Enhanced Bridge Cost Estimating

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16. Abstract

The primary objectives of this research were to: 1) develop an efficient and accurate method for bridge repair and replacement cost estimating; and 2) implement the developed method in a cost estimation worksheet; 3) provide an automated system that allows periodic updating of costs. To accomplish these objectives, several modeling approaches were investigated, including simple linear regression, multiple linear regression, lasso regression, and two versions of case-based reasoning (CBR). Overall, it was found that all approaches could produce more accurate cost predictions for individual pay items than the existing MDOT engineering estimate, and that lasso regression was most effective. Next, cost estimation models were developed for the bridge work types currently used by MDOT. An approach was developed to identify work types within the cost database using primary pay items, and the total work type cost within a project was determined by summing all pay item costs associated with that work type. Several different work type cost approaches were developed: base, supplemental, substitute, and cost average approaches. Both average unit costs and regressed costs were provided. A time-series based MHCCI projection method was developed to consider future cost projections. A cost estimation spreadsheet and automated updating program were developed.

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EXECUTIVE SUMMARY

Accurately estimating bridge repair and replacement project costs is critical for MDOT to properly allocate funding and resources. However, the current bridge cost estimating method used for estimating bridge repair and replacement costs does not provide reliable and consistent estimates. The primary objectives of this research were to: 1) develop an efficient and accurate method for bridge repair and replacement cost estimating; and 2) implement the developed method in a cost estimation worksheet; 3) provide an automated system that allows periodic updating of costs.

To accomplish these objectives, the database of previous project costs was first analyzed to determine possible relationships between project parameters and important single pay items that dominate most project costs. From this analysis, a set of potential continuous and categorical predictor variables was selected. Costs from different project release dates in the database were normalized with the Michigan Highway Construction Cost Index (MHCCI), and data outliers were identified with the median absolute deviation approach, where both truncation and elimination were considered, along with a log scale transformation of the remaining cost data prior to predictive model development.

Several modeling approaches were investigated, including simple linear regression, multiple linear regression, lasso regression, and two versions of case-based reasoning (CBR). Overall, it was found that all approaches could produce more accurate cost predictions for individual pay items than the existing MDOT engineering estimate, and that lasso regression was most effective.

Next, cost estimation models were constructed for the (46) bridge work types currently used by MDOT for scoping rather than individual pay items. An approach was developed to identify work types within the cost database using primary pay items, and the total work type cost within a project was determined by summing all pay item costs associated with that work type. Several different work type cost approaches were developed: the base, supplemental, substitute, and cost average approach. Both average unit costs and regressed costs were provided. A time-series based MHCCI projection method was developed to consider future cost projections. A final cost estimation spreadsheet with these various options, and an associated automated updating program were developed.

CHAPTER 1: INTRODUCTION

1.1. Background

1.1.1. Overview

A primary goal of MDOT's bridge program is to preserve its trunkline bridges. To fulfill this goal, MDOT periodically identifies critical structures and provides fixes to upgrade poor condition ratings whenever possible. MDOT typically implements a "mix of fixes" strategy that utilizes longer and medium-term timelines such as Rehabilitation and Replacement (R&R) as well as short-term fixes such as Capital Preventive Maintenance (CPM). Other fix categories include Capital Scheduled Maintenance (CSM) and Reactive Maintenance (RM). Rehabilitation (3R) is meant to extend the service life of an existing bridge by returning it to structural and functional adequacy, such as by bridge widening, applying concrete overlays, and super and sub-structure repairs. Replacement (4R) concerns significant alternations to the existing structure, such as deck, superstructure, or entire bridge replacement. CPM includes short-term repair and preservation activities meant to delay deterioration, such as replacing pins and hangers, steel repairs, substructure repairs, joint replacement, painting, deck patching, and applying sealants. CSM actions are similarly short-term and are aimed to maintain existing serviceability and reduce the rate of deterioration, with little impact to traffic. Examples include superstructure washing, vegetation removal, spot-painting, and minor concrete patching. RM is generally used to mitigate wearing surface problems such as temporarily filling deck spalls with asphalt, and is generally the least desirable option, as it is not eligible for federal funding.

The process from project formulation to approval for construction involves various steps, including scoping, estimating, letting, contractor bidding, and award. The initial stages of this process are of particular concern, where accurate activity scoping and cost estimation are crucial. In a broad sense, scoping is the process of analyzing the needs of the transportation system and develop projects that address these needs, within the different approach categories discussed above (R&R, CSM, CPM, RM). For a particular bridge structure, scoping is used to identify the types and quantities of work that are needed to define a project. As cost estimation directly follows from scoping, good understanding of the scoping process is essential.

Various considerations enter the scoping process: the broader impacts of the specific project on future projects and potential for corridor coordination; the requirements associated with a particular type of funding template (4R, 3R, CPM etc.); the associated guidelines and policies; work zone safety and mobility; the type of design survey needed; safety review and crash analysis; environmental impacts; the possible need for value engineering on higher-cost projects (i.e. $20 million or greater); and consideration for accelerated bridge construction, among others.

The detailed scoping process for a specific bridge structure is described in the Project Scoping Manual (MDOT 2017), where the structure is assessed with a detailed inspection and field site review to identify areas of deterioration. From this information, feasible repair options are determined and needed quantities are computed. As the condition of the deck is strongly related to the need for rehabilitation or replacement, the Bridge Deck Preservation Matrix has been developed and is used to guide deck repair options. To direct the scoping process, Bridge Scoping

Report & Details Worksheets are used to record scoping information collected for the project. Scoping results are then summarized in the Bridge Scoping Report.

1.1.2. Current Estimating Process

Using the areas of deterioration collected during the inspection and site review, estimating is currently conducted utilizing the Bridge Repair Cost Estimate spreadsheet. A similar CSM worksheet for maintenance exists as well. The worksheet is used by region bridge engineers to program upcoming projects for the purpose of budgeting any specific fiscal year. The MDOT Bridge Scoping Engineer oversees revisions of the worksheet after the end of a fiscal year based on (low-bid) let project costs in the previous year. Here multiple alternative fixes might be estimated for a particular structure. The estimate(s) includes all significant work items for the project, which are either treated as individual pay items or as a lump sum.

Individual pay items are estimated by unit costs for specific items of work (e.g. concrete deck patch, $33 SFT; pier repair, $180 CFT), while lump sum pay items may roll various sub-costs into a single conglomerate item; may be taken as a percentage of the interim project cost (i.e. total project cost without lump sum items); or taken as a single fixed cost item. Examples of lump sum items include contractor staking; mobilization, and site preparation. Other project costs are the support costs, which include: contingency, which varies from 3-30% based on project cost and complexity level; preliminary engineering costs, which include engineering design and plan preparation and depend on the project cost, type of work, bridge location, and other factors, estimated at 8-15% of total cost; and construction engineering costs, where depending on the project cost, location, schedule, and other factors, is estimated at about 15% of total cost. Average weighted unit prices are obtained from estimating software as a function of the item considered, its quantity, and region where the work will take place.

Furthermore, the life cycle stage of the structure is estimated during the scoping phase, based on the history of maintenance and rehabilitation, using expected bridge preservation timelines as given in the Scoping Manual. For example, a deep overlay is expected to last 25-30 years, a superstructure replacement 40 years, etc. This information, along with the site review information, consideration of corridor planning, and alternative repair approach estimates, is used to plan appropriate work items and propose the repair strategy.

Once scoping and estimating is complete, and if the project is programmed for funding and approved for release, most projects are advertised 4 to 5 weeks before the letting date, which typically occurs on the first Friday of each month.

1.2 Statement of the Problem

Accurately estimating bridge repair and replacement project costs is critical for MDOT to properly allocate funding and resources. The current bridge cost estimating worksheet is utilized statewide by hundreds of government agencies to estimate repair and replacement costs for thousands of bridges. However, the current method for estimating bridge repair and replacement costs does not provide reliable and consistent estimates. Improving this system would allow improved condition forecasting and reporting in addition to more accurately estimating future funding needs. Inaccurate estimates can lead to underfunding structures in need and potentially cause delays in needed work. This can have a significant negative impact to stakeholders. As anticipated projects are publically published in the Five Year Transportation Plan, the resulting lack of stability in the program due to delays makes it difficult for stakeholders and to know what and when actual work will be taking place. Cost over-runs are particularly troublesome, as federally funded, Statewide Transportation Improvement Program (STIP) projects require amendment when the programmed cost is exceeded by 25% and when a new a project is being added to a fiscal year. As this can take up to six months for approval in some cases, these delays may lead to further unnecessary deterioration of some structures as well as structures remaining in an undesirable condition longer than anticipated. This increases future costs to MDOT and may decrease the functionality and/or safety margin of some bridges, leading to a decrease in the quality of the trunkline system for motorists.

1.3 Objectives of the Study

The objectives of this research can be broadly summarized with two primary statements:

1. Develop an efficient, accurate method for bridge repair and replacement cost estimating.

2. Implement the developed method in worksheets that are straightforward to update and use for price estimation for a variety of common bridge work types as well as life cycle cost estimation.

1.4 Summary of Research Tasks

This research is composed of the following tasks:

Task 1. Focused Literature Review.

Task 2. Interview Contractors.

Task 3. Data Collection.

Task 4. Develop a method to efficiently analyze the annual weighted average item prices for accurate forecasting and handle outliers.

Task 5. Develop a method to evaluate lump sum prices for accurate cost estimation.

Task 6. Develop a method to estimate R&R costs using NBI bridge data, weighted average item prices, and other variables.

Task 7. Evaluate bridge scoping work types, identify pay items and quantities needed for the work types, and develop a spreadsheet that accurately estimates the cost of the specific work types using the information typically available during scoping.

Task 8. Produce an interactive worksheet that allows the user to input data and generate a rehabilitation scenario.

Task 9. Provide a guidance document that instructs how to use the developed worksheets and facilitates updating cost estimates on a yearly basis.

Task 10. Prepare project deliverables.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A literature review was conducted to identify relevant research and best practices pertaining to bridge price estimation. The review included a search for technical journals, conference proceedings, and other sources such as research reports at the national and state (DOT) level. The specific goals of the literature review were to: 1) identify accurate approaches for construction price estimating, and 2) identify accurate price estimating procedures that have been employed, with a focus on bridge applications.

Various approaches have been used to attempt to improve cost estimation. The most common among these are statistics-based approaches such as multiple linear regression, and machine learning techniques such as artificial neural networks (ANN). Case-Based Reasoning (CBR) has also found to be effective. These approaches are the focus of the literature review and discussed below.

2.2 Case-Based Reasoning (CBR)

CBR is based on the idea of using existing solutions of previous problems as a template to solve a future problem. The use of CBR is described in detail by Aamodt and Plaza (1994). In general, CBR is composed of four steps: retrieve, reuse, revise, and retain. The retrieval step involves finding historic cases most similar to the current problem, using some criterion to measure the similarity between cases. For example, the Euclidean distance might be used, such that the shortest measure indicates the historic case most similar to the present case. The reuse step uses the set of most similar problems to approximate a solution for the new problem. The revise step then evaluates and improves the proposed solution. Retain is the last step, where the solution of the new problem in retained in the database of solutions for future reference/retrieval. CBR systems can thus continuously learn and evolve from past experiences.

Kim et al. (2011) suggested an optimal CBR approach for construction cost estimation by examining combinations of attributes, criteria for similarity, and retrieval ranks, and applied a genetic algorithm (GA) to optimize attribute weights. CBR was found to work best with a five-attribute combination, retrieving six similar cases to the project, and using similarity criteria by applying a penalty in which 10 points are deducted for each 10% similarity difference. Multipe methods were considered for the calculation of similarity between cases, including regression analysis and GA. The final model had a mean absolute error 11.9% and a standard deviation of the absolute error of 12.7%. The model was found to be 30% more effective than the existing approaches for cost estimation (the Ministry of Construction & Transportation and Korea Development Institute models).

Ji and Hong (2010) suggested an approach for the retrieval step in CBR for small project databases that improved accuracy. In particular, it was suggested that the proposed solution value is adjusted by a function of the retrieved case and the current case as follows:

$$ARV_i = \left(\frac{AW_i}{\sum_{i=1}^{n} AW_i} \times PS\right) \times AER_i \tag{2.1}$$

where ARV is the attribute revision value for the i^{th} attribute; AW is the attribute weight; PS the proposed solution value; and AER the attribute error rate. After using this approach, the estimation improved the range of error rate from 40-130% to 20-40% for rank 1 to 9 case similarities.

Lesniak and Zima (2018) used CBR to estimate the preliminary costs of sports fields using 16 predictors and a prior database of 143 construction projects, as well as business facilities. The CBR approach improved the previous cost estimation model accuracy by approximately 17%.

Abdelaty et al. (2020) recently applied CBR to bridge price estimation for Iowa DOT and recommended a process to be used. In the context here, the first step is to retrieve similar construction or maintenance problems to that considered and access the associated price data. The selection process is based on a weighted sum 'similarity score', calculated from different project characteristics. These characteristics may include various items, such as project type (new, R&R, CPM, etc.), location, bridge geometry, beam type, age, extent of damage, as well as others. Different project characteristics are assigned weights based on importance, where the relative importance of characteristics is determined by expert ranking. Once weights are determined, a search algorithm is implemented to scan the historic project information database and retrieve a set of projects with the highest similarity scores.

Two types of project characteristics can be included in the similarity score: continuous variables and discrete variables. An example of a continuous variable is bridge length. For this type of variable, a component similarity score *CS* is calculated from the absolute value of difference between the current project and the past project. For example, | *Span* l*ength current – Span length past* |. For this particular characteristic, historic projects are then ranked in ascending order, with the 1st ranked project receiving a full matching score (1.0) and lower ranked projects receiving increasing reductions in score; for example, the 2nd ranked project may receive a score of 0.9; the 3rd ranked project 0.8, etc. Once a zero score is obtained, no additional projects are included in the ranking (thus in this example, only the 10 most similar projects would be included for bridge length). Discrete variables would be used to assign numerical values to categorical data, such as beam type (i.e. steel girder, PC girder, etc.). Here, only a complete match (score = 1.0) or no match (score = 0) would be used.

Once all past project characteristics are ranked and given a score, the characteristic scores are summed to develop the complete similarity score *SS*, where *w* is the weight assigned to that particular project characteristic:

$$SS = \sum_{i=1}^{n} CS_i \cdot w_i \tag{2.2}$$

Abdelaty et al. (2020) compared CBR results to multiple regression and ANN and concluded that that ANN and regression-based modeling techniques were unreliable, and thus CBR was recommended for use.

2.3 Machine Learning and Artificial Neural Networks

To make future predictions based on historic trends, the ANN method relies upon a framework of various processing layers, each composed of multiple interlinking nodes ("neurons"). Specifically, within a particular layer, each node is linked to the nodes in the previous (upper) layer such that the output of nodes in an upper layer becomes the input to nodes in the next lower layer. For a given node, a weighted sum of its inputs is passed through an activation function, which is traditionally taken as a sigmoid (logistic) function. The purpose of the activation function is to transform the weighted sum of inputs to a desired range of output. During the 'learning' phase, input weights are optimized to maximize the predictive capability of the network.

In an early study, Smith et al. (1997) compared ANN with regression for cost estimates and concluded that which approach is superior depends on the problem type. Specifically, with known cost estimate relationships and a small number of variables, regression produced better results, especially if data are sparse. However, in cases where a large number of variables exist and there are no obvious relationships between variables and outcomes, ANN tends to be more accurate. Smith also noted that, although ANN could be more accurate than parametric models in some cases, it offers minimal explanatory ability and limits the ability to draw insights. Later, Winalytra et al. (2018) continued this research and applied common ANN variations to estimate bridge costs, comparing results with multiple linear regression. It was found that the neural network performed insignificantly better than regression.

To avoid overfitting, Rutkowski (2005) suggested that the size of the training database should not exceed the network size. Here overfitting refers to the situation where the model fits a given dataset very well but produces inaccurate results for a dataset that is only slightly different. To avoid this issue, back testing can be used to check the robustness of the model and estimate realistic model accuracy. This is done by splitting the data into a training set (typically 60-80% of the data, which is used to build the model) and a testing set (the remaining data), to quantify model accuracy.

El-Sawah et al. (2014) compared traditional parametric cost estimating regression techniques to multiple ANN models for timber bridge cost estimation. The ANN models considered were the Back Propagation Neural Network (BPNN), Probabilistic Neural Network (PNN) and Generalized Regression Network (GRNN) approaches. The result showed that estimating error decreased when the number of predictors increased, and the most accurate model was PNN. The study also compared results considering a larger number of low-rise structural steel building costs. In this case, using a training sample size of 30, it was found that BPNN was most accurate (Mean Absolute Percent Error, MAPE = 17%), followed by GRNN and PNN (MAPE= 19% for both), and then regression (MAPE=24%). When only 10 training samples were used, PNN was most accurate (MAPE = 22%), followed by BPNN and GRNN (about 36% for each), and regression (MAPE=85%). Given the small change in error obtained with PNN when the sample size changed, it was regarded as the most stable model.

Juszczyk (2017; 2020a; 2020b) explored the use of multiple Support Vector Machine (SVM) learning methods to estimate the cost of bridge projects, varying meta-parameters C and ε from 7-10 and 0.05-0.10, respectively. The most effective model was found to have $C = 8$ and $\varepsilon = 0.05$, which produced MAPE = 10.94%. He further examined different implementations of ANN by varying the number of layers and the number of neurons per layer (input, hidden and output). The best ANN result occurred with 21, 2, and 1 neuron for the input, hidden, and output layers, respectively, and resulted in MAPE of 16.7%. It was noted that ANN has the potential to learn data pattern without the need for establishing a direct relationship between the dependent and independent variables.

In related work, Wang and Ashuri (2016) presented a method that utilizes highly correlated economic variables to predict the Construction cost index (CCI) by applying the modified k nearest neighbors (k-NN) machine learning algorithm. Although the CCI is a widely used index for cost estimation, since short-term volatilities are high, its use can be problematic to accurately estimate the cost of current construction projects. The k-NN approach is a classification algorithm that, for each new data point, searches the database to find the k closest ("nearest neighbor") data points and assigns the existing data point classification with highest frequency to the new data point. A modified k-NN model can be used as well, which applies weights to its neighboring points before the final classification. For the problem considered, k was varied from 1 to 10, and it was found that the modified k-NN algorithm with k = 4 yielded the smallest prediction error with MAPE = 0.11%.

Other efforts include those by Ambrule and Bhirud (2017), who used ANN to estimate the cost of reinforced concrete building structures and found acceptable performance, while Arabzadeh et al. (2018) compared ANN, regression, and hybrid approaches for storage tank cost estimation, and determined that ANN was most accurate.

2.4 Regression

Flyvbjerg et al. (2002, 2003) found that two advantages exist with multiple linear regression over machine learning approaches such as ANN: interpretation and implementation. In terms of interpretation, linear regression models allow clear quantification of how much of the cost estimate is explained by each cost factor, whereas the ANN approach is often a 'black box' result that provides limited insight to the problem. In terms of implementation, it was further found that regression approaches tend to be more robust, providing greater resistance to error when the dataset changes.

Behmardi et al. (2015) implemented a Frequentist Approach, i.e. Linear Mixture Model (LMM) Analysis; a Bayesian Approach, i.e. Hierarchical Analysis; and the ordinary least squares method (OLS) to predict the lump sum cost of bridge projects using a data set of 190 bridge replacement projects. It was found that LMM had least root mean square error (RMSE) of 4.32, closely followed by the Bayesian approach (4.51), and OLS (6.83). The LMM was thus recommended.

The LMM approach is a multi-level regression model that considers correlations among levels of independent variables in the analysis. It does this by conceptually grouping a set of variables together, and is often used to model hierarchical data, such as which may exist among bridge cost data. For example, rather than treating all cost-influencing parameters as independent as in a traditional regression approach, a set of lower-level parameters (such as bridge length, width, number of girders, etc.), in terms of cost, might be strongly related to a smaller number of higher-level parameters (such as bridge type, location, or age). Conceptually, the larger set of lower-level parameters can be grouped into a single data "point" in the regression, which focuses on the higher-level variables, rather than treating all input parameters as independent variables at the same level of importance.

Tree-based regression (such as random forests, boosting trees, and their variants) has also been used for cost estimation. This is an iterative process that splits the data into partitions or branches, and then continues splitting each partition into smaller groups as the method moves up each branch. Splitting makes the model more flexible than classical regression models (Perner et al. 2001). This method was shown to be accurate in a variety of prediction problems in recent years. It was recently utilized in bridge cost estimation as discussed by Elmousalami (2020) and Chakraborty et al. (2020). An advantage of tree-based regression is that tuning hyperparameters is often more manageable than that of ANN. However, tree approaches often result in poor performance when time series, noisy, or nonlinear data are considered (Curram and Mingers 2017). Common tree-based algorithms include the chi-square automatic interaction detector (CHAID), classification and regression trees (CART); and C4.5/C5.0, where CHAID is meant for categorical parameters and the latter two approaches are applicable to both continuous and categorical parameters (Quinlan 2014; Berry and Linoff 1997; Breiman et al. 1984). Earlier applications include that by Fan et al. (2006), who used a tree approach to estimate house prices, and Moussa et al. (2006), who proposed a tree model using multilevel probabilistic networks.

Crespo and Gret-Regamey (2013) introduced an extension of OLS, mixed Geographically Weighted Regression (mixed-GWR), to better capture the characteristics of housing pricing. The method allows some parameters to vary over space while others remained fixed. For example, specific house characteristics may vary, where the national unemployment rate is a fixed, global parameter. It was found that a global regression model produced a RMSE of 434, a simple GWR had RMSE of 448, while the RMSE of the mixed-GWR model was 295, a significant improvement.

Hannonen (2008) compared two parametric approaches (OLS and robust MM-estimation) to semi-parametric (structural time series estimation) and non-parametric (robust local regression) approaches to predict land prices. It was found that all models performed better than the conventional least squares estimation, with MAPE for OLS, MM-estimation, time series, and local regression equal to 2.56, 2.42, 2.38, and 2.45, respectively.

Hollar and Rasdorf (2013) modelled the preliminary engineering (PE) costs for highway projects using regression. Although the prediction error of the final model was undesirably high (42.7%), the regression analysis did give useful insights into PE cost-estimating. It was found that instances of extremely high or low PE costs may be caused by unpredictable factors such as public resistance and some difficulties in the right-of-way acquisition. The authors suggested that a qualitative approach using comparative case studies could improve cost estimates for unusual cases.

Shahandashti et al (2013) introduced a multivariate time series model, Vector Error Correction (VEC), to project CCI and identify potential explanatory variables. Results of different VEC models were compared to seasonal autoregressive integrated moving average (S-ARIMA) and Holt-Winters exponential smoothing (HW-ES) models. It was found that one of the VEC model variants performed best, with MAPE of 0.84, compared to MAPEs for S-ARIMA and HW-ES of 1.40 and 2.68, respectively.

Zhang and Minchin (2017) used a non-parametric approach, Multivariate Adaptive Regression Splines (MARS), to estimate preconstruction costs for Florida DOT. The dataset consisted of 408 projects, and the 10-fold cross-validation method was employed to assess model performance. The authors concluded that MARS could reasonably well-predict pre-construction costs, although no comparison to baseline results are provided.

Fragkakis et al. (2015) used linear regression to predict culvert construction costs. To identify the most influential parameters, the researchers interviewed civil engineers with significant experience in bridge design, structural experts, as well as academics. The experts suggested four critical cost-influencing parameters for use in the linear regression model, which resulted in an average MAPE of 14%.

Rodriguez et al. (2006) modeled the replacement costs for bridge superstructures, substructures, approaches, and other costs with linear regression, a Cobb–Douglas cost function, and a constrained/transformed Cobb–Douglas cost function. Depending on the bridge type (slab, concrete beam, and steel beam) and type of replacement cost, different approaches among those considered were found to perform best.

Baek and Ashuri (2021) developed multiple time series models to predict the ratio of the lowest bid to the Georgia DOT estimate for bridge construction projects, using a database of over 2,200 bidding records submitted by contractors. The time series models are based on a seasonal autoregressive integrated moving average (ARIMA), with an explanatory variable (ARIMAX) approach. MAPE ranged from 3.8-5.15, depending on model formulation. It was found that the best model was a seasonal ARIMAX that considered Nc, Nb, PPISM, and CCI, and resulted in MAPE of 3.8, where Nc is the total number of projects awarded in the same month at the state level, Nb is the average number of bidders last month, PPISM is the Producer Price Index for Steel Mill products, and CCI is the Construction Cost Index.

2.5 Ensemble Methods

An ensemble method, sometimes referred to as 'fusion learning' represents a hybrid of two or more different algorithms to maximize performance (Hansen and Salamon 1990). Two common ensemble methods are bagging and boosting.

Bagging refers to a variance reduction algorithm based on bootstrapping, where the method works by randomly sampling with replacement to use as training data. A random forest (RF) variant of bagging can be used to increase accuracy while avoiding overfitting (Breiman 2001). It implements bootstrap sampling to form multiple trees which are based on a random subset of parameters. As the parameter selection is random, some parameters may be used in multiple trees while others never used. RF is reported to more effectively account for datasets that are noisy or very large (Breiman 1996; Dietterich 2000).

Schapire (1990) introduced an adaptive resampling approach that 'boosts' the performance of an ensemble of other learning algorithms, which later evolved into AdaBoost (Freund and Schapire 1997). This method focuses on the cases which were poorly predicted in previous iterations by altering the weights that were previously assigned to these cases. It also assigns weights to each algorithm in the ensemble based on each method's demonstrated accuracy in previous iterations (Bauer and Kohavi 1999). Stochastic gradient boosting (SGB) was later found to enhance of gradient boosting in terms of accuracy as well as computational cost reduction by introducing some randomization into the data subsets (Breiman 1996; Freund and Schapire 1996).

The Extreme Gradient Boosting (XGBoost) variant is a scalable ensemble approach used for very large datasets. It has the ability to handle noisy data as well as process a large number of parameters while avoiding overfitting. To increase learning speed, it draws upon parallel computing concepts (Chen and Guestrin 2016).

Various researchers used ensemble approaches to estimate construction costs. These include Chakraborty et al. (2020), who compared the results of linear regression, ANN, random forest, extreme gradient boosting, light gradient boosting, and natural gradient boosting to estimate construction costs, and found that a hybrid of light and natural gradient boosting worked best in terms of accuracy as well as model development (training) time.

At about the same time, Cao et al. (2018) evaluated an ensemble of gradient boosting and random forest approaches to predict highway resurfacing costs. It was found that XGBoost was most accurate. Similar results were recently found by Elmousalami (2019), who conducted a comprehensive review of methods for construction cost estimation. These included fuzzy logic, ANN, regression, CBR, diction tree, random forest, supportive vector machine, AdaBoost, XGBoost, and genetic algorithms. When applied to field canal construction costs, it was concluded ensemble methods such as boosting trees, bagging, random forests, AdaBoost, and supportive vector machine produced low error rates, while XGBoost performed best.

2.6 Other Approaches

A variety of simplified ad-hoc methods have been proposed for cost estimation as well. Some of these include Chou et al. (2005), who proposed a simulation method to produce a 95% confidence interval estimate of preliminary costs of highway bridge replacement, which were estimated as:

$$Project\ Cost = \frac{\sum_{i=1}^{22} ItemCostPerLaneKm_i}{80.2\%} \times (1 + Contingency\%) \qquad (2.3)$$

The approach sums 22 key item sub-costs, which represent 80.2% of the total cost, and multiplies this result by the desired contingency. The research concluded that the simulation is more reliable when considering cost correlations.

Another approach is that presented by Fereshtehnejad et al. (2018), which used deterministic formulas to calculate different costs of bridge maintenance, repair, and replacement (MR&R) projects for Ohio DOT. This approach does not predict unit costs but models the relationship between unit costs and the final lump sum cost. Since the model is neither statistical nor calibrated from data, the accuracy partly depends on the DOT's unit cost estimates/historical record.

A recent example conducted for Texas DOT is that presented by Son and Khwaja (2022), who investigated the preliminary engineering costs of different bridge construction project types, including bridge maintenance, replacement, and bridge widening and rehabilitation. The estimation process used the Mann–Whitney U test on costs between project size groups, which evaluates the null hypothesis that two non-Gaussian distributions are drawn from the same population. It was found that this process was useful to estimate general costs of a particular project type for planning purposes, but more accuracy was desired when estimating costs for individual projects.

2.7 Detecting and Handling Outliers

A large number of methods exist to detect and remove outliers. Numerous approaches are summarized in Iglewicz and Hoaglin (1993) as well as Hodge and Austin (2004). Some of these include: standard deviation exceedance (z-score); the median absolute deviation; studentized residual; Cook's distance; and bidding theory approaches. A few of these methods thought to be most relevant to this study are summarized in further detail below.

A traditional approach is to use a simple z-score; i.e. discarding data that are a certain number of standard deviations from the mean. The problem with this approach is that it tends to be ineffective for smaller data sets (Leys et al. 2013), which is likely to be the case for many projects. In such instances, a more robust method can be used, the median absolute deviation (*MAD*) metric (Iglewicz and Hoaglin 1993). Considering the latter, the test statistic is defined as:

$$MAD = k\, M(|x_i - M_j|) \tag{2.4}$$

where k is a constant depending on the distribution of the data (for example, taken as k= 1.4826 if data are normally distributed); M_j is the median of the data set; x_i a particular data point; and M the median of the new data set formed from the absolute value of the difference $(x_i - M_j)$. Using this metric, a modified z-score can be developed, where outliers are frequently defined as those which fall from 2.5-3.5 standard deviations from the mean. Using 3.0 as an example limiting value, the criteria becomes:

$$\frac{x_i \mp M_j}{MAD} > 3 \tag{2.5}$$

The studentized residual, based on Student's t-statistic, is often useful to detect outliers (Iglewicz and Hoaglin 1993) in regression, which is given as:

$$RSTUDENT_i = \frac{e_i}{s(i)(1 - h_i)^{0.5}} \tag{2.6}$$

where e_i is the residual between observation i and prediction i; $(1 - h_i)s(i)$ is the estimated variance with h_i as the leverage of observation i in the linear regression. A commonly recommend criteria for identify outliers is to use $RSTUDENT_i \geq 2$ and $RSTUDENT_i \leq -2$, which approximately corresponds to 5% chance of exceedance. Once outliers are detected, it is best to test the impact of their removal on the regression model prior to finalizing the decision to exclude from the data.

Cook's Distance (D) is an alternative approach commonly used in regression. This method quantifies how much the model prediction changes with respect to each data point when a particular data point is removed (Cook and Weisberg 1982). Stevens (2002) suggests that if D >1, the data point should be considered for deletion.

Skitmore (2001) assessed several outlier detection models, including those by Friedman (1956), Gates (1967), Carr (1982), and Skitmore (1991) on 3 datasets using different testing frames. It was found that the Friedman and Gates criterion worked best among all. Skitmore (2001) further proposed several methods to identify high bids (outliers), which considered removing the: highest k bids; highest n-m bids (where n is the number of bids in the auction); bids higher than the average bid plus x_1 times the standard deviation; bids x_2 times higher than the mean bid; bids higher than x_3 times the lowest bid; highest x_4% bids. It was additionally proposed that, when considering a set of prices $X_{(1)}, X_{(2)}, \cdots, X_{(N)}$, the two most lowest ($X_{(N)}$ and $X_{(N-1)}$) and two most highest ($X_{(1)}$ and $X_{(2)}$) prices are used for rejection criteria. Considering high price rejection, the criteria becomes: $X_{(1)} + k(X_{(1)} - X_{(2)})$, where prices that exceed this margin are removed from the database. A similar criteria exists to reject low end prices: $X_{(N)} + k(X_{(N)} - X_{(N-1)})$. Here constant k is selected to provide the best fit to the test data.

2.8 Identifying Significant Cost-Influencing Parameters

As noted by Kan (2002), poor parameter identification generally results in a poor quality parametric model in terms of performance and accuracy. On the other hand, the optimal set of parameters has the potential to produce an accurate model with relatively low computation effort. Two broad categories of methods exist to identify important cost parameters: qualitative and quantitative methods.

Qualitative methods include variations of the Delphi method and Likert Scale. In general, the Delphi approach is essentially a summary of expert opinion, where results, usually presented in terms of a ranking of parameter importance, are revised until agreement is reached among the panel (Hsu and Sandford 2007). The Fuzzy Delphi Method variation involves introducing fuzzy logic to further process the Delphi rankings, with the goal to more reliably confirm the intended panel rankings (Ishikawa et al. 1993).

The common Likert Scale approach similarly asks a panel of experts for parameter ranking, while assigning descriptive language to a numerical scale of importance; e.g. “Most important” might be given 4 points; “Important” 3 points; “Slightly important” 2 points; and “Unimportant” a single point. Here the wording and size of the scale is open for selection (Bertram 2017). The panel surveys are collected and statistically analyzed to determine parameter importance.

An alternative ranking approach is the Fuzzy Analytic Hierarchy Process (Laarhoven and Pedrycz 1983), an integration of the analytic hierarchy process (AHP) (Vaidya and Kumar 2006) and fuzzy theory. In this method, the initial values resulting from AHP, which are deterministic, are transformed to fuzzy results to allow uncertainties to be included in the decision process. In some cases, this approach was found to provide a better assessment of critical cost parameters (Elmousalami 2019).

A larger variety of quantitative methods exist. When using such methods, a frequent concern is using a number of parameters that is suitable for the available database. In particular, using too many parameters for the size of the database leads to poor predictive capability (Kohavi and John 1997), and thus parameter reduction is thus a common goal for quantitative methods. Although there are no universally accepted a-priori rules to determine maximum parameter set size, some guidance does exist. For example, Nunnally (1978) and Kass and Tinsley (1979) proposed that the sample size should be between 5 and 10 times the number of variables considered, while Green (1991) suggested that the minimum sample size of (50 + 8k) is needed for an accurate regression model, where k is the number of predictors used.

A common quantitative approach to reduce the number of variables is factor analysis (FA), a machine learning method to identify correlated parameters and reduce them to a critical set. Various types of FA exist; some of these include principal component analysis, canonical factor analysis, and image factoring (Polit and Beck 2012).

Regression analysis can also be used for the determination of critical cost parameters, where common approaches include forward selection, backward selection, and bidirectional selection. In a forward selection method, parameters are ranked by significance and the most critical are added to the model, one at a time, until model results no longer show significant improvement (Ratner 2010; Wilkinson and Dallal 1981). In contrast, backward selection begins with all possible parameters included in the model, and those deemed least critical are removed, one at a time, until the model shows a significant reduction in capability (Field 2009; Draper and Smith 1998). A bi-directional method is initially similar to forward selection, where the model initially contains no parameters, but are added in each iteration based on significance. However, at each iteration, parameters may also be removed similar to backward selection (Flom and Cassell 2007).

Simple elimination based on correlation is an alternative approach, where a parameter that is highly correlated (say with $\rho > 0.80$ or so) with another is removed, while if a parameter is found to have low correlation to the model output (say with $\rho < 0.3$) it is similarly removed (Ozdemir et al. 2001).

Some researchers have used a genetic algorithm (GA) to optimize the model performance based on the selection of various features, such as the number of variables or ANN nodes or levels (Siddique and Adeli 2013; Yang and Honavar 1998; Ozdemir et al. 2001).

Petroutsatou et al. (2012) and ElSawy et al. (2011) found that, for construction cost estimation, the questionnaire-based Fuzzy Analytic Hierarchy Process is most commonly used to identify critical cost parameters. Although many quantitative options exist, a common hurdle to implement these approaches is an insufficient database size and quality (Elmousalami 2019).

After an extensive review of cost estimation models, Elmousalami (2019) recommended that both quantitative and qualitative approaches should be used to identify the most important parameters affecting costs. It was further suggested that fuzzy processes such as FAHP are used for qualitative selection and methods such as GA and ANN are considered for a quantitative approach.

2.9 Summary of Work for DOTs

Several DOTs have recently sponsored research work to improve construction cost estimates, where a variety of methods were used. These include:

Florida DOT: A multivariate adaptive regression spline approach was used to estimate preconstruction costs (Zhang 2017);

Ohio DOT: Deterministic formulas based on Ohio DOT's unit costs were developed to calculate different costs of bridge maintenance, repair, and replacement (MR&R) projects (Fereshtehnejad et al. 2018);

Iowa DOT: a CBR approach was developed and applied to estimate bridge construction prices (Abdelaty et al. 2020);

Georgia DOT: a time series model was used to predict the ratio of the lowest bid to the estimate for bridge construction projects (Baek and Ashuri 2021);

Texas DOT: A Mann–Whitney U test was employed on costs between project size groups, to estimate preliminary engineering costs (Son and Khwaja 2022).

2.10 Summary and Conclusions

A wide variety of methods have been used for cost estimation. These include regression, machine learning approaches such as ANN, CBR, ensemble techniques, as well as others. Researchers have not found consistent results with any particular approach, however, where which method works best is highly problem-dependent. This is evident from the wide variety of methods suggested from cost-estimation research conducted for state DOTs. As such, an ensemble method, where two or more techniques are combined, may have the greatest potential for accurate solution for a universal problem.

A related concern is how data outliers are identified for removal. As with cost estimation approaches, numerous methods have been proposed. Here, some guidance is available for the appropriateness of some approaches depending on problem type, although few clear rules exist. As such, a comparison of the effectiveness of several different options may be best.

Prior to building an effective cost estimation model, it is critical to identify the critical variables that affect costs. Both qualitative and quantitative methods exist for this purpose. Using both types of approaches may provide the greatest likelihood to find an optimum solution.

CHAPTER 3: INTERVIEWS AND SURVEYS

3.1 Contractor Interviews

3.1.1. Introduction.

Two contractors involved in estimating MDOT bridge projects were interviewed to determine what their thoughts were on MDOT estimation discrepancies from actual bid prices and how the process might be improved. As possible, this information was used to help select predictor variables in the cost estimation models discussed in Chapter 5. Some of the questions discussed were:

- What are some major factors that influence unit costs (e.g. project type/activity; bridge characteristics / geometry; accelerated scheduling; half-width construction; location; other factors)?
- Describe cost shifting/front-loading. In what cases would this typically occur? Can this be accounted for/anticipated in unit cost estimating process?
- What causes the MDOT process to inaccurately estimate the project cost?
- How could the MDOT estimation process be revised to better align with contractor bids?

3.1.2. Summary of Comments from a Project Controls/Claims Group Leader.

Traditionally, bid prices may be increased for additional jobs once the contractor's labor resources have been fully committed. As many contractors currently have a large backlog of work, recent bid prices have been higher than usual.

The recent trend of high price inflation causes contractors to be wary of future price increases. This uncertainty leads to increased bid costs to account for this risk.

A resource for some economic indicators, including a national work backlog metric, can be found from the Associated Building Contractors (ABC):

https://www.abc.org/News-Media/News-Releases/entryid/19696/abc-construction-backlog-and-contractor-confidence-waver-in-october [abc.org]

Currently, there is a significant skilled labor shortage. This labor shortage not only applies to tradesmen, as a shortage of construction managers and even estimators exists. As workers are in demand, contractors must offer more pay, increasing labor prices. Another result of the shortage is that contractors hire workers with less than the desired skills and experience. This inadequately skilled labor pool causes work to be done more slowly, up to 50% longer, and increases the number of errors on the job, significantly reducing productivity. These factors also lead to increased bid prices.

With reference to the various types of cost indices available: other types of construction (e.g. residential) are not necessarily related to bridge construction costs since these markets represent different labor pools.

Higher interest rates also lead to higher bid prices, as some contractors finance major equipment such as cranes.

Many contractors use HCSS software to guide their bid estimates (HCSS.com)

A good way to develop a bid for a current job is to reference similar previous jobs, and consider current unit prices from these jobs.

When multiple projects are ongoing, contractors tend to bid bridges collectively over time. That is, rather than develop unit prices for a specific job at a specific time, 'average' unit prices are considered across multiple jobs throughout a longer time period, and these assumed averaged rates are applied to all jobs.

A+B jobs, where "A" represents the initial job cost and "B" any additional costs charged to the contractor for scheduling delays, may have misleading unit prices. This is because the contractor will often increase costs within "A" as a contingency for possible delay charges from "B". These are rare jobs but should be treated as a special case since unit prices are bid differently than other types of work.

<u>3.1.3. Summary of Comments from a Construction Company President.</u>

Inflation is causing universal increases in costs from materials, fuel, transportation, and labor. H-piling represents another significant cost increase. Costs have increased as much as 100% in some cases. Because cost changes are happening rapidly, basing next year's cost estimate on current year costs is likely to produce inaccurate prices.

One cause of high bid prices are the high liquidated damages charges associated with tight construction schedule requirements. These types of projects add significant risk and therefore costs are increased.

Contractors currently have a surplus of work; this increases bid prices. This is not universal, however. Work backlog does not have much of an effect on the bids of contractors that don't intend to pursue additional jobs for which they don't have the current resources to complete. It is not expected that a decrease in available work will significantly lower current bids.

It is not uncommon for contractors to shift charges from unit prices into lump sums, perhaps up to 30% or so. This often occurs for jobs involving rehabilitation, patching, and concrete chipping/removal.

The cost of mobilization is often used as a miscellaneous item to account for various expenses, which may sometimes include overhead, the cost of supplying a job site office trailer, building an access road if needed, etc. Subcontractors also report their own mobilization cost to the prime contractor, and these costs are included as well. If expected mobilization costs exceed allowable limits, they are recovered in different cost items.

The location of a single structure is not that important, but if multiple bridges are bid together, widely differing locations will increase mobilization costs.

MDOT generally overestimates the work item quantities needed. In some cases, this causes contractors to artificially reduce unit prices to maintain a competitive bid.

Part width construction may be roughly 20% more expensive than full-width work, as these jobs involve more labor and time to complete.

Bids may be slightly higher for winter work, but there is not much seasonal variation in prices.

3.2. Cost Factors Survey

A survey was developed and submitted to the RAP to collect expert opinion on what job parameters were thought to be most important predictors of item prices. The survey is given in Appendix A, as well as the results of the 5 responses that were received.

The most common items thought to contribute to item prices were (in no particular order):

1. Project complexity/other considerations such as full/part width, staging, traffic restrictions.
2. MDOT current total bridge program cost.
3. Bridge location / surrounding features near/over/under, traffic volume.
4. Overall project size (total SF/CY affected), total budget, and #of similar structures in the project; corridor vs stand-alone.
5. Scheduling priorities and flexibility (night/expedited, and restrictions day/night/weekend, etc. time of year w.r.t weather).
6. Completeness of bid packet; vague description of work items, inaccurate quantities, unanswered questions.
7. Incentive/liquidated damage stipulations.

As possible, this information was used in Chapter 5 for predictor selection when models were developed.

CHAPTER 4: PRELIMINARY DATA ANALYSIS

4.1 Description and Summary of Dataset

The MDOT cost data used for this study contain unit and lump sum costs for winning bridge project bids from 2/2009 – 1/2023. Data prior to 2009 are not included in this study because they are not recorded in a format that allows feasible linkage to specific project characteristics.

Based on recommendations from the RAP, items with negative quantities (representing policy-based adjustments for unplanned removal, or value engineering) and those with "adjustment" within the item description (representing balancing items) were removed from consideration.

The remaining database contained approximately 1470 structures ("Job-Strc" items) in 843 projects and 1117 different cost items (i.e. items that have different Item Numbers) from years 2009-2023. A summary of this dataset is shown in Figure 4.1 and Tables 4.1-4.4. A large increase in the number of projects occurred since 2018, as shown in Figure 4.1, while the majority of projects are for single structures (Table 4.1). These 1470 structures have 148 description parameters available in the bridge database, such as deck area, county located, year built, etc. Some description data missing, as shown in Table 4.1a. The number of jobs that involve a particular type of work is given in Table 4.2, where substructure repair, deck patch, bridge approach work, epoxy overlays dominate. This does not necessarily mean that these work items dominate project costs, however. The total cost of all items throughout all projects is given in Table 4.3. As shown, *Structures, Rehabilitation, Rem. Portions* dominates overall expenditures, followed by *Supstr Conc,Form,Fin,and Cure,Night Cast*, then *Reinforcement, Steel, Epoxy Coated*. Note that all prices show very large coefficients of variation (V) from one project to the next. Table 4.4 shows the price items that dominate the cost of projects that contain that item. As shown in the table, most projects contain most of the work items listed, where 13 of these items are contained in approximately 80% or more of all projects, and nearly all are contained in approximately 50% or more of projects. Of these, work items relevant to steel structures (cleaning, removal) and items with unique descriptions, which are "supplemental items" dominate project costs. The following are some of the supplemental items which have significant costs: item number 1027060 (Railroad Inspection and Flagging, Design Build, Guaranteed Maximum Price, etc.); item number 7047051 (Cofferdam, Steel Sheet Piling, Dewatering Barrier, etc.); item number 8507051 (Electrical Rehabilitation, Electrical Work, Bridge Mechanical Machinery, Pier Protection System, etc.), as well as others.

