South Dakota
Department of Transportation
Office of Research

U.S. Department of Transportation
Federal Highway Administration

SD2016-06-F

Develop an Improved SDDOT Construction Cost Index

SD2016-06

Final Report

Prepared by

Texas A&M Transportation Institute

College Station, TX

February 2021

DISCLAIMER

ACKNOWLEDGEMENTS

This work was performed under the direction of the SD2016-06 Technical Panel:

Thad Bauer.. Research
Alan Berheim....................Operations Support
Laura Blotske......................Financial Systems
Randy Brown.................Project Development
Jacob Huber...................................... Research
Dave Huft.. Research
Doug Kinniburgh.................................... LGA
Bob Longbons...................................Research
John Matthesen................. Belle Fourche Area
Ben Orsbon..................Office of the Secretary
Chris Ott................................Internal Services
Kirk Van Roekel..................................FHWA

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SD2016-06-F		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
Develop an Improved SDDOT Construction Cost Index	5. Report Date 2/28/2021 6. Performing Organization Code
7. Author(s) H. David Jeong, K. Joseph Shrestha, Maxwell Steadman, Jacqueline Kuzio	8. Performing Organization Report No.
9. Performing Organization Name and Address Texas A&M Transportation Institute 400 Harvey Mitchell Parkway South, Suite 300 College Station, TX 77845-4375	10. Work Unit No. HRY409 11. Contract or Grant No. 311219
12. Sponsoring Agency Name and Address South Dakota Department of Transportation Office of Research 700 East Broadway Avenue Pierre, SD 57501-2586	13. Type of Report and Period Covered Final Report (Mar 2019 – Feb 2021) 14. Sponsoring Agency Code

15. Supplementary Notes

An executive summary is published separately as SD2014-09-X.

16. Abstract

A highway construction cost index (HCCI) is an indicator of the purchasing power of a highway agency. Highway agencies can monitor their construction market conditions using HCCIs to make various financial planning decisions. The main goal of this study is to modernize the HCCI system of South Dakota DOT by developing an enhanced HCCI calculation and forecasting methodologies and a software program by incorporating recent guidance from the Federal Highway Administration and adopting advanced theories on HCCI calculation. To achieve the goal, the study a) reviewed the current HCCI calculation methodology used by the agency, b) interviewed potential HCCI users from South Dakota, c) developed a proven multidimensional HCCI calculation methodology using the concept of the dynamic item basket, and d) developed two methods to forecast HCCIs, and e) developed a software program to automate the HCCI calculation and forecasting processes. In addition to the overall HCCI, more than a dozen sub-HCCIs were developed to show more granular market conditions across the state of South Dakota. The sub-HCCIs showed that specific construction market conditions, such as rural and urban market conditions, do not necessarily follow the trend of the overall statewide market condition. For HCCI forecasting, a linear regression model provided a better result than the weighted time series method. The methodologies and the software program developed for this research are expected to aid SDDOT in improving its ability to monitor the construction market trend closely and more accurately. The availability of more granular market conditions from sub-HCCIs are expected to increase the use of HCCIs at SDDOT.

17. Keywords	18. Distribution Statement
Highway-Construction-Cost-Index, construction-market, inflation, cost-estimating, dynamic-item-basket	No restrictions. This document is available to the public from the sponsoring agency.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	59	

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TABLE OF ACRONYMS

Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
CDOT	Colorado Department of Transportation
CPI	Consumer Price Index
DIB	Dynamic Item Basket
DOT	Department of Transportation
ENT	Engineering News-Record
FHWA	Federal Highway Administration
HCCI	Highway Construction Cost Index
IMF	International Monetary Fund
LCCA	Life Cycle Cost Analysis
LRTP	Long-Range Transportation Plan
MAPE	Mean Absolute Percentage Error
MCI	Maintenance Cost Index
MnDOT	Minnesota Department of Transportation
NCDOT	North Carolina Department of Transportation
ODOT	Ohio Department of Transportation
RMSE	Root Mean Square Error
SDDOT	South Dakota Department of Transportation
STIP	Statewide Transportation Improvement Programs
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
WisDOT	Wisconsin Department of Transportation

1 EXECUTIVE SUMMARY

1.1 Problem Description

A highway construction cost index (HCCI) is an indicator of the purchasing power of a highway agency. Highway agencies can monitor the construction market conditions using the HCCIs to make various financial planning decisions. The Federal Highway Administration (FHWA) developed the Bid Price Index (BPI) as a national HCCI in 1987. Subsequently, many state DOTs including SDDOT have developed their state specific HCCIs. Since its inception, the FHWA has updated its HCCI calculation methodology several times. However, SDDOT's methodology has not been updated for multiple decades. Further, SDDOT HCCI is calculated using only the eight largest bid items which represent a small fraction of the bid items used by the agency. As such, SDDOT users were concerned about the reliability of the HCCIs. Thus, there is a need to develop an improved methodology to compute reliable HCCIs.

1.2 Research Objectives

The main goal of this study is to modernize the HCCI system of South Dakota DOT by developing an enhanced HCCI calculation and forecasting methodologies and a software program by incorporating recent guidance from the FHWA and adopting advanced theories on HCCI calculation.

1.3 Task Descriptions

To achieve the goal, the study a) reviewed the current HCCI calculation methodology used by the agency, b) interviewed potential HCCI users from South Dakota, c) developed a proven multidimensional HCCI calculation methodology using the concept of the dynamic item basket, and d) developed two methods to forecast HCCIs, and e) developed a software program to automate the HCCI calculation and forecasting processes. In addition to the overall HCCI, more than a dozen sub-HCCIs were developed to show more granular market conditions across the state of South Dakota.

1.4 Findings and Conclusions

The research team developed an enhanced framework to compute and forecast multidimensional HCCIs using the concept of dynamic item baskets. The major improvements include a) multidimensional HCCIs that provide the trend of more granular market conditions, b) dynamic item baskets and the chained Fisher index that ensure the use of data from the maximum possible number of bid items, c) forecasting methods that can be used for financial planning for future projects, and d) automation of the HCCI calculation and forecasting processes to reduce the burden of manual processes and improve the accuracy and reliability. In addition to an overall statewide HCCI, the framework and automation tool enable SDDOT engineers to compute multiple sub-HCCIs including sub-HCCIs for rural/urban, federal reservation/non-federal reservation, various administrative regions, various contract sizes, various bid-item characteristics. The HCCI values were forecasted using linear regression and weighted time series models. The error analysis showed that the linear regression model predicted HCCIs with higher accuracies compared to the weighted time series. Noticeable differences were observed when all data was used versus when outliers were removed. However, since FHWA recommends removing outliers, all HCCIs except for the overall HCCIs were calculated using the dataset with outliers removed.

1.5 Recommendations

1.5.1 Use the new SDDOT HCCI Tool

A new HCCI Tool was developed to automate the computation process of calculating multidimensional highway construction cost indexes. This independent software tool is immediately available for use by SDDOT.

1.5.2 Compute and Distribute HCCI Values Annually

The HCCI values should be computed and saved in a portable format annually and distributed to the relevant personnel. The portable format might be an MS Excel, PDF, or web-based information-sharing page. The potentially relevant personnel may include SDDOT employees responsible for STIP and LRTP, city planners, contractors, consulting companies, and state legislature. An annual meeting among the users of HCCIs is recommended where all the users can share their perspectives on the HCCI trends and how it might affect SDDOT's financial resource planning and management. The meeting can also discuss various areas to further improve the HCCI calculation methodologies and/or tools to obtain more benefits from the available data.

1.5.3 *Monitor Potential Warning Signs*

Any sudden changes in the market conditions as indicated by widely fluctuating HCCI values should be investigated to identify the potential reasons behind the fluctuation. Such changes could be a result of reduced competition or increased cost of labor, material, or equipment.

1.5.4 *Develop a Clean Dataset to Recompute All HCCIs and Sub-HCCIs*

SDDOT should develop an automatic data extraction tool to extract and store data that will be used to compute HCCIs. This database should be automatically updated at least once a year after the results of the bids let in the previous year are available.

1.5.5 *Train Current and New Users of the Software Tool*

The computer software tool developed in this project connects to a shared network database by default. Proper training for new users using the user's manual that is available as part of the final products from this project is needed for continuous use of the software tool in case of the main users' retirement or rotation to a different position.

1.6 Research Benefits

The new HCCI calculation and forecasting tool developed as a part of this study will enable SDDOT to accurately track the current construction market conditions and reliably forecast HCCIs. The HCCI values can be used as an inflation factor to improve the accuracy of programming level construction cost estimates for STIP and LRTP. The HCCI values can also be used as an inflation factor for LCCA and Benefit-Cost analysis. It can also be used to improve the accuracy of an engineer's estimate by using specific HCCIs directly relevant to the project's location, type, size, etc.

2 PROBLEM DESCRIPTION

A highway construction cost index (HCCI) is as an indicator of trends and cost changes in the construction market and illustrates the purchasing power of a highway agency. The Federal Highway Administration (FHWA) developed the Bid Price Index (BPI) in 1987 which represents an early version of a national HCCI (Federal Highway Administration (FHWA) 2011). This enabled state Departments of Transportation (DOTs) to calculate their HCCIs to assist with planning, budgeting, and asset management where possible. A state specific HCCI represents the actual market condition in the state and can be utilized as a short-term inflation rate to support early financial decisions by departments of transportation (DOT).

