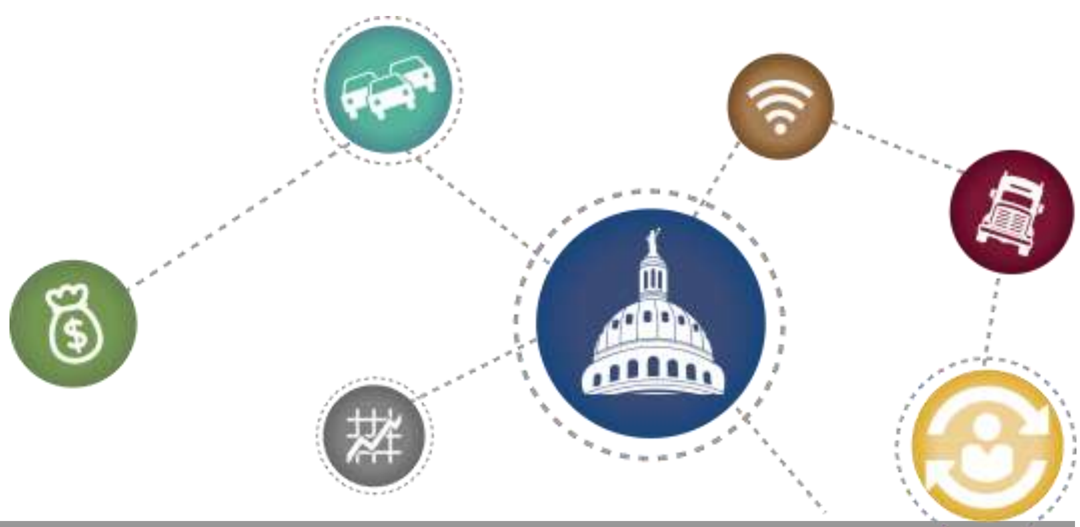
Texas A&M Transportation Institute

Highway Cost Index Estimator Tool

Final report

PRC 17-73



TRANSPORTATION
Policy Research CENTER

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Highway Cost Index Estimator Tool

To plan and program highway construction projects, the Texas Department of Transportation requires accurate construction cost data. However, due to the number of, and uncertainty of, variables that affect highway construction costs, estimating future funding needs can be an exceedingly difficult task. This research project sought to improve future forecasting projections through the creation of a Highway Cost Index Estimator Tool. Key points from the study include:

- TxDOT maintains the Texas Highway Costs Index (HCI) to monitor price changes in 34 items that are highly correlated to the highway construction industry.
- Currently, there are no models that attempt to forecast the Texas HCI, the changes in which indicate that TxDOT's purchasing power has declined substantially since 1997.
- While revenue forecasting has been established, there remains a need to identify purchasing power of that revenue to accurately estimate project costs.
- The HCI, first calculated in 1998, tracks the price and quantity of 34 highway construction items (cement, steel, etc.) and is represented in one-month, three-month, and 12-month moving averages. The moving averages reduce the effects of seasonality in contract letting to indicate a clearer trend.
- Researchers developed the Highway Cost Index Estimator tool to allow users to account for world events and changing markets.
- The tool allows users to input prices of selected construction items to generate an estimated HCI, and also to run what-if scenarios to produce a range of possible outcomes. Estimations generated by the model fall within an acceptable margin of error or less than 10 percent.
- Policymakers can use this tool to create their own cost projections and estimate the purchasing power of dollars dedicated for highway-related expenditures by adjusting the costs per unit of different control items in different market scenarios. Policymakers can also approximate changes in the purchasing power of revenue slated for highway construction or maintenance, allowing for better planning and allocation of future revenues.

Table of Contents

List of Figures

List of Tables

Executive Summary

Each year, the Texas Transportation Commission and the Texas Department of Transportation (TxDOT) actively plan and program transportation projects through planning documents such as the Unified Transportation Plan (UTP) and Statewide Transportation Improvement Program (STIP). Development of these plans begins by examining the current and future revenues available to be spent on construction and maintenance. The dedicated and available funding sets the parameters that determine the number of and size of projects that can be performed.

To effectively plan and program highway construction projects, accurate construction cost data is required. However, due to the number of, and uncertainty of, variables that affect highway construction costs, estimating future funding needs can be an exceedingly difficult task. Inflation of highway construction costs does not directly correlate with inflation of the overall economy. For this reason, TxDOT maintains the Texas Highway Costs Index (HCI) to monitor price changes in 34 items that are highly correlated to the highway construction industry. The HCI indexes the value of current and historic construction and maintenance dollars.

Currently, there are no models that attempt to forecast the Texas HCI. The changes in the HCI since the 1997 base year indicate that there has been a large decline in TxDOT's purchasing power from year to year.[1] However, there is not an established mechanism to determine how the trend will change over time, or how it will react to price changes of construction equipment, materials, or labor over time. While revenue forecasting has been established, there remains a need to identify purchasing power of that revenue to accurately estimate project costs. The purchasing power of future dollars can be determined by estimating the average annual inflation rate of the HCI and forecasting the rate forward as a linear trend. While this method offers an estimated value of construction dollars, it does not take into account possible world events and changing markets, such as energy or oil, which may cause the cost of construction items to deviate from the historic pricing trend.

Researchers developed the Highway Cost Index Estimator tool to allow users to account for these possible events and changing markets. This transparency in the underlying assumptions allows policymakers to create their own cost projections and estimate the purchasing power of dollars dedicated for highway-related expenditures by adjusting the costs per unit of different control items in different market scenarios.

To allow for both flexibility and ease-of-use to policymakers, researchers used the Least Absolute Selection and Shrinkage Operator (Lasso) machine learning approach to eliminate variables in the calculation that had the smallest impact on the final index. Lasso is used in instances where there are many variables, but only a small set of those variables is important for forecasting the outcome.

[1] At the time of publication, researchers were informed that TxDOT has made some adjustments to the current highway cost index base 1997 that are not included in this report. Additionally, TxDOT will be posting a new HCI with a base year of 2012 in the near future.

The resulting estimation returned six control items (independent variables) out of the 34 original control items that had the highest impact on the final index:

- Roadway embankment.
- Cement.
- Surface treatment aggregate.
- Hot mix asphaltic concrete.
- Bridge rail.
- Bridge slab.

Once the control items were selected, their cost values were placed into the equation developed from the Lasso regression analysis. From the results, researchers conclude that the estimation generated by the Lasso model falls within an acceptable margin of error (MOE) of less than 10 percent. The tool that was created from the Lasso analysis allows the user to input the unit price of the selected control items to generate an estimated HCI.

Introduction

The purpose of this tool is to analyze existing construction item cost information provided by TxDOT to estimate a future HCI. The resulting model will allow for the adjustment of funding forecasts to possible future purchasing power, which in turn, will bolster revenue forecasting. To meet these goals, researchers completed the following objectives:

- Examine existing cost indices and how they are used in the highway construction industry.
- Identify and collect data used in creation of the Texas HCI.
- Build an understanding of how the HCI is calculated through the input variables.
- Collect and examine existing literature on existing models that attempt to forecast other highway construction indices.
- Create a methodology for using existing data to predict future HCI.
- Create a tool that allows users to adjust inputs based on industry knowledge.
- Incorporate limits for risk analysis.