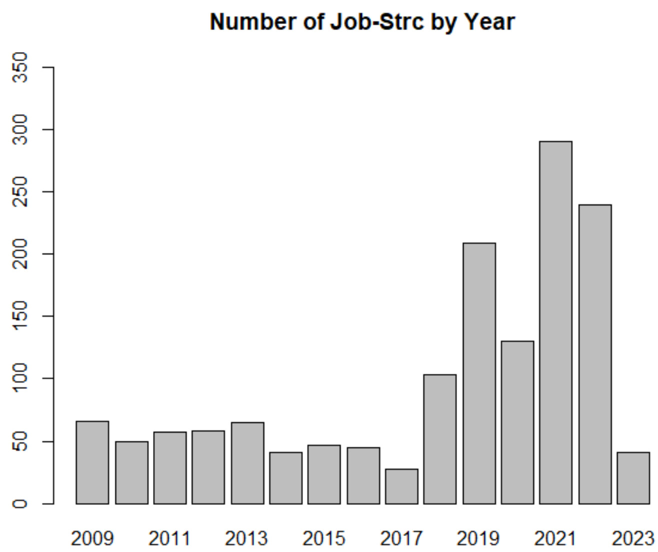


Figure 4.1. Number of Structures in Database.

Table 4.1 Number of Structures within a Project.

Year	Number of Structures
2009	66
2010	50
2011	57
2012	58
2013	65
2014	41
2015	47
2016	45
2017	27
2018	103
2019	209
2020	130
2021	291
2022	240
2023	41
Total:	1470

Number of Structures *n*	Projects with *n* structures	Percent of Projects
1	674	80%
2	78	9%
3	24	3%
4	14	2%
5	11	1%
6	10	1%
7	5	1%
8	6	1%
9	2	<1%
10	5	1%
11	5	1%
12	3	<1%
13	2	<1%
19	1	<1%
31	1	<1%
32	1	<1%
47	1	<1%
Total:	843	

Table 4.1a. Missing Bridge Data.

Number of Descriptors	Percent of structures missing descriptor data	Examples
64	None missing	Deck Area, Year Built
49	2 – 10%	Route Signing, Minimum Lateral Underclearance
14	10 – 50%	Footing Type, Milepoint
9	50 – 80%	Kind of material, Year Reconstructed
12	> 80%	Structure Type - Approach Spans, Critical Feature Inspection Date
Total: 148		

Table 4.2. Number of Jobs that Contain a Particular Work Type.

Type of Work	Number	% of Job-Struc
Substructure Repair	638	44%
Deck Patch	531	36%
Bridge approach	420	29%
Epoxy Overlay	412	28%
Superstructure Repair	337	23%
Joint Replacement	279	19%
Bridge replacement	173	12%
Partial Paint	166	11%
Railing Repair	154	11%
Scour Protection	141	10%
Deep Overlay	126	9%
Full Paint	120	8%
Railing Replace	120	8%
Pin and Hanger	103	7%
Deck Replacement	92	6%
Culvert Replacement	80	6%
Healer Sealer	60	4%
Widen	46	3%
Shallow Overlay	38	3%
HMA Overlay	32	2%
Superstructure Replacement	31	2%
Heat Straightening	17	1%
Concrete Surface Coating	6	0.4%

Table 4.3. Top 20 Item Prices in terms of Total Dollar Amount in the Dataset.

Item Number	Item Description	Number in Database	Total Cost in Database ($)	Mean Price ($)	Coefficient of Variation
7120070	Structures, Rehabilitation, Rem Portions	607	99,380,054	163,723	258%
7060112	Supstr Conc,Form,Fin,and Cure,Night Cast	302	62,339,115	206,421	118%
7060092	Reinforcement, Steel, Epoxy Coated	963	49,568,330	1.76	129%
7150045	Steel Structure, Cleaning, Type 4	163	43,251,388	265,346	135%
7070061	Structural Steel, Plate, Furn and Fab	65	41,234,070	6.12	249%
1027060	*Supplemental item (Railroad Inspection and Flagging, Design Build, Guaranteed Max. Price, etc)*	48	41,003,542	78,863	641%
7060101	Substructure Conc, High Performance	252	40,349,881	963	111%
2040060	Structures, Rem	114	38,084,086	334,071	105%
7047051	*Supplemental item (Cofferdam, Steel Sheet Piling, Dewatering Barrier, etc)*	128	35,998,363	281,237	159%
2040061	Structures, Rem Portions	98	35,390,249	361,125	188%
7150047	Steel Str,Cleaning,Partial,Type 4	323	32,892,309	101,834	131%
4067001	*Supplemental item (Culv, Precast Conc Box)*	56	30,681,681	5,347	62%
7050002	Pile Driving Equipment, Furn	116	23,582,390	203,296	156%
7050034	Pile, Steel, Furn and Driven, 14 inch	61	19,814,946	36.7	74%
7060100	Substructure Conc	198	19,628,705	393	137%
7060050	Expansion Joint Device	600	19,607,539	257	72%
8507051	*Supplemental item (Electrical Rehab, Electrical Work, Bridge Mech. Machinery, Pier Protection, etc)*	100	19,277,890	192,779	301%
7060010	Substructure Conc	333	18,205,164	1,031	92%
2060010	Excavation, Fdn	631	16,284,278	23	102%
2060002	Backfill, Structure, CIP	614	15,193,723	32	84%

Table 4.4. Top Twenty Item Prices that Dominate the Cost of a Project (of 843 Projects).

Item Number	Item Description	Number in Database	% of projects with this item	Mean % cost in a Project*
4067001	*Supplemental item (Culv, Precast Conc Box)*	56	5%	47%
7150045	Steel Structure, Cleaning, Type 4	163	15%	31%
7150047	Steel Str,Cleaning,Partial,Type 4	323	26%	21%
7120070	Structures, Rehabilitation, Rem Portions	607	45%	18%
2040061	Structures, Rem Portions	98	9%	18%
1027060	*Supplemental item (Railroad Inspection and Flagging, Design Build, Guaranteed Max. Price, etc)*	48	3%	16%
7070061	Structural Steel, Plate, Furn and Fab	65	6%	14%
2040060	Structures, Rem	114	11%	13%
7060112	Supstr Conc,Form,Fin,and Cure,Night Cast	302	27%	12%
7047051	*Supplemental item (Cofferdam, Steel Sheet Piling, Dewatering Barrier, etc)*	128	9%	12%
7060010	Substructure Conc	333	31%	7%
7050034	Pile, Steel, Furn and Driven, 14 inch	61	6%	6%
7060050	Expansion Joint Device	600	46%	6%
7060101	Substructure Conc, High Performance	252	22%	5%
7050002	Pile Driving Equipment, Furn	116	11%	5%
7060100	Substructure Conc	198	22%	4%
8507051	*Supplemental item (Electrical Rehab, Electrical Work, Bridge Mech. Machinery, Pier Protection, etc)*	100	4%	4%
7060092	Reinforcement, Steel, Epoxy Coated	963	66%	3%
2060010	Excavation, Fdn	631	53%	1%
2060002	Backfill, Structure, CIP	614	51%	1%

*Of projects that contain that item.

4.2 Initial Statistical Analysis of Dataset

4.2.1 Relationships Between Bridge Parameters and Item Prices

A preliminary analysis was conducted on the dataset to determine if any clear relationships existed between cost items and bridge parameters such as length, deck width, ADTT, year build, etc., on the top twenty costs shown in the Tables above. The parameters chosen for investigation are given in Table 4.4a.

The resulting correlation coefficients for the continuous independent variables (such as bridge length and deck width) and cost items are given in Table 4.5. In the table, darker shading represents higher positive values. Overall, relationships are generally weak to moderate, where most coefficients are less than 0.5, and the top ten coefficients range in value from 0.575-0.273, where the greatest coefficient (0.575) occurs for cost item IN7150045 (Steel Structure, Cleaning, Type 4) and bridge parameter ITEM_49, Length. Scatterplots for the highest nine continuous variable correlations are given in Figure 4.2, where it is clear that most relationships between bridge parameters and cost items are relatively weak.

Table 4.4a. Bridge Parameters Used for Initial Investigation.

Bridge Parameter (ITEM_)	Clarifying Note
52_DECKWIDTH	
49_LENGTH	structure length
66_INV_RATING	inventory rating
48_MAXSPAN	length of maximum span
29_ADTTOTAL	average daily traffic
64MB_MICH_OP_RATING	MI operating rating
27_YEARBUILT	
51_ROADWIDTH	
109_ADTT	
26_FUNCCLASS	functional class
55B_HCLRURT	min. lateral underclearance (right)
54_VCLRUNDER	min. vertical underclearance (of left or right)
34_SKEW	
54D_VCLRRT	min. vertical underclearance (right)
202_YEARPNTD	year painted
56_HCLRULT	min. lateral underclearance (left)
203_YEAROVLY	year an overlay was applied
54B_VCLRLT	min. vertical underclearance (left)
106_YEARRECON	year reconstructed
148_PIN_NUM	number of pin & hanger assemblies

For variables that are categorical (i.e. where a parameter is entered as a specific code in the database rather than a real number, such as for the region in which the structure is located, the type of support, material used for construction, etc.), several hundred boxplots were generated and studied for possible relationships and patterns. In the boxplot, the upper, middle, and lower marks represent the high, median, and low data values, respectively, while the top and bottom of the box correspond to the upper and lower quartile values, the defining the interquartile range. An example of these plots for Cost Item 2040061: Structures, Rem Portions is shown in Figure 4.3 for Region and Footing Type. In this example, it can be seen that the Metro Region clearly has generally higher prices for this item than other Regions, although the variation in price is very large. Similarly, the median price for Footing Type C is clearly greatest, despite the large price variation.

Table 4.5. Correlations Between Bridge Parameters and Item Prices.

	7060010	7120070	2060010	2060002	7060092	7060100	7060050	7150047	2040061	7060112	7060101	2040060	8507051	7050002	7047051	4067001	7070061	1027060	7150045	7050034
ITEM_52_DECKWIDTH	-0.06	0.14	-0.06	-0.07	0	-0.03	0.07	0.06	0	0.17	0.09	0.26	0.15	0.39	0.24	-0.07	0.16	0.07	0.46	0.1
ITEM_49_LENGTH	0.16	0.16	0.07	0.02	-0.03	0.01	-0.03	0.34	0	0.45	0.07	0.35	0.04	0.21	0.03	0.15	-0.1	0	0.47	0.16
ITEM_66_INV_RATING	-0.11	-0.05	-0.01	0	0.03	-0.24	0.1	-0.03	-0.11	-0.08	0.09	0.19	-0.08	-0.05	0.07	0.16	0.96	-0.05	-0.1	0.03
ITEM_48_MAXSPAN	0.15	0.12	0.02	0	-0.04	-0.08	0.03	0.29	0.17	0.32	-0.04	0.34	0.18	0.11	0.13	0.31	-0.14	-0.06	0.55	0.01
ITEM_29_ADTTOTAL	0.12	0.11	0.06	0.03	-0.03	0.01	0.16	-0.03	0.24	0.11	0.06	0.51	-0.11	0.36	0.25	0.3	0	-0.1	0.48	0.52
ITEM_64MB_MICH_OP_RATING	-0.12	-0.05	-0.05	-0.06	0.01	-0.25	0.08	-0.09	-0.05	-0.08	0.07	-0.26	-0.04	-0.05	0.06	-0.24	0.96	-0.02	-0.1	-0.13
ITEM_27_YEARBUILT	-0.22	-0.01	-0.32	-0.35	-0.08	-0.3	-0.09	-0.04	0.1	-0.05	-0.2	-0.33	0.15	-0.29	-0.19	-0.13	-0.38	0.24	-0.1	-0.62
ITEM_51_ROADWIDTH	-0.01	0.18	-0.08	-0.08	-0.03	-0.02	0.07	0.06	0.13	0.16	-0.02	0.01	0.09	0.05	0.19	-0.23	0.21	0.08	0.45	-0.03
ITEM_109_ADTT	0.1	0.2	0	-0.02	-0.03	0.07	0.15	0.05	0.15	0.17	0.01	0.5	-0.04	0.19	0.48	0.23	0.09	-0.12	0.29	0.53
ITEM_26_FUNCCLASS	0.06	0.04	0.01	0.01	-0.06	-0.15	0.08	-0.11	0.18	0.12	0.05	0.09	0.14	0.09	-0.08	-0.04	-0.24	-0.17	0.15	-0.4
ITEM_55B_HCLRURT	-0.03	-0.04	-0.03	-0.02	0.12	-0.07	-0.08	-0.04	0.1	-0.12	-0.04	-0.24	-0.03	-0.02	0.04	-0.17	0.36	0.06	0.02	0.11
ITEM_54_VCLRUNDER	0.06	0.05	0.11	0.07	-0.11	-0.02	0.07	-0.1	-0.08	0.14	0.01	0.21	0.17	0.04	-0.11		-0.24	0.1	-0.04	-0.45
ITEM_34_SKEW	-0.01	0.16	0.04	0.03	-0.05	0.13	0.06	0.09	0.18	0.24	0.09	0.05	-0.15	0.23	-0.1	-0.18	-0.05	-0.14	0.11	0.11
ITEM_54D_VCLRRT	-0.04	0.02	-0.02	0.01	-0.02	0.04	0.03	0.12	-0.17	-0.02	0.09	-0.42	0.02	-0.24	0	0	0.16	-0.17	0	0.19
ITEM_202_YEARPNTD	-0.03	0.04	-0.07	-0.12	0.04	0.05	-0.05	-0.05	0.24	-0.07	-0.06	-0.51	-0.07	-0.3	-0.21	0	-0.03	0.02	-0.06	-0.43
ITEM_56_HCLRULT	-0.03	-0.06	-0.03	-0.02	-0.04	-0.07	0.03	-0.04	-0.17	0.04	-0.04	0.13	-0.03	-0.02	-0.1		-0.13	0.26	-0.12	0.11
ITEM_203_YEAROVLY	-0.02	-0.03	-0.15	-0.17	-0.12	-0.15	-0.16	0.01	-0.45	-0.16	-0.05	0.09	0.01	-0.28	0.01	0	-0.24	0.22	-0.01	0
ITEM_54B_VCLRLT	-0.15	0	-0.08	-0.1	-0.03	0.03	0.04	-0.06	0.08	0.07	-0.07	0.07	-0.13	0.24	0	0	-0.12	0.12	0.01	-0.12
ITEM_106_YEARRECON	0.05	0.22	-0.11	-0.28	-0.14	0.21	-0.09	0.02	-0.27	0.18	0.24	0	0.09	0.01	-0.38	0	-0.34	0.28	-0.19	0
ITEM_148_PIN_NUM	-0.06	0.15	0.05	0.08	-0.07	-0.04	0.12	0.02	0.23	0.3	0.17	0.18	-0.05		0.15		0.25	-0.13	0.13	0.43

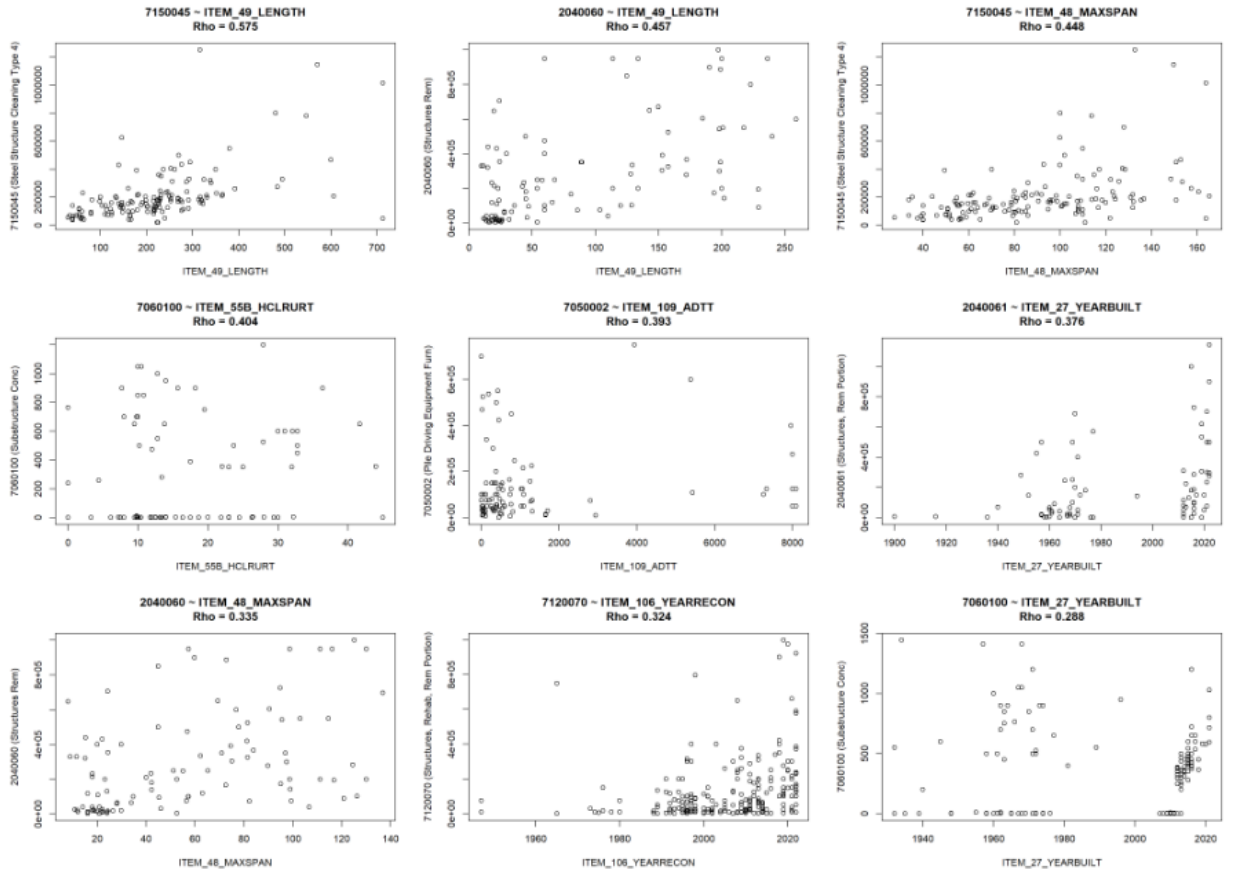
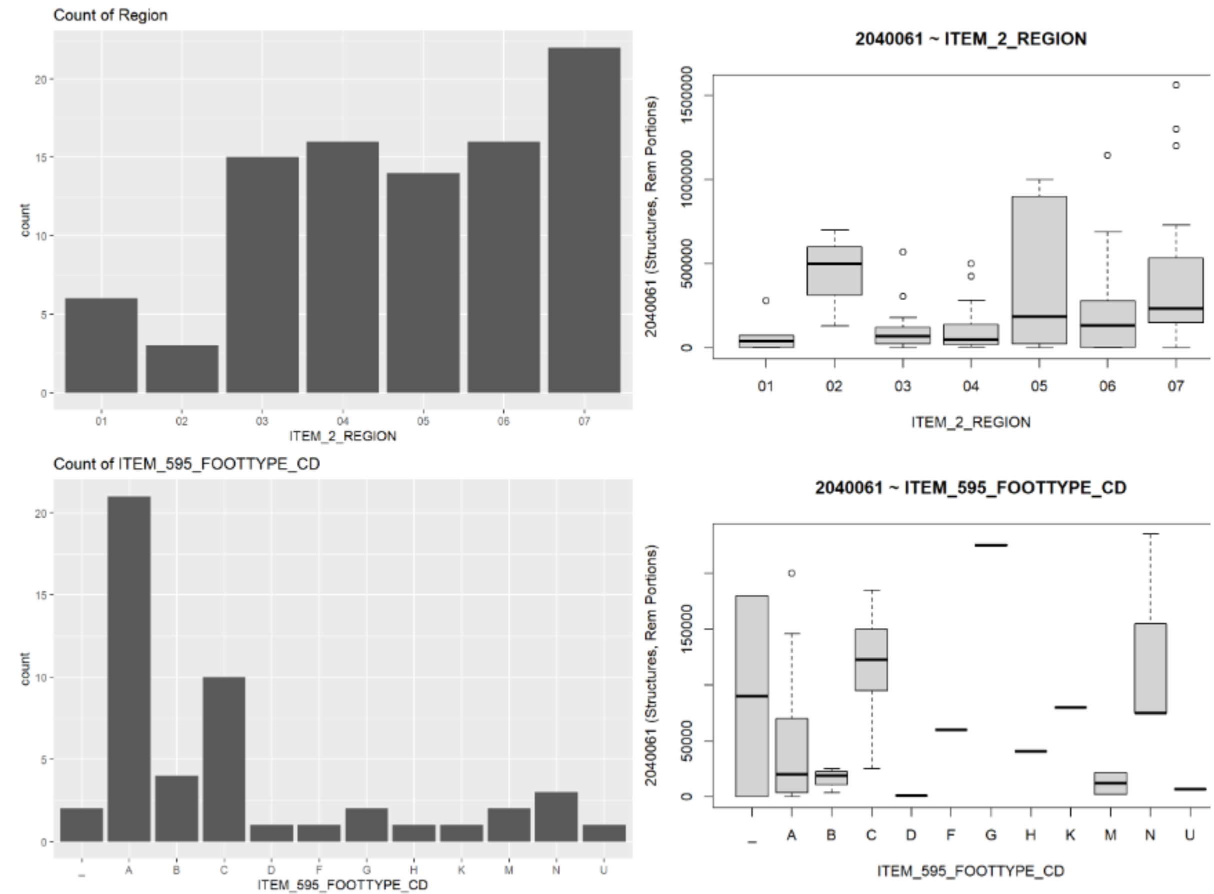


Figure 4.2. Scatterplots For Top 9 Correlations, Initial Analysis.



01 - Superior 02 – North 03 - Grand
05 - Southwest 06 – University 07 - Metro

A Spread Footing on soil B Footing/timber piles C Footing/steel H piles
D Footing /steel tube piles E Footing on Tremie F Pile bents
G Caisson H Curtain wall I Spread footing on rock
J Footing in cofferdam K Gravity Type on Soil L Gravity Type on Timber Piles
M Grav. Type, Steel H-Piles N Grav. Type, Conc. Piles P Gravity Type with Tremie
Q Gravity Type on Rock

Figure 4.3. Example Boxplot of Categorical Variables and Item Prices.

4.2.2 Relationships Between Type of Work and Item Prices

In Table 4.6, point-biserial correlation coefficients are shown between the type of work done and price of various cost items. Similar to the results of Table 4.5, correlations are moderate to weak, where coefficients range from a high of 0.50 to 0.38 for the top 10 relationships. The strongest relationship (0.50) is between the price of IN2040060 (Structures, Rem) and the work type Bridge Replacement.

Table 4.6. Correlations Between Types of Work and Item Prices.

	IN2060010 : Excavation, Fdn	IN7060010 : Substructure Conc	IN7120070 : Structures, Rehabilitation, Rem Portions	IN2060002 : Backfill, Structure, CIP	IN7060092 : Reinforcement, Steel, Epoxy Coated	IN7060050 : Expansion Joint Device	IN7060100 : Substructure Conc	IN7150047 : Steel Str,Cleaning,Partial,Type 4	IN2040061 : Structures, Rem Portions	IN7060101 : Substructure Conc, High Performance	IN7060112 : Supstr Conc,Form, Fin,and Cure,Night Cast	IN7070061 : Structural Steel, Plate, Furn and Fab	IN8507051 : _	IN2040060 : Structures, Rem	IN4067001 : _	IN1027060 : _	IN7050002 : Pile Driving Equipment, Furn	IN7047051 : _	IN7150045 : Steel Structure, Cleaning, Type 4	IN7050034 : Pile, Steel, Furn and Driven, 14 inch
HMA_Overlay	0.03	0.03	(0.05)	0.04	0.07	(0.04)	0.01	(0.04)			(0.08)			(0.10)				0.06	(0.06)	
Epoxy_Overlay	0.13	0.24	(0.03)	0.22	(0.00)	0.31	0.13	0.11	(0.14)	0.40	0.05	0.11					(0.02)		0.10	
Healer_Sealer	0.04	0.00	(0.09)	0.07	(0.01)	(0.04)		0.05	(0.09)	0.03	(0.07)	0.37							(0.06)	
Deep_Overlay	(0.02)	0.04	(0.08)	0.00	(0.04)	(0.02)	0.03	0.11	(0.06)	0.07	(0.07)	0.06		(0.04)				(0.07)	(0.06)	
Shallow_Overlay	0.08	0.01	0.08	0.13	(0.09)	(0.01)	0.15	(0.02)			(0.05)						(0.07)		0.02	
Superstructure_Repair	0.23	0.13	0.08	0.22	(0.11)	0.16	0.38	(0.01)	(0.15)	0.31	0.14	0.38					(0.08)		0.24	
Substructure_Repair	0.38	0.20	0.07	0.38	0.01	0.22	0.28	0.14	(0.04)	0.42	0.20	0.43		(0.04)			0.03	(0.13)	0.13	
Deck_Patch	0.19	0.24	(0.07)	0.24	(0.02)	0.27	0.12	0.11	(0.15)	0.36	(0.03)	0.39					(0.02)		0.05	
Deck_Replacement	0.09	(0.08)	0.26	0.02	(0.08)	0.03	0.21	(0.00)	0.07	0.08	0.27	0.22					0.14	(0.10)	(0.01)	
Superstructure_Replacement	0.01	(0.04)	0.05	0.01	0.01	(0.06)	(0.07)	(0.10)	0.12	(0.04)	(0.14)	(0.07)					(0.08)		(0.08)	
Bridge_replacement	(0.37)	(0.34)	(0.02)	(0.36)	(0.13)	(0.16)	(0.28)		0.41	(0.34)	0.09	(0.41)		0.50			0.13	0.03	(0.03)	(0.20)
Pin_and_Hanger	0.02	(0.02)	(0.04)	0.03	(0.11)	0.02	0.13	0.12	0.04	0.17	0.15	0.29							0.08	
Concrete_Surface_Coating	0.03		0.08	0.01	(0.00)					0.01	(0.06)								(0.10)	
Joint_Replaement	0.13	0.16	0.03	0.16	(0.02)	0.25	0.16	0.06	(0.08)	0.40	0.02	0.19					(0.06)		0.20	
Partial_Paint	0.21	0.01	0.10	0.20	(0.00)	0.08	(0.08)	0.29	(0.12)	0.20	0.20	0.26					(0.02)	(0.09)	0.17	
Full_Paint	0.08	0.18	0.01	0.06	(0.11)	(0.04)	0.39	0.09	(0.02)	(0.03)	0.02	0.25		(0.04)			(0.06)		0.14	
Widen	(0.09)	(0.13)	0.11	(0.13)	(0.05)	(0.11)	0.00	(0.04)	0.02	(0.10)	(0.07)	(0.10)		(0.03)			(0.03)	(0.13)	(0.10)	(0.25)
Heat_Straightening		0.06	(0.06)		(0.02)	(0.05)		(0.14)	(0.09)		(0.05)								(0.01)	
Railing_Replace	0.07	0.16	0.20	0.10	(0.03)	0.02	0.02	(0.10)	0.06	0.27	(0.06)	0.05						(0.07)	(0.07)	
Railing_Repair	0.11	0.15	(0.15)	0.17	0.06	0.10		0.10		0.03	(0.07)	0.15		(0.04)					0.04	
Culvert_Replacement	(0.17)	(0.13)		(0.19)	0.12	(0.03)	0.13		0.03	(0.09)	(0.06)			(0.50)			(0.12)	0.05		0.25
Scour_Protection	0.09	(0.04)	0.01	0.01	0.17	(0.07)	0.19	0.08	(0.01)	0.06	(0.06)	0.28		(0.19)			(0.05)	(0.12)	0.12	0.09
bridge_approach	0.11	0.04	0.05	0.11	(0.03)	0.08	0.27	0.11	0.24	0.05	0.10	0.40		(0.10)			(0.11)	(0.09)	(0.05)	0.18

Boxplots of some of the most significant relationships between work type and item cost are shown in Figure 4.4, where for each item 1-9, the upper graph shows how many projects with that cost item also have the type of work indicated, where the blue bar graph indicates how many projects do have that work type and the orange bar graph indicates how many projects do not. The lower graph is a boxplot of prices for the cost item indicated for these two project groups. As shown, for most cases, a significant difference exists between the median and interquartile range of item prices for projects that have different work types. However, the variation in price for a given cost item is large and the range of prices substantially overlaps in groups that have and do not have the given work type.

As with bridge parameters in the previous section, a large number of boxplots were generated and studied for possible relationships and patterns between item prices and work types. Some examples are given in Figures 4.5 and 4.6. Figure 4.5 considers Cost Item 2060010: Excavation, Fdn, with respect to the work types Superstructure Repair and Pin Type CD. If the project contains the work types Substructure Repair or Superstructure Repair, the price of Excavation, Fdn is clearly higher than for other projects (results shown for superstructure repair; price boxplots are nearly identical for substructure repair, but with less price variation). Similarly, a clear relationship exists between the price of Excavation, Fdn and the Pin Type CD, where the price generally increases as the Pin Type CD code changes from 0 to 4. As shown in previous results, the variation in price for a given item is very large. Figure 4.6 quantifies the variation in price of item 7120070: Structures, Rehabilitation, Rem Portions with respect to Work Category and Deck Replacement. As shown, if the category of work is Bridge Replacement, or if a deck replacement work item is included in the project, the cost of Item 7120070 is clearly greater.

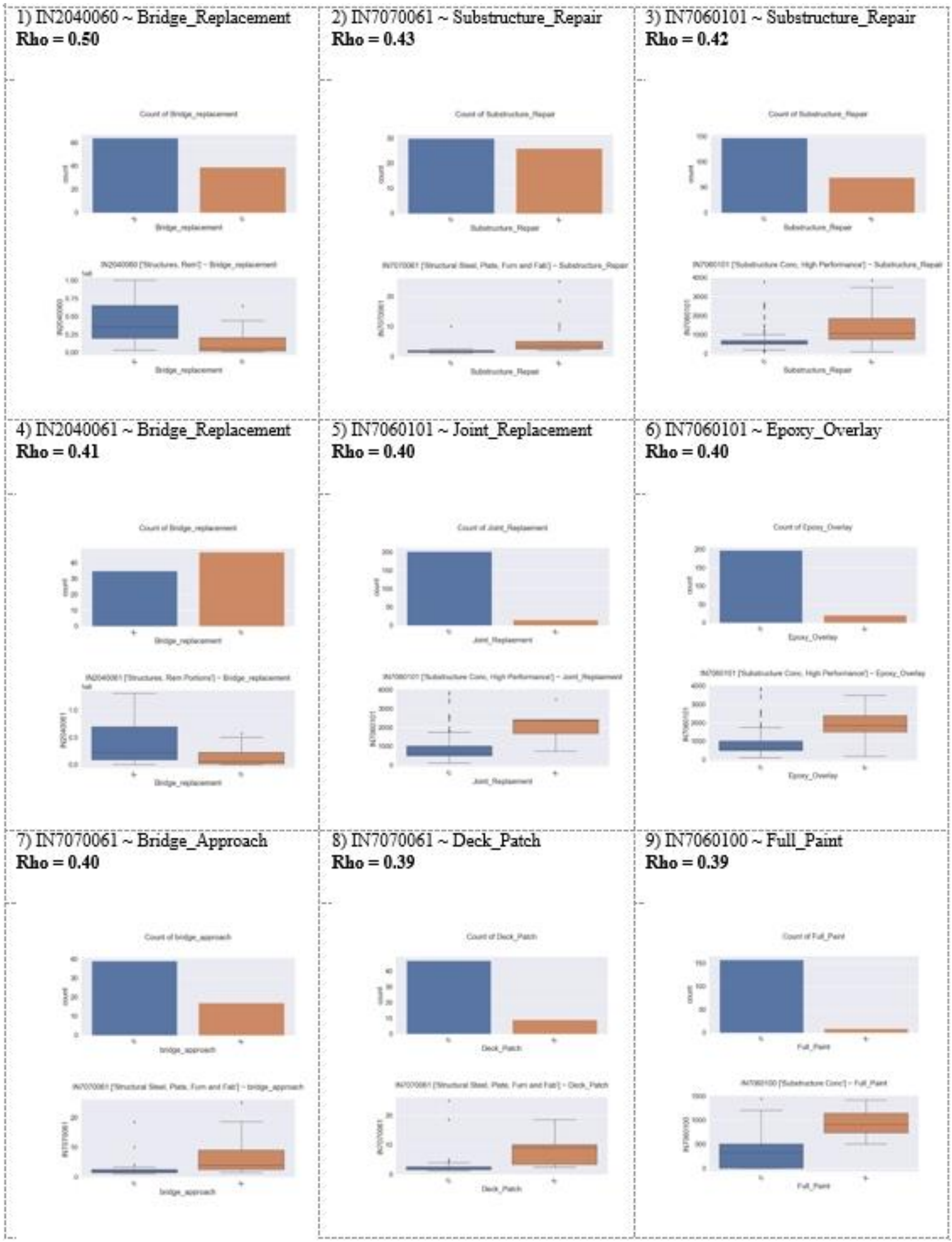


Figure 4.4. Boxplots of Work Type and Item Cost Relationships.

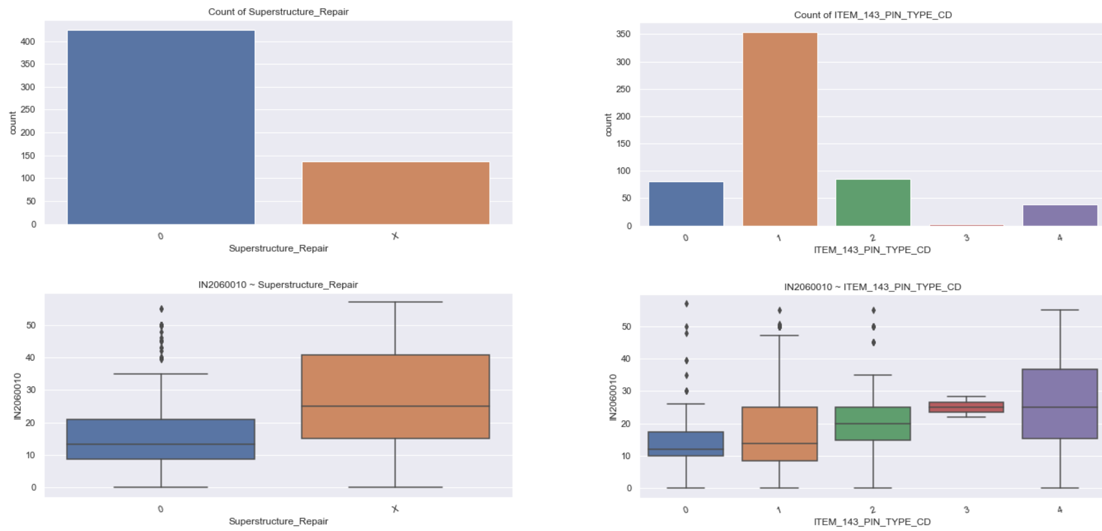


Figure 4.5. Example Boxplots of Excavation, Fnd Price and Work Type.

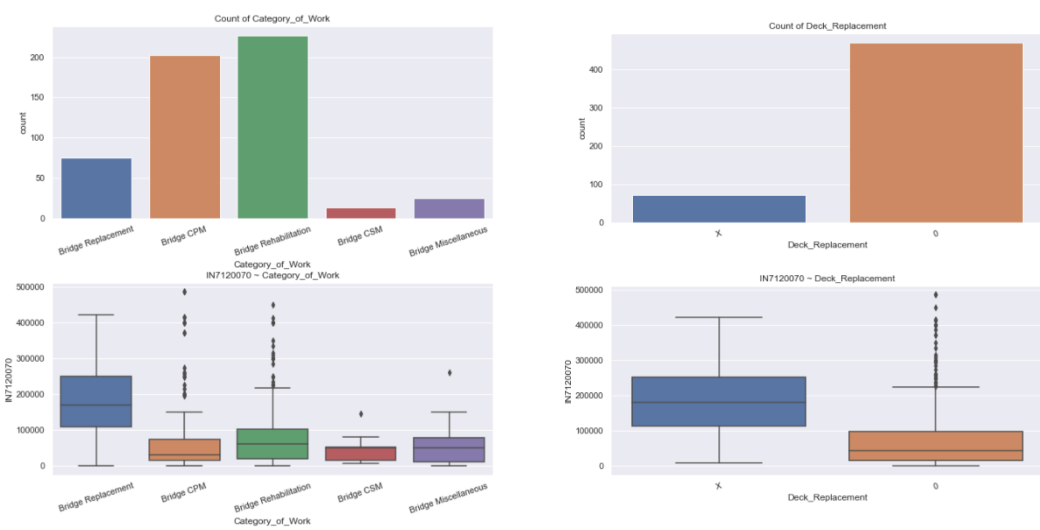


Figure 4.6. Example Boxplots of Structures, Rehabilitation, Rem Portions Price and Work Type.

4.2.3 Artificial Neural Network (ANN) Approach

A 2-layer, deep neural network with variable selection was used to attempt to construct relationships between bridge parameters and item prices. The model considered all feasible bridge description variables (i.e. those without a significant number of missing data) in the dataset as predictors. It was found that the model generally performed poorly, with large RMSE compared to the average item price (RSME typically 61% of average item price). This is not unexpected, as ANN tends to work best when the dataset is large when compared to the number of predictors. Given the very poor initial performance of this method, as well as the difficulty of practical implementation, it was not considered further.

CHAPTER 5: DEVELOPMENT OF PREDICTIVE MODELS

5.1 Introduction

As noted above, there are a large number of potential predictor variables (148 in the bridge database) as well as cost variables (1117). Numerical consideration of all of these items is not only computationally infeasible, but will likely reduce rather than increase the effectiveness of the model, as inclusion of too many similar or partially correlated predictor variables for the size of the database tends to weaken the model. Thus, a careful selection of a smaller number of predictor (i.e. bridge characteristics such as length, deck area, etc.) and cost variables is essential. Although the initial analysis revealed only weak relationships between predictor and cost variables, three issues were identified that could potentially increase the strength of these relationships: the variables considered; data outliers; and price changes over time.

5.2 Refinement of Variable Set

5.2.1 Predictor Variables

In general, as the number of similar/partially correlated variables considered increases for a given database size, the identifiable strength of the relationships between variables tends to weaken. Thus, the number of independent variables as well as the number of cost items considered was refined and reduced.

The predictor (independent) variables used are given in Table 5.1, where 9 continuous and 8 categorical predictors were chosen, based on results of the initial analysis in Chapter 4 as well as additional consideration of the available predictors. Of the initial 20 variables studied (Table 4.4a), four were retained: ITEM_49_LENGTH; ITEM_48_MAXSPAN; ITEM_29_ADTTOTAL; and ITEM_54_VCLRUNDER), which were among the stronger predictive variables for a variety of cost items. In addition, based on information gathered from the RAP, contractor interviews, input from the Factor Surveys provided by MDOT staff, and further consideration by the research team, some additional variables were added. These are given in Table 5.1.

Table 5.1. Independent Variables.

Continuous Variables (9)	Categorical Variables (8)
Proposal.Item.Quantity	Category.of.Work
n_bridge_in_project	ITEM_2_REGION
Annual_Budget_Amount_mil	ITEM_28_LANES_ON
DECK_AREA	ITEM_28_LANES_UNDER
ITEM_29_ADTTOTAL	ITEM_42A_SERVTYPON
ITEM_48_MAXSPAN	water_under
ITEM_49_LENGTH	highway_under
ITEM_54_VCLRUNDER	VCLRUNDER_Positive
MDOT_Award_Date	

These variables are defined as follows:

Proposal.Item.Quantity:

The quantity of the item in the project (no missing values), taken from Column N of the dataset [tab: Project Data]). Here it was thought that if the quantity of the cost item increases, its price may decrease. There were no missing values.

n_bridge_in_project:

The number of structures in the project, as calculated from information in the database. If multiple structures are grouped together in a single project, it was thought that item prices may decrease.

Annual_Budget_Amount_mil:

The fiscal MDOT annual budget in millions, which is calculated from the dataset. For example, the sum of all project costs from October 2021 - September 2022 is taken as the 2022 Annual Budget. Note that this parameter is taken as a predictor for costs for the following fiscal year (i.e. projects from Oct 2022 – Sept 2023) because it is assumed that bidders in the 2023 period will have knowledge of the previous year budget information prior to bid submission.

DECK_AREA:

The deck area of the bridge, taken from Column E of the dataset [tab: Bridge Data]. This replaced the initially considered parameter of deck width, which was found to have a significant relationship to some prices in the initial analysis. It was thought that deck area may be a more direct relationship to deck work cost items. When deck area information was missing from the bridge database, the median value was used for model development.

ITEM_29_ADTTOTAL:

Average daily traffic, taken from Column AF of the dataset [tab: Bridge Data]. Missing values were replaced by the median.

ITEM_48_MAXSPAN:

Length of the maximum span (ft), taken from Column BK of the dataset [tab: Bridge Data]. Missing values were replaced by the median.

ITEM_49_LENGTH:

Overall length of the structure (ft), taken from Column BL of the dataset [tab: Bridge Data]. Missing values were replaced by the median.

ITEM_54_VCLRUNDER:

Minimum vertical underclearance (ft), taken from Column BR of the dataset [tab: Bridge Data]. Missing values were taken as 0.

MDOT_Award_Date:

The date that the project was awarded (converted to seconds), taken from Column G of the dataset [tab: Project Data]. There were no missing values.

Category.of.Work:

Eight categories of work are specified in Column H of the dataset [tab: Bridge - Project]. To reduce the number of variables, these were grouped into 4 broader categories: Bridge CPM, Bridge CSM, Bridge Rehabilitation, and Bridge Replacement, as shown in Table 5.1a. Note that New Road items were removed from the database.

Table 5.1a. Category of Work Groups.

Original	Grouped
Bridge CPM	Bridge CPM
Bridge CSM	Bridge CSM
Bridge - Improve Bridge Miscellaneous Bridge Rehabilitation	Bridge Rehabilitation
New Structure Bridge Replacement	Bridge Replacement
New Roads	(removed)

ITEM_2_REGION:

The region code specifying the bridge location, taken from Column F of the dataset [tab: Bridge Data], where: 01 = Superior; 02 = North; 03 = Grand; 04 = Bay; 05 = Southwest; 06 = University; and 07 = Metro. There were no missing values.

ITEM_28_LANES_ON:

The number of Lanes on the structure, taken from Column AD of the dataset [tab: Bridge Data]. Missing values were replaced by the median.

ITEM_28_LANES_UNDER:

The number of lanes under the structure, taken from Column AE of the dataset [tab: Bridge Data]). Missing values were replaced by the median.

ITEM_42A_SERVTYPON:

The service type on the bridge, taken from Column AW of the dataset [tab: Bridge Data]. These were grouped to reduce the number of categories, as given in Table 5.1b:

Table 5.1b. Service On Bridge Groups.

Code	Original	Grouped
1 5	Highway Highway-pedestrian	Highway
2	Railroad	Railroad
3	Pedestrian-bicycle	Pedestrian-bicycle
4	Highway-railroad	Highway-railroad
6 7 8	Overpass structure at an interchange or second level of a multilevel interchange Third Level (Interchange) Fourth Level (Interchange)	Interchange
9	Building or Plaza	Building or Plaza
0	Other (non-highway)	Other

water_under:

This is taken as a binary variable and indicates whether the bridge spans over water or not. It is based on information from ITEM_42B_SERVTYPUND, in Column AX of the dataset [tab: Bridge Data], where the following codes for service under the bridge are provided:

Code Description
1 Highway, with or without pedestrian
2 Railroad
3 Pedestrian-bicycle
4 Highway-railroad
5 Waterway
6 Highway-waterway
7 Railroad-waterway
8 Highway-waterway-railroad
9 Relief for waterway
0 Other (non-highway) (i.e., recreation trail)

For codes 5-9, the indicator is taken as positive/true, whereas any of the remaining codes, the indication is taken as negative/false.

highway_under:

Similarly, highway_under is derived from ITEM_42B_SERVTYPUND and is taken as an indicator variable indicating whether the structure has highway service under, where codes 1, 4, 6, and 8 are taken as a positive indication.

VCLRUNDER_Positive:

> This is used as an indicator variable to denote whether there is non-zero value given for Minimum Vertical Underclearance, and is derived from ITEM_54_VCLRUNDER, in Column BR of the dataset [tab: Bridge Data].