South Dakota Highway Construction Cost Indexes (HCCIs) represent construction market conditions across the state of South Dakota over time. The South Dakota Department of Transportation (DOT) currently calculates a single overall HCCI using a fixed item basket consisting of eight major bid items. The fixed item basket may get outdated over time as work types and construction methods and technologies change. While a single overall HCCI can provide an overview of the statewide market conditions, it does not provide granular details on the market conditions specific to various regions or project types. Further, the non-chained Fisher index based HCCI calculation methodology currently used by SDDOT is outdated. The FHWA has recommended the use of the chained Fisher index-based HCCIs to better reflect the true cost trend over time and some DOTs such as Montana DOT have already switched their HCCI calculation methodology to the chained Fisher index. Thus, the current methodology used by SDDOT needs to be improved to ensure that cost indexes are representative of the actual market conditions, and various indexes are calculated and available to obtain more granular details of the construction market conditions. Further, manual calculation of HCCIs could be very time consuming and error-prone, especially if more than one HCCI is to be computed. Thus, there is a need to have an automated system for reliable and accurate calculation of HCCIs. Finally, SDDOT is interested in forecasting HCCIs using historical data which could potentially be used to adjust cost estimates in the early phase of project development. This study addresses those challenges by developing an improved SDDOT HCCI system.

3 RESEARCH OBJECTIVES

The main goal of this study is to modernize the HCCI system of South Dakota DOT by developing an enhanced HCCI calculation and forecasting methodology and a software program by incorporating recent guidance from the FHWA and adopting advanced theories on HCCI calculation.

3.1 Identify current and potential uses for construction cost indexes in SDDOT

Identify current and potential uses for construction cost indexes in SDDOT.

The project team reviewed existing literature to understand the current practices of calculating and using HCCIs. The team interviewed SDDOT engineers to understand current uses of HCCIs at SDDOT and the specific need for various sub-HCCIs to provide more granular information of the construction market.

3.2 Develop methodologies for calculating, maintaining, and using a HCCI for each use

Recommend methodologies for calculating, maintaining, and using a CCI for each use.

The project team developed methodologies for calculating, maintaining, and using a HCCI by analyzing the collected historical bid tabulation data from SDDOT. The research team has developed an independent software tool for faster implementation

3.3 Develop an independent tool for calculating and forecasting various CCIs

Evaluate the level of risk or uncertainty for projections made using the CCI methods.

The project team developed a software program based on C++ language that can calculate and forecast various HCCIs.

4 TASK DESCRIPTIONS

The following tasks were undertaken to accomplish the goal of this research project.

4.1 Kick-off Meeting

Meet with the project's technical panel to review the project scope and work plan.

A kick-off meeting with the technical panel was conducted to discuss the project scope and the work plan, research approach, intended outcomes and deliverables. The panel's feedback at the meeting was used as a guiding direction throughout this project.

4.2 Critical Review of Current Leading Practices

Through literature review and contact with other transportation agencies, describe the state of practice of calculating and using construction cost indices in transportation applications.

The research team conducted a comprehensive literature review to document the state of practices of calculating and using construction cost indices in transportation agencies.

4.3 Interview SDDOT staff

Interview SDDOT staff to identify and describe current and possible uses of construction cost indices and concerns regarding their use.

With proper guidance from the technical panel, the research team conducted interviews with several SDDOT employees who provided their experience and insights on the current and possible uses of construction cost indices, concerns regarding their use, and expectations of future improvements.

4.4 Submit Technical Memorandum #1

Submit a technical memorandum to the technical panel detailing the results of Tasks 2 and 3.

The first technical memorandum synthesized the findings from literature review and interviews with SDDOT employees. A web conference was conducted to receive the panel's feedback.

4.5 Suggest Possible Improvements

Suggest possible improvements—such as regional indexing, market basket composition, material-specific indexing, and others identified in Task 2—to SDDOT's current methodology.

Based on the results from Technical Memorandum #1, the research team identified possible improvements that can be made to the current SDCCI system. Possible improvements included regional indices, material-specific indices, project type, and size-specific indices, new indices such as traffic control, reconfiguration of market basket items, and cost index forecasting tools.

4.6 Recommend Appropriate Methodologies for Improvements

For each current and possible use identified in Task 3, recommend an appropriate methodology for calculating, maintaining, and using a construction cost index and estimating its level of confidence.

For each improvement item suggested in the previous task, the research team developed a specific procedural approach and methodology to accomplish each improvement. The research team provided a detailed explanation of what data should be collected and how the data should be organized, processed, and analyzed to meet the objective of each improvement item.

4.7 Submit Technical Memorandum #2

Submit a technical memorandum to the technical panel detailing the results of Tasks 5 and 6.

The technical memorandum #2 was developed to describe the detailed results regarding possible improvements and recommended appropriate methodologies for improvements. A web conference was conducted to receive the panel’s feedback and discuss the next work activities involving data collection, data analysis, and interpretation of the results.

4.8 Calculate Construction Cost Indexes

Using data available from SDDOT and other sources, calculate all construction cost indices identified in Task 7 and estimate their levels of confidence.

The research team a) collected the required data from SDDOT and other sources, b) organized and processed the collected data, c) calculated construction cost indices and their associate risks and uncertainties, and b) built a prototypical tool that can calculate various cost indices and quantify the uncertainties.

4.9 Submit Technical Memorandum #3

Submit a technical memorandum to the technical panel detailing the results of Task 8.

The technical memorandum #3 was developed to describe the results of the previous task. A web conference was conducted to demonstrate the calculation processes and the results to receive the panel’s feedback and make appropriate changes or adjustments.

4.10 Submit Final Report

In conformance with Guidelines for Performing Research for the South Dakota Department of Transportation, prepare a final report summarizing the research methodology, findings, conclusions, and recommendations.

The research team prepared a draft of the final report summarizing the research methodology, findings, conclusions, and recommendations in conformance with the Guidelines for Performing Research for the South Dakota Department of Transportation. The technical panel’s review and comments were incorporated into the final report.

4.11 Make Executive Presentation

Make an executive presentation to the South Dakota Department of Transportation Research Review Board at the conclusion of the project.

As required in the RFP, the research team made an executive presentation to the South Dakota Department of Transportation Research Review Board at the conclusion of the project, highlighting the key findings of this research project, the value of this research for the SDDOT, and implementation ideas.

5 FINDINGS AND CONCLUSIONS

5.1 Literature Review

A literature review was conducted to observe how different states calculate their HCCIs. State DOTs seek to optimize their planning and budgeting strategies by scrutinizing the quality of their current HCCI. An accurate and up-to-date index provides the DOT with a short-term inflation rate that speaks to their purchasing power as an agency. Statewide transportation improvement programs (STIP) and similar planning documents and efforts will incorporate the HCCI for program estimates but uses can expand to asset management and lifecycle cost analysis for certain projects and items.

HCCIs can be complex to construct accurately, leading many states to rely on federal models that can be adapted for each state. Several reports reference the Federal Highway Administration's (FHWA) HCCI 2.0 as the model to follow, given that the 2017 update is an improvement over the previous version. However, because construction costs vary from state to state, some DOTs have opted to keep their index to better reflect the market conditions of their state. This literature review will detail how states approach their HCCI through index formulas, forecasts, item selection, and data manipulation, and will provide a background of general HCCI practices.

5.1.1 Indexing Formulas

There are four main indexing formulas to calculate HCCI: Young, Paasche, Laspeyres, and Fisher (Jeong, Gransberg, and Shrestha 2017). The four approaches provide different inflation predictions depending on the chosen method, due to differences in calculation. A cost index measures the changes in construction costs over time and can convert previous costs into current year dollars. An index is created through the selection of an item basket, base year (arbitrary year 0), and the current year. Item baskets are composed of quantities and prices that are chosen to represent total construction costs. Once this information is collected, one of the following indexes can be applied. Although FHWA recommends the Fisher index as it provides a more balanced approach than others, some state DOTs have continued to use other indexing formulas. Once HCCIs are calculated, various methodologies such as linear regression and time series can be used to forecast HCCIs for planning.

5.1.2 FHWA Methodology

Growing problems caused by the Bid Price Index (BPI) tool encouraged FHWA to replace this process with the improved HCCI. A BPI serves as an inflation indicator for changes in the highway construction market. This tool is created by first obtaining unit prices and quantities of materials from state contracts worth over $500,000 and then evaluating the difference in yearly unit prices (Guerrero 2003). Initially, BPIs were used for annual FHWA reports, pricing information for state use, and as a price deflator to calculate real prices. However, states found this method burdensome due to a large amount of paperwork required, low state response, and incomplete data. To mitigate these shortcomings, a highway construction cost index was created. This new method employs a Fisher index to control for the changing market basket and delivers consistent results by eliminating the volatility of BPI. Furthermore, what makes HCCI functional is the quality of data collected. The presence of missing data is avoided altogether to prevent the Fisher index calculation from failing. Item information gathered from different states is standardized to calculate a national cost index that is representative of states' construction costs.

With this new tool, states can improve both their construction cost predictions and overall budgeting practices.

Several steps are required to calculate a highway construction cost index that involves creating a market basket and picking an index formula. Some states use a categorized market basket, which includes additional unit costs and provides a larger sample to represent true construction costs. Other states use an item level market basket where frequently large items are used to generate an index without the need to categorize them. After the FHWA replaced the BPI with the HCCI, states began to model their index according to FHWA's HCCI by substituting their old index, Laspeyres, or Young, with the Fisher index.

Once states have created their index, they use their new tool to improve planning and budgeting strategies. Their indexes generally predict construction market inflation, indicate the purchasing power of the agency, and facilitate the comparison of costs between different states and FHWA. States also use indexes created by other agencies like the Bureau of Labor Statistics and the Engineering News-Record (ENR) to supplement their predictions. However, some DOTs are unable to produce a practical index even after the improved FWHA's HCCI. These DOTs struggle with selecting a representative item basket or have problems maintaining their data (Shrestha, Jeong, and Gransberg 2016; White and Erickson 2011).