The tool will allow users to estimate a future HCI number based on their knowledge of trends in the current market. It also allows the user to run what-if scenarios that can result in a range of possible outcomes. Using the estimated HCI, policy makers can approximate changes in the purchasing power of revenue slated for highway construction or maintenance. Additionally, changes to project costs can be taken into consideration. Knowing how much construction a dollar will buy under the estimated scenario could allow for better planning and allocation of future infrastructure revenues.

Existing Cost Indices

Several historic price trends of common construction items have been developed at the national level. These include:

- Federal Highway Administration (FHWA) National Highway Construction Cost Index (NHCCI) (will replace FHWA's Bid Price Index [BPI]).
- Federal Highway Administration (FHWA) Maintenance and Operation Cost Trend Index.
- Engineering News Record (ENR) Construction Cost Index.
- Engineering News Record (ENR) Building Cost Index.

In addition to the national cost indices for highway construction, there are also several indices at the state and local level. The following states have produced a highway construction cost index or similar metric for examining cost comparisons or price trends.

- California.
- Colorado.
- Florida.
- Iowa.
- Louisiana.
- Maryland.
- Minnesota.
- New Hampshire.
- Ohio.
- Oregon.
- South Dakota.
- Texas.
- Utah.
- Washington.

Each state uses a unique variable composition and calculation methodology. However, only two of these states appear to predict future highway construction costs. The Colorado Department of Transportation (CDOT) attempts to estimate the Colorado Construction Cost Index through the examination of economic indicators such as oil production, the cost of concrete and steel, and labor wages. The Ohio Department of Transportation (ODOT) generates 5-year highway construction inflation forecasts using historic bid price trends and global economic trends.

Texas Highway Cost Index

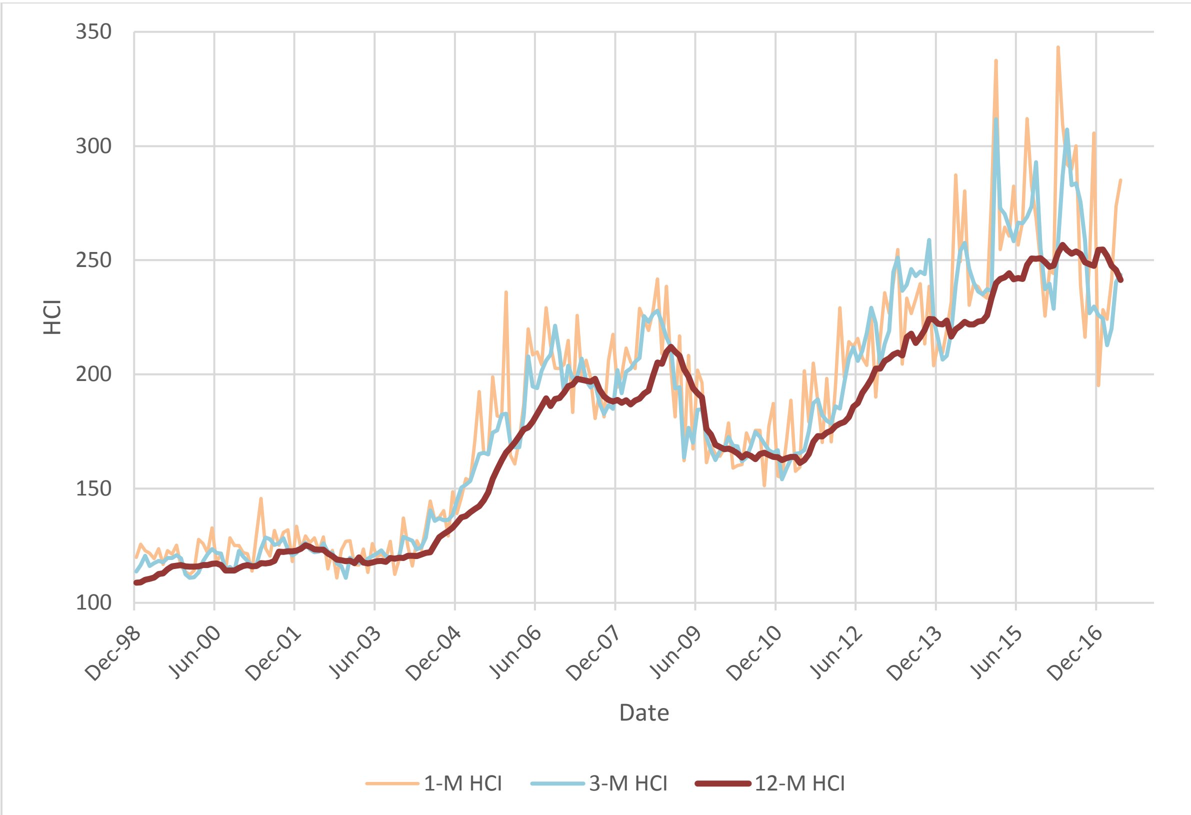
The Texas Highway Cost Index (HCI) uses historic cost and quantity data of common construction items to generate indices to compare costs of highway construction to a base year. The base year for the Texas HCI is 1997. Figure 1 shows the historic HCI since the measure was first calculated in December 1998.

The index is represented in the following three ways:

- 1-month moving average, which includes only the raw price data for that month.
- 3-month moving average, which uses price and quantity of each control item from the preceding three months to weight the prices used in HCI calculation.
- 12-month moving average, which uses price and quantity data from the preceding 12 months to weight the prices in the HCI calculation.

These moving averages adjust for seasonality of contract letting, which results in a clearer trend of price movement.

Figure 1 shows a graphical representation of the HCI from December 1998 to May 2017. Figure 1It is important to note the more extreme index fluctuations with the 1-month compared to the 3-month and 12-month moving averages. For this reason, the 12-month moving average makes more sense to look at in terms of comparisons to the base year as it shows a clearer representation of the overall trend.



Source: Texas Department of Transportation Highway Cost Index (HCI) Index Report for May 2017

Figure 1. Texas Highway Cost Index Jan 2002–Feb 2017.

The HCI in Texas consists of 34 highway construction items over 20 years to identify change in highway construction cost. An example of an item included in the calculation is *Cement*. Each of these items are then grouped into elements of similar items. For example, *Cement* is grouped with *Cement Treatment*, and *Plant Mix* into the element *Cement Treated Subgrade or Base*. Furthermore, similar elements are grouped into categories. An example of this is the *Cement Treated Subgrade or Base* is grouped with the elements *Lime Treated Subgrade or Base*, *Asphalt treated Base or Foundation Course*, and *Flexible Base* into the category *Base Course.* See Figure 3.

The 34 control items used for the creation of the HCI are categorized into 16 Elements and four Categories. The breakdown of each category, *Earthwork*, *Base Course*, *Surfacing*, and *Structures*, can been seen in Figure 2, Figure 3, Figure 4, and Figure 5 respectively.

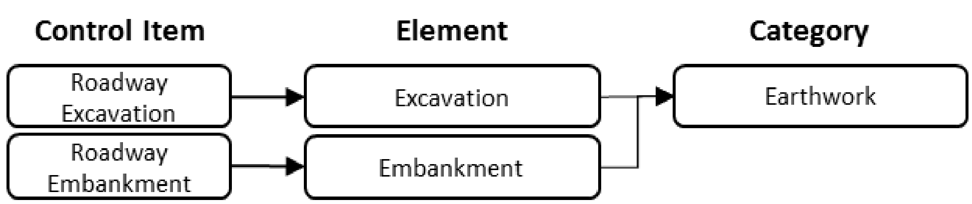


Figure 2. Earthwork Category.