5.2.2 Cost Items

Approximately 1117 different cost item codes exist in the dataset. Of these, 388 are different bridge pay items. To reduce the number of costs to consider, projects were first divided into four general types of work: Bridge Rehabilitation, Bridge Replacement, Bridge CPM (Capital Preventive Maintenance), and Bridge CSM (Capital Scheduled Maintenance), as described in Table 5.1a. Bridge pay items that contributed 3% or more to any type of work were included, while those that contributed under 3% in all types of work were eliminated. It was found that 97 item codes remained for Bridge Rehab, 97 to Bridge Replace, 78 to Bridge CPM, and 39 to Bridge CSM (some overlap). As this still represents a large number of items, further reduction was done by choosing the top 10 bridge pay items within each type of work based on the dollar amount over the years. With some overlap of these sets of top 10 items, 25 cost items remained, representing the most influential cost items, as shown in Table 5.2. The majority of the items found to be most important in the initial data analysis (Table 4.4), above, also appear here. The items in Table 4.4 that represent significant proportions of typical project costs that are not included in Table 5.2 are:

4067001 (Supplemental item). This is mostly a culvert-related item (e.g. Culv, Precast Conc Box, of different sizes).

1027060 (Supplemental item). This contains various descriptions (e.g. Railroad Inspection and Flagging, Design Build, Guaranteed Maximum Price, etc). Note that it was found in recent years, the winning bid price of this item is always 1.0 and the engineering estimates are also 1.0. Thus, it is recommended to estimate this price as 1.0.

7047051 (Supplemental item: Cofferdam, Steel Sheet Piling, Dewatering Barrier, etc.)

8507051 (Supplemental item: Electrical Rehabilitation, Electrical Work, Bridge Mechanical Machinery, Pier Protection System, etc). Note that there is no price data for this item in 2022 or 2023 project years.

These costs, however, although are significant for the projects in which they appear, represent a relatively small number of projects as well as a small proportion of the total budget, as shown in Table 5.2a.

Table 5.2. Cost Items Included.

		Average Weight of Item in Projects that Contain that Item					
Cost Item	Item Description	Data count	Bridge Rehab	Bridge Replace	Bridge CPM	Bridge CSM	Mean
7150045	Steel Structure, Cleaning, Type 4	163	35%	20%	53%	38%	37%
2040061	Structures, Rem Portions	96	32%	19%	30%	52%	33%
7120070	Structures, Rehabilitation, Rem Portions	605	24%	26%	25%	43%	29%
7150047	Steel Str,Cleaning,Partial,Type 4	320	26%	9%	34%	32%	25%
7120022	Epoxy Ovly, Warranty	161	8%	0%	35%	32%	19%
7100025	Penetrating Healer/Sealer, Bridge Deck	51	9%	0%	9%	40%	15%
7122005	Bridge Joint, Strip Seal Gland Replac	24	22%	0%	9%	23%	14%
7120020	Epoxy Ovly	96	12%	5%	29%	6%	13%
7060112	Supstr Conc,Form,Fin,and Cure,Night Cast	300	17%	13%	21%	0%	13%
7120071	Deck Joint, Rem	440	5%	2%	12%	30%	12%
2040060	Structures, Rem	112	22%	24%	0%	0%	11%
7070061	Structural Steel, Plate, Furn and Fab	65	8%	22%	8%	7%	11%
7050002	Pile Driving Equipment, Furn	112	29%	7%	3%	0%	10%
7120076	Hydrodemolition, First Pass	172	11%	7%	20%	0%	9%
7130071	Str Steel,Retrofit,Furn,Fab,& Erect	309	11%	3%	8%	15%	9%
7120025	Bridge Deck Surface Construction	179	13%	3%	17%	0%	8%
7060050	Expansion Joint Device	595	7%	1%	15%	9%	8%
7130080	Support, Column, Temp	316	7%	2%	9%	9%	7%
7060101	Substructure Conc, High Performance	242	6%	8%	12%	0%	6%
7120017	Patch, Forming	821	4%	2%	7%	8%	5%
7060100	Substructure Conc	195	5%	8%	5%	0%	4%
7060092	Reinforcement, Steel, Epoxy Coated	951	4%	7%	2%	4%	4%
7050034	Pile, Steel, Furn and Driven, 14 inch	59	9%	8%	0%	0%	4%
7120007	Hand Chipping, Other Than Deck	836	3%	1%	5%	5%	4%
7120112	Patching Conc, C-L	882	2%	1%	5%	7%	4%

Table 5.2a. Cost Items Not Included (Non-Bridge Pay Items).

Cost Item	Number in Database	% of projects with this item	Mean % cost in a Project*	% of Total Cost, Entire Budget
4067001	56	5%	47%	4.4%
1027060	48	3%	16%	5.8%
7047051	128	9%	12%	5.1%
8507051	100	4%	4%	2.7%

*Of projects that contain that item.

5.3 Accounting for Price Changes Over Time

A strong relationship exists between mean item price and project year, as given by the Michigan Highway Construction Cost Index (MHCCI), as shown in Table 5.3, where regional indices are given in the last 7 columns. Thus, inflation or other price fluctuations due to wider economic factors rather than project details will confound results. To reduce the effect of this variable, all project item prices were normalized by dividing those prices by the quarterly MHCCI. Then, the item price to be predicted in the year considered is multiplied by the MHCCI corresponding to that quarter. Note that MHCCI is reported in terms of calendar year. One drawback in the MHCCI data is that all results are normalized within a given column; i.e. it is not possible to compare or factor prices within the same year to consider differences between the Superior or North regions, for example. Unless otherwise noted, values shown in this report are given in terms of the overall MHCCI.

Table 5.3a. Yearly MHCCI.

YEAR	MHCCI	Bridges & Special Struc. + Struc. Steel	Structural Concrete Work	Superior	North	Grand	Bay	Southwest	University	Metro
2010	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2011	1.02	1.06	1.02	1.03	1.02	1.07	1.02	1.07	1.10	0.98
2012	1.07	0.97	1.10	1.11	1.07	1.10	1.07	1.11	1.11	1.10
2013	1.09	0.98	1.11	1.12	1.06	1.09	1.12	1.15	1.26	1.08
2014	1.20	1.17	1.27	1.22	1.16	1.25	1.17	1.22	1.22	1.34
2015	1.22	1.17	1.43	1.20	1.11	1.28	1.27	1.22	1.35	1.25
2016	1.26	1.18	1.60	1.18	1.09	1.20	1.26	1.29	1.31	1.40
2017	1.27	1.20	1.56	1.21	1.08	1.20	1.34	1.30	1.30	1.37
2018	1.36	1.32	1.59	1.29	1.12	1.28	1.36	1.37	1.48	1.46
2019	1.45	1.38	1.70	1.40	1.30	1.39	1.44	1.46	1.63	1.60
2020	1.44	1.42	1.79	1.42	1.33	1.41	1.49	1.52	1.63	1.66
2021	1.53	1.61	1.75	1.46	1.35	1.54	1.56	1.54	1.66	1.63
2022	1.80	1.85	1.89	1.63	1.46	1.77	1.85	1.84	1.94	2.02

Table 5.3b. Quarterly MHCCI.

Year-Quarter	MHCCI	Bridges & Special Struc. + Struc. Steel	Year-Quarter	MHCCI	Bridges & Special Struc. + Struc. Steel
20101	1.00	1.00	20163	1.22	1.07
20102	0.98	1.26	20164	1.09	1.02
20103	0.99	0.94	20171	1.08	1.02
20104	1.00	0.97	20172	1.07	0.85
20111	0.97	0.93	20173	1.23	0.95
20112	1.06	1.08	20174	1.19	1.08
20113	1.08	1.16	20181	1.21	1.32
20114	1.05	1.04	20182	1.35	1.22
20121	1.04	1.01	20183	1.38	1.05
20122	1.07	1.03	20184	1.34	1.24
20123	1.02	0.71	20191	1.32	1.32
20124	1.05	0.82	20192	1.47	1.40
20131	1.05	0.90	20193	1.49	1.51
20132	1.10	0.93	20194	1.50	1.33
20133	1.09	0.93	20201	1.42	1.39
20134	1.06	0.82	20202	1.50	1.39
20141	1.08	1.05	20203	1.37	1.29
20142	1.09	1.11	20204	1.36	1.30
20143	1.21	1.00	20211	1.41	1.50
20144	1.16	1.13	20212	1.37	1.54
20151	1.11	1.13	20213	1.59	1.81
20152	1.15	1.17	20214	1.60	1.93
20153	1.28	1.10	20221	1.66	1.64
20154	1.14	1.05	20222	1.71	1.66
20161	1.14	1.02	20223	1.98	1.70
20162	1.18	1.18	20224	1.95	1.84

5.4 Consideration of Data Outliers

The initial data analysis described in Chapter 4 did not remove outliers. However, severe outliers can significantly negatively affect model accuracy. Thus, for initial model development, several methods were used to handle outliers.

First, rather than remove outliers entirely, which will eliminate actual winning bid prices and may negatively affect the predictive capability of the model over a wide range of realistic actual prices, the effect of outliers was mitigated by transforming prices into a logarithmic scale prior to consideration. That is, all unit prices as well as continuous variable predictors were transformed to: [log(1 + X)], where X is the predictor (e.g. bridge characteristic) or item price, for use in regression model development (for example, log(1+Unit Price of 7050002) vs log(1+ DECK_AREA)). This reduces the effects of outliers by condensing the range of results.

Second, for the CBR approach, outliers were truncated by the MAD approach, as given by Eqs. 2.4 and 2.5, above. For the Lasso model, alternate versions were explored where outliers were truncated in one case and eliminated in another. All outliers were identified by MAD with a limit of 3.0.

<u>5.5 Simple Linear Regression Model</u>

With these modifications to the database, three linear regression models were developed: simple, multiple, and Lasso regression.

The initial simple linear regression model considered each predictor and item price independently, and was conducted on the item prices given in Table 5.2, resulting in 25*(9 continuous variables + 8 categorical variables), or 425 single linear regression analyses. As with the initial data analysis given in Chapter 4, scatterplots for continuous variables and boxplots for categorical variables were developed and studied. Plots for the strongest 9 relationships are given in Figure 5.1. Note that p-values are all given as 0.00, indicate $p < 0.005$, representing results of high significance.

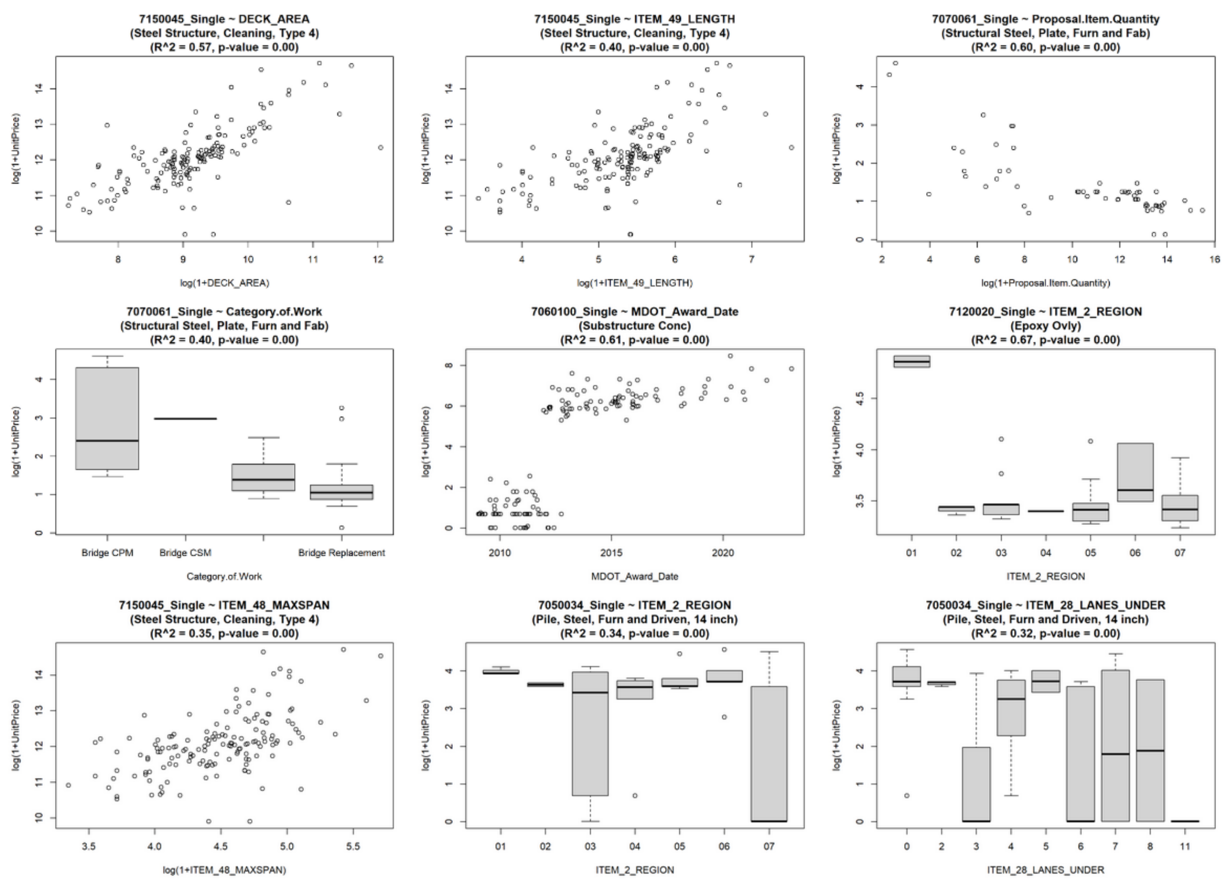


Figure 5.1. Scatter/Boxplot of the top 9 Simple Linear Regression Results.

The single linear regression model was implemented with 5-fold cross-validation for evaluation. After conversion to log scale and dividing by quarterly MHCCI as described above, the validation was done by randomly dividing the price data into 5 groups of approximately equal size; choosing one of the five folds as the test data and fitting the model to the remaining dataset composed of 4 folds; and calculating the Coefficients of Determination (R^2) and corresponding p-values of the model prediction to the test fold. This process was then repeated 5 times, changing the test and remaining model fit data folds each time. The average of the performance metrics given above for each of the 5 sets were then reported.

The Single linear regression results with $R^2 > 0.3$ and p-value < 0.005, indicating the strongest relationships between predictors and prices, are given in Table 5.4. As shown in the table, these top relationships are relatively strong.

Table 5.4. Single Linear Regression Results for $R^2 > 0.3$ and p-Value < 0.005.

Cost Item	Item Description	Predictor	R^2
7120020	Epoxy Ovly	ITEM_2_REGION	0.67
7060100	Substructure Conc	MDOT_Award_Date	0.61
7070061	Structural Steel, Plate, Furn and Fab	Proposal.Item.Quantity	0.60
7150045	Steel Structure, Cleaning, Type 4	DECK_AREA	0.57
7150045	Steel Structure, Cleaning, Type 4	ITEM_49_LENGTH	0.40
7070061	Structural Steel, Plate, Furn and Fab	Category.of.Work	0.40
7150045	Steel Structure, Cleaning, Type 4	ITEM_48_MAXSPAN	0.35
7050034	Pile, Steel, Furn and Driven, 14 inch	ITEM_2_REGION	0.34
7050034	Pile, Steel, Furn and Driven, 14 inch	ITEM_28_LANES_UNDER	0.32
2040061	Structures, Rem Portions	Category.of.Work	0.31

As shown in the table, the strongest predictors for at least one price item appear to be: Region, Award Date, Item Quantity, Deck Area, Length, Category of Work, Maximum Span, and Number of Lanes Under. Note that correlation coefficient is the square root of R^2. Although perhaps only meaningful for continuous variables, even the weakest relationships shown on Table 5.4 (i.e. with $R^2 = 0.31$; equivalent $\rho = 0.56$) are equivalent in significance to the strongest relationship identified in the preliminary analysis, where the single highest correlation was $\rho = 0.575$ (between Length and 7150045, Steel Structure, Cleaning, Type 4). This is due to accounting for price changes and outliers.

This information was used to refine the set of predictor variables to use in a multi-linear regression model, as discussed below.

5.6 Multi-linear regression

The simple linear regression model above uncovered a number of moderately strong relationships between predictor variables and prices. However, it is likely that stronger predictive capability can be developed if multiple predictor variables are considered simultaneously. Thus, a series of multiple-linear regression analyses with 5-fold cross-validation were conducted, where each of the 25 cost items in Table 5.2 were predicted with a set of predictor variables considered together.

Each set was composed of those variables found to be most strongly linked to that particular cost from the single linear regression analysis; in particular, those variables with $p < 0.05$ for that cost. These variables are given in Table 5.5, where green cells indicate p-values less than 0.05.

Table 5.5. Predictor Variables Considered in Multi-Linear Regression Analysis.

Variable Name	7120070_Single	7150047_Single	7150045_Single	7060112_Single	7120025_Single	7120076_Single	7060092_Single	7060050_Single	7130071_Single	7120071_Single	7070061_Single	2040060_Single
Proposal.Item.Quantity	0.00	0.13	0.03	0.81	0.50	0.04	0.00	0.28	0.00	0.01	0.00	0.80
n_bridge_in_project	0.01	0.00	0.53	0.00	0.00	0.65	0.00	0.00	0.00	0.00	0.13	0.06
Annual_Budget_Amount_mil	0.57	0.89	0.20	0.04	0.01	0.00	0.06	0.03	0.00	0.08	0.01	0.01
DECK_AREA	0.00	0.00	0.00	0.00	0.55	0.01	0.31	0.43	0.51	0.94	0.73	0.00
ITEM_29_ADTTOTAL	0.00	0.81	0.00	0.02	0.26	0.64	0.10	0.04	0.11	0.38	0.81	0.23
ITEM_48_MAXSPAN	0.01	0.00	0.00	0.00	0.93	0.09	0.19	0.48	0.01	0.80	0.16	0.13
ITEM_49_LENGTH	0.00	0.00	0.00	0.00	0.85	0.01	0.34	0.76	0.55	0.47	0.74	0.00
ITEM_54_VCLRUNDER	0.75	0.04	0.15	0.00	0.20	0.00	0.00	0.74	0.06	0.50	0.11	0.04
Category.of.Work	0.00	0.46	0.95	0.00	0.01	0.27	0.00	0.00	0.03	0.00	0.00	0.33
ITEM_2_REGION	0.84	0.00	0.81	0.01	0.25	0.00	0.00	0.00	0.00	0.05	0.57	0.01
ITEM_28_LANES_ON	0.05	0.20	0.00	0.04	0.05	0.38	0.63	0.04	0.33	0.67	0.16	0.04
ITEM_28_LANES_UNDER	0.34	0.01	0.13	0.04	0.30	0.00	0.00	0.85	0.00	0.92	0.08	0.01
ITEM_42A_SERVTYPON	0.08	0.05	0.78	0.00	0.29	0.27	0.14	0.03	0.23	0.98	0.88	0.85
water_under	0.22	0.00	0.53	0.01	0.63	0.00	0.00	0.65	0.02	0.13	0.03	0.02
highway_under	0.67	0.07	0.16	0.01	0.29	0.00	0.00	0.47	0.04	0.51	0.10	0.04
VCLRUNDER_Positive	0.77	0.03	0.16	0.00	0.20	0.00	0.00	0.68	0.06	0.54	0.10	0.04

Variable Name	7060101_Single	2040061_Single	7050002_Single	7050034_Single	7060100_Single	7120022_Single	7120017_Single	7120020_Single	7120112_Single	7100025_Single	7130080_Single	7120007_Single	7122005_Single	7047051_BigNon
Proposal.Item.Quantity	0.14	0.37	0.44	0.42	0.01	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.25	0.06
n_bridge_in_project	0.00	0.01	0.80	0.06	0.03	0.09	0.00	0.00	0.69	0.00	0.27	0.00	0.02	0.02
Annual_Budget_Amount_mil	0.01	0.92	1.00	0.42	0.00	0.02	0.00	0.19	0.00	0.44	0.00	0.00	0.05	0.10
DECK_AREA	0.06	0.23	0.00	0.82	0.59	0.00	0.73	0.00	0.32	0.16	0.70	0.61	0.47	0.37
ITEM_29_ADTTOTAL	0.20	0.11	0.19	0.06	0.40	0.00	0.39	0.79	0.47	0.00	0.26	0.57	0.60	0.20
ITEM_48_MAXSPAN	0.50	0.18	0.07	0.82	0.95	0.00	0.21	0.00	0.10	0.52	0.36	0.36	0.72	0.79
ITEM_49_LENGTH	0.11	0.68	0.01	0.60	0.94	0.00	0.31	0.00	0.46	0.07	0.17	0.18	0.07	0.62
ITEM_54_VCLRUNDER	0.16	0.24	0.82	0.00	0.29	0.00	0.04	0.00	0.00	0.00	0.04	0.00	0.47	0.13
Category.of.Work	0.05	0.00	0.46	0.65	0.29	0.02	0.22	0.33	0.00	0.08	0.03	0.01	0.04	0.06
ITEM_2_REGION	0.13	0.03	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.15	0.00	0.13	0.73
ITEM_28_LANES_ON	0.39	0.22	0.14	0.20	0.44	0.11	0.85	0.39	0.09	0.91	0.06	0.79	0.10	0.00
ITEM_28_LANES_UNDER	0.96	0.30	0.53	0.00	0.11	0.01	0.02	0.02	0.02	0.09	0.69	0.00	0.39	0.27
ITEM_42A_SERVTYPON	0.34	0.93	0.64	1.00	0.54	0.86	0.20	0.41	0.23	1.00	0.60	0.31	1.00	1.00
water_under	0.17	0.51	0.94	0.00	0.13	0.00	0.01	0.00	0.00	0.01	0.02	0.00	0.22	0.11
highway_under	0.39	0.06	0.46	0.00	0.36	0.00	0.03	0.00	0.00	0.01	0.03	0.00	0.48	0.30
VCLRUNDER_Positive	0.14	0.24	0.79	0.00	0.27	0.00	0.04	0.00	0.00	0.01	0.03	0.00	0.48	0.14

Results of the multiple regression analysis are given in Table 5.6, where the resulting adjusted R^2 (Adj. R^2) values are provided. Here Adj. R^2 is used rather than R^2, which is usually artificially increased when additional variables are included in the regression, even if no significant additional predictive capability results from those additional variables. In Table 5.6, all results have p-values <0.005 except Item 7122005, with p=0.04, and Item 2040060, with p=0.01. Note that all cost items are in the "single" group (i.e. identified as: Item#_Single). As shown in the table, a number of the relationships are strong, exceeding the R^2 values found from the single linear regression.

Table 5.6. Results of Multiple Regression Model.

Cost Item	Predictors			Adj. R^2
7120020 Epoxy Ovly	Proposal.Item.Quantity ITEM_48_MAXSPAN ITEM_2_REGION highway_under	n_bridge_in_project ITEM_49_LENGTH ITEM_28_LANES_UNDER VCLRUNDER_Positive	DECK_AREA ITEM_54_VCLRUNDER water_under MDOT_Award_Date	0.79
7070061 Structural Steel, Plate, Furn and Fab	Proposal.Item.Quantity water_under	Annual_Budget_Amount_mil MDOT_Award_Date	Category.of.Work	0.73
7060100 Substructure Conc	Proposal.Item.Quantity ITEM_2_REGION	n_bridge_in_project MDOT_Award_Date	Annual_Budget_Amount_mil	0.66
7150045 Steel Structure, Cleaning, Type 4	Proposal.Item.Quantity ITEM_48_MAXSPAN MDOT_Award_Date	DECK_AREA ITEM_49_LENGTH	ITEM_29_ADTTOTAL ITEM_28_LANES_ON	0.58
7060112 Supstr Conc,Form, Fin,and Cure,Night Cast	n_bridge_in_project ITEM_29_ADTTOTAL ITEM_54_VCLRUNDER ITEM_28_LANES_ON water_under MDOT_Award_Date	Annual_Budget_Amount_mil ITEM_48_MAXSPAN Category.of.Work ITEM_28_LANES_UNDER highway_under	DECK_AREA ITEM_49_LENGTH ITEM_2_REGION ITEM_42A_SERVTYPON VCLRUNDER_Positive	0.48
7100025 Penetrating Healer/Sealer, Bridge Deck	Proposal.Item.Quantity ITEM_54_VCLRUNDER highway_under	n_bridge_in_project ITEM_2_REGION VCLRUNDER_Positive	ITEM_29_ADTTOTAL water_under MDOT_Award_Date	0.45
7050034 Pile, Steel, Furn and Driven, 14 inch	ITEM_54_VCLRUNDER water_under MDOT_Award_Date	ITEM_2_REGION highway_under	ITEM_28_LANES_UNDER VCLRUNDER_Positive	0.42
2040061 Structures, Rem Portions	n_bridge_in_project MDOT_Award_Date	Category.of.Work	ITEM_2_REGION	0.41

7130071 Str Steel, Retrofit, Furn,Fab,& Erect	Proposal.Item.Quantity n_bridge_in_project Annual_Budget_Amount_mil ITEM_48_MAXSPAN Category.of.Work ITEM_2_REGION ITEM_28_LANES_UNDER water_under highway_under MDOT_Award_Date	0.39
7120022 Epoxy Ovly, Warranty	Proposal.Item.Quantity Annual_Budget_Amount_mil DECK_AREA ITEM_29_ADTTOTAL ITEM_48_MAXSPAN ITEM_49_LENGTH ITEM_54_VCLRUNDER Category.of.Work ITEM_2_REGION ITEM_28_LANES_UNDER water_under highway_under VCLRUNDER_Positive MDOT_Award_Date	0.34
7122005 Bridge Joint, Strip Seal Gland Replac	n_bridge_in_project Annual_Budget_Amount_mil Category.of.Work MDOT_Award_Date	0.30
2040060 Structures, Rem	Annual_Budget_Amount_mil DECK_AREA ITEM_49_LENGTH ITEM_54_VCLRUNDER ITEM_2_REGION ITEM_28_LANES_ON ITEM_28_LANES_UNDER water_under highway_under VCLRUNDER_Positive MDOT_Award_Date	0.28
7060092 Reinforcement, Steel, Epoxy Coated	Proposal.Item.Quantity n_bridge_in_project ITEM_54_VCLRUNDER Category.of.Work ITEM_2_REGION ITEM_28_LANES_UNDER water_under highway_under VCLRUNDER_Positive MDOT_Award_Date	0.25
7120007 Hand Chipping, Other Than Deck	Proposal.Item.Quantity n_bridge_in_project Annual_Budget_Amount_mil ITEM_54_VCLRUNDER Category.of.Work ITEM_2_REGION ITEM_28_LANES_UNDER water_under highway_under VCLRUNDER_Positive MDOT_Award_Date	0.23
7047051 (supplemental)	n_bridge_in_project ITEM_28_LANES_ON MDOT_Award_Date	0.23
7120076 Hydrodemolition, First Pass	Proposal.Item.Quantity Annual_Budget_Amount_mil DECK_AREA ITEM_49_LENGTH ITEM_54_VCLRUNDER ITEM_2_REGION ITEM_28_LANES_UNDER water_under highway_under VCLRUNDER_Positive MDOT_Award_Date	0.22
7150047 Steel Str, Cleaning, Partial,Type 4	n_bridge_in_project DECK_AREA ITEM_48_MAXSPAN ITEM_49_LENGTH ITEM_54_VCLRUNDER ITEM_2_REGION ITEM_28_LANES_UNDER ITEM_42A_SERVTYPON water_under VCLRUNDER_Positive MDOT_Award_Date	0.21
7120070 Structures, Rehabilitation, Rem Portions	Proposal.Item.Quantity n_bridge_in_project DECK_AREA ITEM_29_ADTTOTAL ITEM_48_MAXSPAN ITEM_49_LENGTH Category.of.Work ITEM_28_LANES_ON MDOT_Award_Date	0.19
7120017 Patch, Forming	Proposal.Item.Quantity n_bridge_in_project Annual_Budget_Amount_mil ITEM_54_VCLRUNDER ITEM_2_REGION ITEM_28_LANES_UNDER water_under highway_under VCLRUNDER_Positive MDOT_Award_Date	0.18
7120025 Bridge Deck Surface Construction	n_bridge_in_project Annual_Budget_Amount_mil Category.of.Work ITEM_28_LANES_ON MDOT_Award_Date	0.17
7050002 Pile Driving Equipment, Furn	DECK_AREA ITEM_49_LENGTH MDOT_Award_Date	0.16
7120112 Patching Conc, C-L	Proposal.Item.Quantity Annual_Budget_Amount_mil ITEM_54_VCLRUNDER Category.of.Work ITEM_2_REGION ITEM_28_LANES_UNDER water_under highway_under VCLRUNDER_Positive MDOT_Award_Date	0.15
7130080	Annual_Budget_Amount_mil ITEM_54_VCLRUNDER Category.of.Work water_under highway_under VCLRUNDER_Positive	0.09

Str Steel, Retrofit, Furn, Fab, & Erect	MDOT_Award_Date	
7060050 Expansion Joint Device	n_bridge_in_project Annual_Budget_Amount_mil ITEM_29_ADTTOTAL Category.of.Work ITEM_2_REGION ITEM_28_LANES_ON ITEM_42A_SERVTYPON MDOT_Award_Date	0.08
7120071 Deck Joint, Rem	Proposal.Item.Quantity n_bridge_in_project Category.of.Work ITEM_2_REGION MDOT_Award_Date	0.07
7060101 Substructure Conc, High Performance	n_bridge_in_project Annual_Budget_Amount_mil Category.of.Work MDOT_Award_Date	0.07

5.7 Lasso regression

As an alternative to the multiple linear regression model, a Lasso (least absolute shrinkage and selection operator) linear regression was conducted. As a method for regularization and predictor variable selection, then intent of Lasso regression is to improve the accuracy of the regression as well as enhance the interpretation of results. It does this by selecting an optimal sub-set of predictor variables to include in the model, while excluding those which do not provide meaningful predictive capability. In this process, all 17 of the predictors given in Table 5.1 were initially included in the analysis. As with the multi-linear regression, 25 separate analyses were conducted, one for each of the price items in Table 5.2. This analysis was repeated three times; when no outliers were truncated or removed; when truncated; and when removed from the database prior to model formation (with a MAD limit of 3.0). In all cases, as with the regression models above, values were also transformed to log scale. Results of the analysis are given in Tables 5.7-5.7b, where an entry of "1" in the table indicates that a predictor was retained for a particular cost item.

A comparison of the multiple linear regression and the Lasso models is given in Table 5.7c, where the model with highest R^2 value for a particular cost item is highlighted in green. As shown, overall model results overall are similar, although the multiple linear regression model has more cost items with highest R^2 than the Lasso models.

Table 5.7. Results of Lasso Regression, All Outliers Retained.

Cost Item	Description	R^2	n_bridge_in_project	Annual_Budget_Amount_mil	DECK_AREA	ITEM_28_LANES_ON	ITEM_28_LANES_UNDER	ITEM_29_ADTTOTAL	ITEM_48_MAXSPAN	ITEM_49_LENGTH	ITEM_54_VCLRUNDER	MDOT_Award_Date	Category.of.Work.Bridge.CPM	Category.of.Work.Bridge.CSM	Category.of.Work.Bridge.Rehabili	Category.of.Work.Bridge.Replace	ITEM_2_REGION.01	ITEM_2_REGION.02	ITEM_2_REGION.03	ITEM_2_REGION.04	ITEM_2_REGION.05	ITEM_2_REGION.06	ITEM_2_REGION.07	ITEM_42A_SERVTYPON.1	ITEM_42A_SERVTYPON.2	ITEM_42A_SERVTYPON.3	ITEM_42A_SERVTYPON.6	water_under.FALSE	water_under.TRUE	highway_under.FALSE	highway_under.TRUE	VCLRUNDER_Positive.FALSE	VCLRUNDER_Positive.TRUE	Proposal.Item.Quantity
7120020	Epoxy Ovly	0.96	1	1				1		1				1		1	1					1	1	1		1		1				1		1
7070061	Structural Steel, Pla	0.60	1	1	1	1	1					1	1	1					1			1				1		1						1
8507051	(supplemental)	0.60																		1														1
7060100	Substructure Conc	0.56	1				1	1	1			1	1		1		1					1	1					1	1					
7060112	Supstr Conc,Form, I	0.53	1	1	1					1		1			1	1		1		1		1				1	1							
7120022	Epoxy Ovly, Warrant	0.41		1				1		1			1		1		1	1					1									1	1	1
7150045	Steel Structure, Cle	0.41			1	1	1	1	1						1		1	1				1			1	1	1			1				
7130071	Structures, Rem Po	0.40	1	1		1			1										1			1	1											1
7050034	Pile, Steel, Furn anc	0.40					1	1															1											
2040060	Structures, Rem	0.21	1	1	1					1		1			1	1		1					1											
7120076	Hydrodemolition, Fir	0.18		1			1	1	1	1		1			1	1	1	1	1	1			1	1										
7120007	Hand Chipping, Oth	0.17	1	1	1	1	1					1			1	1	1		1		1		1	1	1			1	1					1
7130080	Str Steel, Retrofit, F	0.17	1	1		1	1			1				1	1		1					1	1					1		1				1
7120017	Patch, Forming	0.16	1	1	1		1		1	1		1	1		1		1	1	1		1			1	1							1		1
7060092	Reinforcement, Ste	0.16	1		1	1	1	1	1			1		1			1	1	1		1		1	1	1			1	1					1
7120112	Patching Conc, C-L	0.16	1	1		1			1				1		1		1	1	1		1	1		1	1	1				1				1
7100025	Penetrating Healer/	0.13	1		1			1			1			1	1		1				1													1
7150047	Steel Str, Cleaning,	0.12	1	1		1	1	1	1	1		1				1	1	1	1			1			1	1								1
7120070	Structures, Rehabili	0.06	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1			1	1			1	1	1							1
7120025	Bridge Deck Surfac	0.05	1									1			1																			
7060050	Expansion Joint Dev	0.04	1			1		1				1	1	1		1				1	1		1	1			1							1
7047051	(supplemental)	0.04				1							1																					
7120071	Deck Joint, Rem	0.02	1	1		1						1			1	1				1		1	1	1				1						1
7122005	Bridge Joint, Strip S	<0.02	1	1		1	1			1					1							1												
7060101	Substructure Conc,	<0.02	1		1							1			1	1	1			1	1	1		1	1	1				1		1		1
7050002	Pile Driving Equipme	<0.02			1							1								1	1		1							1	1			
2040061	Structures, Rem Po	<0.02	1	1	1	1	1	1	1	1	1	1		1	1	1		1	1	1	1	1	1					1		1	1	1		1

Table 5.7a. Results of Lasso Regression, Outliers Truncated.

Cost Item	Description	R^2	n_bridge_in_project	Annual_Budget_Amount_mil	DECK_AREA	ITEM_28_LANES_ON	ITEM_28_LANES_UNDER	ITEM_29_ADTTOTAL	ITEM_48_MAXSPAN	ITEM_49_LENGTH	ITEM_54_VCLRUNDER	MDOT_Award_Date	Category.of.Work.Bridge.CPM	Category.of.Work.Bridge.CSM	Category.of.Work.Bridge.Reh	Category.of.Work.Bridge.Repl	ITEM_2_REGION.01	ITEM_2_REGION.02	ITEM_2_REGION.03	ITEM_2_REGION.04	ITEM_2_REGION.05	ITEM_2_REGION.06	ITEM_2_REGION.07	ITEM_42A_SERVTYPON.1	ITEM_42A_SERVTYPON.2	ITEM_42A_SERVTYPON.3	ITEM_42A_SERVTYPON.6	water_under.FALSE	water_under.TRUE	highway_under.FALSE	highway_under.TRUE	VCLRUNDER_Positive.FALSE	VCLRUNDER_Positive.TRUE	Proposal.Item.Quantity
7060100_	Substructure Conc	0.60	1	1		1	1	1	1	1		1	1	1		1	1	1	1	1	1		1	1			1	1						1
7120020_	Epoxy Ovly	0.57	1	1	1	1	1					1			1	1	1		1		1		1	1	1			1	1					1
7070061_	Structural Steel, Plat	0.56	1		1							1			1		1		1	1	1		1		1			1	1			1		1
7060112_	Supstr Conc,Form, Fi	0.49	1				1	1	1			1	1		1		1	1				1	1					1	1					
7130071_	Structures, Rem Port	0.42	1	1	1		1		1			1			1		1	1	1		1	1			1	1		1	1	1	1			1
7150045_	Steel Structure, Clea	0.42	1	1		1			1	1					1	1		1	1			1	1		1	1	1			1	1			1
7130080_	Str Steel, Retrofit, Fu	0.34	1	1		1	1	1	1	1					1							1	1											
2040060_	Structures, Rem	0.30		1								1						1	1	1	1													
8507051_	(supplemental)	0.28			1			1	1						1		1					1			1	1	1			1				
7120022_	Epoxy Ovly, Warrant	0.26	1	1	1		1		1	1		1	1		1		1	1	1		1			1	1							1		1
7120112_	Patching Conc, C-L	0.21	1	1	1			1	1	1		1			1	1		1	1	1		1	1	1			1	1						1
7060092_	Reinforcement, Stee	0.21	1	1	1				1				1	1	1		1		1				1					1	1					1
7150047_	Steel Str, Cleaning, P	0.18	1	1		1	1		1			1	1	1	1		1			1		1	1	1	1			1						1
7120007_	Hand Chipping, Othe	0.17														1																		1
7120017_	Patch, Forming	0.16	1	1	1			1	1		1			1	1				1		1	1												1
7050034_	Pile, Steel, Furn and	0.16			1			1				1				1	1	1		1		1	1			1								1
7050002_	Pile Driving Equipme	0.14				1																												
7120076_	Hydrodemolition, Fi	0.14	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1		1	1	1		1	1	1					1		1
7120070_	Structures, Rehabilit	0.13	1			1		1		1		1	1		1		1		1		1		1					1	1			1	1	
7060101_	Substructure Conc, H	0.12	1		1			1				1		1		1	1	1	1		1	1	1	1		1		1	1	1				1
7120025_	Bridge Deck Surface	0.02	1	1	1	1		1		1			1	1		1			1	1		1	1			1		1	1					1
7120071_	Deck Joint, Rem	<0.02	1				1					1			1					1		1												
2040061_	Structures, Rem Port	<0.02	1		1					1		1			1	1		1					1											
7047051_	(supplemental)	<0.02	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1		1					1	1	1	1	1		1
7060050_	Expansion Joint Devi	<0.02					1	1		1													1					1						
7100025_	Penetrating Healer/	<0.02	1	1	1						1	1			1	1		1		1		1				1	1							
7122005_	Bridge Joint, Strip Se	<0.02	1	1	1		1	1	1	1		1			1	1	1	1	1	1			1	1			1	1	1					

Table 5.7b. Results of Lasso Regression, Outliers Removed.

Cost Item	Description	R^2	n_bridge_in_project	Annual_Budget_Amount_mil	DECK_AREA	ITEM_28_LANES_ON	ITEM_28_LANES_UNDER	ITEM_29_ADTTOTAL	ITEM_48_MAXSPAN	ITEM_49_LENGTH	ITEM_54_VCLRUNDER	MDOT_Award_Date	Category.of.Work.Bridge.CPM	Category.of.Work.Bridge.CSM	Category.of.Work.Bridge.Reh	Category.of.Work.Bridge.Repl	ITEM_2_REGION.01	ITEM_2_REGION.02	ITEM_2_REGION.03	ITEM_2_REGION.04	ITEM_2_REGION.05	ITEM_2_REGION.06	ITEM_2_REGION.07	ITEM_42A_SERVTYPON.1	ITEM_42A_SERVTYPON.2	ITEM_42A_SERVTYPON.3	ITEM_42A_SERVTYPON.6	water_under.FALSE	water_under.TRUE	highway_under.FALSE	highway_under.TRUE	VCLRUNDER_Positive.FALSE	VCLRUNDER_Positive.TRUE	Proposal.Item.Quantity
7150045_	Steel Structure, Clea	0.62			1	1			1								1	1				1			1		1							
7120020_	Epoxy Ovly	0.59	1	1		1		1		1			1			1				1		1		1			1			1	1			
7060100_	Substructure Conc	0.41	1	1		1	1		1	1	1	1	1		1		1	1		1	1	1	1	1										1
7070061_	Structural Steel, Plat	0.36						1																1			1							1
7130071_	Structures, Rem Port	0.29	1	1				1	1	1	1				1	1		1	1			1	1		1	1								1
2040060_	Structures, Rem	0.28		1	1					1		1			1	1		1					1											
7060101_	Substructure Conc, H	0.24	1		1						1	1	1				1		1	1	1		1		1									1
7120070_	Structures, Rehabilit	0.23	1	1		1		1		1		1	1	1		1		1	1						1	1	1	1						1
7130080_	Str Steel, Retrofit, Fu	0.22	1	1		1		1	1	1		1	1	1		1				1		1	1	1	1	1		1						1
7120007_	Hand Chipping, Othe	0.20	1	1	1		1	1	1	1		1		1	1	1	1	1	1		1	1	1	1	1		1	1	1			1	1	1
7050002_	Pile Driving Equipme	0.17			1			1				1				1	1	1			1		1			1								1
7120017_	Patch, Forming	0.16	1	1	1		1		1	1		1	1		1		1	1	1		1			1	1							1		1
7120112_	Patching Conc, C-L	0.14	1	1	1		1	1	1						1		1	1			1				1	1		1		1	1	1	1	1
7150047_	Steel Str, Cleaning, P	0.13			1				1	1					1										1			1						
7060092_	Reinforcement, Stee	0.08							1			1				1	1				1							1	1	1	1			1
7060050_	Expansion Joint Devi	0.04	1	1	1	1	1	1	1			1		1	1	1			1	1			1	1										1
7120071_	Deck Joint, Rem	0.04		1								1			1													1	1					
2040061_	Structures, Rem Port	<0.02	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1					1	1	1		1	1	1
7047051_	(supplemental)	<0.02		1		1		1	1			1					1	1	1		1	1	1					1	1					1
7050034_	Pile, Steel, Furn and	<0.02			1																													
7060112_	Supstr Conc,Form, Fi	<0.02	1	1	1	1		1	1		1	1			1	1				1	1			1		1								1
7100025_	Penetrating Healer/	<0.02						1	1	1	1	1		1	1						1	1												1
7120022_	Epoxy Ovly, Warrant	<0.02	1	1					1			1			1							1	1					1						1
7120025_	Bridge Deck Surface	<0.02																																
7120076_	Hydrodemolition, Fi	<0.02				1	1												1				1	1			1							
7122005_	Bridge Joint, Strip Se	<0.02	1					1				1											1											
8507051_	(supplemental)	<0.02																		1			1											1

Table 5.7c. Comparison of Multiple Linear Regression and Lasso Models.

				R^2			
	Typ. Weight	Cost Item	Description	Lasso - none	Lasso - Trunc	Lasso -Rem	Multilinear
1	37%	7150045	Steel Structure, Cleaning, Type 4	--	0.42	0.62	0.58
3	29%	7120070	Structures, Rehabilitation, Rem Portions	0.12	0.13	0.23	0.19
4	25%	7150047	Steel Str, Cleaning, Partial,Type 4	--	0.18	0.13	0.21
5	19%	7120022	Epoxy Ovly, Warranty	0.16	0.26	--	0.34
8	13%	7120020	Epoxy Ovly	0.16	0.57	0.59	0.79
9	13%	7060112	Supstr Conc,Form, Fin,and Cure,Night Cast	0.21	0.49	--	0.48
10	11%	2040060	Structures, Rem	0.96	0.30	0.28	0.28
11	11%	7070061	Structural Steel, Plate, Furn and Fab	0.18	0.56	0.36	0.73
12	10%	7050002	Pile Driving Equipment, Furn	--	0.14	0.17	0.16
13	9%	7120076	Hydrodemolition, First Pass	0.05	0.14	--	0.22
14	9%	7130071	Structures, Rem Portions	0.02	0.42	0.29	0.39
15	8%	7060050	Expansion Joint Device	0.41	--	0.04	0.08
16	6%	7060101	Substructure Conc, High Performance	--	0.12	0.24	0.07
17	5%	7120017	Patch, Forming	0.16	0.16	0.16	0.18
18	4%	7060092	Reinforcement, Steel, Epoxy Coated	0.41	0.21	0.08	0.25
19	4%	7050034	Pile, Steel, Furn and Driven, 14 inch	0.53	0.16	--	0.42
20	4%	7120007	Hand Chipping, Other Than Deck	0.17	0.17	0.20	0.23
21	4%	7120112	Patching Conc, C-L	0.04	0.21	0.14	0.15
25	12%	7120071	Deck Joint, Rem	0.06	--	0.04	0.07
25	7%	7130080	Str Steel, Retrofit, Furn, Fab, & Erect	--	0.34	0.22	0.09

5.8 CBR

Two versions of CBR were implemented, as described below.