5.1.3 State Methodology

5.1.3.1 Colorado

Colorado is improving its highway construction cost predictions by reproducing FWHA's HCCI. Before the HCCI was created, the Colorado Department of Transportation (CDOT) used the Laspeyres method with a base period of 1987 and a unit index of 100. This method produced results that either overestimated or underestimated inflation. CDOT then switched from the Laspeyres method to the Fisher index in 2012, modeling their HCCI after FHWA (Minnesota Department of Transportation 2018). This new index uses a base of 1.0000 starting the first quarter of 2012. CDOT gathers items from major subgroups and averages their prices and quantities to create a cost index. CDOT creates quarterly indexes but leaves out low item quantities that have a minimal impact on results (Walters and Yeh 2012). These items, including earthwork, hot mix asphalt, concrete pavement, structural concrete, and reinforcing steel, are updated periodically based on technological changes. Lastly, according to the 2012 HCCI, CDOT is aware that its method is unable to account for "differences in climate, terrain, and working conditions within the state".

CDOT developed a forecast model to predict how their HCCI will change based on input prices. Although CDOT's HCCI provides information on how construction costs will change, their index is unable to fully capture highway construction costs because the size of the project impacts the composite index. To avoid this drawback, the forecast model uses economic factors and input prices to forecast construction costs. The model is comprised of two specifications—producer input prices and input prices—that use demographic and macroeconomic information from oil, concrete, steel, wages, and construction demand to formulate a forecast (Mills 2013). Multiple regressions are constructed using inputs from previous quarters, known as lagging variables, to estimate future HCCIs (Yu 2012).

5.1.3.2 Minnesota

To test the reliability of the Minnesota Department of Transportation's (MnDOT) HCCI, MnDOT hired a consulting firm to analyze their index (Minnesota Department of Transportation 2018). MnDOT calculates their cost index by using the Laspeyres index method and a base year of 1987. Data is obtained from available documentation and interviews with the appropriate personnel. Information regarding items such as roadway excavation, concrete pavement, and structural steel, to name a few, is collected to represent construction costs. These items are then used to calculate different index categories like excavation, surfacing, and structure with the intention to then create a total cost index.

Due to index methodology differing from state to state, individual indexes are analyzed to compare MnDOT's index with FHWA and other states. Rather than using weights from both the current and base periods (FWHA's method), MnDOT calculates weights by only using information from the base period. Moreover, a composite HCCI was created from FHWA's tool using Minnesota data to measure the difference between the two index methods. This exercise demonstrated that Minnesota's methodology produces indexes similar to FWHA's index technique. There were slight variations in the results but can be attributed to an outdated base period and the 2008 economic recession. From this outcome, the consulting firm made recommendations for improving results. Some proposals include the use of a dynamic item basket, a multidimensional index, and the Fisher index method.

5.1.3.3 Montana

The main problems with Montana DOT's prior HCCI calculation methodology, which uses the Young index, are its small sample size and its inability to deconstruct the total HCCI (Shrestha, Jeong, and Gransberg 2017). Their bid items currently cover between 14-50 percent of construction costs, limiting the accuracy of predicted market conditions. Likewise, the HCCI methodology only provides a holistic view of costs when, in fact, there are specific item categories that greatly affect construction costs.

The solutions to these problems are a dynamic item basket (DIB) and a multidimensional HCCI. A DIB supplements a low sample size by increasing the number of bid items available. New items—that have known costs and quantities—are automatically updated to reflect the most complete costs and largest item basket. To obtain the largest item basket possible, items from both previous and current periods are used to increase sample size and eliminate sampling error. In addition to creating a state cost index, a multidimensional HCCI creates sub-cost indexes for project size, project type, and project location. These sub-HCCIs are notable because construction costs vary depending on the project. For example, larger projects will have different costs than smaller projects based on existing contractors and supplies. Moreover, the location of the project will dictate the availability of resources and transportation costs.

Database development, project filtering, DIB generation, and multidimensional HCCI calculation are the steps needed to combine these two processes. Using Montana bid data to test the proposed improvements, the new method reveals that a greater number of bid items are covered regardless of their frequency or size. Additionally, DOTs can use this new method to customize different business plans based on the size, location, and type of project. By accounting for a lower sample size and improving the ability to look at different sub-HCCIs, a more accurate HCCI is created.

5.1.3.4 North Carolina

As opposed to other state DOTs, North Carolina's Department of Transportation (NCDOT) seeks to create an index that focuses on maintenance rather than construction costs (Nassereddine, Whited, and Hanna 2016). To create a maintenance cost index (MCI), researchers suggest aggregating a basket of tasks for each maintenance category (roadside, maintenance, traffic, bridge), selecting a base year, and entering the information into their index tool created from Excel. To create this MCI, parameters for the 2014 base year were chosen based on the total quantity and total unit costs that were calculated for each task. Work order records and tasks from 2012 to 2015 were used to represent 72 to 76 percent of costs for each maintenance category. The Laspeyres method is used to calculate the index because the quantity of maintenance items is relatively constant and item substitution is not required. Once the index was calculated, results from 2013 to 2015 showed that composite maintenance costs and quantity of tasks rose by 9.4 percent. With these results, several recommendations are made to improve planning practices. For example, costs should be calculated over many years to avoid volatile year to year forecasting costs. NCDOT should also account for rising maintenance costs when preparing their budget and update their tasks if quantities start to fluctuate.

5.1.3.5 Ohio

Ohio DOT uses data from sources like HCCIs and economic trends to explain fluctuations in the construction market (Ohio Department of Transportation (ODOT) 2019). Ohio DOT organizes their items in classes and performs data cleaning through the elimination of outliers and data smoothing procedures (Nassereddine, Whited, and Hanna 2016). Ohio DOT's HCCI reports use the chained Fisher index method, 20 item categories, and a base year of 2012 to create quarterly HCCIs and a 5-year forecast. The January 2019 cost index predicts that inflation will remain at an average of 3.0 percent until 2023. Ohio DOT states that construction cost inflation was significantly impacted by liquid asphalt, structural steel, and concrete prices causing an index increase of 3.4 percent in the year 2018. Possible reasons for the inflation increase are economic and construction trends. For example, the implementation of steel tariffs increased the price of steel while the price fall of crude oil made asphalt more affordable. Many other contributors—oil prices, liquid asphalt, labor, state, and national economies—are also described in Ohio DOT's HCCI.

5.1.3.6 Oregon

Oregon DOT created its index with the AASHTO Trns*port Estimator software but found that it produced unreliable results (Walters and Yeh 2012). The software offered values based on bidding behavior instead of producing indexes from cost changes. As of 2012, Oregon DOT opted to observe the performance of FHWA's HCCI.

5.1.3.7 Texas

Texas Department of Transportation's (TxDOT) highway cost index (HCI) looks at 34 items and groups them into 16 elements and four categories (Huntsman et al. 2017). Some element examples within a category, such as Earthwork, are Excavation and Embarkment. The other categories include Base Course, Surfacing, and Structures. For each of these items, price and quantity information is gathered to calculate a highway cost index or functional index. This index is then used for monthly, quarterly, and yearly estimates.

Working with TxDOT, TTI developed a Highway Cost Index Estimator Tool to monitor price changes in the construction items. This indexing method builds on itself by creating a Current Item Index, Element Index, Category Index, and a Functional Area Index that is simplified by the Least Absolute Selection and Shrinkage Operator (Lasso) approach. The Current Item Index is calculated by multiplying the ratio for the current period unit price and base period unit price by 100. Next, a "base year item weight" is multiplied by the current item index and divided by 100. The latter calculation is done for all the items in an element and then summed to create an Element Index. A Category Index uses the previous calculation steps, except items are replaced with element information. A Functional Area Index follows the same procedure but uses category instead of element information. Overall, this method creates a thorough cost index but makes the calculation process burdensome due to the abundance of prices and quantities that can affect inflation. The estimator tool uses Lasso to simplify the amount of information available and streamline calculations by identifying prices and quantities that have the greatest impact on the highway cost index and dismissing the rest. The tool then produces a highway cost index prediction using the historic data and provides a range of the highest and lowest possible index values.

5.1.3.8 Wisconsin

Wisconsin DOT's (WisDOT) HCCI currently relies on an outdated method that is in need of replacement (Nassereddine, Whited, and Hanna 2016). In 2016, WisDOT used the Laspeyres index and 1990 as its base period. This process requires both the current and base weighted averages of the unit prices and the base quantity. Although this method provided WisDOT with information about their purchasing power and construction cost forecasts, the results became unstable and unreliable as time progressed. The recommended solution, made by a construction cost study, to this outdated method is a two-stage, chained Fisher index approach. A basket is created—consisting of 2,260 items divided into 27 classes—by carefully picking the appropriate number of items to represent construction costs. This filtering process results in a basket comprised of 96 bid items. The first stage then creates an index using the Fisher process while the second stage uses the indexes created to produce a composite cost index using the chained method. To measure the accuracy of this method, WisDOT's product was compared to Ohio's and FHWA's index. The comparison showed that similar cost predictions were generated, and those discrepancies were most likely due to the use of different bid items or index scope.

5.2 Current Uses of HCCIs and Potential Improvements

The research team conducted 14 interviews with 25 individuals to better understand the current and potential future uses of the South Dakota HCCI and determine the improvements that users would like to see in the new HCCI. The interviews were conducted with several groups at SDDOT, such as Project Development, Finance, and Materials & Surfacing. In addition to groups at the SDDOT, the research team interviewed engineers from the City of Sioux Falls and members of trade groups and associations operating in South Dakota. The interviews followed a standard format where the research team worked to determine each interviewee's familiarity with the current HCCI as well as discuss the potential for improvements, changes, or additions when developing the new HCCI.

5.2.1 Uses of HCCIs

The interviews provided a wide cross-section of the DOT and therefore differing levels of familiarity with the current HCCI; most interviewees were aware that the HCCI existed but were often not using it within their work. The current HCCI employed at SDDOT uses eight market basket items and the most common purposes for members of the DOT were to use it for lifecycle cost analysis (LCCA) and in determining a discount or inflation rate to apply to project and program estimates. Other uses included the determination of swap agreements, line-item cost inflation, and construction market trend analysis.