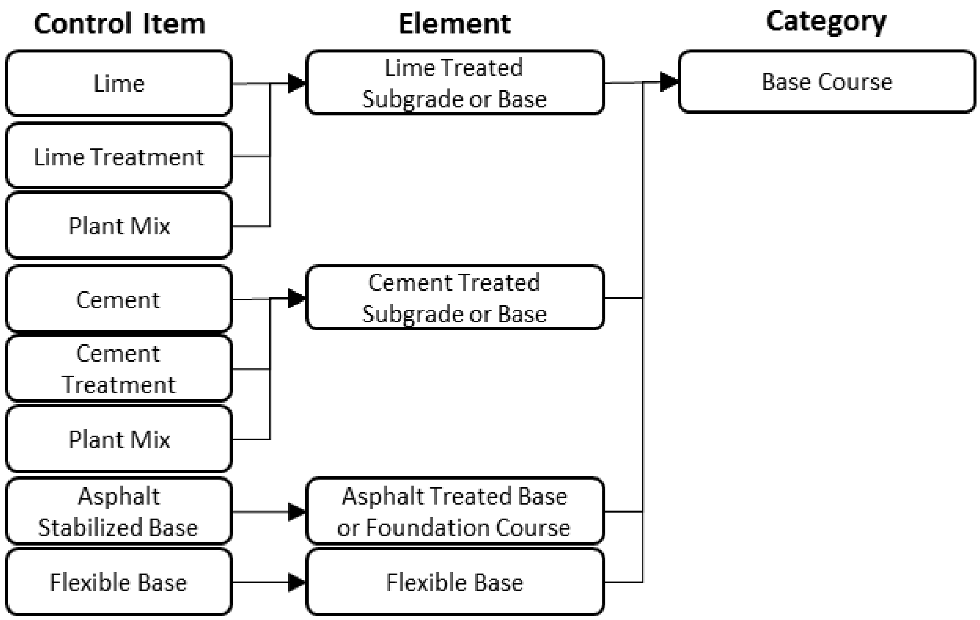


Figure 3. Base Course Category.

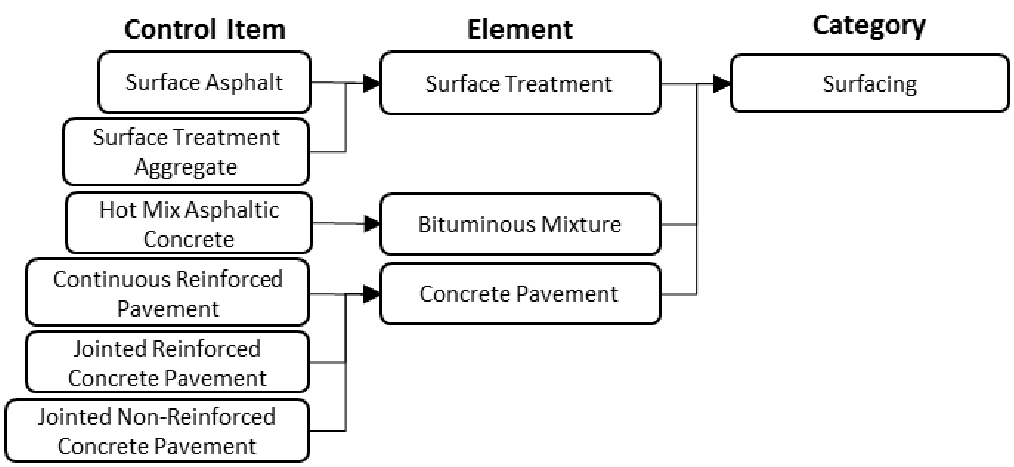


Figure 4. Surfacing Category.

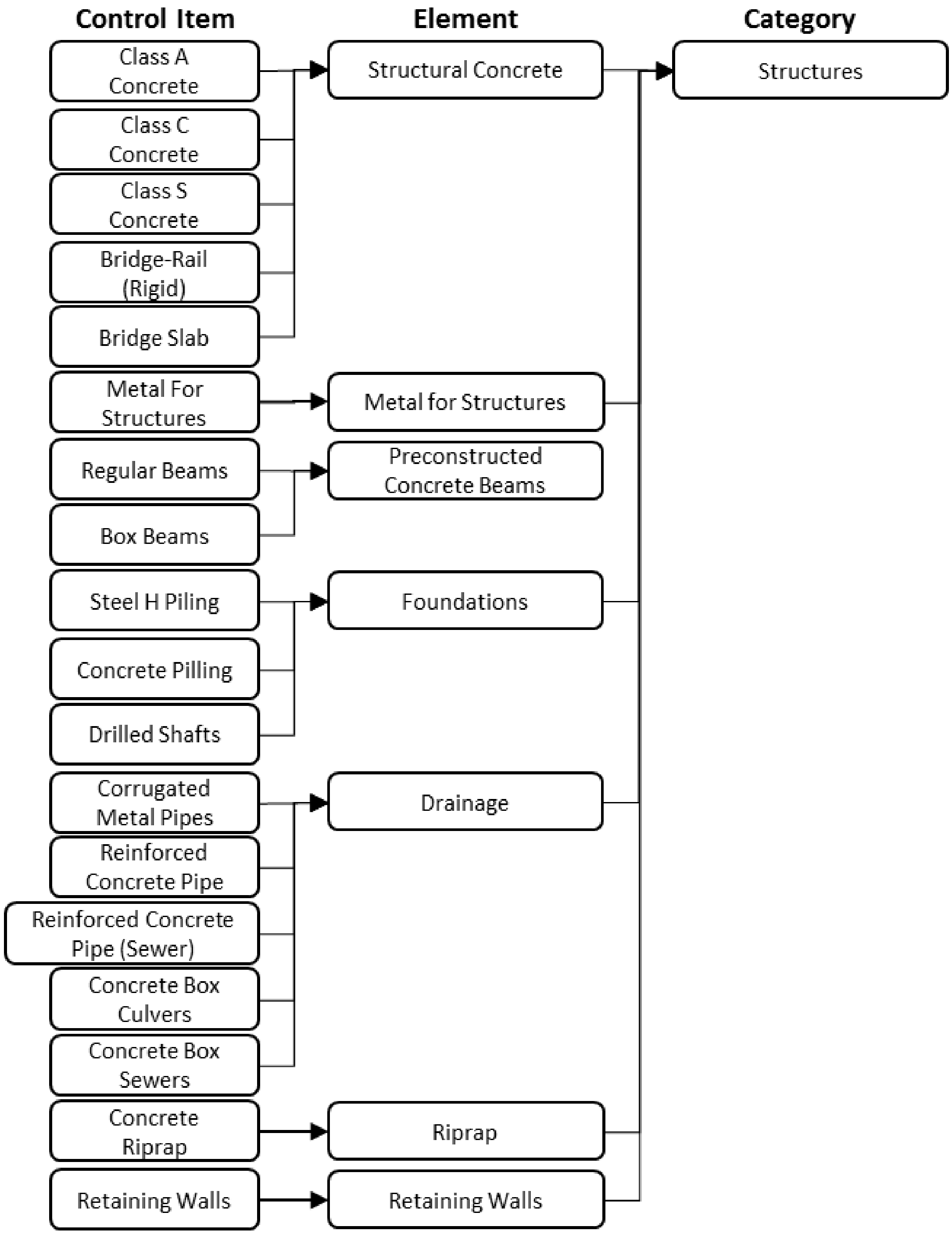


Figure 5. Structures Category.