5.8.1 CBR Version 1

A) Truncate Outliers. Unit price outliers were truncated to the minimum or maximum values determined by +/- 3 MAD.

B) Identify Similar Structures.

1. Compute component similarity score (CS_{ij}) for each predictor variable (component) *i* for each comparison structure *j*. CS for continuous variables is:

   $$CS_{ij} = | E_i – C_{ij} |$$

   where Ei is the value of predictor variable i for the structure to estimated, and Cij is the value of predictor variable i for comparison structure j.

For categorical variables, CSij = 1 for an exact match between the component value of the estimated and comparison structures, and CSij = 0 if otherwise.

2. Rank all component similarities for each comparison structure.

   For a given parameter i that is a continuous variable, CSij values for all comparison structures are sorted from low to high. The comparison structure with lowest CS value, which indicates the closest match between the estimated and comparison structure parameter values, is given a weight of 1.0 for that parameter; as CS values increase, ranks are assigned weight values of 0.75, 0.5, and 0.25, for the 2^{nd}, 3^{rd}, and 4^{th} CS ranks, respectively. CS scores with ranks lower than 4 are given weights of 0. Thus, only the top five CS values are given non-zero weights.

   For categorical variables, CS weights are unchanged from above (i.e. CSi = 1 or 0).

3. Calculate the similarity score (SSj) of each structure j. This is taken as the weighted sum of the CS scores for that structure:

   $$SS_j = \sum_{i=1}^{n} CS_{ij} \cdot w_{ij}$$

   In this CBR version, each parameter is weighted equally, such that wij = 1/17, from the 17 predictor variables (components) considered.

C) Estimate Unit Price.

Prices for a given cost item are estimated by averaging the prices of that cost item from the structures with the top ten Similarity Scores. As discussed above, the final price is then multiplied by the expected quarterly MHCCI value.

5.8.2 CBR Version 2

A) Truncating Outliers. As above.

B) Identify Similar Structures.

1. Compute component similarity scores. As above. However, in this case, a different set of components (predictor variables) is used for each cost item, where the components used are only those found to be significantly related to that cost item. In particular, those that have $p<0.05$ (green shaded) in Table 5.5.

2. Rank component similarities for each comparison structure. As above.

3. Calculate the similarity score of each structure. As above, except in this version, weights wij for component i are computed in correspondence with the relative strength of its R^2 value found from the single linear regression results; i.e.:

   $w_{ij} = R^2_i / \sum R^2_i$

   where R^2_i is the R^2 value for component i and the cost item under consideration.

C) Estimate Unit Price. As above.

As the CBR approach does not develop a regression line, appropriate metrics for model performance are not Adj R^2 and p-value. Rather, a direct comparison is made to actual bid prices, as discussed below.

5.9 Comparative Results to Bid Prices

Results of the two CBR models, the Regression Models, and the Engineering Estimate obtained from MDOT are compared to the actual winning bid item prices in 2022, the most recent year for which all data are available. This comparison is given in Table 5.8, where the mean and coefficient of variation (V) of the predicted/actual winning bid price for each cost item is presented. For results in the comparison/prediction data set (not the training set), cost outliers were removed with MAD (limit of 3). This cut-off was relatively conservative, where only 296 out of 7715 price data among the 25 cost items (3.8%) were removed.

Note that Item 7060100 (Substructure Conc) has no data in year 2022 to compare, and two other items (7050034 and 7120020) have only one item for that year (once outliers were removed).

Table 5.8. Predicted/Actual Ratio Comparison.

				Predicted / Actual Ratio													
Mean %	Importance			Engineer Estimate		Single L.R.		Multiple L.R.		Lasso L.R. -Trunc		Lasso L.R. - Rem		CBR Version 1		CBR Version 2	
of Project	(weight)	Item #	Description	Mean	V	Mean	V	Mean	V	Mean	V	Mean	V	Mean	V	Mean	V
29%	0.09	7120070_S	Structures, Rehabilitation, Rem Portions	0.72	3.91	0.72	1.01	0.72	1.01	3.52	1.09	3.73	0.90	2.50	1.84	3.42	1.16
25%	0.08	7150047_S	Steel Str,Cleaning,Partial,Type 4	0.44	0.80	1.16	0.48	1.21	0.51	1.22	0.67	1.24	0.62	2.82	3.43	2.78	3.38
37%	0.12	7150045_S	Steel Structure, Cleaning, Type 4	0.87	0.47	0.99	0.30	0.99	0.30	1.17	0.31	1.17	0.35	1.38	0.35	1.33	0.29
13%	0.04	7060112_S	Supstr Conc,Form,Fin,and Cure,Night Cast	0.44	0.64	1.52	0.62	1.37	0.79	1.01	0.64	1.10	0.69	0.96	0.49	0.88	0.52
9%	0.03	7120076_S	Hydrodemolition, First Pass	1.49	0.38	1.12	0.39	0.73	0.41	1.34	0.29	1.30	0.28	1.28	0.42	1.13	0.27
4%	0.01	7060092_S	Reinforcement, Steel, Epoxy Coated	1.14	0.32	1.07	0.17	1.05	0.18	0.99	0.17	0.93	0.17	1.00	0.13	0.95	0.18
8%	0.03	7060050_S	Expansion Joint Device	1.37	0.49	0.87	0.27	0.88	0.26	1.29	0.27	1.08	0.24	1.25	0.28	1.25	0.33
9%	0.03	7130071_S	Str Steel,Retrofit,Furn,Fab,& Erect	1.30	0.53	1.29	0.32	1.13	0.34	1.00	0.40	1.08	0.35	1.03	0.52	1.22	0.36
11%	0.04	7070061_S	Structural Steel, Plate, Furn and Fab	0.78	0.03	1.15	0.18	1.21	0.18	0.93	0.16	0.91	0.16	1.16	0.13	1.03	0.19
11%	0.04	2040060_S	Structures, Rem	0.40	0.31	1.52	0.34	0.94	0.28	1.03	0.57	1.09	0.56	1.08	0.72	1.16	0.79
6%	0.02	7060101_S	Substructure Conc, High Performance	1.87	1.57	0.59	0.35	0.63	0.44	1.64	0.71	1.73	1.11	1.77	0.80	1.93	0.78
33%	0.10	2040061_S	Structures, Rem Portions	0.85	0.56	0.76	0.89	0.67	0.71	1.50	0.21	1.72	0.19	8.84	0.81	4.79	0.70
10%	0.03	7050002_S	Pile Driving Equipment, Furn	0.21	0.66	1.34	0.20	0.92	0.22	1.09	0.24	1.29	0.21	1.43	0.28	0.98	0.39
4%	0.01	7050034_S	Pile, Steel, Furn and Driven, 14 inch	0.79	--	1.49	--	1.46	--	0.95	--	1.14	--	0.83	--	0.86	--
19%	0.06	7120022_S	Epoxy Ovly, Warranty	1.01	0.14	0.95	0.11	0.94	0.12	1.04	0.07	1.01	0.02	1.07	0.08	1.07	0.11
5%	0.02	7120017_S	Patch, Forming	17.26	3.27	2.64	0.88	1.84	0.85	12.9	3.44	12.9	3.44	5.38	2.82	2.93	2.41
13%	0.04	7120020_S	Epoxy Ovly	1.25	--	0.91	--	0.89	--	1.05	--	1.01	--	1.10	--	1.13	--
4%	0.01	7120112_S	Patching Conc, C-L	2.25	1.01	1.09	0.54	1.31	0.82	1.73	1.10	1.75	1.09	1.17	0.81	1.13	0.63
15%	0.05	7100025_S	Penetrating Healer/Sealer, Bridge Deck	1.24	0.15	0.95	0.20	0.97	0.20	1.05	0.19	1.04	0.16	1.11	0.19	1.08	0.20
4%	0.01	7120007_S	Hand Chipping, Other Than Deck	27.6	3.29	1.53	0.58	1.78	0.79	16.1	3.33	17.4	3.25	5.62	3.11	2.34	2.11
14%	0.04	7122005_S	Bridge Joint, Strip Seal Gland Replac	1.11	0.46	1.04	0.40	1.07	0.37	1.00	0.06	1.00	0.05	1.06	0.37	1.02	0.44
8%	0.03	7120025_S	Bridge Deck Surface Construction	1345	2.10	0.73	0.64	0.91	0.65	1.65	0.50	1.27	0.40	1280	1.81	1167	1.85
12%	0.04	7120071_S	Deck Joint, Rem	885	5.73	0.91	0.59	0.85	0.58	1.39	0.44	0.94	0.28	658	5.72	505	5.72
4%	0.01	7060100_S	Substructure Conc	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7%	0.02	7130080_S	Support, Column, Temp	5484	7.31	1.40	0.54	1.52	0.65	1.33	1.06	1.16	0.84	4978	7.26	8267	7.28
			Weighted Overestimators:	**2.87**	**0.61**	**1.31**	**0.40**	**1.27**	**0.47**	**1.88**	**0.51**	**1.99**	**0.51**	**2.61**	**0.94**	**2.13**	**0.83**
			Weighted Underestimators:	**0.67**	**1.09**	**0.86**	**0.50**	**0.84**	**0.44**	**0.94**	**0.13**	**0.95**	**0.11**	**0.94**	**0.32**	**0.92**	**0.36**
			Number of Items Improved:			21/24	17/22	21/24	17/22	20/24	16/22	21/24	16/22	19/24	16/22	17/24	17/22

In general, most results for all models as well as the engineering estimate display a significant range of mean predicted/actual ratios as well as high V. For ease of comparison, if a particular model produced a better result than the engineering estimate, it was highlighted in green (dark green for mean and light green for V). As shown, the mean of only one cost item is predicted better by the engineering estimate than any of the models, Item 2040061, Structures Rem Portions, and only one had lower V than any of the models (7070061, Structural Steel, Plate, Furn and Fab. Note that for item 2040061, it is generally under predicted by the engineering estimate (mean 0.85), whereas it is over predicted by the Lasso and CBR models.

Moreover, in terms of mean cost ratio, all models make improvements on the majority of cost items as compared to the engineering estimate, where 3 of the regression models improve 21 of 24 cost items and one improves 20 cost items, while the CBR models improve 17 and 19 cost items. V is improved for 16-17 of 22 cost items across all models (some V not available due to a lack of data).

An overall summary of the results is given at the bottom of the table, where the weighted average of mean and V results for the cost items are given. Weights are based on the mean percentage that a cost item contributes to a project in which that item appears, as given in the leftmost column of the table. For example, since Item 7150047, Steel Str, Cleaning, Partial, Type 4 has the highest mean contribution at 37%, it is given highest proportional weight. Note that taking an unweighted mean does not alter the trends or conclusions. For each estimating method, these summary results are separated into two groups, cost items that are over predicted and those that are under predicted. Note that the 4 items at the bottom of the table are not included in the summary statistics, as they have extremely large deviations from the mean price for the engineering estimate and CBR models, and represent atypical cases, as will be discussed further below.

As shown, all models produce better estimates overall for mean cost ratios for both over and underestimated prices as well as for V for the underestimated items. All models except the CBR models do not improve V for the overestimated items.

For the underestimated items, the Lasso models have mean cost ratios of 0.94 and 0.95, whereas the CBR models have mean ratios of 0.92 and 0.94. For V, however, the Lasso models have a definite advantage, with V of 0.13 and 0.11, compared to CBR with V of 0.32 and 0.36.

For the overestimated items, the Lasso models provide substantially better results than CBR, with mean ratios of 1.88 and 1.99 and V of 0.51, with CBR mean ratios of 2.61 and 2.13, with V of 0.94 and 0.83.

As noted above, the engineering estimate as well as the CBR models for some of the cost items are extremely far off; in particular, for those items at the bottom of Table 5.8, with mean predicted/price ratios over 1000. Although not at extreme, two other cost items are also relatively far off in the engineering estimate and, to a lesser extent, the lasso models (7120017, Patch Forming, and 7120007, Hand Chipping). This occurred because a small number of outliers greatly distorted the summary statistics. If these two items are removed from the dataset and the overall statistics recalculated, the Lasso model results have mean ranging from 1.42-1.50 and V from 0.39-0.40, whereas the single and multiple regression results have mean ranging from 1.10-1.16 and V from 0.34-0.40.

Note that the models were constructed from all projects in the database, from years 2009-2022, whereas the engineering estimate for 2022 is based on data prior 2022. The additional 2022 price data used to form the models may appear to give the models an artificial advantage over the engineering estimate when results are compared. However, recall that prior to model construction, all prices are normalized by dividing by MHCCI. As a result, all prices are placed into a single pool of normalized data for model construction. That is, when 2022 project prices are estimated, the regression models do not directly draw upon 2022 prices. Similarly, when the CBR model comparison results were generated, self-sampling was prohibited, such that to estimate prices for a given 2022 project, the same project is not used in the estimation. Some advantages do exist, however, when 2022 data are included. First, 2022 contains one of the largest data pools in the yearly database, representing approximately 16% of the total number of structures. Removing this data would significantly reduce the size of the database, decreasing model quality. Second, it is expected that 2022 projects would be more similar to other projects in 2022 than other years. This similarity would be expected to enhance model results when prices from the same year are predicted.

To examine this effect, CBR version 1 was rerun, but excluding all 2022 projects from the database to draw upon. The original overall weighted results were (per Table 5.8): for over predictors, mean=2.61 and V=0.94; while for under predictors, mean=0.94 and V=0.32. When the 2022 data were excluded, results were: for over predictors, mean=4.98 and V=0.96; while for under predictors, mean=0.85 and V=0.48. The engineering estimate for over predictors is mean=2.87 and V=0.61, and for under predictors, mean=0.67 and V=1.09. Thus, although results clearly worsened by eliminating the 2022 data, the under predictor results from CBR remain substantially better than the engineering estimate.

Based on the results above, if underestimation is the primary concern, then the Lasso models are best overall, which have greatest accuracy (mean cost ratio 0.94-0.95) as well as least variation (V=0.11-0.13) for the underestimated costs. For the over-estimated costs, the Lasso results are substantially better than the CBR models, but both the single and multiple linear regression models are better, with mean cost ratio of about 1.30 and V from 0.40-0.47.

CHAPTER 6: DEVELOPMENT OF WORK TYPE COST MODEL

6.1. General Approach

In the previous chapters, a method was developed that could significantly improve the accuracy of unit price estimation. However, the primary concern is the total (unit) cost of the work type rather than that of a selection of individual pay items. The work types of interest are given in the current MDOT Bridge Cost Estimation Worksheet (BCEW), as shown in Appendix B. Excluding roadwork and traffic control, there are 46 bridge-specific types of work, which are given in Table 6.1. The normalizing item refers to the parameter that is used as a divisor to convert the total work type cost to a unit cost. The final item is the input quantity which is used on the BCEW. Assumptions necessary for unit conversion, where necessary, are provided at the bottom of the table (note obvious conversions to be used, such as from SF to SY, are not explicitly specified in the table).

Table 6.1. Work Types in Bridge Cost Estimation Worksheet.

Work Type	Normalizing Item	Final Item
NEW BRIDGE		
Single or Mult. Spans, Grade Separation	Bridge deck area (SF)	Bridge deck area (SF)
Single Span, Over Water	Bridge deck area (SF)	Bridge deck area (SF)
Multiple Spans, Over Water	Bridge deck area (SF)	Bridge deck area (SF)
Precast Culvert	Bridge deck area (SF)	Bridge deck area (SF)
Railroad	Bridge deck area (SF)	Bridge deck area (SF)
NEW SUPERSTRUCTURE		
New Superstructure, Grade Separation	Superstructure Concrete (CY)[1]	Bridge deck area (SF)
New Superstructure, Over Water	Superstructure Concrete (CY)[1]	Bridge deck area (SF)
New Superstructure, Combined	Superstructure Concrete (CY)[1]	Bridge deck area (SF)
WIDENING		
Structure Widening	New Deck Area (SF)[2]	Area of add. deck (SF)
NEW DECK		
New Bridge Deck & Barrier	Bridge deck area (SF)	Area of new deck (SF)
DEMOLITION		
Entire Structure, Grade Separation	Bridge deck area (SF)	Bridge deck area (SF)
Entire Structure, Over Water	Bridge deck area (SF)	Bridge deck area (SF)
DECK REPAIR / TREATMENTS		
Bridge Railing Replacement	Railing Length (FT)[3]	Replacement length (FT)
Concrete Brush Block / Curb Patch	Patching Conc, C-L 7120112 (CY)[4]	Patch length (FT)
Concrete Barrier Patch	Patching Conc, C-L 7120112 (CY)[5]	Area of repair (SF)
Concrete Deck Patch	Hand Chipping, Deep 7120004 (SF)	Patch area (SF)
Deep Overlay	Hydrodemolition, First Pass 7120076 (SY)	Overlay area (SF)
Epoxy Overlay	Epoxy Ovly, Warranty 7120022 (SY)	Overlay area (SY)
Expansion Joint Gland Replacement	Bridge Joint, Strip Seal Gland Replac 7122005 (FT)	Replacement length (FT)
Expansion Joint Replacement	Expansion Joint Device 7060050 (FT)	Replacement length (FT)
Full Depth Patch	Patch, Full Depth 7120010 (CY)[5]	Area of repair (SF)
Healer / Sealer	Penetrating Healer/Sealer, Bridge Deck 7100025 (SY)	Application area (SY)

HMA Overlay with WP membrane	Membrane, Preformed Waterproofing 7100008 (SF)	Overlay area (SY)
Overlay Removal	Epoxy Ovly, Rem 7120021 (SY)	Removal area (SY)
Reseal Bridge Joints	Bridge Deck Saw and Polyurethane Seal 7127001 (FT)	Length of repair (FT)
Shallow Overlay	Hydrodemolition, First Pass 7120076 (SY)	Area of repair (SF)
SUPERSTRUCTURE REPAIR		
Bearing Realignment / Replacement	Support Column, Temp 7130080 (EA)	Each bearing (EA)
Heat Straightening	Heat Straightening Steel 7130040 (LS)[6]	Each 35' repair (EA)
Pack Rust Repair	Pack Rust Repair 7137010 (FT)	Length of repair (FT)
Paint - Complete	Steel Structure, Coating, Type 47150046 (LS)[7]	Area of paint (SF)
Paint - Partial / Spot / Zone	Steel Str, Coating, Partial, Type 47150048 (LS)[7]	Area of paint (SF)
PCI Beam End Blockout	Support Column, Temp 7130080 (EA)	Each beam end (EA)
Pin & Hanger Replacement	Hanger Assembly, Rem and Erect 7130031 (EA)	Each assembly (EA)
Structural Steel Repair	Str Steel,Welded Repr, Furn,Fab,and Erect 7130072 (LB)[8]	Each 6' repair (EA)
Structural Steel Repair - Stiffener	Stiff, Furn, Fab, Erect 7130060 (LB)[9]	Each 6' repair (EA)
SUBSTRUCTURE REPAIR		
Substructure Patching	Patching Conc, C-L 7120112 (CY)	Volume of patch (CF)
Substructure Replacement	Substructure Concrete (CY)[10]	Volume of patch (CF)
Substructure Horizontal Surface Sealer	Substructure Horizontal Surface Sealer 7100030 (SY)	Area of application (SY)
Temporary Supports	Support, Column, Temp 7130080 (EA)	Each beam support (EA)
MISCELLANEOUS		
Articulating Concrete Block System	Articulating Conc Block System, 6 inch 2087011 (SY)	Area of application (SY)
Concrete Surface Coating	Conc Surface Coating 7100011 (SY)	Area of application (SY)
Culvert Cleanout	Culvert cleanout 4017001 (FT)	Length of cleanout (FT)
Epoxy Crack Injection	Structural Crack, Repr 7120099 (FT)	Length of repair (FT)
Metal Mesh Panels	Metal Mesh Panels 7070120 (SF)	Area of panels (SF)
Pressure Relief Joint	Joint, Pressure Relief 6020213 (FT)	Length of joint (FT)
Riprap	Riprap, Plain 8130011 (TON)[11]	Area of application (SY)
Silane Treatment	Silane Treatment 7107010 (SF)	Area of application (SF)
Slope Protection Repairs	Slope Protection, Replace 8137011 (SY)	Area of repair (SY)

1. Either: Supstr Conc, Night Casting, High Perform 7060117, or Superstructure Conc, High Performance 7060116, or Supstr Conc 7060110, or Supstr Conc, Night Casting 7060113, or Superstructure Conc, Night Casting 7060021, or Superstruc Conc 7060020, depending on what pay items are present in the project.

CY converted to SF assuming 9" deck thickness (conversion factor = 1/27 * 9/12 = 0.0278).

2. New deck area is taken as: False decking quantity (7060060) – Bridge Deck Area. Here it is assumed that the entire existing and added bridge deck is supported by false decking.

3. Multiple railing types are possible. The normalizing item was taken as the pay item in the project that had "rail" in the description (for example, Brdg Bar Rail, Type 6, Replacement, HP 7112014). See Appendix C, Table C.42 for a full list of possible railing pay items.

4. CY converted to FT assuming a 4” width of a 10” high brush block is patched (conversion factor = 1/27 * 4/12 * 10/12 = 0.0103).

5. CY converted to SF assuming a 4” depth of patch (conversion factor = 1/27 * 4/12 = 0.0123).

6. LS is assumed to be equal to a single repair (EA); conversion factor = 1.0.

7. Complete painted area assumes 2 sides of the web; a beam depth of 0.033xspan length (per AASTHO 2.5.2.6.3-1); 2.5' total width of the flange faces to be painted; 5' overhang width, and 6.5' girder spacing (conversion factor = [Seal perimeter + Coating + Cleaning] ($) / [((2*0.33*max bridge span + 2.5)*bridge length)*(bridge width - 5)/6.5]).

8. Assumes a 6” x 9” x ½” bent plate of 6’ length on each side of the girder, with steel density of 0.238 lb/in^3 (conversion factor = (6” + 9”) * 0.5” * 72” * 2 sides * 0.238 = 257 (lb per each beam repair)).

9. Assumes a 42” deep girder with 1” flange thickness and a 6" x 6" x 0.5" stiffener on each side (conversion factor = (6” + 6”) * 0.5” * 41” (web height) * 2 sides x 0.238 lb/in^3 = 117 (lb per stiffener repair).

10. Either: 7060101 Substructure Conc, High Performance, or 7060100 Substructure Conc, depending on what pay item is present in the project.

11. Assumes 2.475 tons per SY.

A potential approach is to construct a regression model for the total project unit cost (here “project cost” refers to the cost of a single bridge within a project if that project contains multiple structures), after eliminating cost items that are to be separated (such as MOT, approach work, demolition in some cases, etc). However, two difficulties exist with this approach: First, the work types given in the BCEW are identified differently than in the bridge project price database (BPPD), where there are about twice as many types of work indicated in the BDEW than in the price database. The available work types in the BPPD are given in Table 6.2, along with the total number of projects marked to contain that work type. A second difficulty is that, for many work types, few projects exist that are exclusively that work type (i.e. “Solo Count” in Table 6.2). Most projects involve costs of multiple types of work together in the project (“Total Count”). For most of the work types, too few singular work type projects exist to build a reliable cost model—the majority have fewer than 10 singular projects available. Thus, it is necessary to rely upon cost information within projects that contain multiple types of work. However, there is no direct way to separate out only the cost of the singular work type of interest from the total project cost. Another concern is, because most projects have combined work types, a different pricing may have occurred for single-work type projects for the same type of work due to economies of scale and other factors, than for multiple work type projects.

Thus, the two problems to be solved are: 1) identifying projects in the BPPD that have work types indicated in BCEW and 2) separating the costs of only those work types from projects that have multiple types of work combined.

Table 6.2. Work Type Designations in Bridge Project Price Database.

Work Type in BPPD	Total Count	Solo Count	Final Count	Corresponding Work Type in BCEW
HMA Overlay	32	8	28	HMA Overlay with WP Membrane
Epoxy Overlay	412	16	401	Epoxy Overlay
Healer Sealer	60	5	59	Healer / Sealer
Deep Overlay	126	10	109	Deep Overlay
Shallow Overlay	38	3	34	Shallow Overlay
Superstructure Repair	337	35	337	--
Substructure Repair	638	50	638	--
Deck Patch	531	11	464	Concrete Deck Patch
Deck Replacement	92	3	91	Deck Replacement
Superstructure Replacement*	31	16	19	New Superstructure
Grade separation	14	12	10	New Superstructure, Grade Separation
Over water	13	2	9	New Superstructure, Over Water
Bridge Replacement*	173	127	111	New Bridge
Grade separation	74	51	58	Single or Mult. Spans, Grade Separation
Single span over water	46	30	30	Single Span Over Water
Multiple spans over water	31	27	23	Multiple Spans, Over Water
Pin and Hanger	103	1	90	Pin & Hanger Replacement
Concrete Surface Coating	6	0	6	Concrete Surface Coating
Joint Replacement	279	3	234	Expansion Joint Replacement
Partial Paint	166	6	149	Paint – Partial / Spot / Zone
Full Paint	120	2	105	Paint - Complete
Widen	46	7	32	Structure Widening
Heat Straightening	17	1	14	Heat Straightening
Railing Replace	120	8	103	Bridge Railing Replacement
Railing Repair	154	7	154	--
Culvert Replacement	80	58	67	Bridge Replacement - Culvert
Scour Protection	141	44	141	--
Bridge Approach	420	6	420	N/A (item not considered)

*Counts of sub-categories do not sum to the total because the total includes all bridge types in the database (i.e. including R, P, V, and X structures), while the sub-categories include only bridges named B (over water) and S (grade separation).

Problem 1) was addressed as follows. As shown in Tables 6.1 and 6.2, although the lists of work types in the BCEW and BPPD differ, there are some direct equivalents, as shown in Table 6.2. For these, direct identification is possible. For the remaining work types in the BCEW, corresponding projects within the BPPD were identified by use of primary pay items. In this study, primary pay items are defined as a small set of pay items that, if contained together in a project, that project is assumed to contain the corresponding work type. The work types identified using primary pay items are given in Table 6.3, while the list of specific primary pay items assumed for each work type are given in Appendix C.

Table 6.3. Work Types in BCEW Identified By Primary Pay Items.

Work Type	Count
Demolition, Over Water	27
Demolition, Grade Separation	62
Concrete Brush Block / Curb Patch	719
Concrete Barrier Patch	719
Expansion Joint Gland Replace.	24
Full Deck Patch	54
Overlay Removal	106
Reseal Bridge Joints	102
Bearing Realignment / Replace.	84
Pack Rust Repair	4
PCI Beam End Blockout	145
Str. Steel Repair	30
Str. Steel Repair – Stiffener	105
Substructure Patching	719
Substructure Replacement	44
Substr. Horz. Surface Sealer	314
Temporary Supports	373
ACB System	40
Culvert Cleanout	8*
Epoxy Crack Injection	153
Metal Mesh Panels	41
Pressure Relief Joint	26
Riprap	87
Silane Treatment	226
Slope Protection Repairs	129

*Only 3 had the relevant pay item in the normalizing unit used (FT) and were thus usable.

Note the work types in the BCEW under New Bridge are divided into five categories, based on the type of structure: grade separation bridge; single span bridge over water; multiple span bridge over water; precast culvert; and railroad. To account for these differences, in addition to the project identification by work type process discussed above, the work types under New Bridge are further divided into the grade separation, over water, culvert, and railroad projects by consideration of the structure ID label (e.g. "B01-01052"), where those beginning with "B" are taken as a structure over water; those with "S" are taken as a grade separation, those with "C" are taken as a culvert, and those with "R" are taken as railroad. Similarly, a single span or multiple span structure can be identified by Item 45 in the bridge database, Number of Spans in Main Unit (ITEM_45_MAINSPANS). The work types under New Superstructure and Demolition are similarly divided into grade separation and over water categories. Thus, for a project to be included within one of the New Bridge work types, it must be identified as a "Bridge Replacement" project within the BPPD, as well as meet the structural type criteria (type of bridge/culvert and number of spans) outlined above.

Problem 2) requires a more involved solution, as once the projects containing a specific work type in the BCEW are identified, the costs associated only with that work type must be extracted from the projects. This was done by forming a list of all potential pay items relevant to that work type, such that only those costs associated with those specific pay items would be included in the work type cost. These pay items are given in Appendix C.

With these two issues addressed, the following process was used to determine the total unit cost of a work type for a given project:

1. Determine if a project contains the work type considered using the process discussed above.

2. If the project contains the work type, determine the total base cost of that work type within the project.

> 2a. Sum the total cost (unit cost x quantity) of all pay items belonging to the work type that are found within that project (taken from the list given in Appendix C). Note that most projects will not contain all possible work type pay items, as different mutually exclusive selections are possible (such as different beam types and sizes, concrete grades, etc.), and some projects are more extensive than others.
>
> 2b. Determine unit cost. The total project cost for the work type must be divided by a normalizing quantity to produce a unit cost. For work types on the BCEW that use the total deck area (SF) as the unit, the total cost is divided by this value (the DECK_AREA parameter in column E of the bridge database). For other work types, a normalizing pay item that is most representative of the work type must be identified. The unit of this pay item and its quantity will be used for normalization. Here, the total work type cost of the project is divided by the quantity of the normalizing pay item to produce a unit cost. The normalizing pay items that were used and the accompanying units are given in Table 6.1, above. This unit cost result is referred to as the "base" method.
>
> Notes:
>
> The pay item numbering system was changed in projects prior to 2012. Currently, these projects (170 total) are excluded from the analysis, due to the normalizing item based on total deck area.
>
> Two new bridge projects (grade separation) were described as "partial" construction. These two were excluded from the database.
>
> A significant number of projects were described as 'partial construction; for new superstructure, new deck, and widening work, however. To account for partial construction projects for these projects, CY of concrete was chosen as the normalizing item.
>
> The type of pay items included within each bridge work type correspond to those in the current BCEW. Specifically: none include roadwork, approach, or MOT items; New Bridge work does not include demolition/removal pay items; while New Superstructure, New Deck, and others, as indicated, does include removal pay items.

3. Include supplemental items.

Supplemental items refer to unique, project-specific work items. Although supplemental items vary significantly among projects, many projects contain some supplemental items. It was found that, on average, supplemental items make up approximately 13% of a total project cost. Excluding these items will thus generally under predict prices.

As there were nearly 3700 different supplemental item codes found within the cost database, directly including each supplemental item cost is impractical. Another difficulty is that it is not feasible to assign each supplemental item to the different types of work within each project. To address this issue, it was assumed that all supplemental item costs are, on average, divided proportionally among all work types contained within a project. This proportional cost was then used as a multiplier for all work types within the project. This was implemented by summing the total cost of a project, as well as the total cost of the supplemental items within the project, then computing the ratio of the total supplemental item cost to total project cost. The original unit cost of each work type within the project was then assumed to be increased by this fraction. This unit cost result is referred to as the "supplemental" method.

4. Consider biasing results to higher-cost projects.

The above process is mean to provide data for actual project costs, as a function of work type, as accurately as possible on average. However, as under prediction of project costs may be more of a concern than over prediction, it may be more desirable to estimate the higher end of project cost rather than the average or typical cost. To consider the higher end of project costs, the following approach was also implemented as an option. As noted above, the total unit cost of a work type within each project was determined by summing costs of the pay items that exist in that project that are relevant to the work type considered. However, most projects do not contain all of the applicable pay items, as the actual work done varies, and all applicable pay items for that work type are not needed for every project. To simulate costs for more comprehensive and expensive projects, if an applicable pay item for a work type is not present within a project, the average unit cost of that pay item (after outliers removed), calculated from all projects in the BPPD within the work type considered, was added to the existing project unit cost. The unit cost of the existing project was thus increased to that of a hypothetical project that would have contained the additional possible pay items relevant to that work type. Note for pay items that are mutually exclusive, the weighted average cost of items within the mutually exclusive set was included. Prior to calculating the average unit costs for these pay items, the outliers were truncated using MAD as described earlier. This unit cost result is referred to as the "substitute" method.

5. Account for cost changes as a function of time and cost outliers.

As discussed in earlier chapters, prior to considering any pay item, its cost is normalized by dividing by the MHCCI for the corresponding year and quarter when the project was released. This normalization practically coverts all database costs to the expected value at the first quarter of 2010, the time for which MHCCI is given a value of 1.0. Once the cost models are constructed based on these time-consistent cost values, the final cost is then converted to the time desired for estimation (i.e. year of the most recent BCEW) using a multiple developed from the projection process discussed in Section 6.2. Once the database of project work type unit costs was formed, outlier work type unit costs were truncated using the MAD approach discussed earlier prior to inclusion in the cost model.

The resulting average unit costs for each work type using the above process (steps 1-5) are given in Table 6.4a and 6.4b for 2022, the latest year for which MHCCI data are available. Here rather than using the MHCCI projection method of Section 6.2, the final cost was multiplied by the known 2022 MHCCI value. For comparison purposes to the existing MDOT work type unit cost values, this avoids including the additional uncertainty of the future MHCCI projection.

In Table 6.4a and 6.4b, average unit costs are given for the base, supplemental, and substitute methods, as discussed above. Additionally, to provide a result representing a project cost between an expected average and high-cost project, the average unit cost of the supplemental and substitute unit cost results is provided. Results are presented for cost normalization using the general as well as the bridge-specific MHCCI values, as shown in Table 5.3b.

For further comparison, in Table 6.4c, average unit costs are given for 2024, based on the MHCCI projection model given in Section 6.2. Because the RAP reported that recent costs have decreased, for comparison, a cost option was selected for each work type that would allow 2024 projected costs to most closely align with the MDOT 2022 costs as possible. Of course, other selections and comparisons are also possible.

The cost option labels in the second column of Table 6.4c are given by two characters. The first character (letter) has the following meaning with regard to project complexity (i.e. cost method used): S = "simple" (base method); T = "typical" (supplemental method); C = "complex" (substitute method); M = "moderate" (average of typical and substitute method costs). The second character (number) refers to the MHCCI projection method used; either general (0) or bridge-specific (1). Note for the MHCCI projection method, the 2024 MHCCI is taken as the average of the 4 quarters in 2024. Based on these options, the resulting cost is given in the "Option Result" column. Also provided in the table are the MDOT 2022 and 2023 estimates, as well as the ratios of the 2024 Option result to the MDOT 2022 and 2023 estimate costs.

In some cases, given by " -- " in the table, the substitute method result was not applicable. This occurs because all items in the work type are primary pay items, and thus the substitute method will provide identical results as the base method.

As shown, most items can have cost options selected to recover costs for 2024 similar to either 2022 or 2023 costs if desired. Work types with predicted costs that substantially differ from 2022 as well as 2023 (by about 30% or more) previously developed MDOT estimate worksheet costs, and if high or low, are as follows:

Demolition, Entire Structure, Grade Separation (low)
Bridge Railing Replacement (high)
Concrete Brush Block / Curb Patch (high)
Concrete Barrier Patch (high)
HMA Overlay with WP membrane (high)
Overlay Removal – HMA (high)
Heat Straightening (high)

Pack Rust Repair (low)
Paint – Complete (high)
PCI Beam End Blockout (high)
Structural Steel Repair (high)
Structural Steel Repair – Stiffener (high)
Temporary Supports (high)
Culvert Cleanout (low)
Silane Treatment (low)

Large discrepancies between model and MDOT estimated costs usually occur due to consideration of a small number of projects in the MDOT estimate, and when these project costs are not representative of the mean costs in the database. In other cases, the origin of the MDOT cost estimate is unknown as it was not documented. Examples of explanation for these discrepancies are as follows:

Bridge railing replacement: the work type costs for the projects selected by MDOT used to develop the unit cost estimate had a large range of values, from approximately $600 – $1600/FT. The lowest model cost of $1319/FT falls within this range, and represents the average of all work types within the database. That is, the value selected of $600/FT for use in the 2022 cost estimation worksheet does not well represent the average costs found for that work type.

For Culvert cleanout, although $125/FT is listed in the 2022 estimation spreadsheet, a value of $66/SF was the value found within the supporting MDOT calculations (and also that used for the 2023 value). Regardless, even using $66/FT as a comparison value, the highest model value provides a significantly lower value of $34/FT. Here, only three projects were found to have a Culvert cleanout work type. Each of these were substantially lower than the $66/FT value used in the 2022 cost estimation worksheet.

Similarly for Pack rust repair, the MDOT value selected for use in the 2022 worksheet represents an abnormally high project cost, as compared to the average project costs found in the database.

For Silane treatment, the MDOT calculations for the unit cost estimate indicated a value of $4/SF, but it was taken as $7 for the 2022 spreadsheet. The value of $4/SF aligns more closely with the model prediction of $5/SF.

The costs that best represent the actual mean work type costs in the cost database are those from the base and supplemental cost methods. In the cost estimate worksheet, these options are represented by the “Simple” and “Typical” selections, respectively.

Although several roadwork items were also investigated, the results are not provided here. This is because there is a lack of roadwork cost data available within a usable format. The roadwork costs could thus be based only on a very small selection of projects and the resulting model costs are unreliable.

Table 6.4a. Average 2022 Unit Costs, General MHCCI.

	General MHCCI			
Work Item	**Base**	**Supplemental**	**Substitute**	**AVE: Sup+Sub**
NEW BRIDGE				
Single or Mult. Spans, Grade Separation	197	228	482	356
Single Span, Over Water	259	345	537	442
Multiple Spans, Over Water	226	266	496	381
Railroad	259	296	537	416
Precast Culvert	341	453	670	562
NEW SUPERSTRUCTURE				
New Superstructure, Grade Separation	242	253	302	278
New Superstructure, Over Water	141	152	167	160
New Superstructure, Combined	185	199	238	218
WIDENING				
Structure Widening	697	761	2371	1566
NEW DECK				
New Bridge Deck & Barrier	106	115	113	115
DEMOLITION				
Entire Structure, Grade Separation	27	29	--	--
Entire Structure, Over Water	35	40	--	--
DECK REPAIR / TREATMENTS				
Bridge Railing Replacement	1283	1438	1385	1413
Concrete Brush Block / Curb Patch	49	58	49	54
Concrete Barrier Patch	95	109	227	168
Concrete Deck Patch	451	478	--	--
Deep Overlay	279	312	416	365
Epoxy Overlay	44	53	--	--
Expansion Joint Gland Replacement	122	137	--	--
Expansion Joint Replacement	734	869	1132	1000
Full Depth Patch	80	98	--	--
Healer / Sealer	15	16	--	--
HMA Overlay with WP membrane	9	11	22	16
Overlay Removal	18	20	24	22
Overlay Removal – Latex	18	20	24	22
Overlay Removal – Epoxy	15	16	19	18
Overlay Removal – HMA	12	13	15	14
Reseal Bridge Joints	27	29	--	--
Shallow Overlay	257	276	274	276
SUPERSTRUCTURE REPAIR				
Bearing Realignment / Replacement	4221	4962	--	--
Heat Straightening	74312	76305	--	--
Pack Rust Repair	323	460	--	--
Paint - Complete	26	27	27	27

Paint - Partial / Spot / Zone	35	37	35	37
PCI Beam End Blockout	7581	8475	--	--
Pin & Hanger Replacement	9766	10738	10328	10534
Structural Steel Repair	5628	6566	--	--
Structural Steel Repair - Stiffener	1923	2137	--	--
SUBSTRUCTURE REPAIR				
Substructure Patching	7681	8817	7902	8360
Substructure Replacement	9368	10180	18535	14357
Substructure Horizontal Surface Sealer	66	78	--	--
Temporary Supports	4811	5329	--	--
MISCELLANEOUS				
Articulating Concrete Block System	190	296	--	--
Concrete Surface Coating	37	47	--	--
Culvert Cleanout	26	37	--	--
Epoxy Crack Injection	51	62	51	57
Metal Mesh Panels	27	29	--	--
Pressure Relief Joint	111	137	--	--
Riprap	244	321	--	--
Silane Treatment	4	4	--	--
Slope Protection Repairs	190	237	--	--

Table 6.4b. Average 2022 Unit Costs, Bridge-Specific MHCCI.

	Bridge-Specific MHCCI			
Work Item	**Base**	**Supplemental**	**Substitute**	**AVE: Sup+Sub**
NEW BRIDGE				
Single or Mult. Spans, Grade Separation	188	217	470	344
Single Span, Over Water	270	356	540	448
Multiple Spans, Over Water	224	265	489	378
Railroad	226	260	499	380
Precast Culvert	330	438	655	547
NEW SUPERSTRUCTURE				
New Superstructure, Grade Separation	256	275	310	293
New Superstructure, Over Water	128	156	153	154
New Superstructure, Combined	180	193	236	214
WIDENING				
Structure Widening	634	698	2356	1527
NEW DECK				
New Bridge Deck & Barrier	103	111	108	109
DEMOLITION				
Entire Structure, Grade Separation	26	26	--	--
Entire Structure, Over Water	38	44	--	--
DECK REPAIR / TREATMENTS				

Bridge Railing Replacement	1224	1365	1344	1354
Concrete Brush Block / Curb Patch	47	56	47	52
Concrete Barrier Patch	91	105	221	163
Concrete Deck Patch	491	522	--	--
Deep Overlay	277	311	412	363
Epoxy Overlay	38	48	--	--
Expansion Joint Gland Replacement	120	133	--	--
Expansion Joint Replacement	686	807	1079	944
Full Depth Patch	70	93	--	--
Healer / Sealer	14	17	--	--
HMA Overlay with WP membrane	9	10	22	17
Overlay Removal	19	21	22	22
Overlay Removal – Latex	19	21	22	22
Overlay Removal – Epoxy	15	17	18	18
Overlay Removal – HMA	12	13	14	14
Reseal Bridge Joints	26	29	--	--
Shallow Overlay	263	280	280	280
SUPERSTRUCTURE REPAIR				
Bearing Realignment / Replacement	3945	4636	--	--
Heat Straightening	74065	75965	--	--
Pack Rust Repair	313	453	--	--
Paint - Complete	24	27	27	27
Paint - Partial / Spot / Zone	32	36	32	34
PCI Beam End Blockout	7873	8759	--	--
Pin & Hanger Replacement	9311	10436	9670	10053
Structural Steel Repair	5713	6592	--	--
Structural Steel Repair - Stiffener	1802	2203	--	--
SUBSTRUCTURE REPAIR				
Substructure Patching	7343	8497	7695	8097
Substructure Replacement	9272	10091	18542	14316
Substructure Horizontal Surface Sealer	65	77	--	--
Temporary Supports	4749	5193	--	--
MISCELLANEOUS				
Articulating Concrete Block System	180	279	--	--
Concrete Surface Coating	29	41	--	--
Culvert Cleanout	0	31	--	--
Epoxy Crack Injection	50	62	50	56
Metal Mesh Panels	27	29	--	--
Pressure Relief Joint	106	132	--	--
Riprap	250	322	--	--
Silane Treatment	3	3	--	--
Slope Protection Repairs	157	209	--	--

Table 6.4c. Comparison of Selected 2024 Unit Costs to MDOT 2022 and 2023 Estimates.