5.2.1.1 Current Uses of HCCIs

The Materials and Surfacing Department use the HCCI when completing their LCCA for pavement projects; they use the HCCI to understand whether concrete or asphalt will be the most cost-effective for each project. The LCCA only takes costs, specifically construction costs, into account when completing the analysis; the HCCI provides the discount rate that the department can apply when conducting their analysis. This is a long-term analysis as it is aiming to cover the life of the project or infrastructure, in this case, pavement condition; SDDOT operates on a 40-year time frame when conducting the LCCA. The HCCI provides a more accurate discount rate for their purposes than applying a more generic rate for either transportation or other construction projects.

Members of project development and those involved with bids and bid letting used the HCCI to obtain either a discount rate or an inflation rate for their analyses. The State Transportation Improvement Program (STIP) utilizes an inflation rate to determine the cost of the projects planned over the next cycle. Similarly, the HCCI is used by certain members of the DOT to explore trends and to provide an overview of highway construction costs over time to the legislature when necessary. The HCCI provides a way to visualize the changes in highway construction over time and potentially explain the need for greater funding due to reduced purchasing power.

In terms of project cost estimating and bid letting, the HCCI provides SDDOT with a general idea of previous costs and helps them determine whether to approve swap agreements and even conduct line-item cost inflations on occasion. One interviewee mentioned the HCCI as a reference point when considering whether to accept bids and contract changes, especially in terms of swap agreements. It provides a rough estimate of previous costs, which can then be inflated to current dollars. Another use mentioned was the inflation of line item costs; this is linked to decision over swap agreements as it can help to show the difference in price over the construction time frame of a project.

5.2.1.2 New Uses for the HCCI

Uses of the HCCI have been limited to LCCA and inclusion in transportation programming efforts; the interviews yielded ideas for potential new uses of the HCCI. The HCCI informs the STIP as well as LCCA processes that are completed by the DOT, but further uses in planning and programming could be through asset management and performance management. Incorporating the HCCI into performance metrics and using it to monitor assets beyond pavements and hard surfaces would provide the DOT with greater information on the costs incurred through construction efforts and monitor the cost-effectiveness of their bid letting cycle. The Statewide Long-Range Transportation Plan (LRTP) could benefit similar to the STIP from adding the HCCI into their calculations and project estimates, as well as using the basic forecast to show potential cost increases if projects are delayed. In this regard, the HCCI could be used to determine an inflation rate that more accurately reflects the construction industry rather than relying on the Consumer Price Index (CPI). Finally, better use of the HCCI for legislative and policy purposes could communicate the issues with the cost of construction and time of construction to political entities when discussing funding allocation and performance of the DOT. Displaying construction trends and costs over time can speak to the purchasing power of allocated funding in the present versus the past and would assist in explaining project decisions to the public.

Ensuring that the new HCCI is useful to a greater number of departments at the DOT will require updates and maintenance to the index regularly; an interviewee suggested aligning these updates with statewide planning timeframes and project cycles to gain the most benefit from the HCCI. Maintaining up-to-date data and calculations will provide the best possible estimates in terms of forecasting and sub-indexes that can be used by the STIP coordinators and bid letting office when determining projects to program and bids to accept.

The HCCI would be limited to highway construction, but a few interviewees did express an interest in expanding the model to include different modes. Airport construction was viewed as an area where understanding costs and cost changes over time would be useful in their bid letting process. The HCCI would be limited to highway construction; airport pavement and runway specifications are substantially different in terms of materials and so additional data and a potentially different calculations may be needed to suit that purpose.

5.2.2 Challenges to Use Current HCCIs

Although all interviewees knew about the HCCI, not all of them were using it within their department or work. The reasons for this ranged from issues with the geographic scale of the current HCCI, the inability to select specific types of work, and problems with the market basket of items. The state of South Dakota is majority rural but does have two larger population centers in Rapid City and Sioux Falls; this can create issues with the HCCI when both urban and rural project data is included within the calculations.

In attempting to determine why the HCCI was not being fully utilized, the research team found that a number of interviewees had issues related to geography or region. Engineers from Sioux Falls expressed their issues with the HCCI due to the differences between costs when undertaking an urban project rather than rural; due to this, they rely on their cost estimates and bid item averages. Project Development and Operations team members also expressed that the reliability of the HCCI was compromised due to the vast differences in urban and rural projects. One core problem for South Dakota is the amount of Indian Reservation land; projects that are undertaken in Indian Reservations have unique issues and are often subject to specific requirements in terms of labor. The reservations tend to be in remote rural areas, which can exacerbate issues of purchasing and access to materials.

Another reason for the limited use of the HCCI was concerns over the current calculations, as well as the limited market basket. Interviewees expressed the need to update the index to reflect current trends as well as update the market basket. Interviewees outside the DOT were concerned that labor costs and prevailing wage rates were not fully accounted for, as these elements are now a substantial portion of overall construction costs. Finally, many interviewees expressed an interest in the HCCI but were unsure of how it could be used in their work context.

5.3 Potential Improvements

Based on the findings from interviews and literature review, the research team identified seven areas of improvements to address various issues:

- Database Development to Avoid Human Errors,
- Dynamic Item Basket to Utilize Data from More Bid Items,
- Chained Fisher Index to Reflect Newer Construction Project Types and Techniques,
- Multidimensional HCCIs to Provide More Granular Information,
- Custom-Item-Basket-Based Sub-HCCIs to Understand Specific Market Conditions,
- Forecasting to Plan for Future Projects, and
- Automated Tool Development to Ease HCCI Calculations.

5.3.1 Database Development to Avoid Human Errors

Many state DOTs have implemented manual Excel-based HCCI calculation methodologies. However, such methodologies are cumbersome to use and have the potential for human error while manually extracting and transferring data. To automate HCCI computation, a proper database containing essential data attributes needs to be developed. The database will contain data tables for contract and project characteristics, bid data, bid item list, etc.

The FHWA and Ohio DOT removes extremely low and extremely high unit prices of bid items as outliers before calculating unit prices. A similar methodology can be developed to automatically remove such outliers.

5.3.2 Dynamic Item Basket to Utilize Data from More Bid Items

Currently, SDDOT computes HCCIs using a fixed item basket that consists of eight bid items. This existing item basket has two issues: a) small size of the item basket and b) omission of relevant bid items. First, the items in the existing basket represent a small fraction of all the bid items used by SDDOT. These eight items may not represent an accurate picture of the current market conditions. An HCCI should be calculated using unit prices and quantities of the maximum number of relevant items. Second, bids items are added, updated, and removed from SDDOT's specification book over time to include new construction materials, methods, and technologies and to remove those that are no longer in use. Thus, the importance of a bid item in terms of total cost and frequency could change over time. Hence, the items in such a fixed item basket could get outdated and may not be suitable to quantify the current construction market conditions. As an example, SDDOT representatives indicated that the agency has shifted its focus from new construction to maintenance projects. Maintenance projects tend to use different bid items and their quantities than new construction projects. Similarly, the use of intelligent transportation system infrastructure is increasing over time, but it is not currently considered in the HCCI calculation. These items may need to be included in the current item basket used by SDDOT.

To address these issues, the concept of the Dynamic Item Basket (DIB) will be used. In the DIB, the algorithm automatically identifies and utilizes all non-lump-sum bid items that are used in two consecutive periods of interest. If any new bid items are used in the projects, these items will be automatically added to the DIB if data is available for the item. Thus, the DIB represents the optimal item basket for any two periods of interest. The DIB concept will be combined with the chained Fisher index to address the issue discussed above. A more detailed description of the DIB is presented in the next Chapter (5.4.2 Dynamic Item Basket (DIB)).

5.3.3 Chained Fisher Index to Reflect Newer Construction Project Types and Techniques

The Fisher index is the preferred method over other indexing methods such as Laspeyres and Paasche indexes and is recommended by the Federal Highway Administration (FHWA). The Fisher index uses quantities and unit prices from the base period and the current period. Thus, it provides a balanced approach as compared to the Laspeyres and Paasche that tend to overestimate or underestimate the price increases. When using the unchained Fisher index, the items in the item basket can get outdated over time. The combination of the DIB and chained Fisher index will enable the computation of HCCIs that are more reflective of the current market condition. Many state DOTs and FHWA have adopted the chained Fisher index. This includes state DOTs from Ohio, Montana, Wisconsin, and North Dakota.

This chained index and DIB enable the inclusion of data from newer bid items such as intelligent transportation systems when such items are used in any two consecutive periods. This chained Fisher index will be adopted for the new SDDOT HCCI system. More details about the chained Fisher index is provided in the next Chapter (5.4.1.2 Chained Fisher Index).

5.3.4 Multidimensional HCCIs to Provide More Granular Information

The HCCIs computed by many state DOTs cannot currently provide granular details on the market conditions based on project location and size. The SDDOT interviewees acknowledged the price differences between rural/urban projects and Federal Indian Reservation projects. However, such differences in specific market conditions are not quantified in the existing SDDOT HCCI. To overcome this issue, multidimensional HCCIs will be developed in addition to an overall HCCI. Each sub-HCCI will present the market condition for a specific market condition. The multidimensional aspect may include sub-HCCIs for urban/rural areas, reservation/non-reservation, administrative regions, and various contract sizes.

In addition to these project-level sub-HCCIs, bid item level sub-HCCIs can also be developed depending on the availability of data in the desired format. For example, a separate sub-HCCI may be developed for earthwork, asphalt construction, and rigid pavement.