The HCI data consist primarily of two key variables for each control item: price and quantity. For the 1-month HCI (functional index) calculation, the reported price of each item is used to calculate the current item index, which is then multiplied by a base year item weight. Item indices in each element are summed to generate the element index. Each element index is multiplied by a base year element weight. Like the calculation of the elements, each element indices within each category are summed to calculate the category index. Lastly, each category is multiplied by a base year category weight, then the resulting values are summed to generate the final HCI (functional index). Each calculation for the different indices and weights is shown in Table 1.

Table 1. Index Calculation.

1) Current Item Index $= \frac{\text{(Current Period Unit Price)}}{\text{(Base Period Unit Price)}} \times 100$
a) Current Period Unit Price $=$ Weighted Average Unit Price of Item for Current Period
i) Weighted Average Unit Price of Item for Current Period $= \frac{\text{(Current Total Dollars for Item)}}{\text{(Current Total Quantity for Item)}}$
b) Base Period Unit Price $=$ Weighted Average Unit Price of Item for Base Period
i) Weighted Average Unit Price of Item for Base Period $= \frac{\text{(Base Period Total Dollars for Item)}}{\text{(Base Period Total Quantity for Item)}}$
2) Element Index $=$ Sum of Element Index Components
a) Element Index Component $=$ (Base Year Item Weight) $\times \frac{\text{(Current Item Index)}}{100}$
i) Base Year Item Weight $= \frac{\text{(Base Period Dollars for Item)}}{\text{(Sum of Base Period Dollars for all Items in Element)}} \times 100$
(1) Base Period Dollars $=$ (Base Period Unit Price) $\times$ (Base Period Quantity)
(a) Base Period Quantity $=$ Number of Units Purchased During the Base Period
3) Category Index $=$ Sum of Category Index Components
a) Category Index Component $=$ (Base Period Element Weight) $\times \frac{\text{(Element Index)}}{100}$
i) Base Period Element Weight $= \frac{\text{(Base Period Dollars for Element)}}{\text{(Sum of Base Period Dollars for all Elements in Category)}}$
4) Functional Area Index $=$ Sum of Functional Area Index Components
a) Functional Area Index Component $=$ (Base Period Category Weight) $\times \frac{\text{(Category Index)}}{100}$
i) Base Period Category Weight $= \frac{\text{(Base Period Dollars for Category)}}{\text{(Sum of Base Period Dollars for all Categories in Functional Area)}}$

Source: TxDOT Construction Division – HCI Overview

To calculate the 3-month and 12-month moving averages, item prices are weighted by quantity and then calculated as moving average of the past three and twelve months respectively. Once weighted and average prices are calculated, the same calculations used to generate the 1-month HCI are used to generate the 3-month and 12-month HCIs.

HCI Estimation Methodology

Data for this tool was collected from the TxDOT Construction Division for each of the months between January 2002 and May 2017. The data consisted of 34 control items, such as cement or steel, along with each item's monthly price and quantity, which were used as variables. However, to determine trends in the data, researchers needed to examine not only the recorded price and quantity for both the current and past months, but also the change in each of these measures over time, or the first differences. See Figure 6. This created more than 1,200 unique variables that could influence the future HCI, leading researchers to search for a simplified approach to estimating that would reduce the number of variables down to a list of those that had the largest impact on the final index.

Researchers used the Least Absolute Selection and Shrinkage Operator (Lasso) machine learning approach to eliminate variables in the calculation that had the smallest impact on the final HCI. Lasso is used in instances where there are many variables but only a small set of those variables is important for forecasting the outcome. Using a penalty factor, which applies constraints to the process, the Lasso approach obtains the small set of variables, or sparse solution.

The analysis began by determining the optimal penalty for the Lasso estimation. Researchers attempted to see the changes in estimated parameters by assigning different values to the penalty factor. It was observed that the number of non-zero estimated parameters was increasing as the penalty became less constrained.

In each iteration, the penalty factor was increased and a model with a new set of parameters was obtained. The procedure was repeated from the most constrained penalty factor to the least constrained factor. Researchers found the optimal penalty by comparing each model's performance, which was evaluated using cross-validation analysis. The resulting estimation returned six control items (independent variables) out of the 34 original control items that had the highest impact on the final HCI.

Table 2 shows these final variables and their respective category and element groupings. The coefficients estimated using Lasso regression for each of the six-selected variable are used to construct the final equation for forecasting the HCI.[2] Table 4 in the appendix shows selected variable definitions, a detailed list of each control item and specific construction items/tasks that go with each.

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[2] A full description of the statistical analysis can be found in the unpublished work *When Less is More: Estimating and Forecasting the Texas Highway Cost Index with Lasso* by Huseynov, Ribera, and Palma.

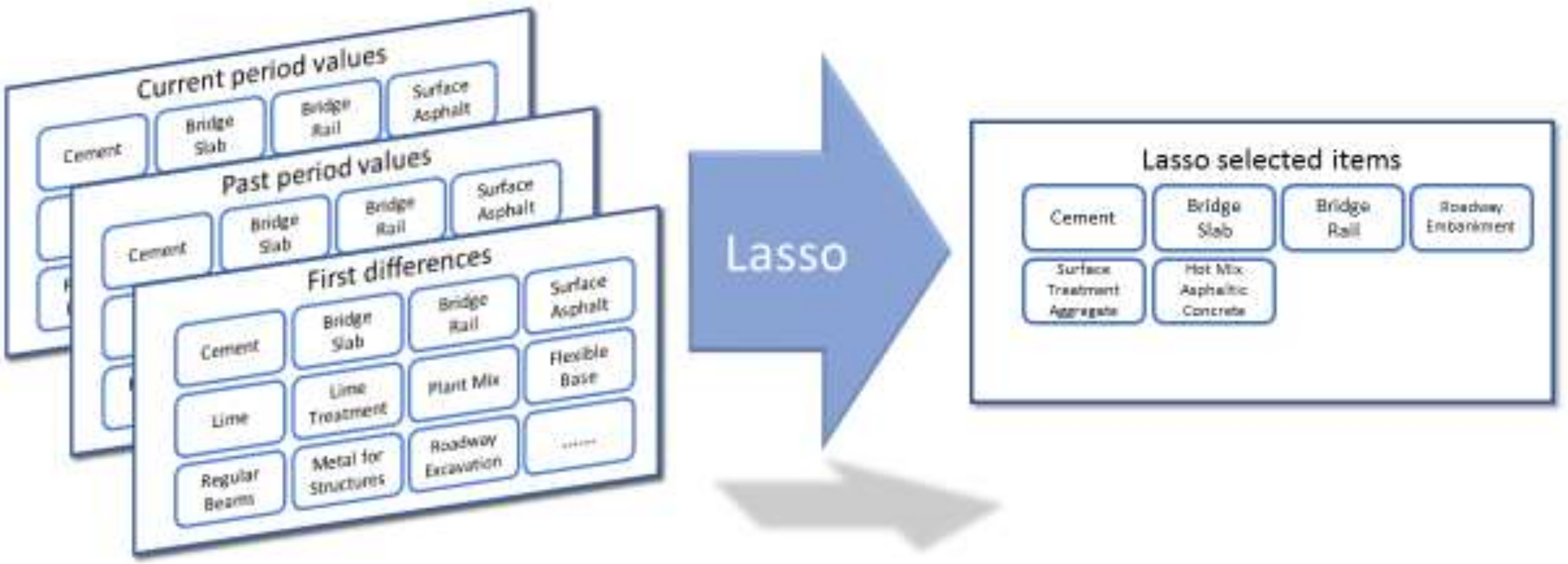

Figure 6. Lasso Approach.

