	520-4104	LOAD TEST, STEEL H, HP 10 X 42	$1.01	$0.10	0.10
2	520-4220	LOAD TEST, PSC, 20 IN SQ	$1.01	$0.11	0.11
3	430-0190	PLAIN PC CONC PVMT, CL 1 CONC, 9 INCH THK	$56.79	$6.62	0.12
4	668-2233	DROP INLET, GP 1, MODIFIED TP M-3	$8,025.23	$1,035.04	0.13
5	520-4125	LOAD TEST, STEEL H, HP 12 X 53	$1.01	0.14	0.14
6	641-9912	TEMPORARY GUARDRAIL ANCHORAGE, TP 12	$2,170.18	$331.35	0.14
7	951-5125	UNDERGROUND CABLE FIBER, SINGLE MODE, _____ COUNT	$6.79	$1.02	0.15
8	668-1115	CATCH BASIN, GP 1, ADDL DEPTH, SPCL DES	$425.06	$65.80	0.15
9	935-3205	FIBER OPTIC CLOSURE, AERIAL (SEALED), 48 FIBER	$1,427.58	$247.04	0.17
10	660-0812	SAN SEWER PIPE, 12 IN, DUCTILE IRON	$89.95	$17.01	0.19

Table 16. Average Range Ratio by Item Category

Item Category	Average Range Ratio
ALL ITEMS	1.320
General Provisions	0.639
Auxiliary Items	N/A
Construction Erosion Control	1.331
Earthwork	1.128
Bases And Subbases	0.908
Pavements	0.778
Bridges	3.239
Minor Drainage Structures	1.021
Incidental Items	1.117
Building Installations	2.279
Materials	1.230

The items with the highest leverage are shown in Table 17. The average item leverage by item category is shown in Table 18.

Table 17. Items with the Highest Leverage

Rank	Item Code	Item Title	Median Quantity	Range	Leverage
1	527-0050	CABLE STAY PROTECTIVE TAPE REPAIR	32,538	$315.74	$10,273,390.25
2	210-0200	GRADING PER MILE	1,052	$8,351.22	$8,785,588.64
3	520-1330	PILING IN PLACE, METAL SHELL, 30 IN OD	20,380	$262.12	$5,342,005.60
4	208-0100	IN PLACE EMBANKMENT	383,100	$7.43	$2,846,433.00
5	206-0002	BORROW EXCAV, INCL MATL	199,850	$10.49	$2,096,426.50
6	205-0001	UNCLASS EXCAV	196,569	$7.78	$1,529,306.82
7	999-0060	BIORETENTION AREA	150	$9,107.00	$1,366,050.00
8	505-1100	COMPOSITE STEEL GRID DECK WITH PRECAST CONCRETE SLAB	14,467	$74.24	$1,074,030.08
9	430-0190	PLAIN PC CONC PVMT, CL 1 CONC, 9 INCH THK	156,464	$6.62	$1,035,791.68
10	500-1006	SUPERSTR CONCRETE, CL AA, BR NO.-	358	$2,510.51	$898,762.58

Table 18. Average Item Leverage by Item Category

Item Category	Average Item Leverage
ALL ITEMS	$71,319.10
General Provisions	$12,416.39
Auxiliary Items	N/A
Construction Erosion Control	$9,064.33
Earthwork	$857,551.96
Bases And Subbases	$94,912.09
Pavements	$94,200.45
Bridges	$205,164.96
Minor Drainage Structures	$12,379.76
Incidental Items	$22,052.48
Building Installations	$12,516.66
Materials	$18,006.02

4.3 Summary of Work Completed and Next Steps

To date, the required input data have been prepared for 20% of the items with available data. Once the remaining 80% of data is properly prepared, subsequent analyses can be performed within spreadsheet software such as Microsoft Excel. A spreadsheet has already been created that will automatically perform necessary calculations as item data is entered. Likewise, much of this chapter has already been drafted, not including the discussion section of the chapter (which can only be written after data preparation is completed).

Many of the analyses within this chapter involve using the AASHTOWare generated unit price confidence intervals in calculations. Once bootstrapping is completed, these analyses will be replicated using bootstrapped confidence intervals, and results will be compared.

5. Cumulative Cost Uncertainty

Chapter 3 of this study describes the items that have the potential to introduce the greatest amount of cost uncertainty to a project. However, it is perhaps more useful to measure the cumulative uncertainty caused by each item over the previous nine years. The following chapter estimates cumulative cost uncertainty as a function of cumulative project bids multiplied by item leverage. Likewise, an estimate of cumulative quantity of items included in bids is included in this chapter.