SDDOT representatives indicated that traffic control and erosion controls are two large lump sum items that they would like to include in the item basket. Including lump sum items in the item basket could create inconsistency in the HCCI. However, a sub-HCCI can be developed using non-lump-sum items in the traffic control and erosion control sub-parts. Such sub-HCCI will be an indicator of the market conditions/competitions for specialty contractors/subcontractors.

5.3.5 Custom-Item-Basket-Based Sub-HCCI To Understand Specific Market Condition

The research team will develop select custom-item-basket-based sub-HCCIs. For example, a traditional type of HCCIs with the 10 largest cost items can be developed.

5.3.6 Forecasting to Plan for Future Projects

Forecasting future HCCIs is essential for budgeting and planning purposes. Several interviewees expressed their interest in an HCCI forecasting feature specific to SDDOT. A forecasting method can be developed and implemented using methods such as time-series and linear regression. It should be noted that these methods will be trend-based rather than cause-based. As such, the accuracy of the result will be limited, and it cannot predict a sudden change in market conditions. A cause-based method will require an extensive investigation to identify external factors that influence market conditions and would provide more accurate forecasts. However, such a method may require SDDOT to collect and maintain relevant data from third parties (such as the Bureau of Labor Statistics) and is out of the scope for this study. If SDDOT is interested, current research can be extended to dive deeper into cause-based forecasting in the future.

5.3.7 Automated Tool Development to Ease HCCI Calculation

The improvements discussed above can be implemented using an automation tool. This will ensure that the HCCI calculations can be done quickly without significant inputs from the users.

5.4 Framework for Improved Highway Construction Cost Index (HCCI) Calculation

This section describes a framework to compute improved Highway Construction Cost Indexes (HCCIs) using Dynamic Item Basket (DIB). It presents a theoretical background of the Fisher Index and the concept of chaining Fisher Indexes. Existing HCCI calculation methodologies suffer from issues such as the possibility of item baskets getting outdated over time and the lack of granular details when a single HCCI is used. The concept of multidimensional HCCIs with DIB is presented to solve these issues.

5.4.1 Theoretical Background

5.4.1.1 Fisher Index

A cost index can be computed using various indexing formulas such as the Fisher Index. The Fisher Index is also known as the *Fisher Ideal Index*. The Fisher index can be presented mathematically as shown in Equation 1 (International Monetary Fund (IMF) 2010).

$$Fisher\ Index, HCCI = \sqrt{\frac{\sum_{i=1}^{N} p_{i,t} q_{j,0}}{\sum_{i=1}^{N} p_{i,0} q_{j,0}} X \frac{\sum_{i=1}^{N} p_{i,t} q_{i,t}}{\sum_{i=1}^{N} p_{i,0} q_{i,t}}} \quad \textbf{(1)}$$

In the above equation, *i* represents a bid item, *p* represents an average unit price, and *q* represents a quantity. Subscript *0* and *t* indicate the base period and the current period, respectively. The average unit price, *p* in equation (1), is calculated as a quantity weighted unit price, i.e. the sum of multiplications of unit prices and corresponding quantities divided by the sum of the quantities:

$$Average\ Unit\ Price\ of\ Bid\ Item\ i, p_i = \frac{\sum_{j=1}^{M} p_{i,j} q_{i,j}}{\sum_{j=1}^{M} q_{i,j}} \quad \textbf{(2)}$$

In equation (2), *j* represents a contract that includes a bid item *i*. Thus, the Fisher index calculation requires bid item unit prices and quantities from two periods: the *base period* and the *current period*. The base period represents the period against which a cost index is computed for the other desired period known as the current period. The collection of items used in calculating a cost index is known as *item basket*.

5.4.1.2 Chained Fisher Index

The equation (1) can be used to compute relative Fisher indexes between a base period and a current period of interest. Thus, if a base period is to be updated for any reason, a cost index will need to be recalculated with respect to the new base period. Further, the items in the item basket can get outdated over time with changes in work types and construction methods and technologies. This issue can be resolved by using the concept of a chained Fisher index. The chained Fisher Index is the methodology recommended by the Federal Highway Administration to compute HCCIs (FHWA 2017). To calculate a chained Fisher index between two periods *t* and *0*, first, relative indexes between all consecutive periods within the two periods are calculated. For example, the relative index between two consecutive periods *t* and *t-1* can be calculated using Equation (3).

$$Relative\ Fisher\ Index, HCCI_{t,t-1} = \sqrt{\frac{\sum_{i=1}^{N} p_{i,t} q_{j,t-1}}{\sum_{i=1}^{N} p_{i,t-1} q_{j,t-1}} X \frac{\sum_{i=1}^{N} p_{i,t} q_{i,t}}{\sum_{i=1}^{N} p_{i,t-1} q_{i,t}}} \quad \textbf{(3)}$$

Then, these relative indexes are multiplied to compute the chained index between the two periods.

$$Chained\ Fisher\ index, HCCI_{t,0} = HCCI_{t,t-1} * \ HCCI_{t-1,t-2} * \ \dots \dots HCCI_{2,1} * HCCI_{1,0} \quad \textbf{(4)}$$

In general, the base year HCCI value ($HCCI_{1,0}$) is adopted as 100. Thus, a chained index value of, say, 102 represents a two percent increase in the cost of construction between the two periods.

5.4.2 Dynamic Item Basket (DIB)

An item basket represents a collection of cost items used in calculating an index. Traditionally, a limited number of bid items that are considered major or important are included in the item basket to compute a cost index. This step dramatically simplifies the cost index calculation process, and such an index can be computed with a limited effort using a simple spreadsheet tool. However, there is a high likelihood that the limited sample may not accurately represent the changes in the market condition. For example, if the eight largest bid items in terms of total dollar value are used to compute a cost index and the unit price of the ninth-largest bid item fluctuates significantly, it could make a visible impact on the overall market conditions. However, because the item is not included in the cost index calculation, the index fails to reflect the change in the market conditions.

The concept of Dynamic Item Basket (DIB) is designed to overcome this inherent problem of a fixed item basket (Figure 1). As stated in section 5.4.1, HCCI calculation requires unit prices and quantities for bid items from the two periods of interest. Thus, instead of using a fixed item basket with a limited number of bid items, a Dynamic Item Basket (DIB) includes all the bid items that appear in the two consecutive periods for calculating the cost indexes (Figure 1). Thus, data from significantly more bid items can be used, and hence the DIB based HCCIs will better represent the cost changes in the actual market conditions.

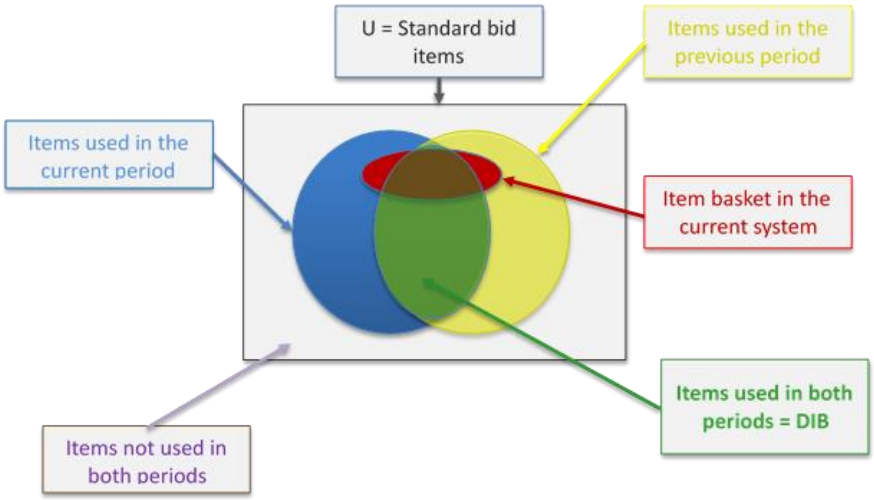


Figure 1 Concept of Dynamic Item Basket (DIB)

5.4.3 Multidimensional Highway Construction Cost Indexes (HCCIs)

The overall HCCI represents the overall market conditions across the state. However, the market conditions in a specific geographical region within the state might fluctuate differently than others. This could be a result of various factors such as rapid urbanization and/or the varying level of competition in different locations. Further, all registered contractors might be able to bid for smaller projects, but only a small number of large contractors may be able to bid on larger projects. Further, smaller projects require smaller quantities of bid items and larger projects require larger quantities of bid items. As such, the competition and hence expected unit prices of bid items for smaller and larger projects could vary differently. Thus, there is a need to develop cost indexes that may serve the SDDOT's specific needs of understanding different cost change trends.

Three different types of sub-HCCIs are developed in this study: a) project and contract characteristics based sub-HCCIs, b) bid item based sub-HCCIs, and c) custom item basket based sub-HCCIs. In the project and contract characteristics based sub-HCCIs, bid data from projects and contracts with a specific characteristic are preselected to compute sub-HCCIs. In the bid item based sub-HCCIs, bid item characteristics are used to preselect the bid data to calculate sub-HCCIs. Custom item basket based sub-HCCIs are developed to track the cost trend of a custom item basket or a fixed item basket.

5.4.3.1 Project and Contract Characteristics Based Sub-HCCI.

Various project and contract characteristics can be used to develop cost indexes. In this study, five different criteria are used to develop five different sets of sub-HCCIs (Table 1). The first three criteria are based on the location of the projects.

Table 1 Sub-HCCIs Based on Project and Contract Characteristics

HCCI Criteria	Sub-HCCI (or HCCI Type)
Rural and Urban	Rural
	Urban
Reservation and Non-Reservation	Reservation
	Non-Reservation
Regional	Aberdeen
	Mitchell
	Pierre
	Rapid City
Oversight	Federal Oversight
	No Federal Oversight
Contract Size	Small Size
	Mid-Size
	Large Size

Figure 2 illustrates the region-specific HCCIs for four regions in South Dakota. For each region-specific HCCI, bid data with the contracts from the corresponding region are selected. If a contract includes projects from multiple regions, then bid data from such contracts are included in multiple region-specific HCCI calculations. This subset of bid data is then used to calculate the chained Fisher index for the region. The same principle is applied to compute 13 different sub-HCCIs under five different categories (Table 1). These characteristics are available in SDDOT's bid data.