Table 2. Lasso Returned Control Items.

<table>
<tr><th>Control Item</th><th>Element</th><th>Category</th></tr>
<tr><td>Roadway Embankment</td><td>Embankment</td><td>Earthwork</td></tr>
<tr><td>Cement</td><td>Cement Treated Subgrade or Base</td><td>Base Course</td></tr>
<tr><td>Surface Treatment Aggregate</td><td>Surface Treatment</td><td rowspan="2">Surfacing</td></tr>
<tr><td>Hot Mix Asphaltic Concrete</td><td>Bituminous Mixtures</td></tr>
<tr><td>Bridge Rail</td><td rowspan="2">Structural Concrete</td><td rowspan="2">Structures</td></tr>
<tr><td>Bridge Slab</td></tr>
</table>

For comparison purposes, Table 3 lists the top 15 control items with the highest 2016 quantities. Of these 15 control items, four of the six items selected by the Lasso model are included (*). The other two items, cement and hot mix asphaltic concrete, can be included, in part, in other control items.

Table 3. Control Items with the Highest 2016 Quantities.

Control Item
Metal for Structure
Surface Asphalt
Roadway Embankment*
Roadway Excavation
Bridge Slab*
Flexible Base
Retaining Walls
Lime Treatment
Cement Treatment
Surface Treatment Aggregate*
Continuous Reinforced Pavement
Regular Beams
Bridge Rail*
Reinforced Concrete Pipe
Drilled Shafts

Once the control items were selected, their cost values for the date range January 2002 (first month of collected data) to May 2016 (one year before the end of the dataset) were inputted into the equation developed from the Lasso regression analysis. These dates and data were used to "train" the model to predict future HCI values. The results of the estimation for the date range May 2016 to April 2017 were then compared to the actual HCI from those dates. See Figure 6.

From the results, researchers conclude that the estimation generated by the Lasso model falls within an acceptable margin of error (MOE) of less than 10 percent.

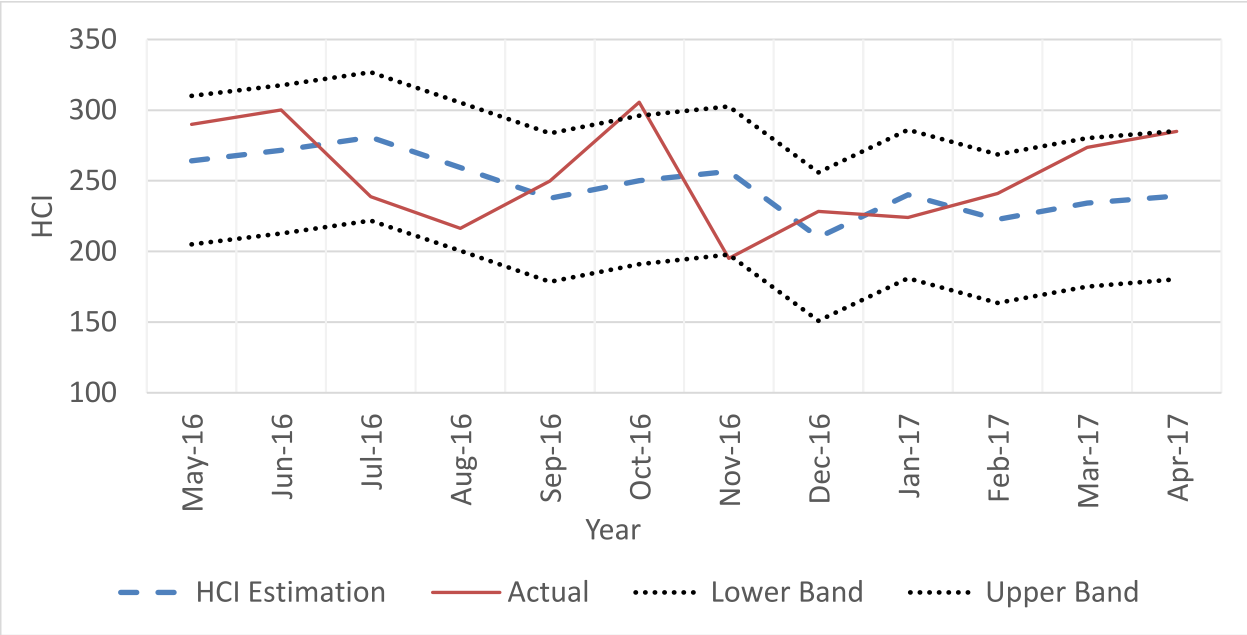

Figure 7. HCI Baseline Estimation.

Highway Cost Index Estimator Tool

The tool that was created from the Lasso analysis allows the user to input the unit price of the selected control items to generate an estimated HCI. The default unit price values in the tool are representative of prices from April 2017 and can be found on the Data tab of the spreadsheet. The tool will estimate a new HCI based on the user inputs, as well as the upper and lower bounds. The upper and lower bounds allow the user to see the range of possible outcomes. Figure **8** illustrates the user inputs and the returned estimate.

Highway Cost Index Estimator		
Item	**Unit Price**	**Unit**
Bridge Rail	$ 50.70	LF
Bridge Slab	$ 14.90	SF
Hot Mix Asphaltic Concrete	$ 74.38	TON
Surface Treatment Aggregate	$ 99.84	CY
Cement	$ 149.04	TON
Roadway Embankment	$ 15.26	CY
Highway Cost Estimated Index		
Estimation	**239.29**	
Lower Bound	180.29	
Upper Bound	285.29	

Figure 8**. HCI Model Baseline Inputs and Estimates.**

Figure 9 depicts the graph included in the tools output of the historic 12-month moving average with the user defined estimate plotted to the right. Historic prices of the selected Control Items are included in Figures 10 – 15 in the Appendix.

Figure 9. Historic Index and Estimation.

Appendix

Table 4. Selected Variable Definitions.