Work Item	Option	Option Result	MDOT Estimation		2024 Option / MDOT	
			2022	2023	2022	2023
NEW BRIDGE						
Single or Mult. Spans, Grade Separation	M1	405	330	415	1.23	0.98
(an alternate Option result for the above):	T1	283	330	415	0.86	0.68
Single Span, Over Water	T0	428	450	500	0.95	0.86
Multiple Spans, Over Water	T0	331	330	450	1.00	0.74
Railroad	T0	367	--	--	--	--
Precast Culvert	T1	516	490	540	1.05	0.96
NEW SUPERSTRUCTURE						
New Superstructure, Grade Separation	S0	300	225	295	1.33	1.02
New Superstructure, Over Water	H0	208	225	300	0.92	0.69
New Superstructure, Combined	T1	227	225	295	1.01	0.77
WIDENING						
Structure Widening	S1	747	550	630	1.36	1.19
NEW DECK						
New Bridge Deck & Barrier	S1	121	120	150	1.01	0.81
DEMOLITION						
Entire Structure, Grade Separation	T0	36	65	75	0.55	0.48
Entire Structure, Over Water	T1	52	65	95	0.80	0.55
DECK REPAIR / TREATMENTS						
Bridge Railing Replacement	S1	1442	600	750	2.40	1.92
Concrete Brush Block / Curb Patch	S1	44	25	29	1.76	1.52
Concrete Barrier Patch	S1	107	76	85	1.41	1.26
Concrete Deck Patch	S1	64	63	68	1.02	0.94
Deep Overlay	T0	43	43	46	1.00	0.93
Epoxy Overlay	S1	44	39	48	1.13	0.92
Expansion Joint Gland Replacement	S1	141	115	125	1.23	1.13
Expansion Joint Replacement	S1	808	740	860	1.09	0.94
Full Depth Patch	T0	122	130	140	0.94	0.87
Healer / Sealer	T1	20	16	30	1.25	0.67
HMA Overlay with WP membrane	S1	91	60	60	1.52	1.52
Overlay Removal	S1	22	22	22	1.00	1.00
Overlay Removal – Latex	M1	26	26	26	1.00	1.00
Overlay Removal – Epoxy	M1	21	22	22	0.95	0.95
Overlay Removal – HMA	S1	14	7	7	2.00	2.00
Reseal Bridge Joints	S1	30	25	28	1.20	1.07
Shallow Overlay	T0	38	40	46	0.95	0.83
SUPERSTRUCTURE REPAIR						
Bearing Realignment / Replacement	S1	4647	3400	6450	1.37	0.72
Heat Straightening	S1	87249	45000	57000	1.94	1.53
Pack Rust Repair	T0	571	850	1150	0.67	0.50
Paint - Complete	S1	28	19	22	1.47	1.27

Paint - Partial / Spot / Zone	S1	38	30	35	1.27	1.09
PCI Beam End Blockout	S1	9274	7200	7200	1.29	1.29
Pin & Hanger Replacement	T0	13337	13000	17000	1.03	0.78
Structural Steel Repair	S1	6731	5700	4000	1.18	1.68
Structural Steel Repair - Stiffener	S1	2123	1350	1500	1.57	1.42
SUBSTRUCTURE REPAIR						
Substructure Patching	S1	320	330	360	0.97	0.89
Substructure Replacement	S1	404	375	375	1.08	1.08
Substructure Horizontal Surface Sealer	S1	77	75	75	1.03	1.03
Temporary Supports	S1	5594	3000	4000	1.86	1.40
MISCELLANEOUS						
Articulating Concrete Block System	T1	328	280	320	1.17	1.03
Concrete Surface Coating	S0	236	280	320	0.84	0.74
Culvert Cleanout	S1	34	32	47	1.06	0.72
Epoxy Crack Injection	T0	45	125	125	0.36	0.36
Metal Mesh Panels	T1	73	70	70	1.04	1.04
Pressure Relief Joint	S1	32	26	28	1.23	1.14
Riprap	S1	125	110	110	1.14	1.14
Silane Treatment	S1	5	7	7	0.71	0.71
Slope Protection Repairs	T0	294	223	275	1.32	1.07

The large variability in unit costs, even for the same project type within the same year, has a significant limiting effect on the ability of the model to predict the average unit costs for a particular project. This variability is shown in Tables 6.4d-f for years 2020, 2021, and 2022, respectively, for the base method. In the tables, note the extreme range (min – max) of the unit costs for most items; in many cases, these may vary over 2-3 orders of magnitude, even after some even more extreme values were truncated. This variation can also be seen with the very high COVs for most unit costs, which in most cases exceed 0.50 and in many cases exceed 1.0. It should be noted that the yearly means for each work type vary significantly even after accounting for cost inflation. That is, if the costs shown in the Tables are adjusted for inflation by normalizing by MHCCI (not shown), a large variability still exists among mean costs among the three different years considered. This is due to the inherent significant variability in individual project costs. To further illustrate this large variation, the individual work type unit costs from each project in 2022 used to compute the means in Table 6.4f is given in Appendix D.

Table 6.4g provides a comparison of the model estimation to actual project costs. For this comparison, 7 random projects of different types were selected from the 2022 database. The total actual cost for a project was computed by summing the actual cost of the pay items associated with each work type within the project, as given in Appendix C. As expected, because mean unit costs are used for the estimation, a significant variation between estimated and actual cost exists from one project to the next. Here, the estimate/actual cost ratios were: 0.82, 0.86, 0.91, 1.08, 1.12, 1.20, and 1.38, with an average ratio of 1.05. As more projects are considered as a group, however, the effect of variability decreases overall, and the sum of the total actual project costs will tend to converge to the sum of the total estimated project costs. Note that the estimate costs were computed using the substitute method for all work types within new bridge, new superstructure, and new deck projects, while the base method was used to estimate all work types within the other multi work type projects. The estimate/actual cost ratios shown above could be further improved if the method type was selected more specifically for each work type to calibrate to 2022 prices for this comparison, as was done for 2024.

Table 6.4d. Work Type Unit Costs Statistics for 2020.

Work Type	Min	Max	Mean	Median	COV
New Bridge Single or Mult. Spans, Gr. Sep.	119	233	160	147	0.26
New Bridge Single Span, Over Water	27	308	207	287	0.76
New Bridge Multiple Spans, Over Water	168	175	172	172	0.03
New Superstructure	144	200	393	172	0.10
New Superstructure, Grade Separation	200	200	200	200	--
New Superstructure, Over Water	144	144	144	144	--
Structure Widening	974	979	976	976	--
New Bridge Deck & Barrier	27	155	78	63	0.55
Demo Entire Structure, Grade Separation	29	89	51	36	0.64
Demo Entire Structure, Over Water	8	34	17	10	0.85
Bridge Railing Replacement	561	1696	1072	1049	0.51
Concrete Brush Block / Curb Patch	1	146	25	6	1.56
Concrete Barrier Patch	1	1441	111	29	2.04
Deep Overlay	149	149	149	149	--
Epoxy Overlay	28	44	32	30	0.13
Expansion Joint Replacement	203	2732	686	485	0.73
Full Depth Patch	1	208	46	24	1.27
HMA Overlay with WP membrane	3	3	3	3	--
Overlay Removal	25	25	25	25	--
Reseal Bridge Joints	8	704	217	115	1.33
Shallow Overlay	103	280	245	272	0.28
Bearing Realignment / Replacement	1003	3523	1955	1766	0.45
Heat Straightening	18385	75490	44465	40693	0.47
Paint - Complete	12	27	18	17	0.31
Paint - Partial / Spot / Zone	5	54	30	35	0.57
PCI Beam End Blockout	1017	14544	6469	7321	0.88
Pin & Hanger Replacement	4457	12750	7641	6679	0.48
Structural Steel Repair	1292	17721	4121	2968	0.77
Structural Steel Repair - Stiffener	736	3531	1908	2153	0.60
Substructure Patching	1	116713	8977	2332	2.04
Substructure Horizontal Surface Sealer	17	201	79	63	0.66
Temporary Supports	1007	8204	3412	3156	0.63
Articulating Concrete Block System (ACB)	14	453	234	234	1.33
Concrete Surface Coating	26	26	26	26	--
Culvert Cleanout	18	18	18	18	--
Epoxy Crack Injection	38	39	38	38	0.01
Riprap	59	226	109	75	0.74
Silane Treatment	1	1	1	1	0.00
Slope Protection Repairs	3	1360	471	49	1.64

Table 6.4e. Work Type Unit Cost Statistics for 2021.

Work Type	Min	Max	Mean	Median	COV
New Bridge Single or Mult. Spans, Gr. Sep.	163	379	242	183	0.49
New Superstructure, Grade Separation	203	203	203	203	--
New Superstructure, Over Water	101	169	121	107	0.27
New Bridge Single Span, Over Water	138	345	240	239	0.37
New Bridge Railroad	274	345	310	310	0.16
New Superstructure	101	203	137	108	0.34
Structure Widening	184	199	191	191	0.06
New Bridge Deck & Barrier	23	704	130	80	1.08
Demo Entire Structure, Grade Separation	21	106	51	50	0.66
Demo Entire Structure, Over Water	13	13	13	13	--
Bridge Railing Replacement	256	2622	1212	1021	0.64
Concrete Brush Block / Curb Patch	1	184	40	20	1.05
Concrete Barrier Patch	1	4540	178	54	2.65
Deep Overlay	117	340	190	187	0.29
Epoxy Overlay	37	37	37	37	--
Expansion Joint Gland Replacement	152	152	152	152	--
Expansion Joint Replacement	387	1282	724	705	0.28
Full Depth Patch	14	10963	1255	84	2.24
Healer / Sealer	12	12	12	12	--
HMA Overlay with WP membrane	6	6	6	6	--
Overlay Removal	1	23	8	3	1.23
Reseal Bridge Joints	14	873	63	20	2.68
Shallow Overlay	213	215	2318	214	--
Bearing Realignment / Replacement	913	6811	3584	3496	0.45
Pack Rust Repair	10	1848	149	18	3.17
Paint - Partial / Spot / Zone	4	65	28	25	0.57
PCI Beam End Blockout	599	43009	12705	5620	1.19
Pin & Hanger Replacement	3966	25297	10820	11366	0.44
Structural Steel Repair	599	43009	10962	8777	0.86
Structural Steel Repair - Stiffener	935	23408	2873	1228	1.44
Substructure Patching	44	367766	14358	4353	2.66
Substructure Horizontal Surface Sealer	18	699	67	50	1.49
Temporary Supports	749	21992	4683	2994	0.90
Articulating Concrete Block System (ACB)	5	358	175	187	0.65
Concrete Surface Coating	22	62	35	27	0.40
Culvert Cleanout	32	75	58	62	0.32
Epoxy Crack Injection	28	175	51	36	0.70
Pressure Relief Joint	91	91	91	91	--
Riprap	114	611	231	194	0.53
Silane Treatment	2	2	2	2	--
Slope Protection Repairs	165	165	165	165	--

Table 6.4f. Work Type Unit Cost Statistics for 2022.

Work Type	Min	Max	Mean	Median	COV
New Bridge Single or Mult. Spans, Gr. Sep.	381	465	415	407	0.09
New Bridge Single Span, Over Water	144	483	368	475	0.53
New Bridge Multiple Spans, Over Water	192	502	364	371	0.33
Precast Culvert	319	319	319	319	--
New Superstructure	47	246	147	147	0.96
New Superstructure, Grade Separation	47	246	246	246	--
New Superstructure, Over Water	47	47	47	47	--
Structure Widening	339	579	487	544	0.27
New Bridge Deck & Barrier	56	192	105	109	0.43
Demo Entire Structure, Grade Separation	0.47	2.7	1.3	0.6	0.90
Demo Entire Structure, Over Water	70	257	190	242	0.55
Bridge Railing Replacement	334	2357	1026	935	0.64
Concrete Brush Block / Curb Patch	2	886	65	38	1.59
Concrete Barrier Patch	4	1932	140	67	1.82
Deep Overlay	136	514	336	354	0.35
Epoxy Overlay	34	140	54	43	0.62
Expansion Joint Gland Replacement	24	349	104	65	0.72
Expansion Joint Replacement	273	1800	967	921	0.49
Full Depth Patch	24	334	80	49	0.97
Healer / Sealer	9	27	13	11	0.38
HMA Overlay with WP membrane	12	12	12	12	--
Overlay Removal	6	17	10	10	0.33
Reseal Bridge Joints	10	145	31	23	1.07
Shallow Overlay	131	151	141	141	0.10
Bearing Realignment / Replacement	1864	28276	8203	6820	1.12
Heat Straightening	62579	149710	120662	149697	0.42
Pack Rust Repair	108	401	254	254	0.82
Paint - Complete	1	76	25	31	0.95
Paint - Partial / Spot / Zone	1	104	30	26	0.82
PCI Beam End Blockout	2480	201770	36132	15675	1.11
Pin & Hanger Replacement	7970	10428	8881	8246	0.15
Structural Steel Repair	1162	20992	8832	8930	0.54
Structural Steel Repair - Stiffener	701	5843	1557	1169	0.67
Substructure Patching	314	156503	11197	5810	1.73
Substructure Replacement	737	737	737	737	--
Substructure Horizontal Surface Sealer	20	394	66	63	0.73
Temporary Supports	946	36685	9353	7573	0.73
Articulating Concrete Block System (ACB)	9	651	294	222	1.09
Concrete Surface Coating	9	100	33	21	1.08
Epoxy Crack Injection	29	843	90	44	1.64
Metal Mesh Panels	5	55	32	35	0.40
Pressure Relief Joint	95	200	149	150	0.22
Riprap	99	370	256	247	0.27
Silane Treatment	2	13	4	3	0.73
Slope Protection Repairs	43	387	184	186	0.52

Table 6.4g.Comparison of Estimation and Actual Project Costs.

	Total Costs ($)	
Work type	Actual*	Estimated
Project 126916_7179		
New Bridge Single or Mult. Spans, Gr. Sep.	4265015	3513145
Total Cost of Work types in Project:	4265015	3513145
Estimated / Actual Total Cost:	0.82	
Project 201328_110		
Concrete Brush Block / Curb Patch	52	502
Concrete Barrier Patch	350	1214
Deep Overlay	263692	202580
PCI Beam End Blockout	46830	121505
Structural Steel Repair	60605	16684
Substructure Patching	28453	98491
Substructure Horizontal Surface Sealer	3027	2457
Silane Treatment	2976	6903
Slope Protection Repairs	14412	20280
Total Cost of Work types in Project:	420396	470615
Estimated / Actual Total Cost:	1.12	
Project 201964_1066		
Bridge Railing Replacement	268006	236636
Concrete Brush Block / Curb Patch	111	49
Concrete Barrier Patch	201	116
Substructure Patching	16338	9420
Total Cost of Work types in Project:	284657	246222
Estimated / Actual Total Cost:	0.86	
Project 205652_10893		
New Bridge Deck & Barrier	1012184	986902
Concrete Brush Block / Curb Patch	678	255
Concrete Barrier Patch	1224	1477
Paint - Partial / Spot / Zone	425120	367812
Structural Steel Repair	40000	27720
Substructure Patching	99536	51440
Slope Protection Repairs	19926	25740
Total Cost of Work types in Project:	1598668	1461346
Estimated / Actual Total Cost:	0.91	
Project 206687_9458		
New Bridge Single Span, Over Water	514179	469985
Articulating Concrete Block System (ACB)	6164	156243
Total Cost of Work types in Project:	520343	626227

Estimated / Actual Total Cost:	1.20		
Project 212366_7840			
Bridge Railing Replacement		653367	840226
Shallow Overlay		291330	464609
Silane Treatment		9069	10358
Total Cost of Work types in Project:		953766	1315193
Estimated / Actual Total Cost:	1.38		
Project 215585_10879			
New Superstructure, Grade Separation		471050	508554
Total Cost of Work types in Project:		471050	508554
Estimated / Actual Total Cost:	1.08		

*Based on the actual cost of the pay items associated with each work type within the project, as given in Appendix C

6. Perform lasso regression.

Using the predictor variables given in Table 5.1, above, and outputs taken as the project unit cost, developed using the approaches discussed above, lasso regression was performed to develop regression equations for each work type given in the BCEW. The costs predicted by these expressions would be multiplied by the MHCCI for the year/quarter for which the cost prediction is desired. Many of the work types currently lack sufficient data to construct the lasso regression model, however. The work types for a lasso regression model is available is given in Table 6.4h. It was generally found that the predictive capability of the regression model was relatively weak due to the large scatter of the data as discussed above. That is, in most cases, there is little advantage of the regression approach beyond using mean costs.

Table 6.4h. Regression Model Work Types.

Work Type
New Bridge - Multiple Spans, Over Water
Demolition – Entire Structure, Grade Separation
Deck Repair Treatments:
Concrete Brush Block / Curb Patch
Concrete Barrier Patch
Epoxy Overlay
Expansion Joint Replacement
Full Depth Patch
Superstructure Repair:
Paint - Complete
Paint - Partial / Spot / Zone
Pin & Hanger Replacement
Structural Steel Repair
Substructure Repair:
Substructure Patching
Substructure Horizontal Surface Sealer
Miscellaneous

Articulating Concrete Block System (ACB)
Epoxy Crack Injection
Pressure Relief Joint
Riprap
Silane Treatment

For the work types for which a regression model was developed, it was generally found that most are not very sensitive to a change in the predictor variable values. This is fundamentally a result of the large scatter in the data for nearly all work types.

6.2 MHCCI Projection Model

6.2.1 General MHCCI Projection

To extrapolate MHCCI to future quarters, a time series analysis using a AutoRegressive Integrated Moving Average (ARIMA) model on log(MHCCI) was developed. The model is seasonal with drift, in the form: ARIMA (0,1,0)(1,0,0), where the non-seasonal portion (0,1,0) is a random walk model with non-stationary output (X), while the seasonal portion (1,0,0) is first-order autoregressive. Note (p,d,q) refers to the order the autoregressive portion (p); the degree of nonseasonal differencing (d), and the order of the moving average portion (q).

The resulting model is:

$$(1 - L)X_t = 0.0137 + 0.3642(1 - L)X_{t-4} + \varepsilon_t \qquad (6.1)$$

or equivalently,

$$X_t - X_{t-1} = 0.0137 + 0.3642(X_{t-4} - X_{t-5}) + \varepsilon_t \qquad (6.2)$$

where L is the lag operator and X_t is the log of MHCCI index at time t. The model results indicated that the first difference of the log of MHCCI is partly (about 36.42%) explained by a quarterly seasonal factor but the remaining portion is noise (ε_t). For Eq. 6.1, the variance of ε_t is 0.003067. The average annual inflation rate is estimated from the model as 8.64%, with a standard deviation of 3.6%. A residual diagnosis revealed that no pattern was detected in the residuals after fitting the ARIMA model, as well a low residual values overall, indicating a high-quality model, as shown in Figure 6.1. In the figure, the leftmost graph is the time plot of residuals, while the rightmost graph is the autocorrelation function (ACF) of residuals. Both plots indicate that the residuals are white noise and there are no remaining predictable components in the residuals by their history. Note that the dashed lines in the auto-correlation function indicate a 95% prediction band for ACF of white noise for non-zero lags. In fact, 16 out of 17 (94%) autocorrelations are within the band.

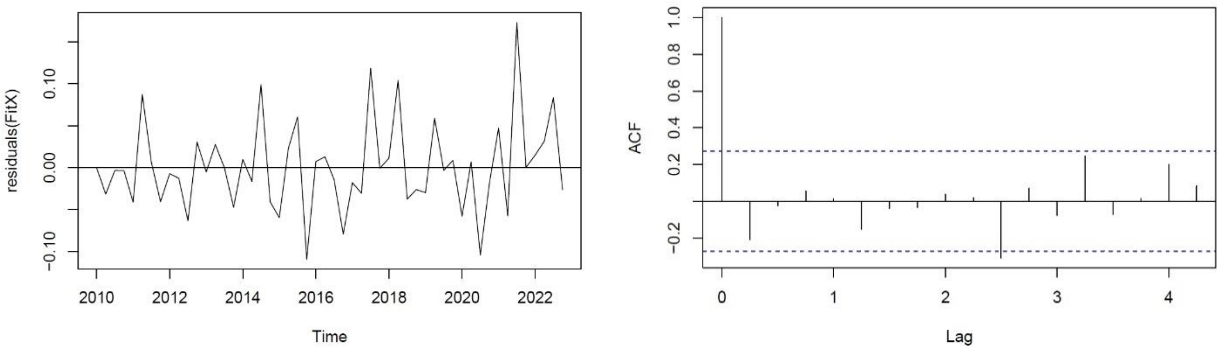


Figure 6.1. Residual Plots for General MHCCI Model.

Using the model, the mean forecasted future MHCCI for the four quarters of 2023 are: 1.987; 2.030; 2.159; and 2.163, as shown in Table 6.5. The mean projection, along with the upper and lower 80th and 95th percentiles, are given in Figure 6.2.

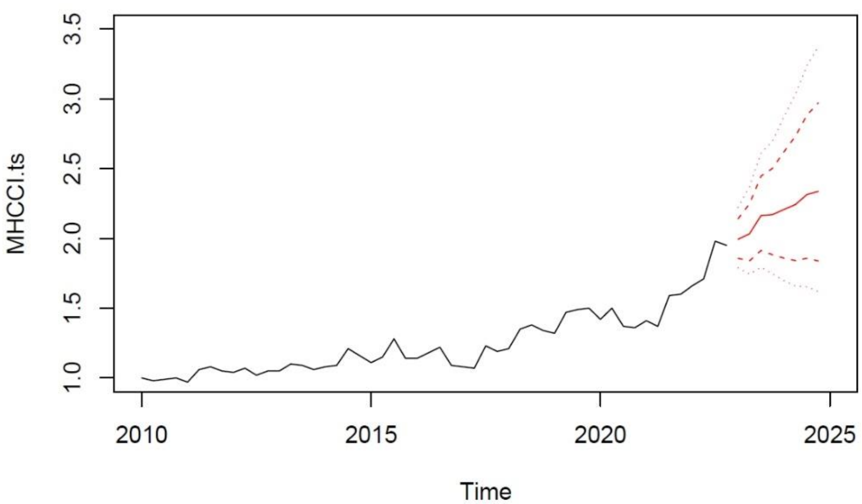


Figure 6.2. Projected General MHCCI from ARIMIA Model.

Table 6.5. General MHCCI Projection.

Year-Quarter	Mean	Lower 80%	Lower 95%	Upper 80%	Upper 95%
2023-1	1.987323	1.851684	1.78367	2.132897	2.214228
2023-2	2.029535	1.836445	1.741781	2.242926	2.364827
2023-3	2.159145	1.910317	1.790422	2.440386	2.603805
2023-4	2.163075	1.877883	1.742464	2.491579	2.685217

6.2.2 Bridge-Specific MHCCI Projection

The above projection is for the general MHCCI value. Considering the bridge-specific MHCCI value (“Bridges & Special Struct. + Struc. Steel”), an ARIMA (0,1,0)(0,0,0) approach, with a white noise model (0,0,0) for the seasonal term, was found to work best. Unlike the general MHCCI index, the MHCCI bridge-specific index was not well explained by past price history. For this model, the annual inflation rate was estimated at 4.78%, with standard deviation of 3.44%.

As shown in Figure 6.3, no pattern was detected in the residuals after fitting the ARIMA model, as well a low residual values overall, indicating a high-quality model.

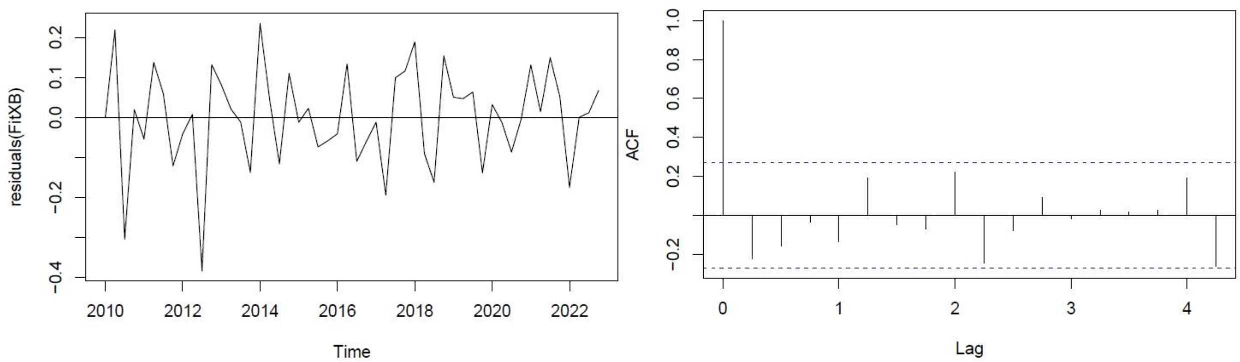


Figure 6.3. Residual Plots for Bridge-Specific MHCCI Model.

Using the model, the mean forecasted future bridge-specific MHCCI for the four quarters of 2023 are: 1.862; 1.885; 1.907; and 1.930, as shown in Table 6.6. The mean projection, along with the upper and lower 80th and 95th percentiles, are given in Figure 6.4.

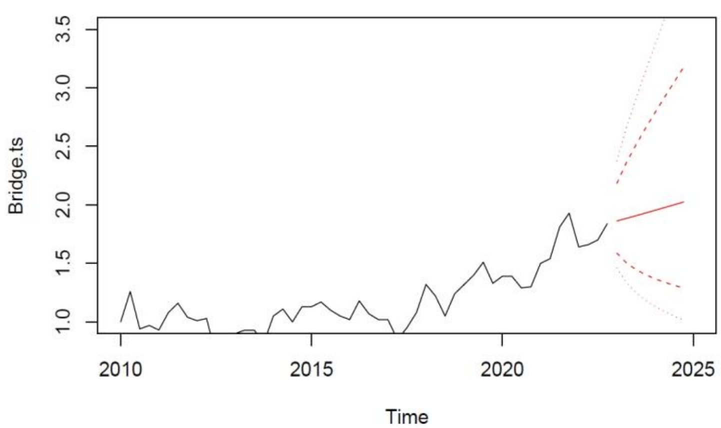


Figure 6.4. Projected Bridge-Specific MHCCI from ARIMIA Model.

Table 6.6. Bridge-Specific MHCCI Projection.

Year-Quarter	Mean	Lower 80%	Lower 95%	Upper 80%	Upper 95%
2023-1	1.857688	1.586331	1.459118	2.175463	2.36513
2023-2	1.879946	1.503696	1.336039	2.350339	2.645278
2023-3	1.902470	1.447224	1.25215	2.500921	2.890543
2023-4	1.925264	1.403888	1.187752	2.640269	3.120722

6.3 Potential Sources of Error

Various sources of uncertainty and error are present in any cost estimation model. Some potentially significant sources of error in the proposed model are:

1. Although care was taken to choose a normalizing item and unit that is representative of the work type, when work types have multiple pay items with different units, as is often the case, the reliability of the resulting unit cost depends strongly on how representative the normalizing item is to the work type cost.

2. Although unlikely, it is possible that an important pay item(s) was overlooked or mis-assigned to a given work type.

3. A work type may be mis-identified in the database due to the choice of primary pay items.

4. A small number of projects exists in some cases, as shown in Tables 6.2 and 6.3, and these may not be representative of a future project. These small counts not only decrease the accuracy of the regression model, but may also provide average unit costs which are unreliable. Those of particular concern to the research team are counts under 40 or so, which affect approximately 16 work types. About a dozen work types have counts less than 15, which are highly likely to result is unreliable estimators. Unfortunately no solution exists for such cases, due to a lack of data.

5. The approach used to account for supplemental item costs assumes that these costs are evenly distributed among all work types that exist with a project. Because supplemental pay items can make up a significant portion of project costs, this approximation will lead to under or over-predictions of individual work type costs for a specific project.

6. The process assumes that the historic MHCCI values accurately account for inflationary cost adjustments over time. As all project costs are normalized by their quarterly MHCCI, accurate yearly MHCCI values are essential. Moreover, the model will be unable to predict sudden changes in inflation that deviate from historic trends.

7. The projected MHCCI value, as discussed in section 6.2, taken as a multiplier on the normalized project cost to represent the future cost, directly impacts the cost estimation. As an extrapolation, there is uncertainty associated with this value.

8. Inherent uncertainty in the data. A significant variation in unit cost exist within each work type than cannot be explained with the available project and historic cost data. It is apparent that factors outside of the data available to MDOT significantly affect contractor pricing.

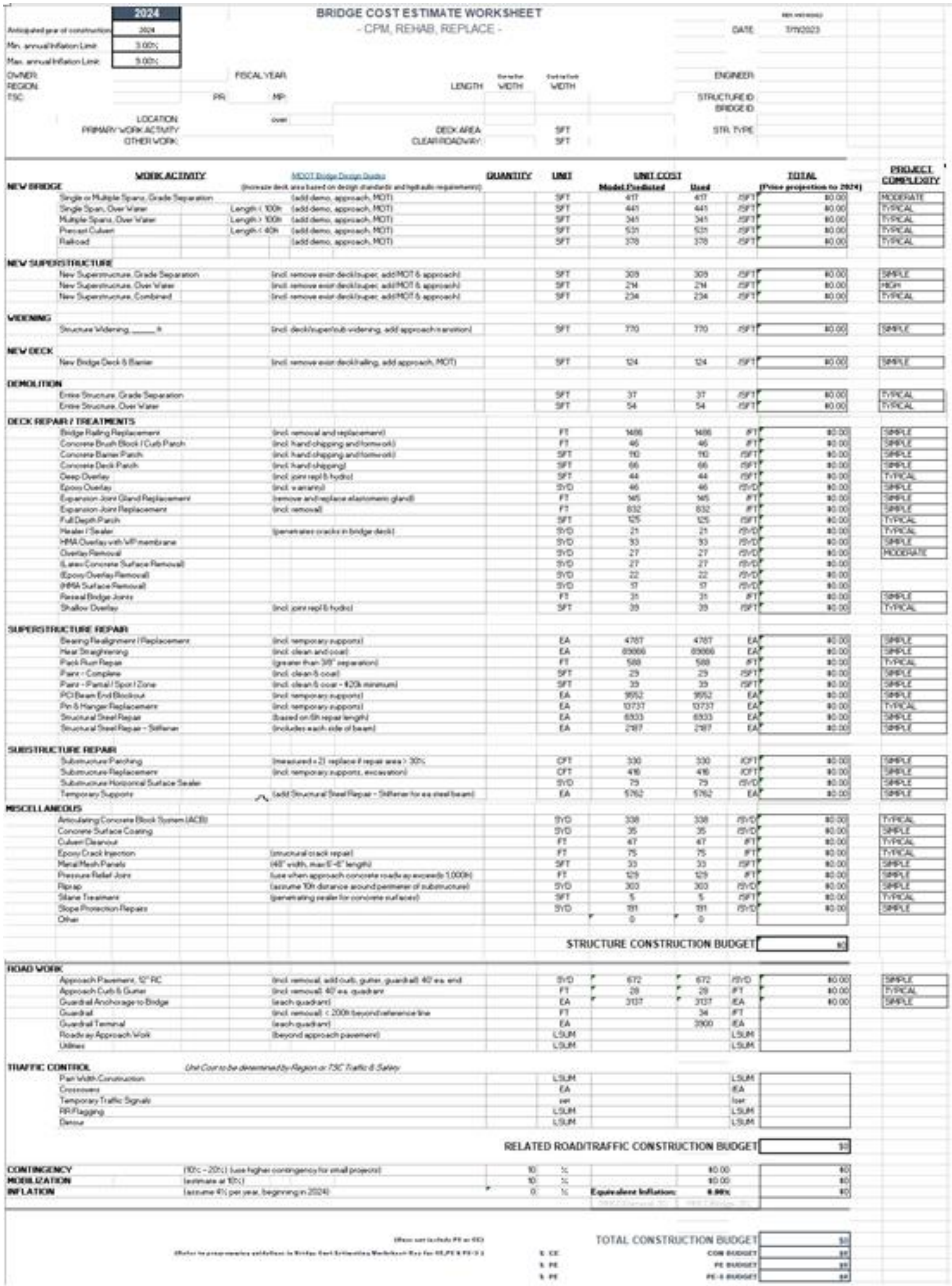
CHAPTER 7: BRIDGE COST ESTIMATION SPREADSHEET

7.1. Overview

As shown in Chapter 6, depending on the assumptions used, different approaches for cost estimation may produce significantly different results, although each approach constructs a model using the past data and projects to the future. These approaches include the scope of costs to consider (base costs, including supplemental items, and including substitute items); the MHCCI projection (in terms of conservatism of the projection, and using a general or bridge-specific or MHCCI values); and considering the average unit cost or regressed cost. Based on discussions with the RAP, it is the understanding of the research team that MDOT has generally found the cost estimations prior to 2022 to significantly under predict the winning bid price, but in the most recent cycle (2024), costs are expected to decrease. However, sudden cost changes that do not follow previous tends cannot be well predicted by the cost projection model, since it relies upon past MHCCI data to estimate future costs. As such, using engineering judgement to modify predicted prices by selecting various different cost options may be the best approach.

It is suggested that using the base cost with supplemental items, combined with the bridge-specific MHCCI and using regression, is theoretically expected to give best results in an ideal case. However, as noted above, this fixed approach will not always provide the best estimate for all cases. This discrepancy may be due to the potential sources of error noted in Chapter 6, but it is also due to an inherent large variability within the cost data from project to project that cannot be explained with statistical models of the available cost and project data. That is, although the estimate may work well on average over many projects, the estimation for any specific project may be associated with significant error. Unfortunately, there is little that can be done in such cases, as it is apparent that, due to the large project to project unit cost variability, even after consideration of regression modelling, factors outside of the available project data exert a significant influence on contractor pricing for any individual project.

To address this concern, the proposed BCEW is flexible, allowing the different options summarized above to be selected by the estimator and worksheet administrator. The proposed BCEW is given in Figure 7.1.



BRIDGE COST ESTIMATE WORKSHEET

- CPM, REHAB, REPLACE -

	2024		
Anticipated year of construction	2024	DATE	7/11/2023
Min. annual Inflation Limit	3.00%		
Max. annual Inflation Limit	9.00%		
OWNER:		FISCAL YEAR:	
REGION:		LENGTH / WIDTH / WIDTH	
TSC:		PR: / MP:	
ENGINEER:		STRUCTURE ID	
		BRIDGE ID	
LOCATION:		over	
PRIMARY WORK ACTIVITY		DECK AREA	SFT
OTHER WORK:		CLEAR ROADWAY:	SFT
STR. TYPE			

	WORK ACTIVITY	MDOT Bridge Design Guides (Increase deck area based on design standards and hydraulic requirements)	QUANTITY	UNIT	UNIT COST Model Predicted	UNIT COST Used		TOTAL (Price projection to 2024)	PROJECT COMPLEXITY
NEW BRIDGE									
	Single or Multiple Spans, Grade Separation	(add demo, approach, MOT)		SFT	417	417	/SFT	$0.00	MODERATE
	Single Span, Over Water	Length < 100ft (add demo, approach, MOT)		SFT	441	441	/SFT	$0.00	TYPICAL
	Multiple Spans, Over Water	Length > 100ft (add demo, approach, MOT)		SFT	341	341	/SFT	$0.00	TYPICAL
	Precast Culvert	Length < 40ft (add demo, approach, MOT)		SFT	531	531	/SFT	$0.00	TYPICAL
	Railroad	(add demo, approach, MOT)		SFT	378	378	/SFT	$0.00	TYPICAL
NEW SUPERSTRUCTURE									
	New Superstructure, Grade Separation	(incl. remove exist deck/super, add MOT & approach)		SFT	309	309	/SFT	$0.00	SIMPLE
	New Superstructure, Over Water	(incl. remove exist deck/super, add MOT & approach)		SFT	214	214	/SFT	$0.00	HIGH
	New Superstructure, Combined	(incl. remove exist deck/super, add MOT & approach)		SFT	234	234	/SFT	$0.00	TYPICAL
WIDENING									
	Structure Widening, ______ ft	(incl. deck/super/sub widening, add approach transition)		SFT	770	770	/SFT	$0.00	SIMPLE
NEW DECK									
	New Bridge Deck & Barrier	(incl. remove exist deck/railing, add approach, MOT)		SFT	124	124	/SFT	$0.00	SIMPLE
DEMOLITION									
	Entire Structure, Grade Separation			SFT	37	37	/SFT	$0.00	TYPICAL
	Entire Structure, Over Water			SFT	54	54	/SFT	$0.00	TYPICAL
DECK REPAIR / TREATMENTS									
	Bridge Railing Replacement	(incl. removal and replacement)		FT	1486	1486	/FT	$0.00	SIMPLE
	Concrete Brush Block / Curb Patch	(incl. hand chipping and formwork)		FT	46	46	/FT	$0.00	SIMPLE
	Concrete Barrier Patch	(incl. hand chipping and formwork)		SFT	110	110	/SFT	$0.00	SIMPLE
	Concrete Deck Patch	(incl. hand chipping)		SFT	66	66	/SFT	$0.00	SIMPLE
	Deep Overlay	(incl. joint repl & hydro)		SFT	44	44	/SFT	$0.00	TYPICAL
	Epoxy Overlay	(incl. warranty)		SYD	46	46	/SYD	$0.00	SIMPLE
	Expansion Joint Gland Replacement	(remove and replace elastomeric gland)		FT	145	145	/FT	$0.00	SIMPLE
	Expansion Joint Replacement	(incl. removal)		FT	832	832	/FT	$0.00	SIMPLE
	Full Depth Patch			SFT	125	125	/SFT	$0.00	TYPICAL
	Healer / Sealer	(penetrates cracks in bridge deck)		SYD	21	21	/SYD	$0.00	TYPICAL
	HMA Overlay with WP membrane			SYD	33	33	/SYD	$0.00	SIMPLE
	Overlay Removal			SYD	27	27	/SYD	$0.00	MODERATE
	(Latex Concrete Surface Removal)			SYD	27	27	/SYD	$0.00	
	(Epoxy Overlay Removal)			SYD	22	22	/SYD	$0.00	
	(HMA Surface Removal)			SYD	17	17	/SYD	$0.00	
	Reseal Bridge Joints			FT	31	31	/FT	$0.00	SIMPLE
	Shallow Overlay	(incl. joint repl & hydro)		SFT	39	39	/SFT	$0.00	TYPICAL
SUPERSTRUCTURE REPAIR									
	Bearing Realignment / Replacement	(incl. temporary supports)		EA	4787	4787	EA	$0.00	SIMPLE
	Heat Straightening	(incl. clean and coat)		EA	89866	89866	EA	$0.00	SIMPLE
	Pack Rust Repair	(greater than 3/8" separation)		FT	588	588	/FT	$0.00	TYPICAL
	Paint - Complete	(incl. clean & coat)		SFT	29	29	/SFT	$0.00	SIMPLE
	Paint - Partial / Spot / Zone	(incl. clean & coat - $20k minimum)		SFT	39	39	/SFT	$0.00	SIMPLE
	PCI Beam End Blockout	(incl. temporary supports)		EA	9552	9552	EA	$0.00	SIMPLE
	Pin & Hanger Replacement	(incl. temporary supports)		EA	10737	10737	EA	$0.00	TYPICAL
	Structural Steel Repair	(based on 6ft repair length)		EA	6933	6933	EA	$0.00	SIMPLE
	Structural Steel Repair - Stiffener	(includes each side of beam)		EA	2187	2187	EA	$0.00	SIMPLE
SUBSTRUCTURE REPAIR									
	Substructure Patching	(measured × 2) replace if repair area > 30%		CFT	330	330	/CFT	$0.00	SIMPLE
	Substructure Replacement	(incl. temporary supports, excavation)		CFT	416	416	/CFT	$0.00	SIMPLE
	Substructure Horizontal Surface Sealer			SYD	79	79	/SYD	$0.00	SIMPLE
	Temporary Supports	(add Structural Steel Repair - Stiffener for ea steel beam)		EA	5762	5762	EA	$0.00	SIMPLE
MISCELLANEOUS									
	Articulating Concrete Block System (ACB)			SYD	338	338	/SYD	$0.00	TYPICAL
	Concrete Surface Coating			SYD	35	35	/SYD	$0.00	SIMPLE
	Culvert Cleanout			FT	47	47	/FT	$0.00	TYPICAL
	Epoxy Crack Injection	(structural crack repair)		FT	75	75	/FT	$0.00	TYPICAL
	Metal Mesh Panels	(48" width, max 6'-6" length)		SFT	33	33	/SFT	$0.00	SIMPLE
	Pressure Relief Joint	(use when approach concrete roadway exceeds 1,000ft)		FT	129	129	/FT	$0.00	SIMPLE
	Riprap	(assume 10ft distance around perimeter of substructure)		SYD	303	303	/SYD	$0.00	SIMPLE
	Silane Treatment	(penetrating sealer for concrete surfaces)		SFT	5	5	/SFT	$0.00	TYPICAL
	Slope Protection Repairs			SYD	181	181	/SYD	$0.00	SIMPLE
	Other				0	0			
					STRUCTURE CONSTRUCTION BUDGET			$0	
ROAD WORK									
	Approach Pavement, 12" RC	(incl. removal, add curb, gutter, guardrail) 40' ea. end		SYD	672	672	/SYD	$0.00	SIMPLE
	Approach Curb & Gutter	(incl. removal) 40' ea. quadrant		FT	28	28	/FT	$0.00	TYPICAL
	Guardrail Anchorage to Bridge	(each quadrant)		EA	3137	3137	/EA	$0.00	SIMPLE
	Guardrail	(incl. removal) < 200ft beyond reference line		FT		34	/FT		
	Guardrail Terminal	(each quadrant)		EA		3900	/EA		
	Roadway Approach Work	(beyond approach pavement)		LSUM			LSUM		
	Utilities			LSUM			LSUM		
TRAFFIC CONTROL	*Unit Cost to be determined by Region or TSC Traffic & Safety*								
	Part Width Construction			LSUM			LSUM		
	Crossovers			EA			/EA		
	Temporary Traffic Signals			per			/per		
	RR Flagging			LSUM			LSUM		
	Detour			LSUM			LSUM		
					RELATED ROAD/TRAFFIC CONSTRUCTION BUDGET			$0	
CONTINGENCY		(10% - 20%) (use higher contingency for small projects)	10	%		$0.00		$0	
MOBILIZATION		(estimate at 10%)	10	%		$0.00		$0	
INFLATION		(assume 4% per year, beginning in 2024)	0	%	Equivalent Inflation:	0.00%		$0	
					TOTAL CONSTRUCTION BUDGET			$0	
			% CE			CON BUDGET		$0	
			% PE			PE BUDGET		$0	
			% PE			PE-S BUDGET		$0	

Figure 7.1. Format of Proposed Bridge Cost Estimation Worksheet.

7.2. Global Options

Some options can be changed on the worksheet that will affect cost estimation values for all work types. These global options are Estimation Options and Project Data. Unless otherwise noted, these options appear in the Global Data Entry sheet.

7.2.1 Estimation Options

There are two global estimation options are the time for costs to be projected and the projection conservatism.

Year Projected (Anticipated year of construction).

The year that MHCCI is to be projected to can be selected (cell C2 in the Estimate Worksheet). This value is carried over to cell E2 on the Global Data Entry sheet. Note that the MHCCI/inflationary projection is conducted on a quarterly basis. For ease of worksheet use, the average MHCCI of the 4 quarters in the year of anticipated construction is used for cost projection in the spreadsheet.

Minimum and maximum allowed rates of inflation.

Limits on the MHCCI projection for future costs, as a function of the equivalent rate of inflation to be used, can be selected (cells C3, C4 in the Estimate Worksheet). The governing equivalent annual inflation for MHCCI that is actually used, as limited by the upper and lower bounds entered, is given in cell L107 in the Estimate Worksheet. This value is provided for comparison purposes. This is calculated as a function of the increase in MHCCI from the current worksheet year (C1) to the anticipated year of construction (C2). That is, the current worksheet year is taken as the baseline year for this conversion. (For projects intended to be constructed in the current worksheet year, enter the prior year into cell C1 to compute an equivalent rate of inflation from the previous year). Different work types may have a different rate of projected inflation, depending on the MHCCI option selected. Thus, the equivalent inflation shown in L107 may vary as different work type quantities are provided.

MHCCI Projection Conservatism.

Selection values for the MHCCI projection are provided for the mean, and upper and lower 80^{th} and 95^{th} percentiles, as discussed in Chapter 3.

7.2.2 Project Data

These data are input values for the predictor variables in the regression expressions, and as such, only affect regressed model costs. However, these parameters generally have little impact in most cases, and it is thus reasonable to leave these entries at the default values in most cases. Exceptions would be projects with parameters that significantly deviate from the typical range of input values. If project data are not entered into any of the cells below (E8-23), values will default to using either the mean or median values in the bridge database. It is recommend to use the median (option 0 in the Default Entry Data entry, cell H5).

Table 7.1. Median and Mean Project Data.

Project Data	Median	Mean
Number of Structures in Project (ea)	2	5
Last FY Total Project Costs (mi)	105	117
Bridge Deck area (SF)	9545	15640
Average Daily Traffic (ADT)	11000	20988
Maximum Span Length (ft)	81	90
Overall Bridge Length (ft)	200	275
Vertical Clearance Under (ft)	15	10
Broad Work Category (1-4)	1	--
Region of Work (1-7)	7	--
Lanes on Bridge (ea)	2	3
Lanes under Bridge (ea)	2	3
Service Type on Bridge (1-7)	1	--
Water Under Bridge (1,0)	0	--
Highway Under Bridge (1,0)	1	--
Positive Vertical Underclearance (1,0)	1	--

Note that since the lasso regression process selects which parameters below are significant and will be included in the regression model, not all of the parameters below will be active for all work types.

<u>Number of Structures in Project (each).</u>

The number of bridges that belong to a specific project. However, note that the Worksheet is to be used to estimate the project cost of a single structure. Quantities for multiple structures combined should not be included.

<u>Last FY Total Project Costs (mil)</u>.

The sum of the prior year total project costs, in millions, which is calculated from the bridge project price database. For example, the sum of all project costs from October 2021 September 2022 is taken as the 2022 total cost.

<u>Bridge Deck area (SF).</u>

The total deck area of the bridge.

<u>Average Daily Traffic (count).</u>

ADT of the bridge.

Maximum Span Length (FT).

The length of the maximum span of the bridge.

Overall Bridge Length (FT).

The overall length of the structure.

Vertical Clearance Under (FT).