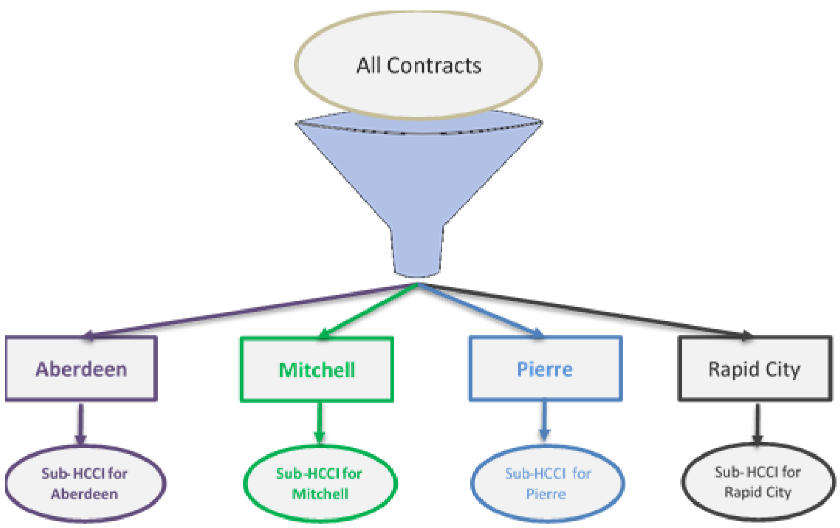


Figure 2 Region-Specific sub-HCCIs

- Rural and Urban

Urban areas represent "densely developed territory, and encompass residential, commercial, and other non-residential urban land uses" (US Census Bureau 2020). The areas not included within an urban area is classified as rural. Out of 1,570 contracts let from 2010 to 2019, 1,266 had projects that were located in rural areas and 336 had projects that are located in urban areas (Table 2). In terms of the dollar values, over three-quarters of the projects were executed in rural areas. Some contracts had multiple projects that were located in rural and urban areas. Such contracts are included in both rural and urban classifications. As such, the sum of the rural and urban contract count and contract amount exceeds the grand total.

Table 2 Project Summary based on the Urban and Rural Categorization

Rural and Urban	Contract Count	Percentage	Total Contract Amount	Percentage
Rural	1,266	80.64%	$ 2,739,276,552.78	78.79%
Urban	336	21.40%	$ 896,758,850.97	25.79%
Grand Total	**1,570**	**100.00%**	**$ 3,476,516,477.74**	**100.00%**

- Federal Reservation/Tribal land versus Other Areas

South Dakota has eight federal reservations and one designated tribal land area (Figure 3). These areas have additional regulations that might affect the construction cost trend. If a contract includes projects in any reservation or tribal land area, bid data from those contracts are used to compute sub-HCCIs for reservation area.

The data shows that 241 contracts had projects located in the reservations and/or tribal land areas and cost 15.16% of the total value of all contracts. The percentage of contract counts with projects in reservation and/or tribal land areas (15.35%) is almost the same as its percentage in dollar value (15.16%) (Table 3).

Table 3 Project Summary based on the Reservation and Tribal Land Area Categorization

Description	Contract Count	Percentage	Total Contract Amount	Percentage
Reservation/Tribal land	241	15.35%	$ 527,046,014.65	15.16%
Other areas	1,363	86.82%	$ 3,050,444,333.86	87.74%
Grand Total	**1,570**	**100.00%**	**$ 3,476,516,477.74**	**100.00%**

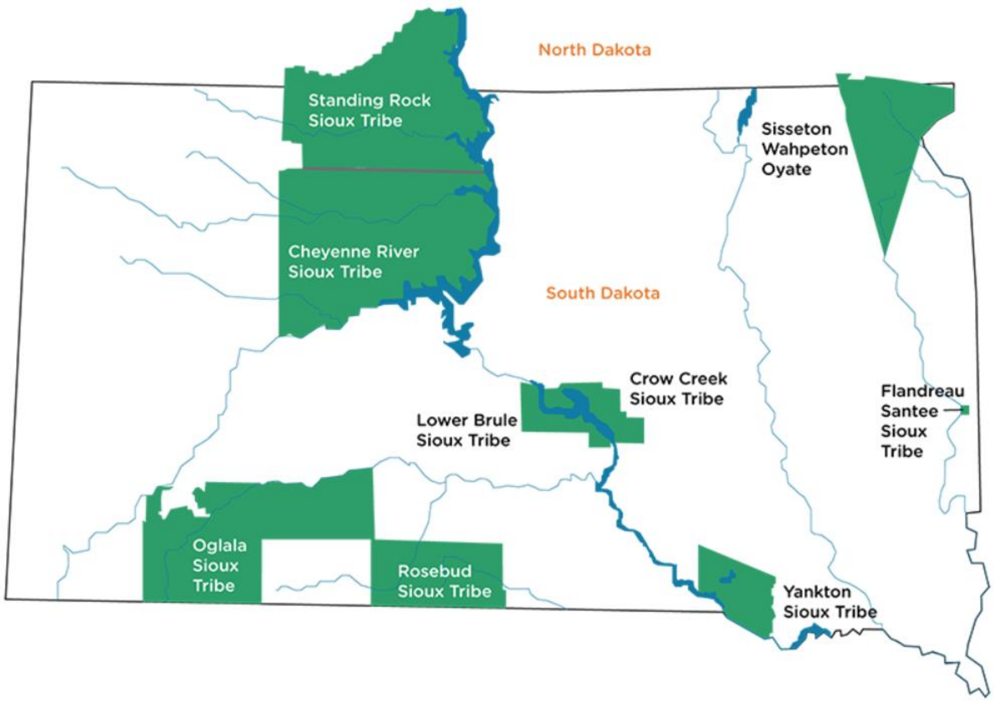


Figure 3 Indian Reservation and Tribal Land Areas in South Dakota

➢ Administrative Regions

South Dakota DOT is divided into 4 regions: Aberdeen, Mitchell, Pierre, and Rapid City as shown in Figure 4. If any contract includes projects in multiple regions, the data from the contract are used to calculate sub-HCCIs for each of the regions.

Figure 4 Four Main Regions in South Dakota

Table 4 shows that the region with the highest and the lowest highway construction activities are the Mitchell region and Pierre region, respectively. In the Mitchell region, the percentage of dollar value is higher than the percentage of contract count, which indicates that the contracts in that region are likely to be larger in size or construction is expensive in that region compared to others. Note that some contracts included projects in multiple regions. Such contracts are included in multiple regions. As such, the total number of contracts and the total contract amount adds up to more than the grand totals.

Table 4 Project Summary based on the Regions

Region	Contract Count	Percentage	Total Contract Amount	Percentage
Aberdeen	447	28.47%	$ 856,097,700.28	24.63%
Mitchell	509	32.42%	$ 1,193,151,590.19	34.32%
Pierre	312	19.87%	$ 773,838,793.10	22.26%
Rapid City	369	23.50%	$ 907,093,790.31	26.09%
Grand Total	**1,570**	**100.00%**	**$ 3,476,516,477.74**	**100.00%**

- Federal Oversight Projects

Projects with Federal oversight need to follow more regulations than other projects. The data collected from the SDDOT show that 146 contracts were under Federal oversight (Table 5). Although these projects account for only 9.30% of all project count, the total dollar value of the contracts is significant (42.51%). Some contracts included multiple projects. Some of the projects had federal oversight and others did not. As such, the sum of the contract count and total contract amount exceeds the grand total.

Table 5 Project Summary based on Federal Oversight

Federal Oversight	Contract Count	Percentage	Total Contract Amount	Percentage
Yes	146	9.30%	$1,477,811,797.22	42.51%
No	1,431	91.15%	$2,058,032,264.93	59.20%
Grand Total	**1,570**	**100.00%**	**$3,476,516,477.74**	**100.00%**

- Contract Size

The contract size is also a factor that may influence the item price. Generally, large quantity items tend to have a lower unit price due to the economy of scale. In this study, contracts were classified into three categories based on the contract amount. Contract amount ranges for the three sizes were selected so that about 70% of the contracts in the middle fall under the mid-sized contract category. After analyzing SDDOT data, contracts from $200,000 to $4,500,000 were selected as the mid-sized contracts as they represent approximately 70% of the contracts in the middle. The contracts below $200,000 are categorized as small-sized contracts, and the contracts above $4,500,000 categorized as large-sized contracts (Table 9). This categorization is purely for this research purpose. If SDDOT is interested in categorizing contract sizes into different ranges, it can be customized later.

Table 6 Contract Summary based on Dollar Values

Contract Size	Contract Count	Percentage (Number)	Total Contract Amount	Percentage (Dollar Value)
Small-Size	243	15.48%	$28,829,462.47	0.83%
Mid-Size	1,116	71.08%	$1,359,870,663.60	39.12%
Large-Size	211	13.44%	$2,087,816,351.67	60.05%
Grand Total	**1,570**	**100.00%**	**$3,476,516,477.74**	**100.00%**

The 243 small-sized projects account for roughly 0.83% of the total dollar value. The 211 large-sized projects account for around 60.05% of the total contract amount.

5.4.3.2 Bid Item Characteristics based Sub-HCCI.

In the bid item characteristics based sub-HCCIs, bid data from certain types of bid items are selected to calculate a cost index. The first set of six sub-HCCIs are based on the six parts listed under Division II Construction Details in the 2015 South Dakota Standard Specifications for Roads and Bridges (SDDOT 2015). The second set of sub-HCCIs is developed specifically for a) Traffic Control and b) Erosion Control and Water Pollution Control. The traffic control sub-HCCIs use bid data from all the bid items whose bid item ID number begins with 634. The erosion control and water pollution control sub-HCCI uses all the bid items whose bid item ID number begins with 734.