Item Name	HCI Item No.	Category	Element	Main Item	Main Item Name	Description
Bridge Rail	14104	Structures	Structural Concrete	450	Railing	The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Railing" of the type specified. This price will be full compensation for furnishing, preparing, and placing concrete, expansion joint material, reinforcing steel, structural steel, aluminum, cast steel, pipe, anchor bolts or bars, testing of epoxy anchors, and all other materials required in the finished railing; removal and disposal of salvageable materials; and hardware, paint and painting of metal railing, galvanizing, equipment, labor, tools, and incidentals.
Bridge Slab	14105	Structures	Structural Concrete	422	Concrete Super-structures	This price is full compensation for furnishing, hauling, mixing, placing, curing, and finishing concrete; furnishing and placing reinforcing steel; grouting and pointing; furnishing and placing drains and expansion joint material (except where specifically furnished under another Item); furnishing and placing metal flashing strips; forms (removable and permanent) and falsework; pre-stressed concrete panels; furnishing and placing concrete and reinforcement for raised medians, sidewalks, sign mounts, luminaire brackets, and other concrete appurtenances; removing designated portions of existing slab; cleaning, bending, and cutting exposed existing reinforcing steel; welding reinforcing steel; doweling; cleaning and preparing concrete surfaces; and equipment, labor, tools, and incidentals.
Cement	12301	Base Course	Cement Treated	275	Cement Treatment	Cement will be paid for at the unit price bid for "Cement." This price is full compensation for materials, delivery, equipment, labor, tools, and incidentals

Item Name	HCI Item No.	Category	Element	Main Item	Main Item Name	Description
			Subgrade or base		(Road-Mixed)	
				276	Cement Treatment (Plant-Mixed)	Cement treatment will be paid for at the unit price bid for "Cement Treatment (Existing Material)," "Cement Treatment (New Base)," or "Cement Treatment (Mixing Existing Material and New Base)," for the depth specified. No payment will be made for thickness or width exceeding that shown on the plans. This price is full compensation for shaping existing material, loosening, mixing, pulverizing, spreading, applying cement, compacting, microcracking, finishing, curing, curing materials, blading, shaping and maintaining shape, replacing mixture, disposing of loosened materials, processing, hauling, preparing secondary subgrade, water, equipment, labor, tools, and incidentals.
Hot Mix Asphaltic Concrete	13201	Surfacing	Bituminous Mixtures	340	Dense-Graded Hot-Mix Asphalt (Small Quantity)	The work performed and materials furnished in accordance with this Item and measured as provided under Article 340.5., "Measurement," will be paid for at the unit bid price for "Dense Graded Hot-Mix Asphalt (SQ)" of the mixture type, SAC, and binder specified. These prices are full compensation for surface preparation, materials including tack coat, placement, equipment, labor, tools, and incidentals
				341	Dense-Graded Hot-Mix Asphalt	The work performed and materials furnished in accordance with this Item and measured as provided under Section 341.5., "Measurement," will be paid for at the unit bid price for "Dense Graded Hot-Mix Asphalt" of the mixture type, SAC, and binder specified. These prices are full compensation for surface preparation, materials including tack coat, placement, equipment, labor, tools, and incidentals.
				3000		N/A
				3022		N/A
				3063		N/A

Item Name	HCI Item No.	Category	Element	Main Item	Main Item Name	Description
				3116		N/A
				3117		N/A
				3146		N/A
Roadway Embankment	11201	Earthwork	Embankmen t	132	Embankmen t	The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Embankment (Final)," "Embankment (Original)," or "Embankment (Vehicle)" of the compaction method and type specified. This price is full compensation for furnishing embankment; hauling; placing, compacting, finishing, and reworking; disposal of waste material; and equipment, labor, tools, and incidentals.
Surface Treatment Aggregate	13102	Surfacing	Surface Treatment	316	Seal Coat	The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit prices bid for "Asphalt," "Aggregate," and "Loading, Hauling, and Distributing Aggregate" of the types-grades specified on the plans. These prices are full compensation for surface preparation; furnishing, preparing, hauling, and placing materials; removing existing pavement markers and excess aggregate; rolling; cleaning up stockpiles; and equipment, labor, tools, and incidentals.
				318		N/A

1) The description of each item is found in "Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges" published by TxDOT in 2014.

2) The description is located under payment section of each main item chapter.

3) The controlled item and its corresponding main items can be found in page 42 of "Highway Cost Index (1997 Base) Index Report for May 2017."

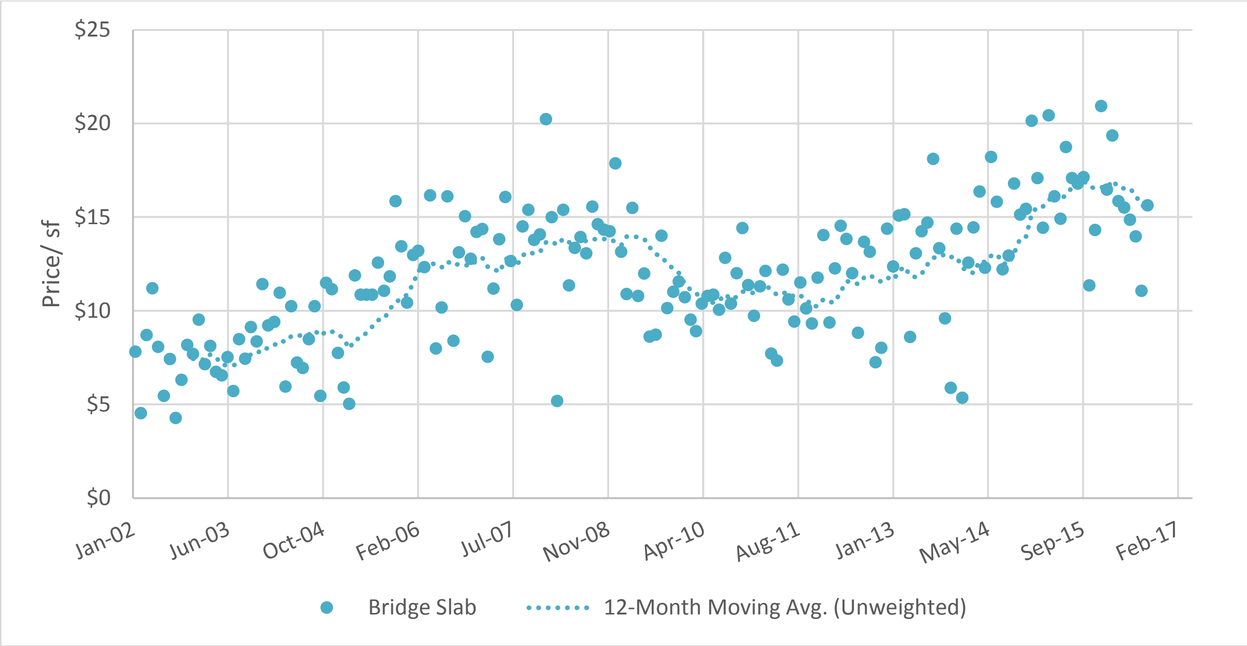

Figure 10. Bridge Slab Price Trend.