The minimum vertical under clearance.

Broad Work Category (categorical).

Enter a numerical value as follows:

Work Category	Entry Number
Bridge CPM	1
Bridge CSM	2
Bridge - Improve Bridge Miscellaneous Bridge Rehabilitation	3
New Structure Bridge Replacement	4

Region of Work (categorical).

Enter a numerical value as follows:

Region	Entry Number
Superior	1
North	2
Grand	3
Bay	4
Southwest	5
University	6
Metro	7

Lanes on Bridge (count).

The number of traffic lanes on the bridge.

Lanes under Bridge (count).

The number of traffic lanes under the bridge.

Service Type on Bridge (categorical).

Service on Bridge	Entry Number
Highway	1
Highway-pedestrian	1
Railroad	2
Pedestrian-bicycle	3
Highway-railroad	4
Overpass structure at an interchange or second level of a multilevel interchange	5
Third Level (Interchange)	5
Fourth Level (Interchange)	5
Building or Plaza	6
Other (non-highway)	7

Water Under Bridge (categorical).

Enter "1" if the bridge spans a waterway and "0" if the bridge does not.

Highway Under Bridge (categorical).

Enter "1" if the bridge passes over a highway and "0" if the bridge does not.

Positive Vertical Under clearance (categorical).

Enter "1" if non-zero vertical under clearance exists for the bridge and "0" otherwise. Note that a value of "1" will only apply to grade separation structures; if a feature other than a highway or railroad (such as a waterway) crosses under the structure, a value of "0" should be entered.

Estimated Award Date (date format).

This is an alternative method to estimate inflation based on direct regression rather than MHCCI projection. It is recommended to use the MHCCI projection model rather than this regression approach for inflation. As such, it is recommended to insert a value in cell E23 with a year no greater than the year of the worksheet (i.e. the year found in cell C1 on the Estimate Worksheet). Inserting a value beyond the year of the worksheet will doubly-count inflation; once from the MHCCI projection model and again from the inflation regression model.

7.3 Work Type Specific Options

Each work type has four estimation options: the MHCCI type to use, the project cost scope, the unit cost method, and the regressed multiplier type.

7.3.1 MHCCI Type (hidden column R).

Either the general MHCCI (enter "0"), or the bridge-specific MHCCI (enter "1") can be used.

7.3.2 Cost Scope.

As discussed in Chapter 6, three ways were used to determine work type unit costs: using the 'base' cost (enter "1"); including supplemental items (enter "0"), including substitute items (enter "2"), and the average of the supplemental and substitute methods (enter "3"). In the worksheet, these are represented as the following options in an alternative pull-down menu:

"Simple" – base method
"Typical" – supplemental method
"Moderate" – average cost of supplemental and substitute methods
"Complex" – substitute method

For work types that have only a single pay item, or for which the set of primary pay items contains all possible pay items, the "Moderate" and "Complex" options will not be available, and costs for these will be given as zero.

7.3.3 Unit Cost Method (hidden column T).

Either the average (option 0) or regressed (option 1) model costs can be used in estimate costs in column K. If there is insufficient data to construct a regression model, a regression cost of 0 will appear when option 1 is selected. Column U shows a "r" when a regression model is available. The default selection provided uses the regression model if available. However, because of the large variability as well as scarcity of the data, in most cases the regression is weak and it will have little impact on most work type costs.

Both unit costs (average and regressed) are provided because the regressed costs may give inaccurate values in some circumstances, such as if atypical project values are entered, or for an unexpected combination of input parameters. Inaccuracies may also occur if there are few projects in the database that align with the project parameters that were input. Thus if the regressed cost seems unrealistic, the estimator may choose to use the average cost.

7.3.4 Regressed Multiplier (hidden column S).

When a regression model is available and used, the result is scaled such that selecting either the mean (option 0) or median (option 1) database values in the Global Data Entry sheet (column E) will recover the average unit costs given in the Estimate Worksheet column W. It is recommend to leave this value at the median (option 1).

7.4 Recommendations

As noted previously As the method used estimate future costs is based on historic data, sudden changes in yearly costs that do not follow the historical trend are not possible to accurately predict.

In such instances, engineering judgement might be used to modify predicted prices. Based on comments from the Research Advisory Panel, project complexity values, which modify the price prediction, were pre-selected to better align with observed recent trends. In particular, an observation that federal cost numbers in 2023 have declined relative to 2022. Based on this observation, the settings given in Table 7.2 were selected to provide unit cost values for 2024, as possible, similar to 2022 MDOT expected values. Of course, these settings can be readily changed in the worksheet as desired. Note "MHCCI Type" is pre-selected and in a hidden column in the Estimate Worksheet (column R). It is typically not meant to be changed.

Table 7.2 Recommended Cost Settings.

Work Item		Project Complexity	MHCCI Type
NEW BRIDGE			
Single or Mult. Spans, Grade Separation		Moderate	1
	OR:	Typical	0
Single Span, Over Water		Typical	0
Multiple Spans, Over Water		Typical	0
New Bridge Railroad		Typical	0
Precast Culvert		Typical	1
NEW SUPERSTRUCTURE			
New Superstructure, Grade Separation		Simple	0
New Superstructure, Over Water		High	0
New Superstructure, Combined		Typical	1
WIDENING			
Structure Widening		Simple	1
NEW DECK			
New Bridge Deck & Barrier		Simple	1
DEMOLITION			
Entire Structure, Grade Separation		Typical	0
Entire Structure, Over Water		Typical	1
DECK REPAIR / TREATMENTS			
Bridge Railing Replacement		Simple	1
Concrete Brush Block / Curb Patch		Simple	1
Concrete Barrier Patch		Simple	1
Concrete Deck Patch		Simple	1
Deep Overlay		Typical	0
Epoxy Overlay		Simple	1
Expansion Joint Gland Replacement		Simple	1
Expansion Joint Replacement		Simple	1
Full Depth Patch		Typical	0
Healer / Sealer		Typical	1
HMA Overlay with WP membrane		Simple	1
Overlay Removal		Simple	1
Overlay Removal - Latex		Moderate	1
Overlay Removal - Epoxy		Moderate	1
Overlay Removal - HMA		Simple	1
Reseal Bridge Joints		Simple	1
Shallow Overlay		Typical	0
SUPERSTRUCTURE REPAIR			

Bearing Realignment / Replacement	Simple	1
Heat Straightening	Simple	1
Pack Rust Repair	Typical	0
Paint - Complete	Simple	1
Paint - Partial / Spot / Zone	Simple	1
PCI Beam End Blockout	Simple	1
Pin & Hanger Replacement	Typical	0
Structural Steel Repair	Simple	1
Structural Steel Repair - Stiffener	Simple	1
SUBSTRUCTURE REPAIR		
Substructure Patching	Simple	1
Substructure Replacement	Simple	1
Substructure Horizontal Surface Sealer	Simple	1
Temporary Supports	Simple	1
MISCELLANEOUS		
Articulating Concrete Block System	Typical	1
OR:	Simple	0
Concrete Surface Coating	Simple	1
Culvert Cleanout	Typical	0
Epoxy Crack Injection	Typical	1
Metal Mesh Panels	Simple	1
Pressure Relief Joint	Simple	1
Riprap	Simple	1
Silane Treatment	Typical	0
Slope Protection Repairs	Simple	1
ROAD WORK		
Approach Pavement, 12" RC	Simple	1
Approach Curb & Gutter	Typical	0
Guardrail Anchorage to Bridge	Simple	1

Using the settings in Table 7.2, Work types with 2024 predicted costs that substantially differ from 2022 as well as 2023 (by about 30% or more) previously developed MDOT estimate worksheet prices are given in Table 7.3. Explanations for these differences are provided in Section 6.1, and do not necessarily imply that the model values are inaccurate.

Table 7.3. Work Types that Differ Substantially from MDOT Estimates.

	Cost Ratios	
Work type	2024 Model/MDOT 2022	2024 Model/MDOT 2023
Demolition, Grade Separation	0.55	0.48
Bridge Railing Replacement	2.40	1.92
Concrete Brush Block / Curb Patch	1.76	1.52
Concrete Barrier Patch	1.41	1.26
HMA Overlay with WP membrane	1.52	1.52
Overlay Removal – HMA	2.00	2.00
Heat Straightening	1.94	1.53
Pack Rust Repair	0.67	0.50
Paint – Complete	1.47	1.27
PCI Beam End Blockout	1.29	1.29

Structural Steel Repair	1.18	1.68
Structural Steel Repair – Stiffener	1.57	1.42
Temporary Supports	1.86	1.40
Culvert Cleanout	0.36	0.36
Silane Treatment	0.71	0.71

It is not recommended to use the model roadwork item results. This is due to a lack of roadwork cost data available within a usable format. These results are based on a very small selection of projects and are considered unreliable.

CHAPTER 8: INSTRUCTIONS FOR WORKSHEET USE AND UPDATING

8.1 Instructions for Estimator

1. Select anticipated year of construction (cell C2).

Commentary:

The selection menu in C2 was formulated in Excel for Office365. It will work with earlier versions of Excel, but may have duplicate and blank selections; these can be ignored.

2. Enter minimum and maximum allowed rates of inflation (cells C3, C4).

The equivalent annual inflation that is used, calculated from the current worksheet year to the anticipated year of construction, is given in cell L107.

Commentary:

A projection method is used to estimate the Michigan Highway Construction Cost Index (MHCCI) at the anticipated year of construction. This projected MHCCI is used as a default to estimate future price changes.

For comparison purposes, MHCCI is converted to an equivalent rate of annual inflation. This is calculated as a function of the increase in MHCCI from the current worksheet year (C1) to the anticipated year of construction (C2). That is, the current worksheet year is taken as the baseline year for this conversion. (For projects intended to be constructed in the current worksheet year, enter the prior year into cell C1 to compute an equivalent rate of inflation from the previous year).

Lower and upper bounds, in terms of annual inflation, can be entered to constrain this projected value. The governing equivalent annual inflation for MHCCI, as limited by the upper and lower bounds entered, is given in cell L107.

Different work types may have a different rate of projected inflation. Thus, the equivalent inflation shown in L107 may vary as different work type quantities are provided.

3. Enter quantity of work type item in column I.

4. For each work type, select the anticipated project complexity in column P.

Default, recommended project complexity selections are pre-selected for each work type. Not all options will be available for all work types. If a selection option is not available, the cost for that option will be given as zero. The unit cost predicted by the model will appear in column K. This cost is used by default and also appears in column L. As desired, the estimator may modify the cost used for the total price of the work type by typing in an override value into column L.

Commentary:

Simple - does not account for average cost of supplementary items.
Typical - accounts for average cost of supplementary items.
Moderate - an average of Typical and Complex work type costs.
Complex - assumes the work type will have all non-mutually exclusive pay items.

Further Discussion:

Unit costs in the worksheet are based on historical cost data. For a given work type, its cost within a project is found by summing its individual pay item costs after normalizing for inflation. The unit cost provided in the worksheet is then determined by averaging work type costs from all previous project data that have that work type, projecting to the anticipated year of construction.

Some work types have a single pay item, whereas other work types have multiple possible pay items. Some work types with multiple pay items are identified in the cost database by the presence of primary pay items. The primary pay items are a smaller list of all possible pay items for that work type that must have been present for that work type to have occurred in a project, and thus for its cost to have been included in the average cost calculation.

"Simple" (base method) costs are calculated directly from all instances of that work type as describe above.

"Typical" (supplemental method) costs include an increase for the possibility of supplemental items. When a work type is identified in project with supplemental items, the percentage of the supplemental item cost to the entire project is calculated. The work type cost is increased by this same percentage. That is, it is assumed that the supplemental item costs within a project are proportionally distributed to all work types with that project. On average, it was found that supplemental items increase project costs by about 13% when present.

"Complex" (substitute method) costs are based on summing the average costs of all possible non-mutually exclusive pay items for a work type. Note that most projects will not have all possible pay items for that work type, but just the primary pay items, or a list of pay items between all possible and the minimum possible (i.e. the primary items). For complex costs, for a project that was found to have the given work type, but lacked all of the possible pay items for that work type, the average costs of the missing pay items were artificially added to the total work type cost. Thus, complex costs are based on a hypothetical list of projects that have all possible pay items for that work type.

The "Moderate" costs for a work type are based on the average of the typical and complex costs.

For work types that have only a single pay item, or for which the set of primary pay items contains all possible pay items, the “Moderate” and “Complex” options will not be available, and costs for these will be given as zero.

Pre-selected Complexity Recommendations:

As the method used estimate future costs is based on historic data, sudden changes in yearly costs that do not follow the historical trend are not possible to accurately predict. In such instances, engineering judgement might be used to modify predicted prices. Based on comments from the Research Advisory Panel, project complexity values, which modify the price prediction, were pre-selected to better align with observed recent trends. In particular, an observation that federal cost numbers in 2023 have declined relative to 2022. Based on this observation, the settings below were pre-selected to provide unit cost values for 2024, as possible, similar to 2022 MDOT expected values.

Note “MHCCI Type” is pre-selected and in a hidden column in the Estimate Worksheet (column R). It is typically not meant to be changed.

Table 8.1. Pre-Selected Estimate Worksheet Options.

Work Item		Project Complexity	MHCCI Type
NEW BRIDGE			
Single or Mult. Spans, Grade Separation		Moderate	1
	OR:	Typical	0
Single Span, Over Water		Typical	0
Multiple Spans, Over Water		Typical	0
New Bridge Railroad		Typical	0
Precast Culvert		Typical	1
NEW SUPERSTRUCTURE			
New Superstructure, Grade Separation		Simple	0
New Superstructure, Over Water		High	0
New Superstructure, Combined		Typical	1
WIDENING			
Structure Widening		Simple	1
NEW DECK			
New Bridge Deck & Barrier		Simple	1
DEMOLITION			
Entire Structure, Grade Separation		Typical	0
Entire Structure, Over Water		Typical	1
DECK REPAIR / TREATMENTS			
Bridge Railing Replacement		Simple	1
Concrete Brush Block / Curb Patch		Simple	1
Concrete Barrier Patch		Simple	1
Concrete Deck Patch		Simple	1
Deep Overlay		Typical	0
Epoxy Overlay		Simple	1
Expansion Joint Gland Replacement		Simple	1
Expansion Joint Replacement		Simple	1

Full Depth Patch	Typical	0
Healer / Sealer	Typical	1
HMA Overlay with WP membrane	Simple	1
Overlay Removal	Simple	1
Overlay Removal - Latex	Moderate	1
Overlay Removal - Epoxy	Moderate	1
Overlay Removal - HMA	Simple	1
Reseal Bridge Joints	Simple	1
Shallow Overlay	Typical	0
SUPERSTRUCTURE REPAIR		
Bearing Realignment / Replacement	Simple	1
Heat Straightening	Simple	1
Pack Rust Repair	Typical	0
Paint - Complete	Simple	1
Paint - Partial / Spot / Zone	Simple	1
PCI Beam End Blockout	Simple	1
Pin & Hanger Replacement	Typical	0
Structural Steel Repair	Simple	1
Structural Steel Repair - Stiffener	Simple	1
SUBSTRUCTURE REPAIR		
Substructure Patching	Simple	1
Substructure Replacement	Simple	1
Substructure Horizontal Surface Sealer	Simple	1
Temporary Supports	Simple	1
MISCELLANEOUS		
Articulating Concrete Block System	Typical	1
OR:	Simple	0
Concrete Surface Coating	Simple	1
Culvert Cleanout	Typical	0
Epoxy Crack Injection	Typical	1
Metal Mesh Panels	Simple	1
Pressure Relief Joint	Simple	1
Riprap	Simple	1
Silane Treatment	Typical	0
Slope Protection Repairs	Simple	1
ROAD WORK		
Approach Pavement, 12" RC	Simple	1
Approach Curb & Gutter	Typical	0
Guardrail Anchorage to Bridge	Simple	1

Cautionary Items:

Work types with predicted costs that substantially differ from 2022 as well as 2023 (by about 30% or more) previously developed MDOT estimate worksheet prices, and if high or low, are given below. It is suggested that these prices are used with caution.

Demolition, Entire Structure, Grade Separation (low)
Bridge Railing Replacement (high)

Concrete Brush Block / Curb Patch (high)
Concrete Barrier Patch (high)
HMA Overlay with WP membrane (high)
Overlay Removal – HMA (high)
Heat Straightening (high)
Pack Rust Repair (low)
Paint – Complete (high)
PCI Beam End Blockout (high)
Structural Steel Repair (high)
Structural Steel Repair – Stiffener (high)
Temporary Supports (high)
Culvert Cleanout (low)
Silane Treatment (low)

<u>Roadwork Items:</u>

It is *not recommended* to use the model roadwork item results. This is due to a lack of roadwork cost data available within a usable format. These results are based on a very small selection of projects and are considered unreliable.

<u>Project Cost Variation:</u>

A large variation in unit cost exists for the same pay items and work types from one project to another that cannot be explained by the available historic project data. This suggests that factors other than the project data available to MDOT significantly influences contractor pricing decisions. Moreover, inflationary trends that do not follow historic expectations further add to cost prediction uncertainty. As such, worksheet estimated costs should not be expected to accurately predict the work type costs for a particular project. Rather, this tool should be thought of as a predictor for the mean costs of a set of projects over time; as more projects are considered, the mean of this set will tend to converge to the predicted costs.

8.2. Instructions for Administrator

There are 10 hidden worksheets/tabs in the Excel file. They can be displayed by right-clicking over the "Estimate Worksheet" Tab and selecting "Unhide".

Items meant to be modifiable in the worksheets by the administrator are highlighted in green.

Estimate Worksheet

MHCCI Type (hidden column R).

A general MHCCI that considers all construction types (option 0) and a bridge-specific MHCCI exist (option 1) which can be used for price projection. The general approach tends to provide higher inflationary estimates.

The equivalent inflation (cell L107) of overall project cost is based on a weighted average of equivalent inflation (depending on the MHCCI Type chosen for that work type) for the cost contribution of each work type to the total cost.

Note that the MHCCI/inflationary projection is conducted on a quarterly basis. For ease of worksheet use, the average MHCCI of the 4 quarters in the year of anticipated construction (cell C2 on the Estimate Worksheet) is used for cost projection in the spreadsheet.

Regressed Multiplier (hidden column S).

When a regression model is available, the result is scaled such that selecting either the mean (option 0) or median (option 1) database values in the Global Data Entry sheet (column E) will recover the average unit costs given in the Estimate Worksheet column W. It is recommend to leave this value at the median (option 1).

Unit Cost Method (hidden column T).

Either the average (option 0) or regressed (option 1) model costs can be used in column K. If there is insufficient data to construct a regression model, a regression cost of 0 will appear when option 1 is selected. Column U shows a "r" when a regression model is available. The default selection provided uses the regression model if available. However, because of the large variability as well as scarcity of the data, in most cases the regression is weak and it will have little impact on most work type costs.

Global Data Entry

Estimation Options

MHCCI Projection Conservatism (cell E3).

Selection values for the MHCCI projection are provided for the mean, and upper and lower 80th and 95th percentiles, as discussed in Chapter 3 of the Project Final Report SPR-1732. The mean represents the most probable projection of MHCCI from the historical trend and is thus generally recommended.

Project Data

These inputs only affect regressed model costs, and are intended to be input by the Estimator for each project to be estimated. However, as noted above, these parameters generally have little impact in most cases, and it is thus reasonable to leave these entries at the default values in most cases. Exceptions would be projects with parameters that significantly deviate from the typical range of input values.

Default Entry Data (cell G5).

If project data are not entered into any of the cells below (E8-23), values will default to using either the mean or median values in the bridge database. It is recommend to use the median (option 0).

Number of Structures in Project (each).

The number of bridges that belong to a specific project. However, note that the Worksheet is to be used to estimate the project cost of a single structure. Do not include quantities for multiple structures combined.

Last FY Total Project Costs (mil).

The sum of the prior year total project costs, in millions, which is calculated from the bridge project price database. For example, the sum of all project costs from October 2021 September 2022 is taken as the 2022 total cost.

Bridge Deck area (SF).

The total deck area of the bridge.

Average Daily Traffic (count).

ADT of the bridge.

Maximum Span Length (FT).

The length of the maximum span of the bridge.

Overall Bridge Length (FT).

The overall length of the structure.

Vertical Clearance Under (FT).

The minimum vertical under clearance.

Broad Work Category (categorical).

Enter a numerical value as follows:

Work Category	Entry Number
Bridge CPM	1
Bridge CSM	2
Bridge - Improve Bridge Miscellaneous Bridge Rehabilitation	3
New Structure Bridge Replacement	4

Region of Work (categorical).

Enter a numerical value as follows:

Region	Entry Number
Superior	1
North	2
Grand	3
Bay	4
Southwest	5
University	6
Metro	7

Lanes on Bridge (count).

The number of traffic lanes on the bridge.

Lanes under Bridge (count).

The number of traffic lanes under the bridge.

Service Type on Bridge (categorical).

Service on Bridge	Entry Number
Highway	1
Highway-pedestrian	1
Railroad	2
Pedestrian-bicycle	3
Highway-railroad	4
Overpass structure at an interchange or second level of a multilevel interchange	5
Third Level (Interchange)	5
Fourth Level (Interchange)	5
Building or Plaza	6
Other (non-highway)	7

Water Under Bridge (categorical).

Enter “1” if the bridge spans a waterway and “0” if the bridge does not.

Highway Under Bridge (categorical).

Enter “1” if the bridge passes over a highway and “0” if the bridge does not.

Positive Vertical Under clearance (categorical).

Enter “1” if non-zero vertical under clearance exists for the bridge and “0” otherwise.

Estimated Award Date (date format).

This is an alternative method to estimate inflation based on direct regression rather than MHCCI projection. It is recommended to use the MHCCI projection model rather than this regression approach for inflation. As such, it is recommended to insert a value in cell E23 with a year no greater than the year of the worksheet (i.e. the year found in cell C1 on the Estimate Worksheet). Inserting a value beyond the year of the worksheet will doubly-count inflation; once from the MHCCI projection model and again from the inflation regression model.

Conversion Factors

Work Type Unit Conversion Factors

Several work types require unit conversion factors or other assumptions to convert pay item costs to the worksheet unit costs. The assumptions and formulas used to develop the conversion factors are given here. Specific parameter values within the formulas may be changed by over-riding the default values given in columns E-I. Alternatively, the final conversion factor in column D can be typed in directly. Note for the Paint-complete and Paint-partial work types, the formula is a function of project-specific values in the historic price database and thus is integrated into the Updating Program; see below.

The specific work types that use these conversion factors are as follows:

Conversion Factor	Work Types Affected
1	All 3 New Superstructure work types
2	Concrete Brush Block/Curb Patch
3	Concrete Barrier Patch & Full Depth Patch
4	Pin & Hanger Replacement
5	Structural Steel Repair
6	Pressure Relief Joint

Weight Factors for Overlay Removal Costs

The Overlay Removal work type is sub-divided into Latex, Epoxy, and HMA removal. The Epoxy and HMA removal costs are taken as a proportion of the Latex removal costs, based on previous overlay removal cost proportions in the database from 2012-2023. These cost proportions (cells B14 & 15) can be modified if desired.

Date_MAD_Inputs File

Dates

The date range for the projects in the cost database to be used to calculate the model costs in the Estimate Worksheet can be entered in cells B2 & B3. Note that the earliest time range allowed is 2012-01-01. In general, it is recommended to use all data available. However, if recent trends deviate substantially from historic data, short-term trends future trends may be better predicted with more recent rather than historic data. Note that if the data pool is too small, the program will not run successfully and result in an error. Moreover, some work types may not have model estimates available.

MAD Outlier Treatment

Cost outlier values can be either truncated or removed (cell B2), with a specified cut-off limit given in cell B3; see the Final Project Report Chapter 2.7 and Chapter 5 for the meaning and effects of these parameters. Changing these options will modify what and how costs are included in the model. Default recommended values are truncate and 3.0, respectively, where ‘remove’ and decreasing the cut-off limit will eliminate more outlier data.

Updating Program

The Updating Program can be run as often as desired to update the Estimate Worksheet as new bridge data become available. Instructions are as follows:

1) Create a folder to contain the following files:

a. *‘MDOT_BridgeEstimation_AllFilesCompiled.R’* *(program file)*
b. *‘Bridge Project Data v20230302.xlsx’* *(input file)*
c. *‘calculate_annual_budget.xlsx’* *(input file)*
d. *‘Date_MAD_Inputs.xlsx’* *(input file)*
e. *‘MHCCIForecast.csv’* *(input file)*
f. *‘MHCCI Quarterly Index Values.xlsx’* *(input file)*
g. *‘Pay Items – Mapping to Work Item, Primary, and Normalizing.xlsx’* *(input file)*
h. *‘formulas constants.xlsx’* *(input file)*
i. ‘BridgeEstimation_OUTPUTS.xlsx’ *(output file)*

Do not change the names of these files.

2) Download and install R - https://cran.r-project.org/bin/windows/base/

3) Download and install RStudio https://posit.co/download/rstudio-desktop/

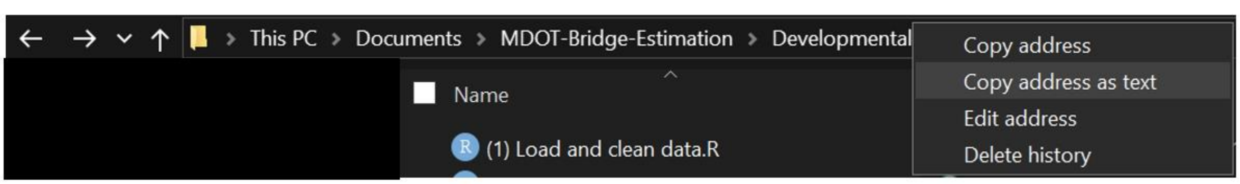
4) Open the ‘*MDOT_BridgeEstimation_AllFilesCompiled.R’* file in RStudio.

a. Right click on file in file explorer.
b. Hover over ‘Open with’
c. Select ‘RStudio’

5) In ‘*MDOT_BridgeEstimation_AllFilesCompiled.R’* paste the file path of the folder created in part 1 into line 15 of the program.

a. Open the folder created during Step 1 in file explorer.

b. Copy the path to that folder as text by right clicking the path visible in file explorer and selecting ‘Copy address as text’.



c. Paste this address in-between the “ ” on line 8 of the .R file where it says ‘path <-‘

d. Depending on the computer/network configuration, you may have to replace any ‘\’ in the file path with ‘/’ (or vice-versa). A terminal run error will occur immediately upon program execution (step 7) if the path syntax is incorrect. Also note that paths that are too long (i.e. too many subfolders) may also cause an execution error.

e. Add an additional '/' (or '\' , as appropriate) to the end of the file path. See example below:

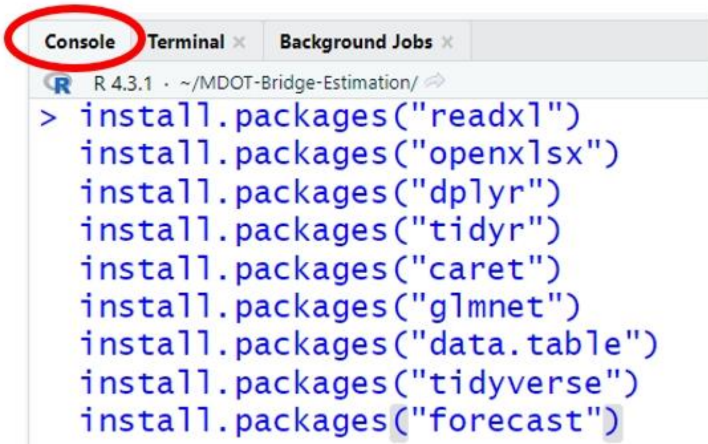
```
8 path <- "PASTE FILE PATH HERE"
```

```
8 path <- "C:\Users\erika\OneDrive\Documents\MDOT-Bridge-Estimation\Developmental Files\"
```

6) Install necessary packages.

a. Copy and paste the following text into the Console (the bottom left pane) after the ">" cursor and then hit enter:

```
install.packages("readxl")
install.packages("openxlsx")
install.packages("dplyr")
install.packages("tidyr")
install.packages("caret")
install.packages("glmnet")
install.packages("data.table")
install.packages("tidyverse")
install.packages("forecast")
```

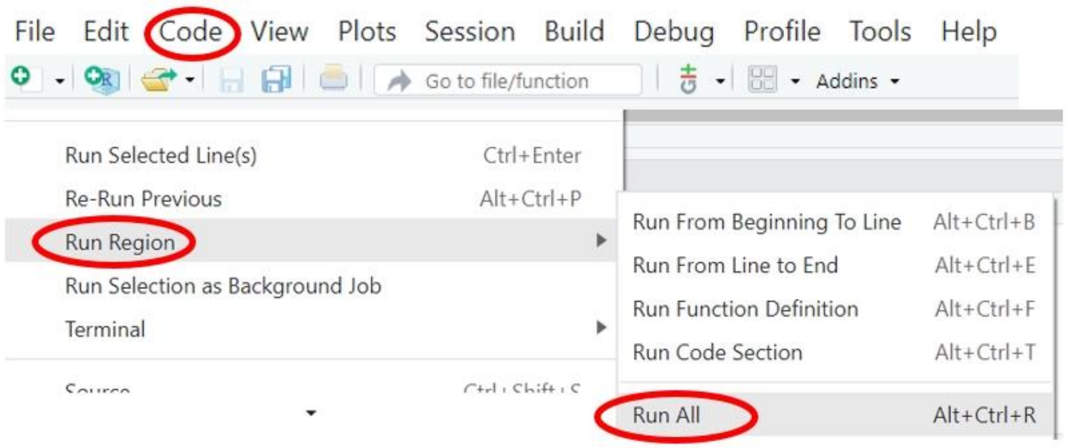


Note: the above steps 1-6 need to be done only once on a given computer. If the same machine will run the program again in the future, it is not necessary to set up R again.

7) Run the program.

a. Select 'Code' in the top left corner of the window.

b. Near the bottom of the menu, hover over 'Run Region', and then select 'Run All'.



c. Allow the program to run; this may take 5 or more minutes depending on the computer speed. The program is complete when the top right of the console no longer shows a small stop sign symbol and the console outputs "PROGRAM COMPLETE".

8) Update the cost estimation worksheet using the program outputs.

a. Open the '*BridgeEstimation_OUTPUTS.xlsx'* file.

b. Refer to the table below to determine where to paste the output results into the estimation worksheet:

Table 8.2. Updating Program Output File Placement.

Output File Sheet	**Estimation Worksheet**	**Instructions**
Mean-Median Predictors	Global Data Entry	Copy numerical values in output file, paste into cells G8:H22.
Work Item Averages	Work Item Averages	Copy entire sheet from output file and paste into sheet of same name in estimation worksheet.
MHCCI Forecast - General	MHCCI Values for projection	In the output files, copy values from columns A to F, paste onto Estimation WS sheet tab "MHCCI Values for projection" **grey** cells of columns A to F.
MHCCI Forecast - Bridge	MHCCI Values for projection	In the output files, copy values from columns A to F, paste onto Estimation WS sheet tab "MHCCI Values for projection" **grey** cells of columns H to M.
Lasso Coefficient	Lasso Coefficient	Copy entire sheet from output file and paste into sheet of same name in estimation worksheet.

Lasso Coefficient - Bridge	Lasso – Coefficient Bridge	Copy entire sheet from output file and paste into sheet of same name in estimation worksheet.

Note that, if desired, a different set of program updating parameters can be used for different work types. That is, the Updating Program can be run with one set of input parameter selections intended for only a selection or work types, and the output lines that correspond just to those work types can be inserted into the estimation worksheet.

This was done for the current Estimate Worksheet for the work type: New Bridge – Precast Culvert (corresponding to input row 5 within the hidden worksheet tabs in the table above), where the 2023 project information was excluded by changing the date in the Date_MAD_Inputs File to include up to 2022 projects only. This was done because erroneous information appears in the bridge database for a 2023 culvert project, which resulted in significantly inaccurate mean cost predictions if that case was included.

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APPENDIX A. Factors Survey

A.1 Enhanced Bridge Cost Estimating Survey

Results of this survey will be used in conjunction with other methods to assist the research team to identify the most critical parameters that influence unit cost items.

Choose and rank the top 10 bridge-related factors that you believe most affect winning bid UNIT (not total) costs. This survey is interested in local factors rather than wider economic variables such as inflation, employment rate, interest rate, etc.

Some example factors are listed below. Your choices may extend beyond this list.

- Type of work/items included (new construction, deck widening, patch, replacement, overlay; beam end repair, beam replacement, etc)
- Project complexity and other special construction considerations (e.g. full/part width)
- Scheduling requirements (night/expedited, etc)
- Incentive/liquidated damage stipulations
- Bridge geometric information (length, width, # of spans, # of girders, etc)
- Overall size of project (total anticipated budget; total SF/CY affected)
- Type of bridge/girder/deck (steel, PC, RC, etc)
- Bridge location/surrounding features (water vs roadway under; traffic volume on roadway; MDOT region)
- Traffic restrictions
- MDOT current total bridge program cost (may affect contractor's work load)
- Corridor projects vs standalone projects
- Time of the year when projects are let
- Any other factors

Rank	Factor (be specific as possible)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

A.2 All Comments From Survey

1. Project complexity and other special construction considerations (e.g. full/part width) – part width may be 50% more in cost vs full width
2. MDOT current total bridge program cost (may affect contractor's work load) – likely a primary driver for recent increase in costs.
3. Bridge location/surrounding features (water vs roadway under; traffic volume on roadway; MDOT region)
    a. Limited bridge contractors willing to work in Superior Region, opportunity costs mobilizing crews to North/Superior.
4. Overall size of project (total anticipated budget; total SF/CY affected)
5. Scheduling requirements (night/expedited, etc) – everything seems to be expedited work these days

Rank	Factor (be specific as possible)
1	• Efficiency - Can we do large qty's in single stage/mob.
2	• Staging - Number of mobilizations
3	• Grouping of similar work items
4	• Completeness of bid packet o Vague description of work items - Crack injection at discretion of engineer o Inaccurate qty's o Unanswered/insufficiently answered questions.
5	• Location of project
6	• Day/Night/Weekend restrictions
7	• Window to get job done - Not Duration of Project - i.e., closure of 2 days but anytime in next 3 months vs 2 days on the 3rd weekend in July.
8	• Is work scheduled for the appropriate time of year - weather.
9	• Time line- if work includes materials with shelf life shorter than scheduled completion I have to cover possible escalations
10	• Unreasonable LD's

Rank	Factor (be specific as possible)
1	Size of project, number of bridges with similar scope and bridge proximity to other. Corridor projects potentially have better cost per unit compared to single or 2 bridge rehabs.
2	MOT – significant increase in cost per unit when comparing part width vs full width.
3	Schedule flexibility, the more bridges that can be worked on simultaneously the better cost per unit will be.
4	Schedule requirements, specifying night work only will drastically increase cost per unit, lower production, more safety equipment, splitting crews in half, weekly cycles getting thrown off because "losing" daytime working hours of specified crew.
5	Water vs roadway, water will drive up cost per unit, water diversion, over water, scour, work around water is highly unpredictable and damaging events out of contractor control.
6	Location, cost per unit may be slightly down if multiple smaller level projects are let within the same area / region, that contractor may win bid on multiple projects in the area
7	
8	
9	
10	

Rank	Factor (be specific as possible)
1	Size of Bridge Program (currently) – Schedule (more typical years), including time of year
2	Maintenance of Traffic (MOT) – part width and full width plays a role here
3	Work Type – the more labor the higher the cost
4	Complexity of project – this includes location and size
5	
6	
7	
8	
9	
10	

I've shared this with our bridge management staff but for our squad's projects, the biggest factor contributing to the bridge bid costs in the last few years was corridor road projects packaged with bridge work. We've seen the highest bid prices when there is major bridge work on a large overall project, but the prime is a road contractor. Although the bridge subcontractor's unit prices get bid very high, they still bid lowest since the bridge work is a small percentage of the overall project.

Here are my rankings:

1) Corridor projects vs standalone projects
2) Scheduling requirements (night/expedited, etc)
3) Project complexity and other special construction considerations (e.g. full/part width)
4) Traffic restrictions
5) Bridge location/surrounding features (water vs roadway under; traffic volume on roadway; MDOT region)
6) Overall size of project (total anticipated budget; total SF/CY affected)
7) Incentive/liquidated damage stipulations
8) Bridge geometric information (length, width, # of spans, # of girders, etc)
9) MDOT current total bridge program cost (may affect contractor's work load)
10) Time of the year when projects are let

APPENDIX B. MDOT 2023 (Existing) Bridge Cost Estimation Worksheet

2023

BRIDGE COST ESTIMATE WORKSHEET

- CPM, REHAB, REPLACE -

REV. 01/31/2023

DATE: 7/11/2023

OWNER: FISCAL YEAR: ENGINEER:

REGION: LENGTH | Out to Out WIDTH | Curb to Curb WIDTH

TSC: PR: MP: STRUCTURE ID:

BRIDGE ID:

LOCATION: over

PRIMARY WORK ACTIVITY DECK AREA: SFT STR. TYPE:

OTHER WORK: CLEAR ROADWAY: SFT

WORK ACTIVITY	MDOT Bridge Design Guides	QUANTITY	UNIT	UNIT COST	TOTAL
NEW BRIDGE	(increase deck area based on design standards and hydraulic requirements)				
Single or Multiple Spans, Grade Separation	(add demo, approach, MOT)		SFT	$415.00 /SFT	
Single Span, Over Water	Length < 100ft (add demo, approach, MOT)		SFT	$500.00 /SFT	
Multiple Spans, Over Water	Length > 100ft (add demo, approach, MOT)		SFT	$450.00 /SFT	
Precast Culvert	Length < 40ft (add demo, approach, MOT)		SFT	$540.00 /SFT	
NEW SUPERSTRUCTURE					
New Superstructure, Grade Separation	(incl. remove exist deck/super; add MOT & approach)		SFT	$295.00 /SFT	
New Superstructure, Over Water	(incl. remove exist deck/super; add MOT & approach)		SFT	$300.00 /SFT	
WIDENING					
Structure Widening, ____ ft	(incl. deck/super/sub widening, add approach transition)		SFT	$630.00 /SFT	
NEW DECK					
New Bridge Deck & Barrier	(incl. remove exist deck/railing, add approach, MOT)		SFT	$150.00 /SFT	
DEMOLITION					
Entire Structure, Grade Separation			SFT	$75.00 /SFT	
Entire Structure, Over Water			SFT	$95.00 /SFT	
DECK REPAIR / TREATMENTS					
Bridge Railing Replacement	(incl. removal and replacement)		FT	$750.00 /FT	
Concrete Brush Block / Curb Patch	(incl. hand chipping and formwork)		FT	$28.47 /FT	
Concrete Barrier Patch	(incl. hand chipping and formwork)		SFT	$85.40 /SFT	
Concrete Deck Patch	(incl. hand chipping)		SFT	$68.17 /SFT	
Deep Overlay	(incl. joint repl & hydro)		SFT	$46.21 /SFT	
Epoxy Overlay	(incl. warranty)		SYD	$48.00 /SYD	
Expansion Joint Gland Replacement	(remove and replace elastomeric gland)		FT	$125.00 /FT	
Expansion Joint Replacement	(incl. removal)		FT	$859.43 /FT	
Full Depth Patch			SFT	$140.72 /SFT	
Healer / Sealer	(penetrates cracks in bridge deck)		SYD	$30.00 /SYD	
HMA Overlay with WP membrane			SYD	$60.29 /SYD	
Overlay Removal	(Epoxy: $22/syd | Latex: $26/syd | HMA: $7/syd)		SYD	$22.00 /SYD	
Reseal Bridge Joints			FT	$28.00 /FT	
Shallow Overlay	(incl. joint repl & hydro)		SFT	$46.00 /SFT	
SUPERSTRUCTURE REPAIR					
Bearing Realignment / Replacement	(incl. temporary supports)		EA	$6,450.00 EA	
Heat Straightening	(incl. clean and coat)		EA	$57,000.00 EA	
Pack Rust Repair	(greater than 3/8" separation)		FT	$1,150.00 /FT	
Paint - Complete	(incl. clean & coat)		SFT	$22.00 /SFT	
Paint - Partial / Spot / Zone	(incl. clean & coat - $20k minimum)		SFT	$35.00 /SFT	
PCI Beam End Blockout	(incl. temporary supports)		EA	$7,200.00 EA	
Pin & Hanger Replacement	(incl. temporary supports)		EA	$17,000.00 EA	
Structural Steel Repair	(based on 6ft repair length)		EA	$4,000.00 EA	
Structural Steel Repair - Stiffener	(includes each side of beam)		EA	$1,500.00 EA	
SUBSTRUCTURE REPAIR					
Substructure Patching	(measured x 2) replace if repair area > 30%		CFT	$360.00 /CFT	
Substructure Replacement	(incl. temporary supports, excavation)		CFT	$375.00 /CFT	
Substructure Horizontal Surface Sealer			SYD	$75.00 /SYD	
Temporary Supports	(add Structural Steel Repair - Stiffener for ea steel beam)		EA	$4,000.00 EA	
MISCELLANEOUS					
Articulating Concrete Block System (ACB)			SYD	$320.00 /SYD	
Concrete Surface Coating			SYD	$47.00 /SYD	
Culvert Cleanout			FT	$125.00 /FT	
Epoxy Crack Injection	(structural crack repair)		FT	$70.00 /FT	
Metal Mesh Panels	(48" width, max 6'-6" length)		SFT	$28.00 /SFT	
Pressure Relief Joint	(use when approach concrete roadway exceeds 1,000ft)		FT	$110.00 /FT	
Riprap	(assume 10ft distance around perimeter of substructure)		SYD	$275.00 /SYD	
Silane Treatment	(penetrating sealer for concrete surfaces)		SFT	$7.00 /SFT	
Slope Protection Repairs			SYD	$150.00 /SYD	
Other					
				STRUCTURE CONSTRUCTION BUDGET	$0
ROAD WORK					
Approach Pavement, 12" RC	(incl. removal; add curb, gutter, guardrail) 40' ea. end		SYD	$230.00 /SYD	
Approach Curb & Gutter	(incl. removal) 40' ea. quadrant		FT	$57.00 /FT	
Guardrail Anchorage to Bridge	(each quadrant)		EA	$2,540.00 /EA	
Guardrail	(incl. removal) < 200ft beyond reference line		FT	$41.00 /FT	
Guardrail Terminal	(each quadrant)		EA	$3,900.00 /EA	
Roadway Approach Work	(beyond approach pavement)		LSUM	LSUM	
Utilities			LSUM	LSUM	
TRAFFIC CONTROL	*Unit Cost to be determined by Region or TSC Traffic & Safety*				
Part Width Construction			LSUM	LSUM	
Crossovers			EA	/EA	
Temporary Traffic Signals			set	/set	
RR Flagging			LSUM	LSUM	
Detour			LSUM	LSUM	
				RELATED ROAD/TRAFFIC CONSTRUCTION BUDGET	$0
CONTINGENCY	(10% - 20%) (use higher contingency for small projects)	10	%	$0.00	$0
MOBILIZATION	(estimate at 10%)	10	%	$0.00	$0
INFLATION	(assume 4% per year, beginning in 2024)	0	%	$0.00	$0

(Does not include PE or CE)		TOTAL CONSTRUCTION BUDGET	$0
(Refer to programming guidelines in Bridge Cost Estimating Worksheet-Key for CE,PE & PE-S)	% CE	CON BUDGET	$0
	% PE	PE BUDGET	$0
	% PE	PE-S BUDGET	$0

APPENDIX C. Work Type Pay Items

The pay item lists given in the following tables are used to determine the total cost of a work type within the Bridge Project Price Database. In Tables C.1.a-C.41, for work types identified by primary pay items, the primary pay items are highlighted in green; if none are highlighted, then all items on the list are taken as the primary items.

Pay items given without an item number in the tables but a description only refer to a larger list of sub-types of pay items. These lists are given in Table C.42. On these lists, any single item that is labeled with "OR" may count as a primary pay item (i.e. only one of these must be present for work type identification).

Table C.1.a. New Bridge Pay Items.