Table 7 Sub-HCCIs based on Bid Item Characteristics

HCCI Criteria	Sub-HCCI (or HCCI Type)
Item Part	Earthwork
	Granular Bases and Surfacing
	Asphalt Construction
	Rigid Pavement
	Structures
	Incidental Construction
Subparts	Traffic Control
	Erosion Control and Water Pollution Control

5.4.3.3 Custom Item Basket Based Sub-HCCIs

A custom item basket enables tracking the market conditions for a prespecified or a fixed item basket. For example, a custom item basket with 10 largest bid items based on the total item cost can be developed. The list of bid items in the custom item basket is presented in Table 8.

Different customized item baskets based on specific needs may be created in the future and embedded in the software tool.

Table 8 Top 10 Largest Bid Items

Bid Item ID	Bid Item Description
320E0005	PG 58-34 Asphalt Binder
320E0008	PG 64-34 Asphalt Binder
320E1203	Class Q3R Hot Mixed Asphalt Concrete
120E0010	Unclassified Excavation
260E1010	Base Course
320E1202	Class Q2R Hot Mixed Asphalt Concrete
360E0042	CRS-2P Asphalt for Surface Treatment
320E0007	PG 64-28 Asphalt Binder
380E0100	10.5" Nonreinforced PCC Pavement

5.4.4 Data Preprocessing

The raw bid tabulation data that were obtained from the SDDOT were processed for: a) outlier removal and b) lump sum items removal, which were recommended by FHWA.

5.4.4.1 Outlier Removal

In calculating cost indexes, FHWA has developed outlier removal techniques based on the unit price distribution of bid items to minimize any bias. South Dakota DOT engineers have expressed interest in understanding how the HCCIs would vary when such outliers are removed versus when all data are included. Thus, two different versions of overall HCCIs were calculated for this comparison (one with outliers removed, and the other with all data). But, for other cost indexes, the dataset with outliers removed was used.

An overview of the rationale behind the outlier removal technique used by FHWA is provided here. For further details about this approach, readers can refer to any statistical textbooks such as Ott and Longnecker (2015). Figure 5 shows a probability distribution function of normally distributed data. The vertical axis represents the probability distribution function, and the horizontal axis represents the value (x) such as the unit price of a bid item. The normal distribution is a theoretical distribution and real-life data may not follow a perfectly normal distribution.

The figure illustrates the amount of data that lies within certain standard deviations (σ) from the mean (μ). Specifically, 68.27% of all data lies within one standard deviation from the mean, i.e. ($\mu - \sigma$) to ($\mu + \sigma$). Similarly, 95.45% of all data lies within two standard deviations. Finally, almost all the data (99.73%) lies within three standard deviations. Thus, any values that are further away (over three standard deviations) from the mean can be considered as outliers and these outliers are eliminated. Statistically, the percentage of outliers will be approximately 0.27%.

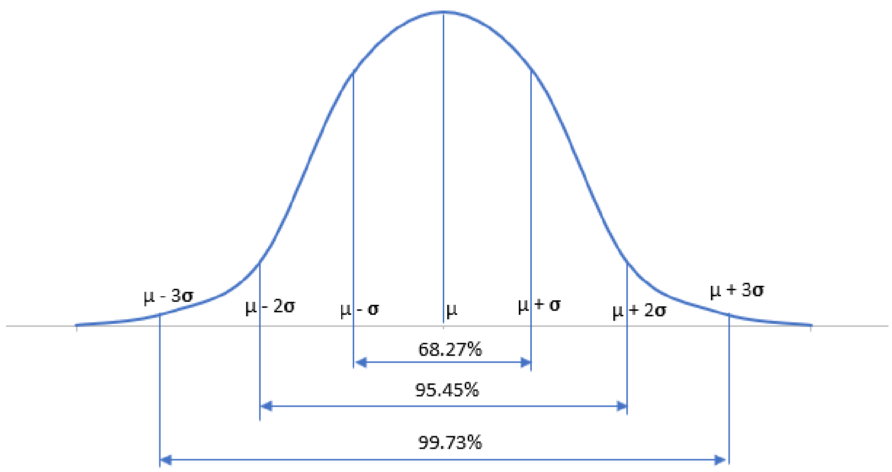


Figure 5 Probability Density Function for Normal Distribution

However, it should be noted that the unit prices do not follow a perfectly normal distribution. As such, sometimes all the unit prices may lie within the three times the standard deviation range, i.e. (μ - 3σ) to (μ + 3σ). In other extreme cases, the standard deviations might be so large that (μ - 3σ) would become a negative number, which does not represent the reality.

Finally, the standard deviation and the mean can be calculated for each item using all historical bid data or bid data from a limited number of years. The nominal dollar value was used for calculating the standard deviation and mean. Thus, using historical bid data from all years to compute a universal outlier range for a specific bid item could be problematic if the unit prices of a bid item change dramatically over time. Thus, in this study, an outlier range for a specific bid item for the immediate last three years was calculated instead of all past years. Further, the outlier determination of a bid item was done for the overall HCCI, not at each sub-HCCI level due to a limited number of data points.

5.4.4.2 Lump-sum Item Removal

The quantity of a lumpsum item does not represent a true quantity of work to be performed or the amount of material to be used. The quantity of such an item is generally assigned as 1 irrespective of the actual quantity of the work or the quantity of materials to be used. For example, 009E0010 Mobilization is an item that generally has a unit of one. Thus, such an item cannot be used to calculate HCCIs. In other words, if the quantity does not change while the unit price changes, a cost index calculated using such items fails to reflect the true market conditions. For example, assume two contracts. The first one was executed last year, and the contract amount was $100,000. The second one was executed this year and the contract amount was $200,000. Since both contracts are a single contract, we can use a quantity of 1 for both cases. If we were to calculate the inflation rate using these two data points, the conclusion would be that construction cost this year is two times the last year's cost. However, this conclusion could be completely wrong if this year's quantity of work is twice the last year's project. The real inflation is zero. The use of lump-sum items will have the same effect on the cost index. Thus, it is desirable to remove all lump-sum items in the cost index calculation.

One state DOT uses the percentage of total cost as the quantity of a lumpsum item. Such method will likely result in an inaccurate analysis. For example, consider a roadway construction project with $15,000 traffic control and $100,000 contract amount. The quantity of the traffic control will be 15%. Consider another similar project with twice the length of the previous one and assume that the total traffic control is $30,000 and the total contract amount is $200,000. In this case, the quantity of the traffic control for this second project will also be 15% while it should be about twice as much. Further, if the unit price of traffic control is calculated by dividing the total traffic control cost by the virtual computed quantity (i.e.,15%), it would be $1,000/unit(%) for the first case and $2,000/unit(%) for the second case – essentially indicating the 100% inflation. Thus, including such virtual quantities will result in misleading HCCI values and are not considered for this study.

South Dakota DOT engineers expressed interest in using data of lump-sum items. The major rationale was that a) traffic control and b) erosion control and pollution control items have become larger portions of the construction costs in recent years. However, because of the reasons stated above, such lump-sum items cannot be used. Instead, non-lump-sum items from traffic control and erosion control and pollution control were used to compute sub-HCCIs. The data analysis shows that the non-lump-sum items represent 64% of traffic control items and 91% of erosion control items.

5.5 Highway Construction Cost Index (HCCI) Forecasting Framework

Cost Indexes are indicators of historical market conditions. However, South Dakota DOT wants to have an ability to forecast the future market conditions so that they may use the forecasted cost indexes as inflation rates for budgeting and programming future construction projects. This section describes two approaches to forecasting cost indexes: a) linear regression and b) weighted time series.

5.5.1 Linear Regression

Linear regression assumes that the distribution of data points can be represented with sufficient accuracy with a straight line known as the best fit line (Figure 6). It assumes that any future values will lie in the same straight line. Mathematically, it can be represented as a simple linear equation as shown in Equation (5) below.

$$HCCI_{t,0} = a * t + b \qquad \textbf{(5)}$$

In the above equation, a Chained Fisher Index ($HCCI_{t,0}$) for period t (number of years from the base year) is predicted using the period (t). the constants a and b are computed based on historical data. For a more detailed technical description of linear regression theory, readers can refer to any standard textbooks on statistics such as Ott and Longnecker (2015).

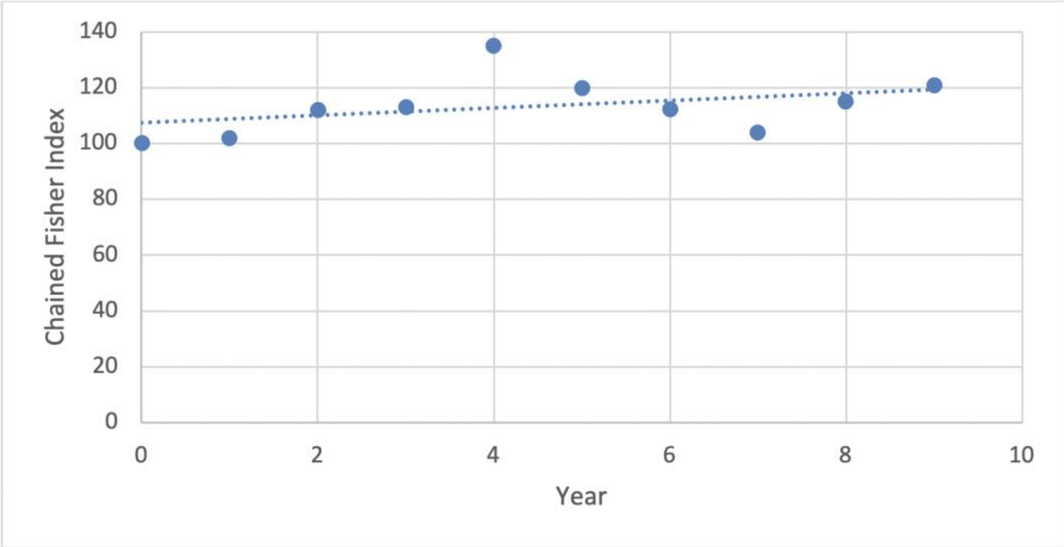


Figure 6 Linear Regression Using 10 Years of Historical Data

The linear regression puts equal weight on all data points irrespective of the closeness of data points to the present time. Thus, the linear regression may not be theoretically the most suitable method for forecasting time-dependent values. However, the methodology can be improved to partially account for such limitation by using only the recent data to plot the best fit line and forecast instead of using all the data. In Figure 7, only the last 3 years of data, i.e. data from 7^{th}, 8^{th}, and 9^{th} years, are used to plot the best-fit line that will be used to forecast future values. Thus, a steeper upward trend is visible in the chart than the line in Figure 5. This steeper slope may represent a more accurate picture of the growth in the market conditions in recent history. However, such trend may or may not continue in the future. Thus, the number of years for developing a regression model should be carefully selected to ensure optimum forecasts.