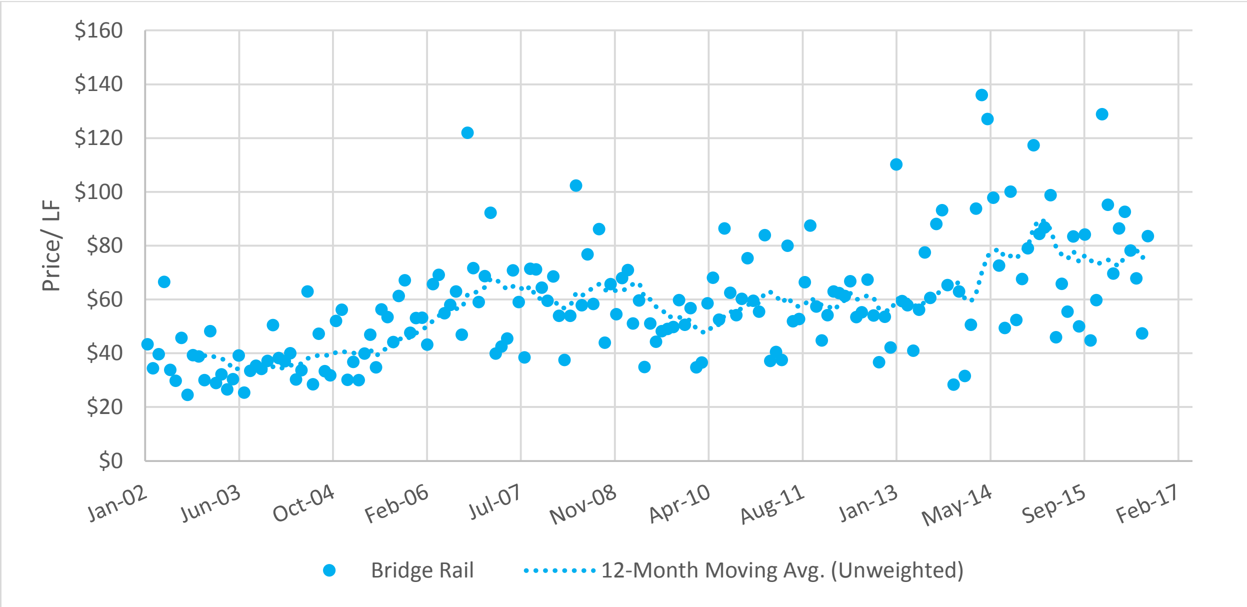

Figure 11. Bridge Rail Price Trend.

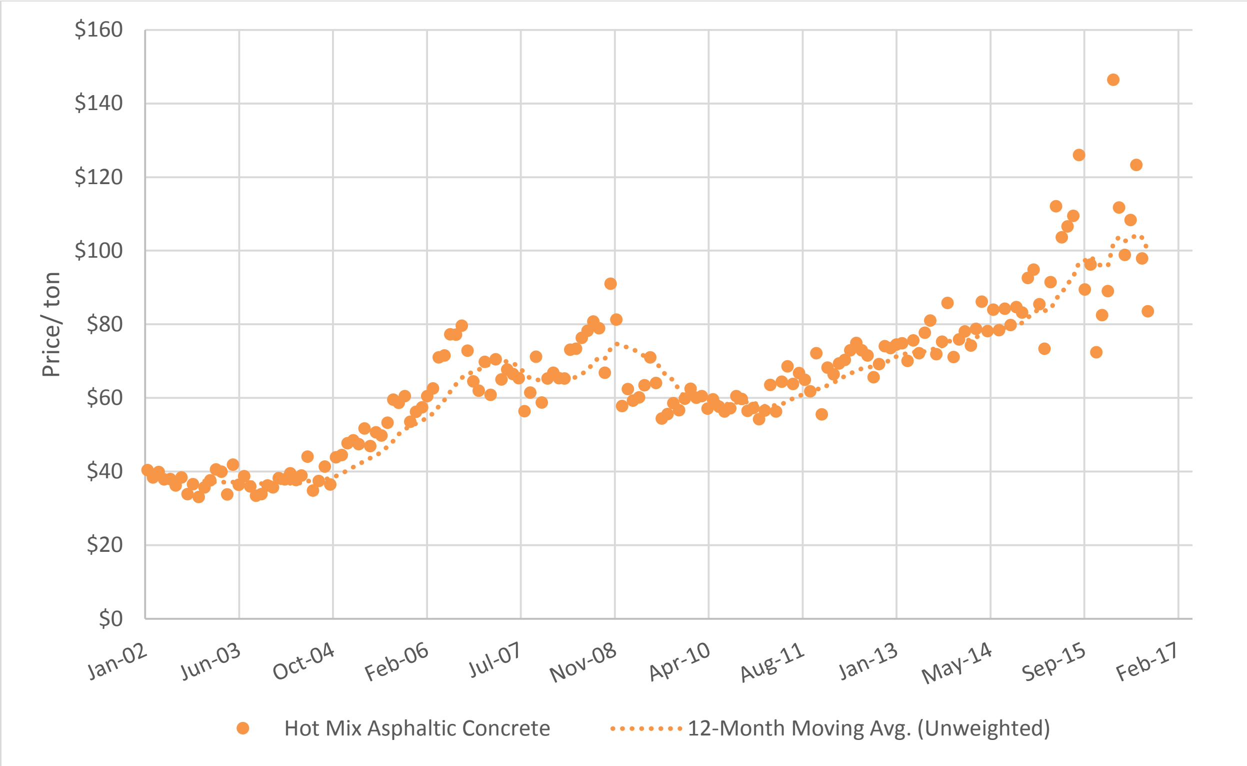

Figure 12. Hot Mix Asphaltic Concrete Price Trend.

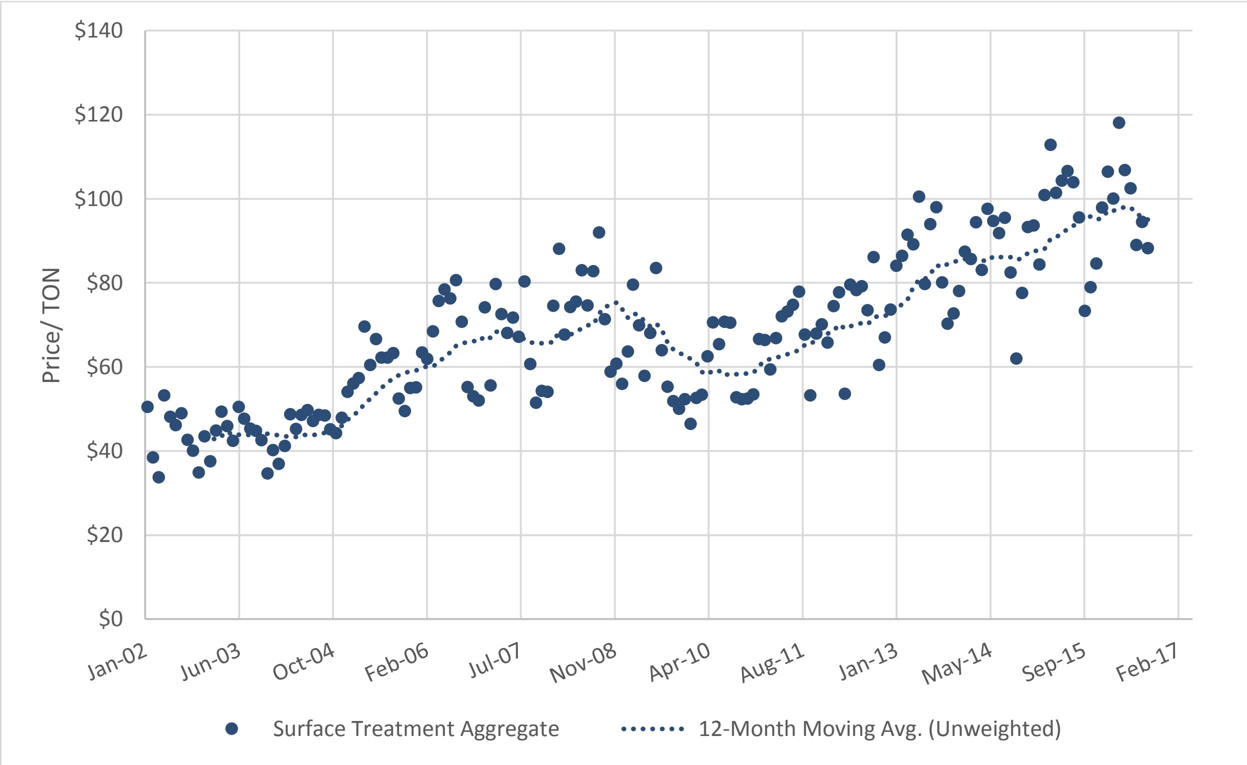

Figure 13. Surface Treatment Aggregate Price Trend.