5.1 Methodology

The following section details the methods used to calculate cumulative project cost uncertainty and cumulative bid quantity, which are three metrics that can be used to help identify items that are greatest contributors to project cost uncertainty.

5.2.1 Item Cumulative Bid Cost Uncertainty

Item cumulative project bid cost uncertainty can be calculated using data already collected by multiplying the number of bids an item has been present in by the item's leverage. As described in Chapter 3, leverage is a measure of an item's per-bid cost uncertainty. Multiplying per-bid price uncertainty by number of bids results in cumulative bid cost uncertainty.

Equation 4 $\boldsymbol{Item\ Cumulative\ Cost\ Uncertainty = Leverage\ x\ Total\ Bids}$

5.2.2 Item Cumulative Bid Quantity

Similarly, item cumulative bid quantity can be estimated using previously collected data by multiplying the median item quantity by the total number of bids an item has been present in.

Equation 5 $\boldsymbol{Item\ Cumulative\ Bid\ Quantity = Median\ Quantity\ x\ Total\ Bids}$

However, using median bid quantity instead of average bid quantity will result in some inaccuracy. One extreme example is shown in Figure 10. There are 92 observed instances of type 4 concrete spillways being included in bids, but more than half of those observations record a quantity of 1. Thus, the median quantity of type 4 concrete spillways used in a project is 1 and using equation 5 would result in the item cumulative bid quantity being reported as 92, even though the true item cumulative bid quantity is 168.