Item #	Description
1040001	Contractor Staking
2040001	Asbestos Materials, Rem and Disposal
2040045	Masonry and Conc Structure, Rem
2040060	Structures, Rem
2040064	Structure Demolition Plan, Complex
2040080	Exploratory Investigation, Vertical
2050010	Embankment, CIP
2050012	Embankment, Structure, CIP
2050018	Excavation, Rock
2050031	Non Haz Contam Matl Handling & Disp, LM
2050050	Non Haz Contam Mat'l Handling & Disp, LM
2060002	Backfill, Structure, CIP
2060010	Excavation, Fdn
2060011	Excavation, Rock Fdn
2080004	Erosion Control, Gravel Filter Berm
2080011	Erosion Control, Filter Bag
2080012	Erosion Control, Sand Bag
2080014	Erosion Control, Filter Bag
2080018	Erosion Control, Gravel Filter Berm
2080028	Erosion Control, Sand Bag
2080034	Erosion Control, Sediment Trap
2080036	Erosion Control, Silt Fence
2080040	Ero Con, Temp Plastic Sheet/Geotex Cover
2080042	Ero Con,Turbidity Curtain, Deep
2080044	Ero Con,Turbidity Curtain, Shallow
2087011	Articulating Conc Block System, 6 inch
4017001	Culvert Cleanout
4040031	Underdrain, Fdn, 4 inch
4040033	Underdrain, Fdn, 6 inch
4040091	Underdrain Outlet, 4 inch
4040111	Underdrain, Outlet Ending, 4 inch

4040113	Underdrain, Outlet Ending, 6 inch
6050101	Conc Quality Initiative
7040001	Steel Sheet Piling, Permanent
7040002	Steel Sheet Piling, Temp
7040003	Steel Sheet Piling, Temp, Left in Place
7040007	Cofferdams
7040009	Cofferdams, Left in Place
7050001	Prebore, Fdn Piling
7050002	Pile Driving Equipment, Furn
7050022	Pile, CIP Conc, Furn and Driven, 14 inch
7050023	Test Pile, CIP Conc, 14 inch
7050025	Pile Point, CIP Conc
7050026	Pile, CIP Conc, Furn and Driven, 16 inch
7050027	Test Pile, CIP Conc, 16 inch
7050030	Pile, Steel, Furn and Driven, 12 inch
7050031	Test Pile, Steel, 12 inch
7050034	Pile, Steel, Furn and Driven, 14 inch
7050035	Test Pile, Steel, 14 inch
7050038	Pile, Galv
7050039	Pile Point, Steel
7050050	Pile, Steel, Splice
7057050	Test Pile, Furn Dynamic Analysis Equipment
7060001	Bridge Ltg, Furn and Rem
7060002	Bridge Ltg, Oper and Maintain
7060003	Conc, Grade S2, Subfooting
7060004	Conc, Grade T
7060008	Conc Quality Assurance, Structure
7060011	Conc, Grade S2
7060012	Conc, Grade S2, Subfooting
7060013	Conc, Grade T
7060025	Conc Surface Coating
7060027	Substructure Horizontal Surface Coating
7060028	Substructure Horizontal Surface Sealer
7060031	Expansion Joint Device
7060032	False Decking
7060034	Reinforcement, Steel
7060035	Reinforcement, Steel, Epoxy Coated
7060040	Elec Grounding System
7060050	Expansion Joint Device
7060051	Expansion Joint Device, Cover Plate
7060060	False Decking
7060080	Wall Drain
7060089	Reinforcement, Stainless Steel
7060090	Reinforcement, Steel
7060092	Reinforcement, Steel, Epoxy Coated

7060200	Mech Stabiliz Earth Wall, Precast, Furn
7060201	Mech Stabiliz EarthWall, Precast, Instal
7060202	Mech Stab EarthWall,WF,Temp, Furn
7060203	Mech Stab EarthWall,WF,Temp, Install
7060206	Mech Stab Earth Wall Coping, Precast
7060207	Mech Stab Earth Wall Coping, CIP
7060208	Mech Stab Earth Wall, Level Pad, Conc
7060209	Liner, PVC, 30 mil
7060220	Sealing Localized Cracks
7062000	Conc, Grade 3500, Subfooting
7062001	Conc, Grade 3500
7062005	Aesthetic Texturing
7070013	Structural Steel, Mixed, Furn and Fab
7070040	Shear Developers
7070053	Steel Dia, Prest Conc Beam, Furn and Fab
7070054	Steel Dia, Prest Conc Beam, Erect
7070080	Shear Developers
7100001	Joint Waterproofing
7100003	Joint Waterproofing, Expansion
7100008	Membrane, Preformed Waterproofing
7100010	Conc Surface Coating
7100011	Conc Surface Coating
7120020	Epoxy Ovly
7120044	Bolt, Adhesive Anchored, 1 inch
7120070	Structures, Rehabilitation, Rem Portions
7120084	Reinforcement, Mechanical Splice
7130008	Str Steel, Retrofit, Furn, Fab, & Erect
7130010	Beam Plate, Seal Perimeter
7140002	Structures, Temp, Rem
7160001	Field Rpr of Damaged Coating
7170010	Drain Casting Assembly
7180010	Drilled Shaft Equipment, Furn
7180042	Drilled Shaft, 42 inch
7180100	Obstruction Removal
7180110	Permanent Casing
7180121	Temp Casing-Left in Place
8020070	Downspout Header, Conc
8080110	Fence, Structure
8130005	Riprap, Heavy
8130010	Riprap, Plain
8130011	Riprap, Plain
8130012	Riprap, Plain, LM
8130015	Slope Paving Header
8130020	Slope Paving, Conc
8190157	Conduit, Schedule 80 PVC, 2 inch

8190176	Conduit,Schedule 80 PVC,1 1/2",Structure
8240001	Contractor Staking
8240020	Structure Survey During Construction
8240021	Staking Plan Errors and Extras, 2 Person
8240022	Staking Plan Errors and Extras, 3 Person
	Superstructure Conc
	Surface Treatment
	Substructure Conc
	Bearing Elastomeric
	Bridge Railing
	Girders or Prestressed deck

Table C.1.b. Culvert Pay Items.

Item #	Description
8150016	Abies balsamea, bareroot, 18-24 inch
7120028	Adhesive Anchoring of Horizontal Bar,3/4
7120034	Adhesive Anchoring of Vertical Bar, 3/4
7120034	Adhesive Anchoring of Vertical Bar, 3/4"
7120035	Adhesive Anchoring of Vertical Bar, 7/8"
2060005	Aggregate
3020010	Aggregate Base, 4 inch
2060001	Aggregate, 6A
2040001	Asbestos Materials, Rem and Disposal
2060004	Backfill, Select
2060002	Backfill, Structure, CIP
7070021	Bearing, Elastomeric, 3 1/4 inch
7110071	Brdg Rail Aes Para Tube, Dt 2, Hi Perf
7060001	Bridge Ltg, Furn and Rem
7060002	Bridge Ltg, Oper and Maintain
7110008	Bridge Railing, 2 Tube
7110010	Bridge Railing, 4 Tube
7110005	Bridge Railing, Aesthetic Parapet Tube
8190238	Cable, Equipment Grounding Wire, 1/C#10
8190237	Cable, Equipment Grounding Wire, 1/C#8
7040007	Cofferdams
7040009	Cofferdams, Left in Place
8120081	Conc Barrier, Temp, Furn
8120082	Conc Barrier, Temp, Oper
7060008	Conc Quality Assurance, Structure
6050101	Conc Quality Initiative
7100010	Conc Surface Coating
7062001	Conc, Grade 3500

7062002 Conc, Grade 3500HP
7060010 Conc, Grade D
7060001 Conc, Grade D
7060002 Conc, Grade S2
7060011 Conc, Grade S2
7060003 Conc, Grade S2, Subfooting
7060013 Conc, Grade T
7060004 Conc, Grade T
7060020 Conc, Low Temperature Protection
7060030 Conc, Low Temperature Protection
8190027 Conduit, DB, 1, 1 1/2 inch
8190106 Conduit, Galv Steel, 1 inch
8190155 Conduit, Schedule 80 PVC, 1 inch
8190159 Conduit, Schedule 80 PVC, 3 inch
4060005 Culv Bedding, Box Culv
4010885 Culv Bedding, Box Culv
4010868 Culv End Sect, Metal, 48 inch
4010138 Culv, Cl A, 48 inch
4010142 Culv, Cl A, 72 inch
4010144 Culv, Cl A, 84 inch
4010208 Culv, Cl A, CSP, 60 inch
4010212 Culv, Cl A, CSP, 84 inch
4010214 Culv, Cl A, CSP, 96 inch
4010346 Culv, Cl C, 72 inch
4060130 Culv, Prec Conc Box, 10 foot by 6 foot
4060153 Culv, Prec Conc Box, 12 foot by 12 foot
4060145 Culv, Prec Conc Box, 12 foot by 4 foot
4060146 Culv, Prec Conc Box, 12 foot by 5 foot
4060148 Culv, Prec Conc Box, 12 foot by 7 foot
4060149 Culv, Prec Conc Box, 12 foot by 8 foot
4060229 Culv, Prec Three-Sided or Arch, 24ftX8ft
4060234 Culv, Prec Three-Sided or Arch,28ftX10ft
4060238 Culv, Prec Three-Sided or Arch,32ftX10ft
4060249 Culv, Prec Three-Sided or Arch,42ftX13ft

2030002 Culv, Rem, 24 inch to 48 inch
2030003 Culv, Rem, Over 48 inch
8120090 Culv, Temp
4011109 Dr Marker Post
2030010 Dr Structure, Abandon
2050010 Embankment, CIP
7120020 Epoxy Ovly

2080026	Ero Con, Maintenance, Sediment Rem
2080026	Ero Con, Maintenance, Sediment Removal
2080023	Ero Con, Maintenance, Sediment Removal
2080030	Ero Con, Temp Plastic Sheet/Geotex Cover
2080040	Ero Con, Temp Plastic Sheet/Geotex Cover
2080042	Ero Con,Turbidity Curtain, Deep
2080044	Ero Con,Turbidity Curtain, Shallow
2080012	Erosion Control, Check Dam, Stone
2080002	Erosion Control, Check Dam, Stone
2080014	Erosion Control, Filter Bag
2080011	Erosion Control, Filter Bag
2080016	Erosion Control, Gravel Access Approach
2080018	Erosion Control, Gravel Filter Berm
2080004	Erosion Control, Gravel Filter Berm
2080028	Erosion Control, Sand Bag
2080012	Erosion Control, Sand Bag
2080032	Erosion Control, Sediment Basin
2080020	Erosion Control, Sediment Basin
2080022	Erosion Control, Sediment Trap
2080034	Erosion Control, Sediment Trap
2080036	Erosion Control, Silt Fence
2080025	Erosion Control, Silt Fence
2050015	Excavation, Channel
2060010	Excavation, Fdn
2050018	Excavation, Rock
2060011	Excavation, Rock Fdn
7060050	Expansion Joint Device
2040080	Exploratory Investigation, Vertical
7060032	False Decking
7060060	False Decking
8080110	Fence, Structure
8260148	Flowable Fill, Non-Structural
2050148	Flowable Fill, Non-Structural
1090002	Force Account
3030020	Geotextile Separator
3080005	Geotextile, Separator
3082000	Geotextile, Separator, Non-Woven
3080010	Geotextile, Stabilization
2050024	Granular Material, Cl III
8190250	Hh, Polymer Conc
8190261	Hh, Square
8120035	High Intensity Light, Type B, Furn
8120036	High Intensity Light, Type B, Oper

7100001	Joint Waterproofing
7100003	Joint Waterproofing, Expansion
7060209	Liner, PVC, 30 mil
1080001	Liquidated Damages
1080000	Liquidated Damages, Oversight
2040045	Masonry and Conc Structure, Rem
7060202	Mech Stab EarthWall,WF,Temp, Furn
7060203	Mech Stab EarthWall,WF,Temp, Install
8160028	Mulch Blanket, High Velocity
1090003	Negotiated Force Account
2050031	Non Haz Contam Matl Handling & Disp, LM
2050050	Non Haz Contam Mat'l Handling & Disp, LM
2050031	Non Haz Contam Matl HandlingandDisp, LM
7180100	Obstruction Rem
4011115	Outfall Label
7050002	Pile Driving Equipment, Furn
7050039	Pile Point, Steel
7050020	Pile, CIP Conc, Furn and Driven, 12 inch
7050030	Pile, Steel, Furn and Driven, 12 inch
7050034	Pile, Steel, Furn and Driven, 14 inch
7050050	Pile, Steel, Splice
8200115	Power Co. (Est. Cost to Contractor)
7080038	Prest Conc I Beam, Erect, 70 inch
7080037	Prest Conc I Beam, Furn, 70 inch
7120084	Reinforcement, Mechanical Splice
7060090	Reinforcement, Steel
7060034	Reinforcement, Steel
7060092	Reinforcement, Steel, Epoxy Coated
7060035	Reinforcement, Steel, Epoxy Coated
8130011	Riprap, Plain
8130010	Riprap, Plain
8130012	Riprap, Plain, LM
8160035	Seeding, Mixture CR
4021239	Sewer Bulkhead, 48 inch
4021245	Sewer Bulkhead, 84 inch
4020009	Sewer, Cl A, 36 inch, Tr Det A
4020011	Sewer, Cl A, 48 inch, Tr Det A
7070040	Shear Developers
8150001	Site Preparation, Max
8160100	Slope Restoration, Type A
8160051	Slope Restoration, Type A
8160101	Slope Restoration, Type B
8160052	Slope Restoration, Type B

7040001	Steel Sheet Piling, Permanent
7040002	Steel Sheet Piling, Temp
7040003	Steel Sheet Piling, Temp, Left in Place
7070050	Structural Steel, Mixed, Erect
7070014	Structural Steel, Mixed, Erect
7070051	Structural Steel, Mixed, Furn and Fab
7070013	Structural Steel, Mixed, Furn and Fab
2040060	Structures, Rem
2040020	Structures, Rem
2040061	Structures, Rem Portions
7140001	Structures, Temp
7140002	Structures, Temp, Rem
2050041	Subgrade Undercutting, Type II
7060100	Substructure Conc
7060010	Substructure Conc
7060101	Substructure Conc, High Performance
7060110	Superstructure Conc
7060113	Superstructure Conc, Night Casting
7060111	Superstructure Conc,Form,Finish,and Cure
7060112	Supstr Conc,Form,Fin,and Cure,Night Cast
7050031	Test Pile, Steel, 12 inch
7050035	Test Pile, Steel, 14 inch
4021260	Trench Undercut and Backfill
4040091	Underdrain Outlet, 4 inch
4040093	Underdrain Outlet, 6 inch
4040031	Underdrain, Fdn, 4 inch
4040033	Underdrain, Fdn, 6 inch
4040035	Underdrain, Fdn, 8 inch
4040111	Underdrain, Outlet Ending, 4 inch
4040113	Underdrain, Outlet Ending, 6 inch
1200000	Value Engineering
4040200	Video Inspection of Underdrain
7060140	Water Repellent Treatment, Penetrating
7060040	Water Repellent Treatment, Penetrating
8150002	Watering&Cultivating,1st Seasn,Min
8150003	Watering&Cultivating,2nd Seasn,Min
8190496	Wood Pole, Fit Up, Sec Serv Pole

Table C.2. New Superstructure Pay Items.

Item #	Description
2050010	Embankment, CIP

2060002	Backfill, Structure, CIP
2060010	Excavation, Fdn
4011109	Dr Marker Post
4040031	Underdrain, Fdn, 4 inch
4040091	Underdrain Outlet, 4 inch
4040111	Underdrain, Outlet Ending, 4 inch
7060001	Bridge Ltg, Furn and Rem (Str No)
7060002	Bridge Ltg, Oper and Maintain
7060050	Expansion Joint Device
7060060	False Decking
7060092	Reinforcement, Steel, Epoxy Coated
7060140	Water Repellent Treatment, Penetrating
7060220	Sealing Localized Cracks (Str No)
7070053	Steel Diaphragm, Prest Conc Beam, Furn and Fab
7070054	Steel Diaphragm, Prest Conc Beam, Erect
7100001	Joint Waterproofing
7100003	Joint Waterproofing, Expansion
7120032	Adhesive Anchoring of Vertical Bar, 1/2 inch
7120034	Adhesive Anchoring of Vertical Bar, 3/4 inch
7120070	Structures, Rehabilitation, Rem Portions (Str No)
7160001	Field Repr of Damaged Coating (Str No)
	Aggregate Base
	Substructure Conc
	Superstructure Conc
	Bearing Elastomeric
	Surface Treatment
	Bridge Railing
	Girders or Prestressed deck

Table C.3. Structure Widening Pay Items.

Item #	Description
2050010	Embankment, CIP
2060002	Backfill, Structure, CIP
2060010	Excavation, Fdn
4011109	Dr Marker Post
4040031	Underdrain, Fdn, 4 inch
4040091	Underdrain Outlet, 4 inch
4040111	Underdrain, Outlet Ending, 4 inch
7040007	Cofferdams
7040009	Cofferdams, Left in Place
7050002	Pile Driving Equipment, Furn
7050034	Pile, Steel, Furn and Driven, 14 inch
7050039	Pile Point, Steel
7050050	Pile, Steel, Splice

7057050	Test Pile, Furn Dynamic Analysis Equipment
7057050	Test Pile, Furn Dynamic Analysis Equipment
7060001	Bridge Ltg, Furn and Rem
7060002	Bridge Ltg, Oper and Maintain
7060050	Expansion Joint Device
7060060	False Decking
7060092	Reinforcement, Steel, Epoxy Coated
7060140	Water Repellent Treatment, Penetrating
7060220	Sealing Localized Cracks
7070053	Steel Dia, Prest Conc Beam, Furn and Fab
7070054	Steel Dia, Prest Conc Beam, Erect
7100001	Joint Waterproofing
7100003	Joint Waterproofing, Expansion
7120028	Adhesive Anchoring of Horizontal Bar,3/4
7120032	Adhesive Anchoring of Vertical Bar, 1/2"
7120034	Adhesive Anchoring of Vertical Bar, 3/4"
7120070	Structures, Rehabilitation, Rem Portions
7160001	Field Rpr of Damaged Coating
	Aggregate Base
	Substructure Conc
	Superstructure Conc
	Bearing Elastomeric
	Girders or Prestressed deck
	Surface Treatment
	Bridge Railing

Table C.4. New Deck Pay Items.

Item #	Description
2050010	Embankment, CIP
2060002	Backfill, Structure, CIP
2060010	Excavation, Fdn
4011109	Dr Marker Post
4040031	Underdrain, Fdn, 4 inch
4040091	Underdrain Outlet, 4 inch
4040111	Underdrain, Outlet Ending, 4 inch
7060001	Bridge Ltg, Furn and Rem
7060002	Bridge Ltg, Oper and Maintain
7060050	Expansion Joint Device
7060060	False Decking
7100001	Joint Waterproofing
7100003	Joint Waterproofing, Expansion
7120032	Adhesive Anchoring of Vertical Bar, 1/2"
7120034	Adhesive Anchoring of Vertical Bar, 3/4"
7120060	Structures, Rehabilitation, Rem Portions, Modified (Str No)

7120061	Shear Developer, Rem
7120062	Shear Developer, Spec
7120070	Structures, Rehabilitation, Rem Portions
7120100	Top Flanges and Beam Ends,Clean and Coat
	Aggregate Base
	Superstructure Conc
	Bridge Railing
	Surface Treatment

Table C.5. Demolition Pay Items.

Item #	Description
2040061	Structures, Rem Portions
2040020	Structures, Rem
2040021	Structures, Rem Portions
2040060	Structures, Rem

Table C.6. Bridge Railing Replacement Pay Items.

Item #	Description
7060092	Reinforcement, Steel, Epoxy Coated
7120032	Adhesive Anchoring of Vertical Bar, 1/2"
7120070	Structures, Rehabilitation, Rem Portions
7120120	Embedded Galvanic Anode
	Bridge Railing

Table C.7. Concrete Brush Block / Curb Patch Pay Items.

Item #	Description
7120007	Hand Chipping, Other Than Deck
7120017	Patch, Forming
7120112	Patching Conc, C-L

Table C.8. Concrete Barrier Patch Pay Items.

Item #	Description
7062003	Concrete Grade 4500
7120007	Hand Chipping, Other Than Deck
7120017	Patch, Forming
7060092	Reinforcement, Steel, Epoxy Coated
7120112	Patching Conc, C-L
7120120	Embedded Galvanic Anode

Table C.9. Concrete Deck Patch Pay Items.

Item #	Description
7062003	Concrete Grade 4500
7120004	Hand Chipping, Deep

Table C.10. Deep Overlay Pay Items.

Item #	Description
5010006	HMA Patch, Rem
7060050	Expansion Joint Device
7060051	Expansion Joint Device, Cover Plate
7060060	False Decking
7060092	Reinforcement, Steel, Epoxy Coated
7062003	Concrete Grade 4500
7120001	Scarifying
7120025	Bridge Deck Surface Construction
7120027	Conc, Silica Fume Modified
7120071	Deck Joint, Rem
7120076	Hydrodemolition, First Pass
7120077	Hydrodemolition, 2nd Pass
7120120	Embedded Galvanic Anode

Table C.11. Epoxy Overlay Pay Items.

Item #	Description
7120022	Epoxy Ovly, Warranty

Table C.12. Expansion Joint Gland Replacement Pay Items.

Item #	Description
7122005	Bridge Joint, Strip Seal Gland Replacement

Table C.13. Expansion Joint Replacement Pay Items.

Item #	Description
7060050	Expansion Joint Device
7060060	False Decking
7060092	Reinforcement, Steel, Epoxy Coated
7062003	Concrete Grade 4500
7120071	Deck Joint, Rem
7120120	Embedded Galvanic Anode

Table C.14. Full Depth Patch Pay Items.

Item #	Description
7120004	Hand Chipping, Deep
7120010	Patch, Full Depth

Table C.15. Healer / Sealer Pay Items.

Item #	Description
7100025	Penetrating Healer/Sealer, Bridge Deck

Table C.16. HMA Overlay with WP Membrane Pay Items.

Item #	Description
7100008	Membrane, Preformed Waterproofing
5010061	HMA Approach
	HMA

Table C.17. Overlay Removal Pay Items.

Item #	Description
7120072	Latex Conc Surface, Rem
	Overlay REM

Table C.18. Reseal Bridge Joints Pay Items.

Item #	Description
7127001	Bridge Joints, Clean and Seal

Table C.19. Shallow Overlay Pay Items.

Item #	Description
7060050	Expansion Joint Device
7060060	False Decking
7060092	Reinforcement, Steel, Epoxy Coated
7120001	Scarifying
7120025	Bridge Deck Surface Construction
7120071	Deck Joint, Rem
7120076	Hydrodemolition, First Pass
7120077	Hydrodemolition, 2nd Pass
7120120	Embedded Galvanic Anode
5010006	HMA Patch, Rem
7060051	Expansion Joint Device, Cover Plate
7062003	Concrete Grade 4500

Table C.20. Bearing Realignment / Replacement Pay Items.

Item #	Description
7130080	Support, Column, Temp
7130050	Rocker, Realign,

Table C.21. Heat Straightening Pay Items.

Item #	Description
7130040	Heat Straightening Steel (Str No)

Table C.22. Pack Rust Repair Pay Items.

Item #	Description
7137001	Pack Rust Repair

Table C.23. Paint – Complete Pay Items.

Item #	Description
7130010	Beam Plate, Seal Perimeter
7150045	Steel Structure, Cleaning, Type 4 (Str No)
7150046	Steel Structure, Coating, Type 4 (Str No)

Table C.24. Paint – Partial / Spot / Zone Pay Items.

Item #	Description
7130010	Beam Plate, Seal Perimeter
7150047	Steel Structure, Cleaning, Partial, Type 4 (Str No)
7150048	Steel Structure, Coating, Partial, Type 4 (Str No)

Table C.25. PCI Beam End Blockout Pay Items.

Item #	Description
7127021	Latex Modified Conc, Spec
7130080	Support, Column, Temp

Table C.26. Pin & Hanger Replacement Pay Items.

Item #	Description
7070030	Bushing
7130030	Hanger Assembly, Field Measurement
7130031	Hanger Assembly, Rem and Erect
7130070	Structural Steel, Furn and Fab, Pin and Hanger
7130082	Support, Suspension, Temp

Table C.27. Structural Steel Repair Pay Items.

Item #	Description
7130071	Structural Steel, Retrofit, Furn, Fab, and Erect - $Lb
7130072	Structural Steel, Welded Repr, Furn, Fab, and Erect - $Lb

Table C.28. Structural Steel Repair – Stiffener Pay Items.

Item #	Description
7130060	Stiffeners, Furn, Fab, and Erect

Table C.29. Substructure Patching Pay Items.

Item #	Description
7060092	Reinforcement, Steel, Epoxy Coated
7120007	Hand Chipping, Other Than Deck
7120017	Patch, Forming
7120112	Patching Conc, C-L
7120120	Embedded Galvanic Anode

Table C.30. Substructure Replacement Pay Items.

Item #	Description
7060092	Reinforcement, Steel, Epoxy Coated
7120070	Structures, Rehabilitation, Rem Portions
7120084	Reinforced Mechanical Splice
7120120	Embedded Galvanic Anode
7130060	Stiffeners, Furn, Fab, and Erect
7130080	Support, Column, Temp
7150010	End Diaphragm, Rem & Repl
	Substructure Conc

Table C.31. Substructure Horizontal Surface Sealer Pay Items.

Item #	Description
7100030	Substructure Horizontal Surface Sealer

Table C.32. Temporary Supports Pay Items.

Item #	Description
	Temp supports

Table C.33. Articulating Concrete Block System (ACB) Pay Items.

Item #	Description
2087011	Articulating Conc Block System, 6 inch

Table C.34. Concrete Surface Coating Pay Items.

Item #	Description
7100011	Concrete Surface Coating

Table C.35. Culvert Cleanout Pay Items.

Item #	Description
4017001	Culv Cleanout

Table C.36. Epoxy Crack Injection Pay Items.

Item #	Description
7120098	Flushing Cracks, Water
7120099	Structural Crack, Repr

Table C.37. Metal Mesh Panels Pay Items.

Item #	Description
7070120	Metal Mesh Panels

Table C.38. Pressure Relief Joint Pay Items.

Item #	Description
6020213	Joint, Pressure Relief

Table C.39. Riprap Pay Items.

Item #	Description
	Riprap

Table C.40. Silane Treatment Pay Items.

Item #	Description
7107010	Silant Treatment

Table C.41. Slope Protection Repairs Pay Items.

Item #	Description
8137011	Slope Protection, Replace

Table C.42. Pay Item Sub-Types.

Item #	Description	
	Bridge Railing	
7110001	Bridge Barrier Railing, Type 4	OR
7110002	Bridge Barrier Railing, Type 5	OR
7110003	Reflective Marker, Permanent Barrier	OR
7110004	Bridge Railing, Aesthetic Parapet Tube, High Performance	OR
7110005	Bridge Railing, Aesthetic Parapet Tube	OR
7110008	Bridge Railing, 2 Tube	OR
7110009	Bridge Railing, 3 Tube with Pickets	OR
7110010	Bridge Railing, 4 Tube	OR
7110011	Bridge Barrier Railing, Type 6	OR
7110012	Bridge Barrier Railing, Type 7	OR
7110015	Bridge Barrier Railing, Type 4, High Performance	OR
7110016	Bridge Barrier Railing, Type 5, High Performance	OR
7110017	Bridge Barrier Railing, Type 6, High Performance	OR
7110018	Bridge Barrier Railing, Type 7, High Performance	OR
7110020	Pipe Railing, Alum	OR
7110021	Pipe Railing, Galv Steel	OR
7110032	Bridge Railing, Aesthetic Parapet Tube, Det 1	OR
7110033	Bridge Railing, Aesthetic Parapet Tube, Det 2	OR
7110070	Bridge Railing, Aesthetic Parapet Tube, Det 1, High Performance	OR
7110071	Bridge Railing, Aesthetic Parapet Tube, Det 2, High Performance	OR
7110080	Bridge Railing, Conc Block Retrofit Non-High Performance	OR
7112000	Bridge Barrier Railing, Type 4, Replacement	OR
7112001	Bridge Barrier Railing, Type 5, Replacement	OR
7112002	Bridge Barrier Railing, Type 6, Replacement	OR
7112003	Bridge Barrier Railing, Type 7, Replacement	OR
7112012	Bridge Barrier Railing, Type 4, Replacement, High Performance	OR
7112013	Bridge Barrier Railing, Type 5, Replacement, High Performance	OR
7112014	Bridge Barrier Railing, Type 6, Replacement, High Performance	OR

7112015	Bridge Barrier Railing, Type 7, Replacement, High Performance	OR
7112024	Bridge Barrier Railing, Aesthetic, Type 4, Det 1	OR
7112025	Bridge Barrier Railing, Aesthetic, Type 5, Det 1	OR
7112026	Bridge Barrier Railing, Aesthetic, Type 6, Det 1	OR
7112027	Bridge Barrier Railing, Aesthetic, Type 7, Det 1	OR
7112036	Bridge Barrier Railing, Aesthetic, Type 4, Det 2	OR
7112037	Bridge Barrier Railing, Aesthetic, Type 5, Det 2	OR
7112038	Bridge Barrier Railing, Aesthetic, Type 6, Det 2	OR
7112039	Bridge Barrier Railing, Aesthetic, Type 7, Det 2	OR
7112048	Bridge Barrier Railing, Aesthetic, Type 4, Det 1, High Performance	OR
7112049	Bridge Barrier Railing, Aesthetic, Type 5, Det 1, High Performance	OR
7112050	Bridge Barrier Railing, Aesthetic, Type 6, Det 1, High Performance	OR
7112051	Bridge Barrier Railing, Aesthetic, Type 7, Det 1, High Performance	OR
7112060	Bridge Barrier Railing, Aesthetic, Type 4, Det 2, High Performance	OR
7112061	Bridge Barrier Railing, Aesthetic, Type 5, Det 2, High Performance	OR
7112062	Bridge Barrier Railing, Aesthetic, Type 6, Det 2, High Performance	OR
7112063	Bridge Barrier Railing, Aesthetic, Type 7, Det 2, High Performance	OR
7112072	Bridge Barrier Railing, Aesthetic, Type 4, Det 1, Replacement	OR
7112073	Bridge Barrier Railing, Aesthetic, Type 5, Det 1, Replacement	OR
7112074	Bridge Barrier Railing, Aesthetic, Type 6, Det 1, Replacement	OR
7112075	Bridge Barrier Railing, Aesthetic, Type 7, Det 1, Replacement	OR
7112084	Bridge Barrier Railing, Aesthetic, Type 4, Det 2, Replacement	OR
7112085	Bridge Barrier Railing, Aesthetic, Type 5, Det 2, Replacement	OR
7112086	Bridge Barrier Railing, Aesthetic, Type 6, Det 2, Replacement	OR
7112087	Bridge Barrier Railing, Aesthetic, Type 7, Det 2, Replacement	OR
7112096	Bridge Barrier Railing, Aesthetic, Type 4, Det 1, Replacement, High Performance	OR
7112097	Bridge Barrier Railing, Aesthetic, Type 5, Det 1, Replacement, High Performance	OR
7112098	Bridge Barrier Railing, Aesthetic, Type 6, Det 1, Replacement, High Performance	OR
7112099	Bridge Barrier Railing, Aesthetic, Type 7, Det 1, Replacement, High Performance	OR
7112108	Bridge Barrier Railing, Aesthetic, Type 4, Det 2, Replacement, High Performance	OR
7112109	Bridge Barrier Railing, Aesthetic, Type 5, Det 2, Replacement, High Performance	OR
7112110	Bridge Barrier Railing, Aesthetic, Type 6, Det 2, Replacement, High Performance	OR
7112111	Bridge Barrier Railing, Aesthetic, Type 7, Det 2, Replacement, High Performance	OR

	Bearing Elastomeric	
7130050	Rocker, Realign,	OR

7070050	Structural Steel, Mixed, Erect	
7070051	Structural Steel, Mixed, Furn and Fab	OR
7070010	Bearing, Elastomeric, 1/2 inch	OR
7070011	Bearing, Elastomeric, 3/4 inch	OR
7070012	Bearing, Elastomeric, 1 inch	OR
7070013	Bearing, Elastomeric, 1 1/4 inch	OR
7070014	Bearing, Elastomeric, 1 1/2 inch	OR
7070015	Bearing, Elastomeric, 1 3/4 inch	OR
7070016	Bearing, Elastomeric, 2 inch	OR
7070017	Bearing, Elastomeric, 2 1/4 inch	OR
7070018	Bearing, Elastomeric, 2 1/2 inch	OR
7070019	Bearing, Elastomeric, 2 3/4 inch	OR
7070020	Bearing, Elastomeric, 3 inch	OR
7070021	Bearing, Elastomeric, 3 1/4 inch	OR
7070022	Bearing, Elastomeric, 3 1/2 inch	OR
7070023	Bearing, Elastomeric, 3 3/4 inch	OR
7070024	Bearing, Elastomeric, 4 inch	OR
	Girders or Prestressed deck	
7080001	Prest Conc Deck, 12 inch	OR
7080015	Post Tensioning	
7080002	Prest Conc Deck, 17 inch	OR
7080015	Post Tensioning	
7080003	Prest Conc Deck, 21 inch	OR
7080015	Post Tensioning	
7080004	Prest Conc Deck, 27 inch	OR
7080015	Post Tensioning	
7080005	Prest Conc Deck, 33 inch	OR
7080015	Post Tensioning	
7080006	Prest Conc Deck, 39 inch	OR
7080015	Post Tensioning	
7080007	Prest Conc Deck, 42 inch	OR
7080015	Post Tensioning	
7080008	Prest Conc Deck, 48 inch	OR
7080015	Post Tensioning	
7080009	Prest Conc Deck, 54 inch	OR
7080015	Post Tensioning	
7080010	Prest Conc Deck, 60 inch	OR
7080015	Post Tensioning	
7080021	Prest Conc I Beam, Furn, 28 inch	OR
7080022	Prest Conc I Beam, Erect, 28 inch	
7080025	Prest Conc I Beam, Furn, 36 inch	OR

7080026	Prest Conc I Beam, Erect, 36 inch	
7080029	Prest Conc I Beam, Furn, 45 inch	OR
7080030	Prest Conc I Beam, Erect, 45 inch	
7080033	Prest Conc I Beam, Furn, 54 inch	OR
7080034	Prest Conc I Beam, Erect, 54 inch	
7080037	Prest Conc I Beam, Furn, 70 inch	OR
7080038	Prest Conc I Beam, Erect, 70 inch	
7080040	Prest Conc I Beam, Furn, 72 inch	OR
7080041	Prest Conc I Beam, Erect, 72 inch	
7080051	Prest Conc Box Beam, Furn, 12 inch	OR
7080052	Prest Conc Box Beam, Erect, 12 inch	
7080055	Prest Conc Box Beam, Furn, 17 inch	OR
7080056	Prest Conc Box Beam, Erect, 17 inch	
7080061	Prest Conc Box Beam, Furn, 21 inch	OR
7080062	Prest Conc Box Beam, Erect, 21 inch	
7080065	Prest Conc Box Beam, Furn, 27 inch	OR
7080066	Prest Conc Box Beam, Erect, 27 inch	
7080071	Prest Conc Box Beam, Furn, 33 inch	OR
7080072	Prest Conc Box Beam, Erect, 33 inch	
7080075	Prest Conc Box Beam, Furn, 39 inch	OR
7080076	Prest Conc Box Beam, Erect, 39 inch	
7080081	Prest Conc Box Beam, Furn, 42 inch	OR
7080082	Prest Conc Box Beam, Erect, 42 inch	
7080085	Prest Conc Box Beam, Furn, 48 inch	OR
7080086	Prest Conc Box Beam, Erect, 48 inch	
7080091	Prest Conc Box Beam, Furn, 54 inch	OR
7080092	Prest Conc Box Beam, Erect, 54 inch	
7080095	Prest Conc Box Beam, Furn, 60 inch	OR
7080096	Prest Conc Box Beam, Erect, 60 inch	
7080101	Prest Conc 1800 Beam, Furn	OR
7080102	Prest Conc 1800 Beam, Erect	
7080110	Prest Conc Bulb-Tee Beam, Furn, 36 inch by 49 inch	OR
7080111	Prest Conc Bulb-Tee Beam, Erect, 36 inch by 49 inch	
7080115	Prest Conc Bulb-Tee Beam, Furn, 42 inch by 49 inch	OR
7080116	Prest Conc Bulb-Tee Beam, Erect, 42 inch by 49 inch	
7080120	Prest Conc Bulb-Tee Beam, Furn, 48 inch by 49 inch	OR
7080121	Prest Conc Bulb-Tee Beam, Erect, 48 inch by 49 inch	
7080125	Prest Conc Bulb-Tee Beam, Furn, 54 inch by 49 inch	OR
7080126	Prest Conc Bulb-Tee Beam, Erect, 54 inch by 49 inch	
7080130	Prest Conc Bulb-Tee Beam, Furn, 60 inch by 49 inch	OR
7080131	Prest Conc Bulb-Tee Beam, Erect, 60 inch by 49 inch	
7080135	Prest Conc Bulb-Tee Beam, Furn, 66 inch by 49 inch	OR
7080136	Prest Conc Bulb-Tee Beam, Erect, 66 inch by 49 inch	
7080140	Prest Conc Bulb-Tee Beam, Furn, 72 inch by 49 inch	OR
7080141	Prest Conc Bulb-Tee Beam, Erect, 72 inch by 49 inch	

7080145	Prest Conc Bulb-Tee Beam, Furn, 36 inch by 61 inch	OR
7080146	Prest Conc Bulb-Tee Beam, Erect, 36 inch by 61 inch	
7080150	Prest Conc Bulb-Tee Beam, Furn, 42 inch by 61 inch	OR
7080151	Prest Conc Bulb-Tee Beam, Erect, 42 inch by 61 inch	
7080155	Prest Conc Bulb-Tee Beam, Furn, 48 inch by 61 inch	OR
7080156	Prest Conc Bulb-Tee Beam, Erect, 48 inch by 61 inch	
7080160	Prest Conc Bulb-Tee Beam, Furn, 54 inch by 61 inch	OR
7080161	Prest Conc Bulb-Tee Beam, Erect, 54 inch by 61 inch	
7080165	Prest Conc Bulb-Tee Beam, Furn, 60 inch by 61 inch	OR
7080166	Prest Conc Bulb-Tee Beam, Erect, 60 inch by 61 inch	
7080170	Prest Conc Bulb-Tee Beam, Furn, 66 inch by 61 inch	OR
7080171	Prest Conc Bulb-Tee Beam, Erect, 66 inch by 61 inch	
7080175	Prest Conc Bulb-Tee Beam, Furn, 72 inch by 61 inch	OR
7080176	Prest Conc Bulb-Tee Beam, Erect, 72 inch by 61 inch	
7070060	Structural Steel, Plate, Erect	
7070061	Structural Steel, Plate, Furn and Fab	OR
7070040	Shear Developers (Str No)	
7070070	Structural Steel, Rolled Shape, Erect	
7070071	Structural Steel, Rolled Shape, Furn and Fab	OR
7070040	Shear Developers (Str No)	
	Superstructure Conc	
7060110	Superstructure Conc	
7060111	Superstructure Conc, Form, Finish, and Cure	OR
7060112	Superstructure Conc, Form, Finish, and Cure, Night Casting	
7060113	Superstructure Conc, Night Casting	
7060111	Superstructure Conc, Form, Finish, and Cure	
7060112	Superstructure Conc, Form, Finish, and Cure, Night Casting	OR
7060116	Superstructure Conc, High Performance	
7060117	Superstructure Conc, Night Casting, High Performance	
7060020	Superstructure Conc	
7060021	Superstructure Conc, Night Casting	OR
7060022	Superstructure Conc,Form,Finish,and Cure	
7060023	Supstr Conc,Form,Fin,and Cure,Night Cast	
	Substructure Conc	
7060100	Substructure Conc	OR
7060101	Substructure Conc, High Performance	OR
	Surface Treatment	
7107010	Silane Treatment	OR
7100009	Conc Surface Coating, Warranty (Str No)	OR

7060140	Water Repellent Treatment, Penetrating	OR
7100030	Substructure Horizontal Surface Sealer	OR
	Aggregate Base	
3020001	Aggregate Base	OR
3030030	Open-Graded Dr Cse, CIP	OR
	Conc Ovly	
7120027	Conc, Silica Fume Modified	OR
7120023	Conc, Bridge Deck Ovly	OR
	HMA	
5012012	HMA, 3EL	OR
5012024	HMA, 4EL	OR
5012036	HMA, 5EL	OR
	Overlay REM	
7120021	Epoxy Ovly, Rem	OR
5010005	HMA Surface, Rem	OR
	Temp support	
7130080	Support, Column, Temp	OR
7130060	Stiffeners, Furn, Fab, and Erect	
7130081	Support, Diaphragm, Temp	
7150010	End Diaphragm, Rem & Repl	OR
7130071	Structural Steel, Retrofit, Furn, Fab, and Erect	
7130082	Support, Suspension, Temp	OR
	Riprap	
8130011	Riprap, Plain	OR
8130001	Riprap, Grouted	OR

APPENDIX D. Example Work Type Unit Costs for 2022.