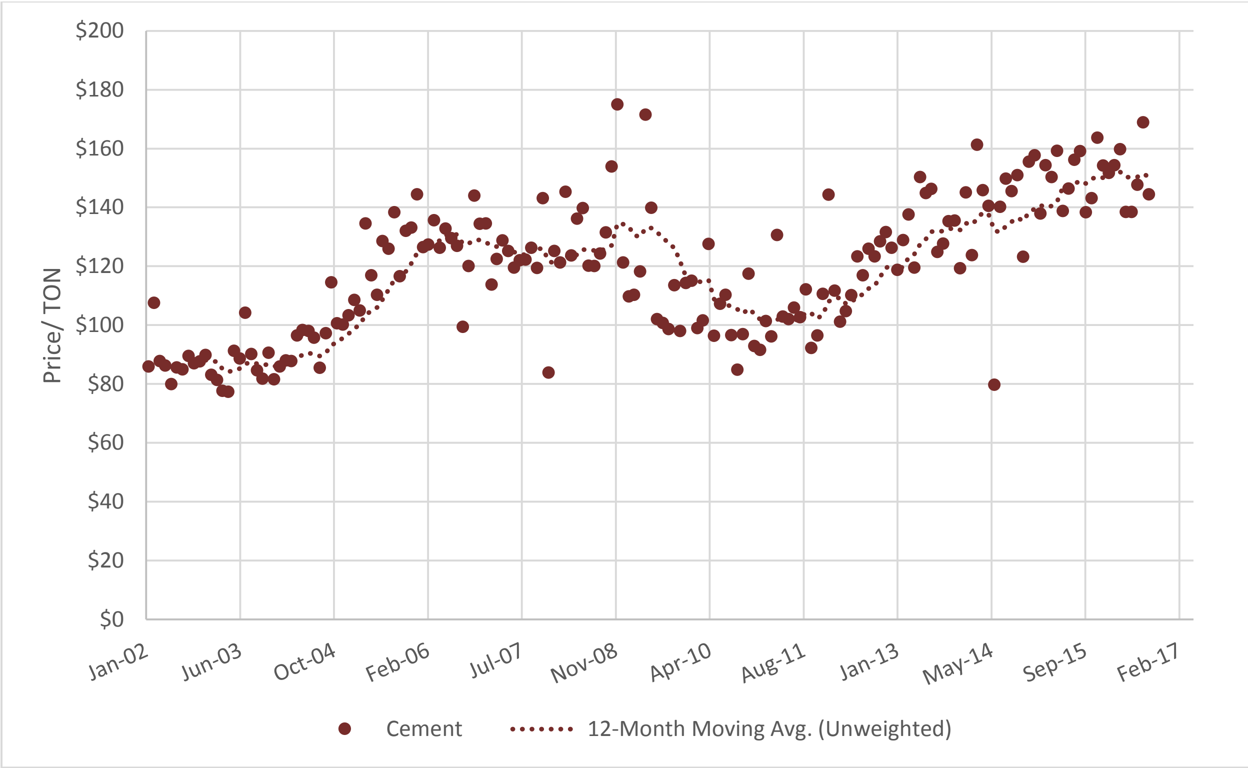

Figure 14. Cement Price Trend.

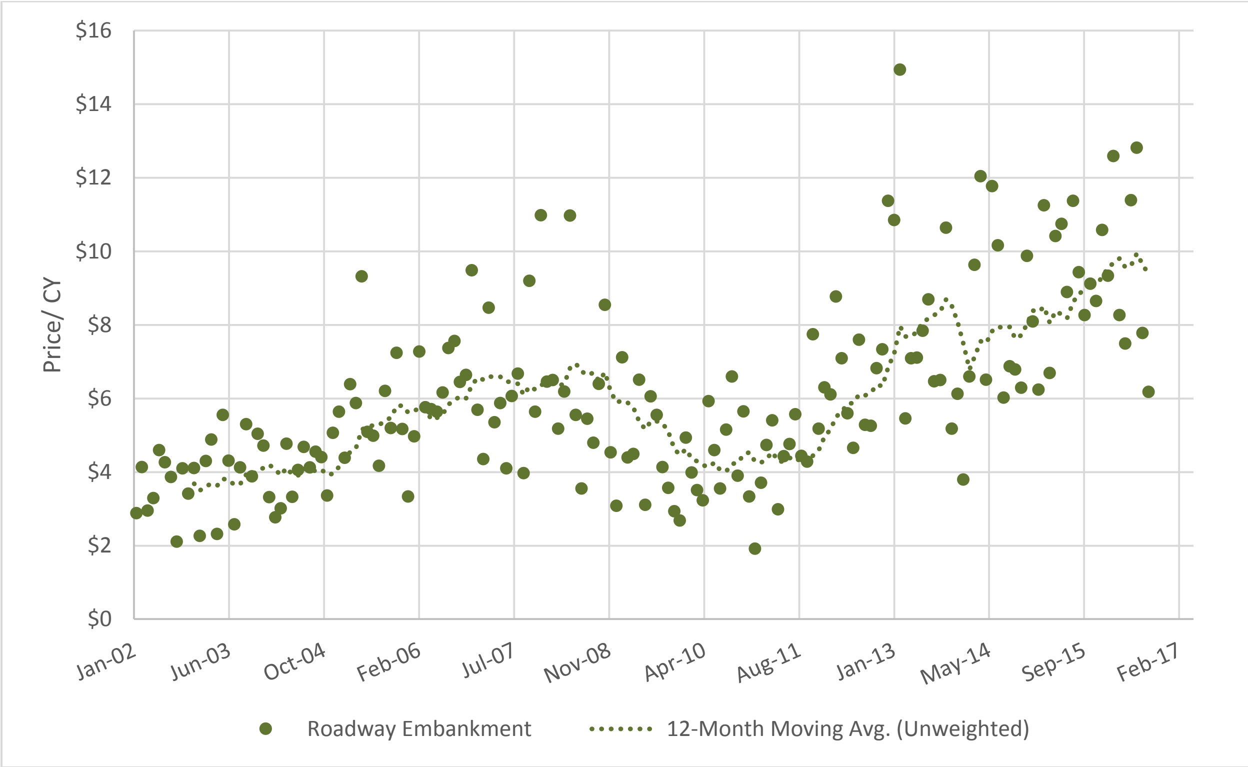

Figure 15. Roadway Embankment Price Trend.