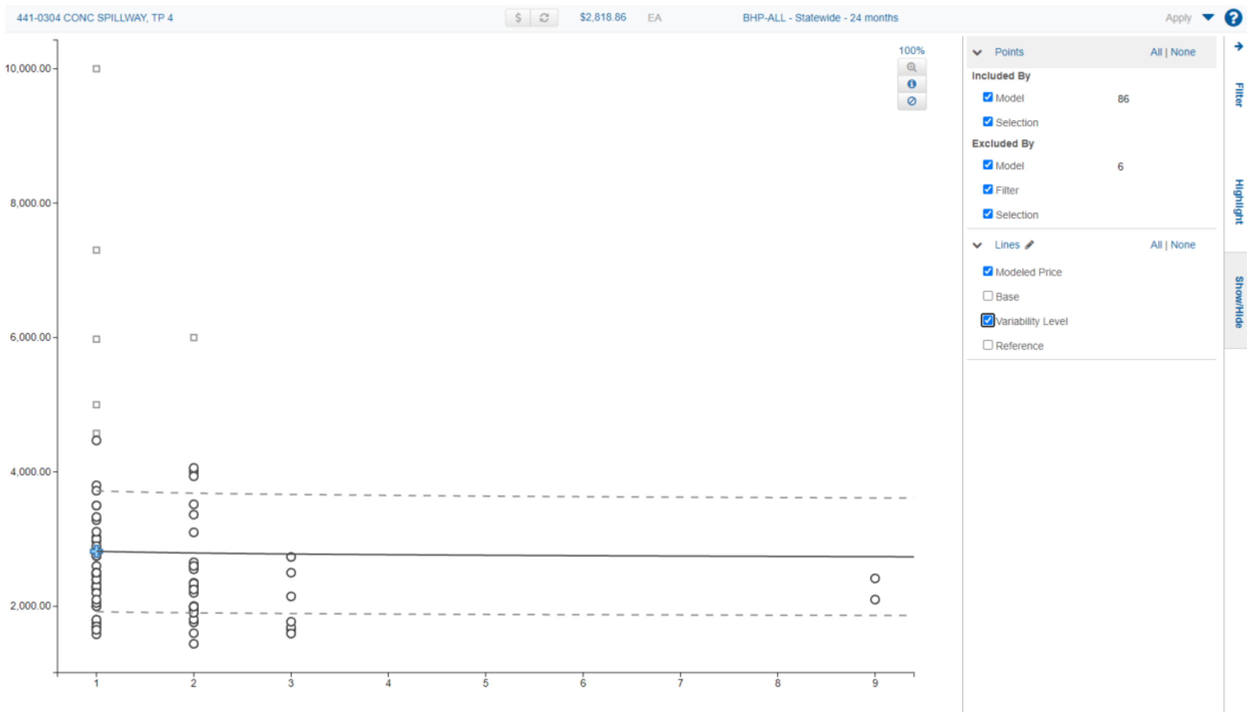

Figure 10. Price vs. Quantity Analysis - Item 441-0304: CONC SPILLWAY, TP 4

It is possible to find the average item bid quantity, and using the average item bid quantity would yield a more accurate estimation of cumulative item bid quantity. However, since there is no current way to export item bid data to a .csv file, this process would require manually transcribing every item bid quantity into a spreadsheet. This process is infeasible for many items, as shown in Table 10 previously. Thus, the median item bid quantity has been used with the understanding that this estimate has some degree of inaccuracy. Generally, an item's median quantity will be less than its average quantity because many item quantities are discrete integers, potentially resulting in several observations at the exact same quantity. In these cases, it's likely that the largest clumps of observations will be at lower quantities, as displayed in Figure 9. This observation is supported by Benford's law, which suggests that "in many collections of numbers, be they, e.g., mathematical tables, real-life data, or combinations thereof, the leading significant digits are not uniformly distributed, as might be expected, but are heavily skewed toward the smaller digits" (Berger and Hill, 2011). Therefore, this methodology is more likely to underestimate the cumulative bid quantity of items than it is to overestimate the cumulative bid quantity of items.

5.2 Results

Table 19 contains a list of the items with the highest cumulative cost uncertainty between 2014 and 2023. Table 20 contains the cumulative cost uncertainty by item category.

Table 19. Items with the Highest Cumulative Cost Uncertainty (2014-2023)

Rank	Item Code	Item Title	Item Leverage	Total Bids	Item Cumulative Cost Uncertainty
1	402-3130	RECYCLED ASPH CONC 12.5 MM SUPERPAVE, GP 2 ONLY, INCL BITUM MATL & H LIME	$372,167.60	2,045	$761,082,742.00
2	500-1011	SUPERSTR CONCRETE, CL D, BR NO.-	$631,604.76	762	$481,282,827.12
3	500-1006	SUPERSTR CONCRETE, CL AA, BR NO.-	$898,762.58	528	$474,546,642.24
4	402-4510	RECYCLED ASPH CONC 12.5 MM SUPERPAVE, GP 2 ONLY, INCL POLYMER MODIFIED BITUM MATL & H LIME	$378,718.32	1,028	$389,322,432.96
5	402-3103	RECYCLED ASPH CONC 9.5 MM SUPERPAVE, TYPE II, GP 2 ONLY, INCL BITUM MATL & H LIME	$252,247.53	1,017	$256,535,738.01
6	205-0001	UNCLASS EXCAV	$1,529,306.82	165	$252,335,625.30
7	206-0002	BORROW EXCAV, INCL MATL	$2,096,426.50	117	$245,281,900.50
8	500-3002	CLASS AA CONCRETE	$230,260.02	858	$197,563,354.56
9	402-1812	RECYCLED ASPH CONC LEVELING, INCL BITUM MATL & H LIME	$74,959.80	2,522	$189,048,615.60
10	400-3206	ASPH CONC 12.5 MM OGFC, GP 2 ONLY, INCL POLYMER MODIFIED BITUM MATL & H LIME	$824,316.56	196	$161,566,045.76

Table 20. Cumulative Cost Uncertainty by Item Category (2014-2023)

Item Category	Cumulative Cost Uncertainty
General Provisions	$45,691,799.60
Auxiliary Items	N/A
Construction Erosion Control	$254,898,007.28
Earthwork	$770,568,275.71
Bases And Subbases	$246,238,677.31
Pavements	$2,905,008,389.48
Bridges	$2,557,065,280.08
Minor Drainage Structures	$71,560,165.64
Incidental Items	$1,837,258,366.08
Building Installations	$250,333.20
Materials	$57,455,337.97

Likewise, Table 21 contains a breakdown of cumulative cost uncertainty ranges by number of items.

Table 21. Item Cumulative Cost Uncertainties by Magnitude

Cumulative Cost Uncertainty Range	Number of Items
Over $100,000,000	17 (1.2%)
$10,000,000 - $99,999,999	107 (7.4%)
$1,000,000 - $9,999,999	310 (21.4%)
Under $1,000,000	664 (45.8%)
N/A	352 (24.2%)

Table 22 contains a list of the items with the highest cumulative bid quantities between 2014 and 2023. Table 23 contains a list of items with the highest estimated cumulative bid quantity by item category over the same time period.