Project	Work Item	Unit Cost
126916_7179	New Bridge Single or Mult. Spans, Gr. Sep.	393
212647_3844	New Bridge Single or Mult. Spans, Gr. Sep.	422
212647_3845	New Bridge Single or Mult. Spans, Gr. Sep.	381
213129_10896	New Bridge Single or Mult. Spans, Gr. Sep.	465
126916_7160	New Bridge Single Span, Over Water	483
126916_7161	New Bridge Single Span, Over Water	475
206687_9458	New Bridge Single Span, Over Water	144
126916_7162	New Bridge Multiple Spans, Over Water	502
126916_7163	New Bridge Multiple Spans, Over Water	493
201222_7913	New Bridge Multiple Spans, Over Water	225
201222_7914	New Bridge Multiple Spans, Over Water	192
201293_7616	New Bridge Multiple Spans, Over Water	368
201293_7617	New Bridge Multiple Spans, Over Water	371
206687_9459	New Bridge Multiple Spans, Over Water	394
128554_14376	Precast Culvert	319
215585_10879	New Superstructure	246
130141_3079	New Superstructure	47
130141_3079	Structure Widening, _____ ft	339
204907_3802	Structure Widening, _____ ft	579
204907_3803	Structure Widening, _____ ft	544
130131_6179	New Bridge Deck & Barrier	56
130131_6180	New Bridge Deck & Barrier	56
130174_11562	New Bridge Deck & Barrier	141
201328_117	New Bridge Deck & Barrier	127
202982_6436	New Bridge Deck & Barrier	192
204907_3802	New Bridge Deck & Barrier	77
204907_3803	New Bridge Deck & Barrier	75
205652_10893	New Bridge Deck & Barrier	109
205652_10894	New Bridge Deck & Barrier	110
127621_4413	Demo Entire Structure, Grade Separation	0.6
127621_4428	Demo Entire Structure, Grade Separation	0.6
201253_4745	Demo Entire Structure, Grade Separation	2.7
210047_4424	Demo Entire Structure, Grade Separation	0.5
210047_4425	Demo Entire Structure, Grade Separation	0.5
212647_3845	Demo Entire Structure, Grade Separation	2.7
130141_3079	Demo Entire Structure, Over Water	70
201222_7913	Demo Entire Structure, Over Water	257
201222_7914	Demo Entire Structure, Over Water	242
130131_6179	Bridge Railing Replacement	335
130131_6180	Bridge Railing Replacement	334
201255_4751	Bridge Railing Replacement	869
201964_1066	Bridge Railing Replacement	1526
204942_3805	Bridge Railing Replacement	457
212366_12831	Bridge Railing Replacement	1076
212366_7840	Bridge Railing Replacement	935
213268_13058	Bridge Railing Replacement	1345
213444_7083	Bridge Railing Replacement	2357
127477_4834	Concrete Brush Block / Curb Patch	122
127621_4409	Concrete Brush Block / Curb Patch	31
127621_4412	Concrete Brush Block / Curb Patch	38
127621_4413	Concrete Brush Block / Curb Patch	18
127621_4414	Concrete Brush Block / Curb Patch	48
127621_4415	Concrete Brush Block / Curb Patch	11
127621_4428	Concrete Brush Block / Curb Patch	10
130131_6179	Concrete Brush Block / Curb Patch	4
130131_6180	Concrete Brush Block / Curb Patch	4

130131_6181	Concrete Brush Block / Curb Patch	4
130131_6183	Concrete Brush Block / Curb Patch	5
130131_6184	Concrete Brush Block / Curb Patch	5
130131_6185	Concrete Brush Block / Curb Patch	4
130141_3079	Concrete Brush Block / Curb Patch	93
130174_11562	Concrete Brush Block / Curb Patch	21
130174_11563	Concrete Brush Block / Curb Patch	23
130174_11565	Concrete Brush Block / Curb Patch	23
130174_11566	Concrete Brush Block / Curb Patch	22
130174_11568	Concrete Brush Block / Curb Patch	20
130174_11571	Concrete Brush Block / Curb Patch	21
130174_11575	Concrete Brush Block / Curb Patch	11
130174_11577	Concrete Brush Block / Curb Patch	11
130174_11584	Concrete Brush Block / Curb Patch	15
130174_11585	Concrete Brush Block / Curb Patch	21
130176_3078	Concrete Brush Block / Curb Patch	33
132974_7181	Concrete Brush Block / Curb Patch	179
200646_11734	Concrete Brush Block / Curb Patch	62
201253_4745	Concrete Brush Block / Curb Patch	70
201255_4751	Concrete Brush Block / Curb Patch	123
201324_4805	Concrete Brush Block / Curb Patch	107
201324_4817	Concrete Brush Block / Curb Patch	86
201324_4818	Concrete Brush Block / Curb Patch	37
201328_110	Concrete Brush Block / Curb Patch	4
201328_117	Concrete Brush Block / Curb Patch	5
201328_121	Concrete Brush Block / Curb Patch	4
201957_1268	Concrete Brush Block / Curb Patch	25
201964_1066	Concrete Brush Block / Curb Patch	113
203387_1275	Concrete Brush Block / Curb Patch	66
203664_7180	Concrete Brush Block / Curb Patch	128
204371_109	Concrete Brush Block / Curb Patch	4
204778_9491	Concrete Brush Block / Curb Patch	51
204907_3802	Concrete Brush Block / Curb Patch	63
204907_3803	Concrete Brush Block / Curb Patch	63
204942_3804	Concrete Brush Block / Curb Patch	48
204942_3805	Concrete Brush Block / Curb Patch	48
204972_2618	Concrete Brush Block / Curb Patch	55
205652_10893	Concrete Brush Block / Curb Patch	167
205652_10894	Concrete Brush Block / Curb Patch	146
208041_11292	Concrete Brush Block / Curb Patch	2
208041_11619	Concrete Brush Block / Curb Patch	2
208041_11620	Concrete Brush Block / Curb Patch	2
208041_11622	Concrete Brush Block / Curb Patch	2
208041_11623	Concrete Brush Block / Curb Patch	2
208059_777	Concrete Brush Block / Curb Patch	45
208857_10895	Concrete Brush Block / Curb Patch	97
208874_1856	Concrete Brush Block / Curb Patch	47
208874_1857	Concrete Brush Block / Curb Patch	48
209015_10847	Concrete Brush Block / Curb Patch	35
209666_11837	Concrete Brush Block / Curb Patch	40
209666_11839	Concrete Brush Block / Curb Patch	29
209666_11845	Concrete Brush Block / Curb Patch	38
209666_11865	Concrete Brush Block / Curb Patch	16
209666_11866	Concrete Brush Block / Curb Patch	49
209666_11869	Concrete Brush Block / Curb Patch	62
209666_11875	Concrete Brush Block / Curb Patch	53
209666_11876	Concrete Brush Block / Curb Patch	55
210047_4424	Concrete Brush Block / Curb Patch	22
210047_4425	Concrete Brush Block / Curb Patch	18

210047_4426	Concrete Brush Block / Curb Patch	22
210047_4427	Concrete Brush Block / Curb Patch	33
210084_11279	Concrete Brush Block / Curb Patch	20
210084_11280	Concrete Brush Block / Curb Patch	97
210092_402	Concrete Brush Block / Curb Patch	169
210095_7900	Concrete Brush Block / Curb Patch	8
210095_7901	Concrete Brush Block / Curb Patch	13
210095_7902	Concrete Brush Block / Curb Patch	25
210095_7903	Concrete Brush Block / Curb Patch	57
210095_7904	Concrete Brush Block / Curb Patch	13
210095_7905	Concrete Brush Block / Curb Patch	15
210095_7906	Concrete Brush Block / Curb Patch	21
210095_7908	Concrete Brush Block / Curb Patch	17
210095_7909	Concrete Brush Block / Curb Patch	38
210095_7918	Concrete Brush Block / Curb Patch	26
210132_3102	Concrete Brush Block / Curb Patch	33
210132_3103	Concrete Brush Block / Curb Patch	38
210132_4239	Concrete Brush Block / Curb Patch	21
210132_4271	Concrete Brush Block / Curb Patch	43
210132_595	Concrete Brush Block / Curb Patch	26
210217_11533	Concrete Brush Block / Curb Patch	159
210217_11534	Concrete Brush Block / Curb Patch	33
210217_11606	Concrete Brush Block / Curb Patch	37
210217_11781	Concrete Brush Block / Curb Patch	604
210217_11782	Concrete Brush Block / Curb Patch	180
210218_6078	Concrete Brush Block / Curb Patch	76
210218_6110	Concrete Brush Block / Curb Patch	31
210218_6116	Concrete Brush Block / Curb Patch	37
210218_6145	Concrete Brush Block / Curb Patch	81
210218_6156	Concrete Brush Block / Curb Patch	33
210218_7933	Concrete Brush Block / Curb Patch	33
210221_11523	Concrete Brush Block / Curb Patch	118
210222_11190	Concrete Brush Block / Curb Patch	206
210222_11194	Concrete Brush Block / Curb Patch	228
210222_11268	Concrete Brush Block / Curb Patch	92
210222_11589	Concrete Brush Block / Curb Patch	27
210222_11822	Concrete Brush Block / Curb Patch	34
210222_11824	Concrete Brush Block / Curb Patch	47
210233_11191	Concrete Brush Block / Curb Patch	241
210233_11192	Concrete Brush Block / Curb Patch	175
210233_11195	Concrete Brush Block / Curb Patch	90
210233_11196	Concrete Brush Block / Curb Patch	64
210233_11197	Concrete Brush Block / Curb Patch	60
211554_4172	Concrete Brush Block / Curb Patch	886
211554_8465	Concrete Brush Block / Curb Patch	66
211554_8500	Concrete Brush Block / Curb Patch	63
212581_1269	Concrete Brush Block / Curb Patch	52
213059_11150	Concrete Brush Block / Curb Patch	62
213268_13058	Concrete Brush Block / Curb Patch	41
214354_5949	Concrete Brush Block / Curb Patch	121
216594_11393	Concrete Brush Block / Curb Patch	62
216594_11394	Concrete Brush Block / Curb Patch	141
127477_4834	Concrete Barrier Patch	902
127621_4409	Concrete Barrier Patch	40
127621_4412	Concrete Barrier Patch	54
127621_4413	Concrete Barrier Patch	33
127621_4414	Concrete Barrier Patch	74
127621_4415	Concrete Barrier Patch	14
127621_4428	Concrete Barrier Patch	19

130131_6179	Concrete Barrier Patch	115
130131_6180	Concrete Barrier Patch	92
130131_6181	Concrete Barrier Patch	5
130131_6183	Concrete Barrier Patch	10
130131_6184	Concrete Barrier Patch	7
130131_6185	Concrete Barrier Patch	49
130141_3079	Concrete Barrier Patch	256
130174_11562	Concrete Barrier Patch	202
130174_11563	Concrete Barrier Patch	40
130174_11565	Concrete Barrier Patch	53
130174_11566	Concrete Barrier Patch	38
130174_11568	Concrete Barrier Patch	35
130174_11571	Concrete Barrier Patch	32
130174_11575	Concrete Barrier Patch	15
130174_11577	Concrete Barrier Patch	16
130174_11584	Concrete Barrier Patch	23
130174_11585	Concrete Barrier Patch	25
130176_3078	Concrete Barrier Patch	43
132974_7181	Concrete Barrier Patch	231
200646_11734	Concrete Barrier Patch	83
201253_4745	Concrete Barrier Patch	96
201255_4751	Concrete Barrier Patch	436
201324_4805	Concrete Barrier Patch	147
201324_4817	Concrete Barrier Patch	129
201324_4818	Concrete Barrier Patch	53
201328_110	Concrete Barrier Patch	29
201328_117	Concrete Barrier Patch	94
201328_121	Concrete Barrier Patch	46
201957_1268	Concrete Barrier Patch	33
201964_1066	Concrete Barrier Patch	641
203387_1275	Concrete Barrier Patch	85
203664_7180	Concrete Barrier Patch	175
204371_109	Concrete Barrier Patch	20
204778_9491	Concrete Barrier Patch	63
204907_3802	Concrete Barrier Patch	213
204907_3803	Concrete Barrier Patch	247
204942_3804	Concrete Barrier Patch	100
204942_3805	Concrete Barrier Patch	260
204972_2618	Concrete Barrier Patch	77
205652_10893	Concrete Barrier Patch	470
205652_10894	Concrete Barrier Patch	1932
208041_11292	Concrete Barrier Patch	26
208041_11619	Concrete Barrier Patch	9
208041_11620	Concrete Barrier Patch	9
208041_11622	Concrete Barrier Patch	4
208041_11623	Concrete Barrier Patch	4
208059_777	Concrete Barrier Patch	65
208857_10895	Concrete Barrier Patch	118
208874_1856	Concrete Barrier Patch	142
208874_1857	Concrete Barrier Patch	101
209015_10847	Concrete Barrier Patch	79
209666_11837	Concrete Barrier Patch	51
209666_11839	Concrete Barrier Patch	38
209666_11845	Concrete Barrier Patch	53
209666_11865	Concrete Barrier Patch	21
209666_11866	Concrete Barrier Patch	67
209666_11869	Concrete Barrier Patch	85
209666_11875	Concrete Barrier Patch	71
209666_11876	Concrete Barrier Patch	72

210047_4424	Concrete Barrier Patch	33
210047_4425	Concrete Barrier Patch	29
210047_4426	Concrete Barrier Patch	28
210047_4427	Concrete Barrier Patch	42
210084_11279	Concrete Barrier Patch	27
210084_11280	Concrete Barrier Patch	137
210092_402	Concrete Barrier Patch	206
210095_7900	Concrete Barrier Patch	11
210095_7901	Concrete Barrier Patch	17
210095_7902	Concrete Barrier Patch	31
210095_7903	Concrete Barrier Patch	82
210095_7904	Concrete Barrier Patch	16
210095_7905	Concrete Barrier Patch	36
210095_7906	Concrete Barrier Patch	61
210095_7908	Concrete Barrier Patch	77
210095_7909	Concrete Barrier Patch	65
210095_7918	Concrete Barrier Patch	103
210132_3102	Concrete Barrier Patch	78
210132_3103	Concrete Barrier Patch	70
210132_4239	Concrete Barrier Patch	29
210132_4271	Concrete Barrier Patch	85
210132_595	Concrete Barrier Patch	36
210217_11533	Concrete Barrier Patch	207
210217_11534	Concrete Barrier Patch	42
210217_11606	Concrete Barrier Patch	45
210217_11781	Concrete Barrier Patch	763
210217_11782	Concrete Barrier Patch	240
210218_6078	Concrete Barrier Patch	95
210218_6110	Concrete Barrier Patch	43
210218_6116	Concrete Barrier Patch	49
210218_6145	Concrete Barrier Patch	101
210218_6156	Concrete Barrier Patch	55
210218_7933	Concrete Barrier Patch	45
210221_11523	Concrete Barrier Patch	155
210222_11190	Concrete Barrier Patch	302
210222_11194	Concrete Barrier Patch	381
210222_11268	Concrete Barrier Patch	116
210222_11589	Concrete Barrier Patch	34
210222_11822	Concrete Barrier Patch	42
210222_11824	Concrete Barrier Patch	95
210233_11191	Concrete Barrier Patch	314
210233_11192	Concrete Barrier Patch	220
210233_11195	Concrete Barrier Patch	112
210233_11196	Concrete Barrier Patch	187
210233_11197	Concrete Barrier Patch	115
211554_4172	Concrete Barrier Patch	1532
211554_8465	Concrete Barrier Patch	360
211554_8500	Concrete Barrier Patch	111
212581_1269	Concrete Barrier Patch	75
213059_11150	Concrete Barrier Patch	78
213268_13058	Concrete Barrier Patch	643
214354_5949	Concrete Barrier Patch	399
216594_11393	Concrete Barrier Patch	90
216594_11394	Concrete Barrier Patch	188
211554_4172	Concrete Deck Patch	11
211554_8500	Concrete Deck Patch	11
212178_4119	Concrete Deck Patch	6
212178_4120	Concrete Deck Patch	6
212178_8416	Concrete Deck Patch	6

130131_6185	Deep Overlay	380
132974_7181	Deep Overlay	278
201253_4745	Deep Overlay	339
201255_4751	Deep Overlay	354
201324_4805	Deep Overlay	136
201328_110	Deep Overlay	388
201328_121	Deep Overlay	483
203664_7180	Deep Overlay	280
204942_3804	Deep Overlay	416
204942_3805	Deep Overlay	514
208874_1856	Deep Overlay	185
208874_1857	Deep Overlay	184
211554_8465	Deep Overlay	434
130131_6179	Epoxy Overlay	38
130131_6180	Epoxy Overlay	38
130131_6183	Epoxy Overlay	38
130131_6184	Epoxy Overlay	38
201324_4818	Epoxy Overlay	57
208041_11292	Epoxy Overlay	34
209015_10847	Epoxy Overlay	42
209666_11837	Epoxy Overlay	40
209666_11845	Epoxy Overlay	40
209666_11865	Epoxy Overlay	40
209666_11869	Epoxy Overlay	40
210047_4424	Epoxy Overlay	45
210047_4426	Epoxy Overlay	45
210047_4427	Epoxy Overlay	45
210095_7903	Epoxy Overlay	34
210095_7918	Epoxy Overlay	34
210217_11606	Epoxy Overlay	44
210217_11781	Epoxy Overlay	44
210217_11782	Epoxy Overlay	44
210222_11824	Epoxy Overlay	44
211554_8500	Epoxy Overlay	53
212178_4119	Epoxy Overlay	140
212178_4120	Epoxy Overlay	140
212178_8416	Epoxy Overlay	140
127621_4409	Expansion Joint Gland Replacement	65
127621_4412	Expansion Joint Gland Replacement	65
127621_4414	Expansion Joint Gland Replacement	65
127621_4415	Expansion Joint Gland Replacement	65
127621_4428	Expansion Joint Gland Replacement	65
130131_6183	Expansion Joint Gland Replacement	24
130131_6184	Expansion Joint Gland Replacement	24
130174_11566	Expansion Joint Gland Replacement	130
130174_11584	Expansion Joint Gland Replacement	130
204371_109	Expansion Joint Gland Replacement	144
208059_777	Expansion Joint Gland Replacement	50
209666_11845	Expansion Joint Gland Replacement	150
209666_11866	Expansion Joint Gland Replacement	150
209666_11869	Expansion Joint Gland Replacement	150
210047_4426	Expansion Joint Gland Replacement	65
210047_4427	Expansion Joint Gland Replacement	65
210222_11263	Expansion Joint Gland Replacement	349
216594_11394	Expansion Joint Gland Replacement	125
130131_6179	Expansion Joint Replacement	1800
130131_6180	Expansion Joint Replacement	1791
130174_11565	Expansion Joint Replacement	1086
130174_11568	Expansion Joint Replacement	1047
130174_11571	Expansion Joint Replacement	962

204972_2618	Expansion Joint Replacement	651
208041_11619	Expansion Joint Replacement	1105
208041_11620	Expansion Joint Replacement	1105
208059_777	Expansion Joint Replacement	1771
209015_10847	Expansion Joint Replacement	692
210095_7918	Expansion Joint Replacement	987
210132_3102	Expansion Joint Replacement	1597
210132_3103	Expansion Joint Replacement	1608
210218_6156	Expansion Joint Replacement	903
210221_11663	Expansion Joint Replacement	639
210222_11194	Expansion Joint Replacement	325
210222_11824	Expansion Joint Replacement	301
210233_11191	Expansion Joint Replacement	284
210233_11196	Expansion Joint Replacement	273
210233_11197	Expansion Joint Replacement	311
211554_4172	Expansion Joint Replacement	702
211554_8500	Expansion Joint Replacement	899
212534_4849	Expansion Joint Replacement	921
213268_13058	Expansion Joint Replacement	891
213444_7083	Expansion Joint Replacement	800
214354_5949	Expansion Joint Replacement	1439
216599_586	Expansion Joint Replacement	1221
127621_4413	Full Depth Patch	85
127621_4414	Full Depth Patch	24
130131_6179	Full Depth Patch	69
130174_11565	Full Depth Patch	49
130174_11566	Full Depth Patch	44
130174_11568	Full Depth Patch	122
130174_11571	Full Depth Patch	43
130174_11585	Full Depth Patch	54
201957_1268	Full Depth Patch	334
208041_11292	Full Depth Patch	106
209015_10847	Full Depth Patch	67
209666_11837	Full Depth Patch	73
209666_11845	Full Depth Patch	202
210084_11280	Full Depth Patch	83
210095_7903	Full Depth Patch	30
210095_7905	Full Depth Patch	49
210095_7908	Full Depth Patch	31
210095_7909	Full Depth Patch	27
210217_11533	Full Depth Patch	44
210217_11534	Full Depth Patch	41
210218_6077	Full Depth Patch	77
210218_6078	Full Depth Patch	53
210218_6156	Full Depth Patch	299
210222_11190	Full Depth Patch	44
210222_11194	Full Depth Patch	41
216594_11393	Full Depth Patch	47
216594_11394	Full Depth Patch	26
208041_11622	Healer / Sealer	9
208041_11623	Healer / Sealer	9
209666_11839	Healer / Sealer	16
210095_7900	Healer / Sealer	11
210095_7901	Healer / Sealer	11
210222_11190	Healer / Sealer	11
210222_11822	Healer / Sealer	11
210233_11192	Healer / Sealer	11
210233_11196	Healer / Sealer	11
210233_11197	Healer / Sealer	11

211037_11309	Healer / Sealer	13
211037_11310	Healer / Sealer	13
212534_4849	Healer / Sealer	27
127621_4415	HMA Overlay with WP membrane	12
210047_4426	HMA Overlay with WP membrane	12
210047_4427	HMA Overlay with WP membrane	12
130131_6185	Overlay Removal	6
201255_4751	Overlay Removal	10
204942_3804	Overlay Removal	10
204942_3805	Overlay Removal	10
208874_1856	Overlay Removal	10
208874_1857	Overlay Removal	10
211554_8465	Overlay Removal	17
127621_4409	Reseal Bridge Joints	23
127621_4412	Reseal Bridge Joints	23
127621_4413	Reseal Bridge Joints	23
127621_4414	Reseal Bridge Joints	23
127621_4415	Reseal Bridge Joints	23
127621_4428	Reseal Bridge Joints	23
128561_12454	Reseal Bridge Joints	140
128561_12481	Reseal Bridge Joints	140
130131_6183	Reseal Bridge Joints	10
130131_6184	Reseal Bridge Joints	10
130131_6185	Reseal Bridge Joints	10
200121_12392	Reseal Bridge Joints	26
202982_6436	Reseal Bridge Joints	136
204371_109	Reseal Bridge Joints	28
208041_11292	Reseal Bridge Joints	15
208041_11619	Reseal Bridge Joints	15
208041_11620	Reseal Bridge Joints	15
208041_11622	Reseal Bridge Joints	15
208041_11623	Reseal Bridge Joints	15
208857_10895	Reseal Bridge Joints	39
209015_10847	Reseal Bridge Joints	16
209666_11837	Reseal Bridge Joints	15
209666_11839	Reseal Bridge Joints	15
209666_11865	Reseal Bridge Joints	15
209666_11866	Reseal Bridge Joints	15
209666_11869	Reseal Bridge Joints	15
210047_4424	Reseal Bridge Joints	23
210047_4425	Reseal Bridge Joints	23
210047_4426	Reseal Bridge Joints	23
210047_4427	Reseal Bridge Joints	23
210084_11279	Reseal Bridge Joints	30
210084_11280	Reseal Bridge Joints	30
210095_7900	Reseal Bridge Joints	17
210095_7901	Reseal Bridge Joints	17
210095_7902	Reseal Bridge Joints	17
210095_7903	Reseal Bridge Joints	17
210095_7904	Reseal Bridge Joints	17
210095_7908	Reseal Bridge Joints	17
210218_6077	Reseal Bridge Joints	40
210222_11190	Reseal Bridge Joints	30
210222_11194	Reseal Bridge Joints	30
210222_11251	Reseal Bridge Joints	30
210222_11268	Reseal Bridge Joints	30
210222_11824	Reseal Bridge Joints	30
210233_11192	Reseal Bridge Joints	30
211037_11309	Reseal Bridge Joints	17

211037_11310	Reseal Bridge Joints	17
211554_4172	Reseal Bridge Joints	145
213268_13058	Reseal Bridge Joints	15
214354_5949	Reseal Bridge Joints	27
216594_11394	Reseal Bridge Joints	41
212366_12831	Shallow Overlay	131
212366_7840	Shallow Overlay	151
209015_10847	Bearing Realignment / Replacement	28276
209666_11839	Bearing Realignment / Replacement	6820
210095_7900	Bearing Realignment / Replacement	1864
210095_7909	Bearing Realignment / Replacement	1995
210222_11186	Bearing Realignment / Replacement	7485
210233_11196	Bearing Realignment / Replacement	7235
212534_4836	Bearing Realignment / Replacement	3743
209345_10913	Heat Straightening	149697
213205_2507	Heat Straightening	62579
213444_7083	Heat Straightening	149710
201253_4745	Pack Rust Repair	108
203387_1275	Pack Rust Repair	401
130131_6179	Paint - Complete	33
130131_6180	Paint - Complete	31
130174_11562	Paint - Complete	0
132974_7181	Paint - Complete	10
202982_6436	Paint - Complete	51
203387_1275	Paint - Complete	1
203664_7180	Paint - Complete	9
209666_11837	Paint - Complete	76
209666_11866	Paint - Complete	34
210095_7908	Paint - Complete	0
210095_7909	Paint - Complete	32
200646_11734	Paint - Partial / Spot / Zone	9
201253_4745	Paint - Partial / Spot / Zone	32
201255_4751	Paint - Partial / Spot / Zone	20
201324_4817	Paint - Partial / Spot / Zone	104
201328_117	Paint - Partial / Spot / Zone	12
201328_121	Paint - Partial / Spot / Zone	24
204907_3803	Paint - Partial / Spot / Zone	0
205652_10893	Paint - Partial / Spot / Zone	38
205652_10894	Paint - Partial / Spot / Zone	37
208041_11292	Paint - Partial / Spot / Zone	24
209015_10847	Paint - Partial / Spot / Zone	26
209666_11839	Paint - Partial / Spot / Zone	35
209666_11845	Paint - Partial / Spot / Zone	15
209666_11865	Paint - Partial / Spot / Zone	51
210095_7918	Paint - Partial / Spot / Zone	0
210217_11533	Paint - Partial / Spot / Zone	36
210217_11534	Paint - Partial / Spot / Zone	40
210217_11781	Paint - Partial / Spot / Zone	10
210217_11782	Paint - Partial / Spot / Zone	31
210218_6145	Paint - Partial / Spot / Zone	38
212667_4237	Paint - Partial / Spot / Zone	26
212667_4238	Paint - Partial / Spot / Zone	30
213205_2507	Paint - Partial / Spot / Zone	2
214354_5949	Paint - Partial / Spot / Zone	90
216851_2483	Paint - Partial / Spot / Zone	9
201255_4751	PCI Beam End Blockout	26209
201324_4805	PCI Beam End Blockout	20451
201324_4818	PCI Beam End Blockout	16568
201328_110	PCI Beam End Blockout	3122

201328_121	PCI Beam End Blockout	2480
202982_6436	PCI Beam End Blockout	201770
208874_1857	PCI Beam End Blockout	14782
210132_4271	PCI Beam End Blockout	3673
201328_121	Pin & Hanger Replacement	7970
209015_10847	Pin & Hanger Replacement	10428
213205_2507	Pin & Hanger Replacement	8246
127621_4409	Structural Steel Repair	3079
127621_4413	Structural Steel Repair	3079
127621_4414	Structural Steel Repair	3079
127621_4415	Structural Steel Repair	3079
130174_11562	Structural Steel Repair	6174
130174_11568	Structural Steel Repair	6174
130174_11584	Structural Steel Repair	6174
201253_4745	Structural Steel Repair	5087
201255_4751	Structural Steel Repair	4105
201324_4817	Structural Steel Repair	6414
201328_110	Structural Steel Repair	20992
203387_1275	Structural Steel Repair	6051
204907_3802	Structural Steel Repair	1162
204907_3803	Structural Steel Repair	1447
205652_10893	Structural Steel Repair	8847
205652_10894	Structural Steel Repair	8847
208041_11292	Structural Steel Repair	2212
209015_10847	Structural Steel Repair	7183
209345_10913	Structural Steel Repair	11543
210095_7900	Structural Steel Repair	11059
210095_7905	Structural Steel Repair	11059
210095_7906	Structural Steel Repair	11059
210095_7908	Structural Steel Repair	11059
210095_7909	Structural Steel Repair	11059
210095_7918	Structural Steel Repair	11059
210132_3102	Structural Steel Repair	9013
210132_3103	Structural Steel Repair	9013
210132_4239	Structural Steel Repair	9013
210132_4271	Structural Steel Repair	9013
210132_6913	Structural Steel Repair	9013
210217_11533	Structural Steel Repair	16674
210217_11534	Structural Steel Repair	16674
210217_11781	Structural Steel Repair	16674
210218_6078	Structural Steel Repair	7741
210218_6145	Structural Steel Repair	9208
210222_11186	Structural Steel Repair	16674
210222_11251	Structural Steel Repair	15820
210222_11255	Structural Steel Repair	16674
210222_11263	Structural Steel Repair	12617
210233_11197	Structural Steel Repair	10780
212667_4237	Structural Steel Repair	3990
212667_4238	Structural Steel Repair	4005
213205_2507	Structural Steel Repair	14890
213444_7083	Structural Steel Repair	4618
214748_11173	Structural Steel Repair	7696
216851_2483	Structural Steel Repair	5408
200646_11734	Structural Steel Repair - Stiffener	1753
204907_3802	Structural Steel Repair - Stiffener	1125
204907_3803	Structural Steel Repair - Stiffener	1125
208059_777	Structural Steel Repair - Stiffener	3519
209015_10847	Structural Steel Repair - Stiffener	2454
209666_11839	Structural Steel Repair - Stiffener	1169

209666_11845	Structural Steel Repair - Stiffener	1169
209666_11866	Structural Steel Repair - Stiffener	1169
209666_11875	Structural Steel Repair - Stiffener	1169
209666_11876	Structural Steel Repair - Stiffener	1169
210095_7900	Structural Steel Repair - Stiffener	2015
210095_7904	Structural Steel Repair - Stiffener	2015
210095_7905	Structural Steel Repair - Stiffener	2015
210095_7906	Structural Steel Repair - Stiffener	2015
210095_7909	Structural Steel Repair - Stiffener	2015
210095_7918	Structural Steel Repair - Stiffener	2015
210218_6078	Structural Steel Repair - Stiffener	1511
210222_11186	Structural Steel Repair - Stiffener	701
210222_11190	Structural Steel Repair - Stiffener	876
210222_11194	Structural Steel Repair - Stiffener	728
210222_11251	Structural Steel Repair - Stiffener	876
210222_11255	Structural Steel Repair - Stiffener	770
210222_11589	Structural Steel Repair - Stiffener	834
210222_11822	Structural Steel Repair - Stiffener	876
210222_11824	Structural Steel Repair - Stiffener	876
210233_11191	Structural Steel Repair - Stiffener	852
210233_11196	Structural Steel Repair - Stiffener	750
210233_11197	Structural Steel Repair - Stiffener	831
212534_4836	Structural Steel Repair - Stiffener	2337
213205_2507	Structural Steel Repair - Stiffener	5843
214354_5949	Structural Steel Repair - Stiffener	1688
127477_4834	Substructure Patching	73046
127621_4409	Substructure Patching	3277
127621_4412	Substructure Patching	4365
127621_4413	Substructure Patching	2644
127621_4414	Substructure Patching	6033
127621_4415	Substructure Patching	1130
127621_4428	Substructure Patching	1526
130131_6179	Substructure Patching	9306
130131_6180	Substructure Patching	7423
130131_6181	Substructure Patching	366
130131_6183	Substructure Patching	845
130131_6184	Substructure Patching	561
130131_6185	Substructure Patching	3937
130141_3079	Substructure Patching	20768
130174_11562	Substructure Patching	16338
130174_11563	Substructure Patching	3244
130174_11565	Substructure Patching	4332
130174_11566	Substructure Patching	3045
130174_11568	Substructure Patching	2866
130174_11571	Substructure Patching	2561
130174_11575	Substructure Patching	1245
130174_11577	Substructure Patching	1327
130174_11584	Substructure Patching	1874
130174_11585	Substructure Patching	2056
130176_3078	Substructure Patching	3480
132974_7181	Substructure Patching	18734
200646_11734	Substructure Patching	6718
201253_4745	Substructure Patching	7778
201255_4751	Substructure Patching	35283
201324_4805	Substructure Patching	11884
201324_4817	Substructure Patching	10473
201324_4818	Substructure Patching	4315
201328_110	Substructure Patching	2371
201328_117	Substructure Patching	7622

201328_121	Substructure Patching	3707
201957_1268	Substructure Patching	2710
201964_1066	Substructure Patching	51959
203387_1275	Substructure Patching	6871
203664_7180	Substructure Patching	14136
204371_109	Substructure Patching	1647
204778_9491	Substructure Patching	5097
204907_3802	Substructure Patching	17225
204907_3803	Substructure Patching	20038
204942_3804	Substructure Patching	8067
204942_3805	Substructure Patching	21040
204972_2618	Substructure Patching	6258
205652_10893	Substructure Patching	38095
205652_10894	Substructure Patching	156503
208041_11292	Substructure Patching	2101
208041_11619	Substructure Patching	736
208041_11620	Substructure Patching	736
208041_11622	Substructure Patching	314
208041_11623	Substructure Patching	314
208059_777	Substructure Patching	5225
208857_10895	Substructure Patching	9540
208874_1856	Substructure Patching	11505
208874_1857	Substructure Patching	8152
209015_10847	Substructure Patching	6428
209666_11837	Substructure Patching	4170
209666_11839	Substructure Patching	3117
209666_11845	Substructure Patching	4285
209666_11865	Substructure Patching	1682
209666_11866	Substructure Patching	5448
209666_11869	Substructure Patching	6867
209666_11875	Substructure Patching	5749
209666_11876	Substructure Patching	5870
210047_4424	Substructure Patching	2642
210047_4425	Substructure Patching	2334
210047_4426	Substructure Patching	2241
210047_4427	Substructure Patching	3380
210084_11279	Substructure Patching	2163
210084_11280	Substructure Patching	11079
210092_402	Substructure Patching	16650
210095_7900	Substructure Patching	865
210095_7901	Substructure Patching	1338
210095_7902	Substructure Patching	2512
210095_7903	Substructure Patching	6635
210095_7904	Substructure Patching	1308
210095_7905	Substructure Patching	2890
210095_7906	Substructure Patching	4933
210095_7908	Substructure Patching	6257
210095_7909	Substructure Patching	5251
210095_7918	Substructure Patching	8323
210132_3102	Substructure Patching	6337
210132_3103	Substructure Patching	5701
210132_4239	Substructure Patching	2379
210132_4271	Substructure Patching	6902
210132_595	Substructure Patching	2880
210217_11533	Substructure Patching	16791
210217_11534	Substructure Patching	3429
210217_11606	Substructure Patching	3628
210217_11781	Substructure Patching	61767
210217_11782	Substructure Patching	19461

210218_6078	Substructure Patching	7680
210218_6110	Substructure Patching	3451
210218_6116	Substructure Patching	3980
210218_6145	Substructure Patching	8148
210218_6156	Substructure Patching	4466
210218_7933	Substructure Patching	3661
210221_11523	Substructure Patching	12587
210222_11190	Substructure Patching	24452
210222_11194	Substructure Patching	30866
210222_11268	Substructure Patching	9387
210222_11589	Substructure Patching	2734
210222_11822	Substructure Patching	3407
210222_11824	Substructure Patching	7669
210233_11191	Substructure Patching	25399
210233_11192	Substructure Patching	17848
210233_11195	Substructure Patching	9060
210233_11196	Substructure Patching	15166
210233_11197	Substructure Patching	9328
211554_4172	Substructure Patching	89237
211554_8465	Substructure Patching	9955
211554_8500	Substructure Patching	6505
212581_1269	Substructure Patching	6043
213059_11150	Substructure Patching	6352
213268_13058	Substructure Patching	52121
214354_5949	Substructure Patching	23211
216594_11393	Substructure Patching	7317
216594_11394	Substructure Patching	15214
214354_5949	Substructure Replacement	10681
130131_6179	Substructure Horizontal Surface Sealer	72
130131_6180	Substructure Horizontal Surface Sealer	72
130131_6183	Substructure Horizontal Surface Sealer	96
130131_6184	Substructure Horizontal Surface Sealer	96
130131_6185	Substructure Horizontal Surface Sealer	120
130174_11562	Substructure Horizontal Surface Sealer	86
130174_11563	Substructure Horizontal Surface Sealer	86
130174_11565	Substructure Horizontal Surface Sealer	86
130176_3078	Substructure Horizontal Surface Sealer	65
200646_11734	Substructure Horizontal Surface Sealer	45
201253_4745	Substructure Horizontal Surface Sealer	52
201255_4751	Substructure Horizontal Surface Sealer	20
201324_4805	Substructure Horizontal Surface Sealer	63
201324_4817	Substructure Horizontal Surface Sealer	63
201324_4818	Substructure Horizontal Surface Sealer	63
201328_110	Substructure Horizontal Surface Sealer	86
201328_117	Substructure Horizontal Surface Sealer	86
201328_121	Substructure Horizontal Surface Sealer	86
202982_6436	Substructure Horizontal Surface Sealer	38
204907_3802	Substructure Horizontal Surface Sealer	26
204907_3803	Substructure Horizontal Surface Sealer	26
204942_3804	Substructure Horizontal Surface Sealer	26
204942_3805	Substructure Horizontal Surface Sealer	26
204972_2618	Substructure Horizontal Surface Sealer	82
208874_1856	Substructure Horizontal Surface Sealer	61
208874_1857	Substructure Horizontal Surface Sealer	61
209015_10847	Substructure Horizontal Surface Sealer	65
209666_11837	Substructure Horizontal Surface Sealer	65
209666_11845	Substructure Horizontal Surface Sealer	65
209666_11866	Substructure Horizontal Surface Sealer	65
209666_11869	Substructure Horizontal Surface Sealer	50

209666_11875	Substructure Horizontal Surface Sealer	50
209666_11876	Substructure Horizontal Surface Sealer	50
210095_7901	Substructure Horizontal Surface Sealer	30
210095_7902	Substructure Horizontal Surface Sealer	30
210095_7903	Substructure Horizontal Surface Sealer	30
210095_7904	Substructure Horizontal Surface Sealer	30
210095_7905	Substructure Horizontal Surface Sealer	30
210095_7906	Substructure Horizontal Surface Sealer	30
210095_7908	Substructure Horizontal Surface Sealer	30
210132_4271	Substructure Horizontal Surface Sealer	54
210218_6077	Substructure Horizontal Surface Sealer	77
210218_6078	Substructure Horizontal Surface Sealer	77
210218_6110	Substructure Horizontal Surface Sealer	77
210218_6116	Substructure Horizontal Surface Sealer	77
210218_6145	Substructure Horizontal Surface Sealer	77
210218_6156	Substructure Horizontal Surface Sealer	77
210218_7933	Substructure Horizontal Surface Sealer	77
210221_11663	Substructure Horizontal Surface Sealer	76
210222_11190	Substructure Horizontal Surface Sealer	54
210222_11194	Substructure Horizontal Surface Sealer	54
210222_11824	Substructure Horizontal Surface Sealer	54
210233_11191	Substructure Horizontal Surface Sealer	54
210233_11196	Substructure Horizontal Surface Sealer	54
210233_11197	Substructure Horizontal Surface Sealer	54
212647_3844	Substructure Horizontal Surface Sealer	65
212647_3845	Substructure Horizontal Surface Sealer	65
213268_13058	Substructure Horizontal Surface Sealer	80
213444_7083	Substructure Horizontal Surface Sealer	394
214354_5949	Substructure Horizontal Surface Sealer	43
204907_3802	Temporary Supports	10132
204907_3803	Temporary Supports	9713
208059_777	Temporary Supports	6686
209015_10847	Temporary Supports	4117
209666_11839	Temporary Supports	7342
209666_11845	Temporary Supports	6669
209666_11866	Temporary Supports	7805
209666_11875	Temporary Supports	9524
209666_11876	Temporary Supports	9576
210095_7900	Temporary Supports	2122
210095_7904	Temporary Supports	946
210095_7905	Temporary Supports	12139
210095_7906	Temporary Supports	12322
210095_7909	Temporary Supports	3043
210095_7918	Temporary Supports	5077
210218_6078	Temporary Supports	17269
210222_11186	Temporary Supports	10142
210222_11190	Temporary Supports	6120
210222_11194	Temporary Supports	14211
210222_11251	Temporary Supports	17208
210222_11255	Temporary Supports	19813
210222_11589	Temporary Supports	6257
210222_11822	Temporary Supports	5700
210222_11824	Temporary Supports	6227
210233_11191	Temporary Supports	6191
210233_11196	Temporary Supports	6608
210233_11197	Temporary Supports	10715
212534_4836	Temporary Supports	2120
213205_2507	Temporary Supports	36685
214354_5949	Temporary Supports	8119

130131_6181	Articulating Concrete Block System (ACB)	432
131589_13002	Articulating Concrete Block System (ACB)	9
206687_9458	Articulating Concrete Block System (ACB)	11
210045_5744	Articulating Concrete Block System (ACB)	11
210132_4225	Articulating Concrete Block System (ACB)	651
210132_4226	Articulating Concrete Block System (ACB)	651
208041_11292	Concrete Surface Coating	9
208041_11622	Concrete Surface Coating	9
208041_11623	Concrete Surface Coating	9
213268_13058	Concrete Surface Coating	32
213444_7083	Concrete Surface Coating	40
214294_4968	Concrete Surface Coating	100
130131_6179	Epoxy Crack Injection	34
130131_6180	Epoxy Crack Injection	34
130131_6181	Epoxy Crack Injection	34
130174_11563	Epoxy Crack Injection	41
130174_11575	Epoxy Crack Injection	41
130174_11584	Epoxy Crack Injection	41
130176_3078	Epoxy Crack Injection	38
200121_12392	Epoxy Crack Injection	67
200646_11734	Epoxy Crack Injection	56
201324_4818	Epoxy Crack Injection	38
204371_109	Epoxy Crack Injection	40
204907_3802	Epoxy Crack Injection	44
204907_3803	Epoxy Crack Injection	44
204942_3804	Epoxy Crack Injection	44
204942_3805	Epoxy Crack Injection	44
204972_2618	Epoxy Crack Injection	59
208041_11622	Epoxy Crack Injection	29
208041_11623	Epoxy Crack Injection	29
208874_1856	Epoxy Crack Injection	56
208874_1857	Epoxy Crack Injection	56
209666_11845	Epoxy Crack Injection	135
209666_11875	Epoxy Crack Injection	135
209666_11876	Epoxy Crack Injection	843
210084_11279	Epoxy Crack Injection	34
210084_11280	Epoxy Crack Injection	34
210095_7904	Epoxy Crack Injection	133
210218_6145	Epoxy Crack Injection	99
214294_4968	Epoxy Crack Injection	180
214302_4838	Epoxy Crack Injection	180
216832_4258	Epoxy Crack Injection	72
127621_4412	Metal Mesh Panels	42
127621_4413	Metal Mesh Panels	42
127621_4414	Metal Mesh Panels	42
127621_4415	Metal Mesh Panels	42
127621_4428	Metal Mesh Panels	42
130174_11566	Metal Mesh Panels	22
201324_4805	Metal Mesh Panels	5
201328_121	Metal Mesh Panels	28
208874_1856	Metal Mesh Panels	16
208874_1857	Metal Mesh Panels	16
209666_11845	Metal Mesh Panels	39
210047_4424	Metal Mesh Panels	42
210047_4425	Metal Mesh Panels	42
210047_4426	Metal Mesh Panels	42
210047_4427	Metal Mesh Panels	42
210095_7903	Metal Mesh Panels	22
210095_7905	Metal Mesh Panels	22
210095_7906	Metal Mesh Panels	22

210095_7908	Metal Mesh Panels	22
210095_7909	Metal Mesh Panels	22
210132_6913	Metal Mesh Panels	30
210217_11533	Metal Mesh Panels	55
210217_11534	Metal Mesh Panels	55
210218_6077	Metal Mesh Panels	24
208059_777	Pressure Relief Joint	200
210132_1691	Pressure Relief Joint	150
210132_3102	Pressure Relief Joint	150
210132_3103	Pressure Relief Joint	150
210218_6156	Pressure Relief Joint	95
212534_4836	Pressure Relief Joint	150
126916_7160	Riprap	99
126916_7161	Riprap	99
201293_7616	Riprap	238
201293_7617	Riprap	238
209464_11636	Riprap	247
210045_5744	Riprap	190
210132_2493	Riprap	310
210132_3102	Riprap	335
210132_3103	Riprap	335
210132_4225	Riprap	310
210132_4226	Riprap	310
210132_595	Riprap	310
210222_11186	Riprap	247
210222_11190	Riprap	247
210222_11194	Riprap	247
210222_11268	Riprap	247
210222_11822	Riprap	247
210222_11824	Riprap	247
210233_11196	Riprap	247
210233_11197	Riprap	247
214294_4968	Riprap	370
126916_7160	Silane Treatment	2
126916_7161	Silane Treatment	2
126916_7162	Silane Treatment	2
126916_7163	Silane Treatment	2
127621_4409	Silane Treatment	3
127621_4412	Silane Treatment	3
127621_4413	Silane Treatment	3
127621_4414	Silane Treatment	3
127621_4415	Silane Treatment	3
127621_4428	Silane Treatment	3
130131_6179	Silane Treatment	2
130131_6180	Silane Treatment	2
130131_6183	Silane Treatment	2
130131_6184	Silane Treatment	2
130131_6185	Silane Treatment	2
130174_11575	Silane Treatment	3
130174_11577	Silane Treatment	3
130174_11584	Silane Treatment	3
130174_11585	Silane Treatment	3
131589_13002	Silane Treatment	3
132974_7181	Silane Treatment	2
200121_12392	Silane Treatment	11
201293_7616	Silane Treatment	6
201293_7617	Silane Treatment	6
201328_110	Silane Treatment	2
201328_117	Silane Treatment	2

201328_121	Silane Treatment	2
203664_7180	Silane Treatment	2
208041_11619	Silane Treatment	2
208041_11620	Silane Treatment	2
208041_11622	Silane Treatment	2
208041_11623	Silane Treatment	2
208857_10895	Silane Treatment	4
208874_1856	Silane Treatment	2
208874_1857	Silane Treatment	2
209015_10847	Silane Treatment	3
209666_11839	Silane Treatment	3
209666_11845	Silane Treatment	3
209666_11865	Silane Treatment	3
209666_11866	Silane Treatment	3
209666_11869	Silane Treatment	3
210047_4424	Silane Treatment	3
210047_4425	Silane Treatment	3
210047_4426	Silane Treatment	3
210047_4427	Silane Treatment	3
210084_11279	Silane Treatment	9
210084_11280	Silane Treatment	9
210095_7900	Silane Treatment	3
210095_7901	Silane Treatment	3
210095_7902	Silane Treatment	3
210095_7903	Silane Treatment	3
210095_7904	Silane Treatment	3
210095_7918	Silane Treatment	3
211037_11309	Silane Treatment	2
211037_11310	Silane Treatment	2
212178_4119	Silane Treatment	5
212178_4120	Silane Treatment	5
212178_8416	Silane Treatment	5
212366_12831	Silane Treatment	3
212366_7840	Silane Treatment	3
212647_3844	Silane Treatment	8
212647_3845	Silane Treatment	8
213444_7083	Silane Treatment	12
214312_11394	Silane Treatment	13
216594_11394	Silane Treatment	12
127621_4412	Slope Protection Repairs	299
127621_4413	Slope Protection Repairs	299
127621_4415	Slope Protection Repairs	299
130131_6184	Slope Protection Repairs	96
132974_7181	Slope Protection Repairs	200
201328_110	Slope Protection Repairs	144
201328_117	Slope Protection Repairs	144
203664_7180	Slope Protection Repairs	200
205652_10893	Slope Protection Repairs	172
205652_10894	Slope Protection Repairs	172
208041_11292	Slope Protection Repairs	43
208041_11619	Slope Protection Repairs	43
208041_11620	Slope Protection Repairs	43
208857_10895	Slope Protection Repairs	172
209015_10847	Slope Protection Repairs	200
209666_11839	Slope Protection Repairs	200
210092_399	Slope Protection Repairs	387
212178_8416	Slope Protection Repairs	200
215585_10879	New Superstructure, Grade Separation	246
130141_3079	New Superstructure, Over Water	47