Table 22. Items with the Highest Estimated Cumulative Bid Quantity (2014-2023)

Rank	Item Code	Item Title	Item Cumulative Bid Quantity	Units
1	001-9996	TRANSPORTATION ENHANCEMENT ACTIVITY – LIMITED PARTICIPATION	410,291,250	*$*
2	432-5010	MILL ASPH CONC PVMT, VARIABLE DEPTH	132,599,826	SY
3	511-3000	SUPERSTR REINF STEEL, BR NO. -	93,230,580	LB
4	424-5107	SINGLE SURFACE TRTMT, STN SIZE 7, GP 2 ONLY	55,860,640	SY
5	713-3012	WOOD FIBER BLANKET, TP II, SHOULDERS	39,790,200	SY
6	205-0001	UNCLASS EXCAV	32,433,885	CY
7	413-0750	TACK COAT	27,537,944	GL
8	461-1000	RESEALING ROADWAY JOINTS AND CRACKS, TP-	24,240,000	LF
9	206-0002	BORROW EXCAV, INCL MATL	23,382,450	CY
10	511-1000	BAR REINF STEEL	22,538,100	LB

Table 23. Items with the Highest Estimated Cumulative Bid Quantity by Item Category (2014-2023)

Item Category	Item Code	Item Title	Item Cumulative Bid Quantity	Unit
General Provisions	001-9996	TRANSPORTATION ENHANCEMENT ACTIVITY – LIMITED PARTICIPATION	410,291,250	*$*
Auxiliary Items	158-1000	TRAINING HOURS	152,000	HR
Construction Erosion Control	171-0030	TEMPORARY SILT FENCE, TYPE C	8,721,170	LF
Earthwork	205-0001	UNCLASS EXCAV	32,433,885	CY
Bases And Subbases	310-1101	GR AGGR BASE CRS, INCL MATL	5,428,353	TN
Pavements	432-5010	MILL ASPH CONC PVMT, VARIABLE DEPTH	132,599,826	SY
Bridges	511-3000	SUPERSTR REINF STEEL, BR NO. -	93,230,580	LB
Minor Drainage Structures	573-2006	UNDDR PIPE INCL DRAINAGE AGGR, 6 IN	297,000	LF
Incidental Items	713-3012	WOOD FIBER BLANKET, TP II, SHOULDERS	39,790,200	SY
Building Installations	754 -5000	BENCH	90	EA
Materials	999-9410	MIGRATORY BIRD EXCLUSIONARY BARRIER FOR BRIDGE, BR NO. -	838,736	SF

5.3 Summary of Work Completed and Next Steps

The analyses performed in this chapter rely on the exact same input data as required for chapter 4. Therefore, approximately the same amount of progress has been made. Like chapter 4, the analyses required for this chapter can easily be performed within a spreadsheet, and a Microsoft Excel spreadsheet has already been created to automate calculations as data is entered. Again, much of this chapter has already been drafted, not including the discussion section of the chapter (which can only be written after data preparation is completed).

Many of the analyses within this chapter involve using the AASHTOWare generated unit price confidence intervals in calculations. Once bootstrapping is completed, these analyses will be replicated using bootstrapped confidence intervals, and results will be compared.

6. Inclusion of Sustainable Items in Pay Item Indices

This section will contain analyses focused on sustainable design elements contained within the GDOT reference item index. The first step towards completing this process will be to identify the subset of items that quality as sustainable design elements. This has yet to be completed but will be completed simultaneously with the assignment of reference items to their item group category as described in section 0.1.2. Once the subset of sustainable design elements has been identified, analyses will be performed on the quality of existing bid history data for these items in comparison to the remainder of the reference item index Likewise, the availability of sustainable alternatives to commonly used items will be assessed. Like the chapters before, these analyses will simply require the use of spreadsheet software and will not be particularly time intensive.

7. Applications for Lifecycle Cost Analysis

AASHTOWare's bid-based item unit price estimations only capture the cost of constructing / installing the item in question. However, lifecycle cost analysis is a critical component of cost estimation. Chapter 7 will explore the applicability of this study's findings to lifecycle cost analysis. This chapter will largely rely on the conclusions drawn from the previous chapters. Thus, it has not been possible to begin work on this chapter at this time.

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Data Summary

Products of Research

The Georgia Department of Transportation Road Inventory data can be downloaded from the GDOT Road & Traffic Data webpage here:

> Georgia DOT. "Road & Traffic Data." *GDOT*, 31 Dec. 2022, http://www.dot.ga.gov/DS/Data#tab-4. Accessed 26 August 2024.

The data used in this project can be accessed here:

> Reichard, W. (2024). Enhanced Accounting for Item Cost Variability in AASHTOWare Project Software Dataset [Data set]. Zenodo. https://doi.org/10.5281/zenodo.13901113

Data Format and Content

Data can be downloaded in a variety of formats from the sources noted above.

Data Access and Sharing, Reuse and Redistribution

See above.

Appendix A. Items Used for Bootstrap Analysis

Table 24. Items Used for Bootstrap Analysis

Item Code	Item Name
001-9996	TRANSPORTATION ENHANCEMENT ACTIVITY – LIMITED PARTICIPATION
158-1000	TRAINING HOURS
167-1500	WATER QUALITY INSPECTIONS
205-0001	UNCLASS EXCAV
206-0002	BORROW EXCAV, INCL MATL
208-0100	IN PLACE EMBANKMENT
225-4340	SOIL-LIME TREATED ROADBED, CL C, 8 IN
225-4840	SOIL-LIME TREATED SUBBASE, CL B, 8 IN
400-3206	ASPH CONC 12.5 MM OGFC, GP 2 ONLY, INCL POLYMER
420-0300	BITUMNOUS SCRUB SEAL TYPE C
424-5107	SINGLE SURFACE TRTMT, STN SIZE 7, GP 2 ONLY
430-0185	PLAIN PC CONC PVMT, CL 1 CONC, 8 ½ IN THK
430-0190	PLAIN PC CONC PVMT, CL 1 CONC, 9 INCH THK
441-6022	CONC CURB & GUTTER, 6 IN x 30 IN, TP 2
461-1000	RESEALING ROADWAY JOINTS AND CRACKS, TP-
505-1100	COMPOSITE STEEL GRID DECK WITH PRECAST CONCRETE SLAB
509-0005	PRESTRESSING CAST-IN-PLACE CONC, BR NO. -
514-1000	EPOXY COATED SUPERSTR REINF STEEL, BR NO. -
520-1330	PILING IN PLACE, METAL SHELL, 30 IN OD
520-4104	LOAD TEST, STEEL H, HP 10 X 42
520-4125	LOAD TEST, STEEL H, HP 12 X 53
520-4173	LOAD TEST, STEEL H, HP 14 X 102
520-4179	LOAD TEST, STEEL H, HP 14 X 117
520-4220	LOAD TEST, PSC, 20 IN SQ
527-0050	CABLE STAY PROTECTIVE TAPE REPAIR
610-2375	REMOVE WATER MAIN, 10 IN
610-2401	REM WOVEN WIRE FENCE, INCL POSTS

Item Code	Item Name
636-1077	HIGHWAY SIGNS, ALUM EXTRUDED PANELS, REFL SHEETING, TP 9
641-9912	TEMPORARY GUARDRAIL ANCHORAGE, TP 12
652-5301	SOLID TRAF STRIPE, 6 IN, WHITE
653-0220	THERMOPLASTIC PVMT MARKING, WORD, TP 2
653-6210	AUDIBLE PROFILED THERMOPLASTIC SOLID TRAF STRIPE W/OMNI RPM, 5 IN, (125MM) (WHITE)
655-6020	PREFORMED PLASTIC PVMT MKG ARROW, CONRAST (BLACK-WHITE), TP 2
656-1004	REMOVE EXIST SKIP TRAF STRIPE, 4 IN, PAINT
660-0812	SAN SEWER PIPE, 12 IN, DUCTILE IRON
660-1120	TEMPORARY BYPASS PUMPING
660-1245	SEWER FORCE MAIN, 16 IN, -
660-1425	GRAVITY SEWER MAIN, 8 IN, -
660-4020	STEEL CASING, 10 IN
664-0610	REMOVAL OF UNDERGROUND ELECTRIC DISTRIBUTION (SECONDARY SERVICE) 600 V OR LESS
665-0050	SHORT SIDE SERVICE TIE OVER -
668-1115	CATCH BASIN, GP 1, ADDL DEPTH, SPCL DES
668-2233	DROP INLET, GP 1, MODIFIED TP M-3
670-2080	GATE VALVE, 8 IN
725-0010	WEED CONTROL
754-5000	BENCH
935-1113	OUTSIDE PLANT FIBER OPTIC CABLE, LOOSE TUBE, SINGLE MODE, 24 FIBER
935-1119	OUTSIDE PLANT FIBER OPTIC CABLE, LOOSE TUBE, SINGLE MODE, 288 FIBER
935-3205	FIBER OPTIC CLOSURE, AERIAL (SEALED), 48 FIBER
935-5020	FIBER OPTIC CONNECTORS, MM
937-6000	MICROWAVE RADAR DETECTION ASSEMBLY
951-5125	UNDERGROUND CABLE FIBER, SINGLE MODE, ______ COUNT
999-0060	BIORETENTION AREA
999-8018	TRELLIS