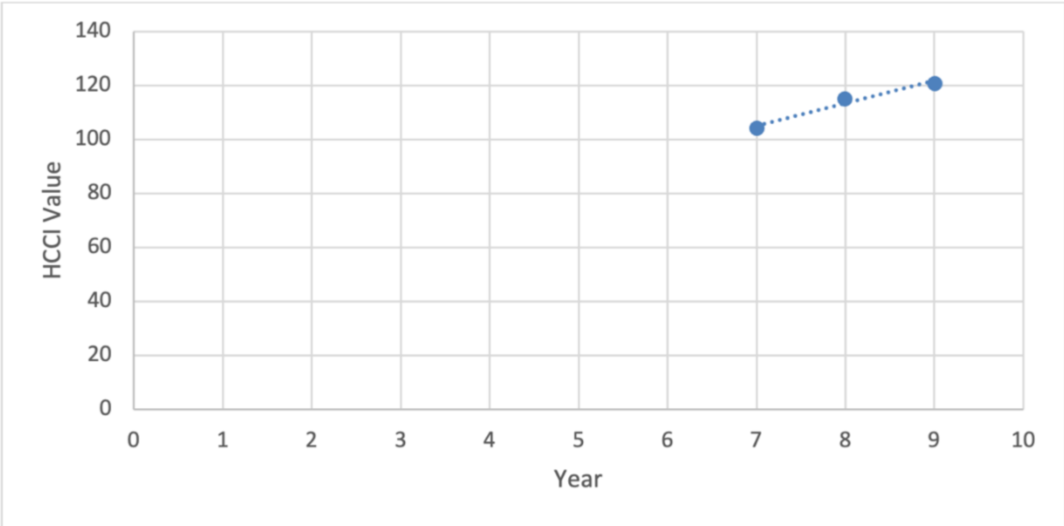


Figure 7 Linear Regression Using 3 Years of Historical Data

5.5.2 *Weighted Time Series*

Weighted time series assumes that the future will be more similar to the most recent history and less similar to the older histories. Mathematically, a Weighted Time Series can be expressed as:

$$HCCI_{t,t-1} = \frac{\sum_{i=1}^{t-1} i * HCCI_{i,i-1}}{\sum_{i=1}^{t-1} i} \quad \textbf{(6)}$$

In the above equation, a Relative Fisher Index ($HCCI_{t,t-1}$) is forecasted for a future year which is then chained to compute a Chained Fisher Index ($HCCI_{t,0}$). By default, it can only forecast one future year of HCCI. However, the forecast for the next year is then used as historical data to continue to forecast cost indexes of future years. For more details on the time series analysis, readers can refer to statistical textbooks such as Chiulli (1999).

5.5.3 *Error Analysis*

The forecasting models can be evaluated by the goodness of fit measures such as Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE). In both methods, some parts of the historical HCCI data are used to train a model and the remaining data are used to evaluate the performance of the model. For example, HCCI values up to 2015 are used to develop a model to forecast HCCI values for 2016, 2017, etc. Then, those forecasted values are compared against the actual HCCI values. The difference between those two values is then used to compute MAPE and RMSE using Equations (7) and (8) below.

$$MAPE = \frac{100}{n} * \sum_{i=1}^{n} \left| \frac{HCCI_{i,actual} - HCCI_{i,forecasted}}{HCCI_{i,actual}} \right| \quad \textbf{(7)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (HCCI_{i,actual} - HCCI_{i,forecasted})^2}{n}} \quad \textbf{(8)}$$

The models with the lower values of MAPE and RMSE are better at forecasting the HCCI values with higher accuracies. More details about error analysis can be found in statistical textbooks such as Yaffee and McGee (2000).

5.5.4 *Limitations of Forecasting Techniques*

Forecasting techniques rely on historical data to predict the future. This inherently means that those techniques assume that the historical trend in the market conditions will continue in the future. Thus, if there is a dramatic change in the market conditions because of external factors, such forecasts are unlikely to be able to reliably predict the future market conditions.

5.6 Results

This section presents the HCCIs computed and forecasted using the methodologies described in the previous section.

5.6.1 *Data Collection*

Two main datasets were collected from SDDOT to compute various cost indexes. The first dataset consists of various contract and project characteristics such as contract ID, letting date, region, reservation, and rural/urban. The second dataset includes bid item details such as contract ID, item ID, quantity, and unit price. The dataset collected from SDDOT included data from the calendar year 2009 to 2019. The year 2010 is set as the base year. Thus, data from 2009 is ignored. Table 9 provides a summary of contracts and projects let from 2010 to 2019 that represent over $4.7 billion worth of construction.

Table 9 Summary of Contracts and Projects

Let Year	Contract Count	Project Count	Total Contract Amount
2010	207	250	422,011,826.84
2011	179	251	491,035,704.13
2012	189	248	642,550,815.91
2013	141	188	459,245,230.29
2014	158	186	343,725,383.01
2015	124	153	476,698,182.00
2016	153	183	456,116,931.32
2017	151	179	571,463,567.59
2018	158	191	505,564,988.63
2019	110	128	382,544,212.52
Total	**1570**	**1957**	**4,750,956,842.24**

5.6.2 *Dynamic Item Basket and Outlier Removal*

Different dynamic item baskets are generated for various HCCIs and sub-HCCIs for different years. Table 10 shows the number of bid items included in the dynamic item baskets and their dollar values which were used to calculate overall HCCIs for various years. The table includes values when all data are included and when outliers are removed.

Table 10 Number of Items and Their Dollar Values in Dynamic Item Basket (DIB) for Overall HCCI Calculation

Year	Number of Items in DIB			Total Item Amount in Previous Year			Total Item Amount in Current Year		
	Outliers Not Removed	Outliers Removed	Percentage Difference	Outliers Not Removed	Outliers Removed	Percentage Difference	Outliers Not Removed	Outliers Removed	Percentage Difference
2011	980	979	0.10%	$270,686,132	$269,790,541	0.33%	$298,875,030	$297,048,941	0.61%
2012	1103	1100	0.27%	$365,419,757	$363,877,170	0.42%	$279,437,911	$278,550,012	0.32%
2013	1126	1125	0.09%	$301,052,591	$299,967,617	0.36%	$383,462,238	$382,006,604	0.38%
2014	1020	1020	0.00%	$222,323,393	$220,230,089	0.94%	$292,090,027	$291,297,440	0.27%
2015	978	978	0.00%	$267,753,457	$266,273,830	0.55%	$222,781,640	$221,098,485	0.76%
2016	994	993	0.10%	$286,819,069	$286,046,194	0.27%	$278,209,457	$276,081,535	0.76%
2017	1083	1083	0.00%	$292,406,934	$290,923,606	0.51%	$278,683,505	$277,860,512	0.30%
2018	1012	1012	0.00%	$299,181,822	$297,718,952	0.49%	$287,278,254	$285,468,287	0.63%
2019	924	923	0.11%	$231,885,755	$231,184,220	0.30%	$287,660,716	$286,426,795	0.43%

The number of items used does not decrease significantly when the outliers are removed. In both cases, approximately 900 to 1,100 bid items are used to compute the overall HCCIs. The difference in the dollar values of the items used for the current year and previous year is also less than 1% for all the years. Note that the values for 2010 are not provided as 2010 is set as the base year with a default value of 100.

5.6.3 Highway Construction Cost Indexes (HCCIs)

5.6.3.1 Overall Highway Construction Cost Indexes (HCCIs)

The relative cost indexes between two consecutive years are the values calculated before calculating the chained Fisher indexes. The relative HCCIs using all the data and after removing outliers are presented in Table 11 and Figure 8. The difference between the two sets of relative HCCIs is visible. Sometimes relative HCCIs using all data is higher, other times relative HCCIs after removing the outliers are higher. However, the relative HCCIs after removing outliers is higher more often and by larger percentages. Higher relative HCCIs when outliers are removed could indicate several scenarios: a) the current year had some unit prices that were on the lower end of the unit price distribution and hence are removed as outliers, b) the prior year had some unit prices that were on the higher end of the unit price distribution and hence are removed as outliers, or c) the combination of the two.

Table 11 Relative Overall HCCI With and Without Removing Outliers

Year	Relative HCCI		
	Outliers Not Removed	Outliers Removed	Percentage Difference
2010	1.0000	1.0000	0.00%
2011	0.9700	1.0192	-5.07%
2012	1.0600	1.0985	-3.63%
2013	1.0600	1.0094	4.77%
2014	1.2045	1.1936	0.90%
2015	0.8800	0.8887	-0.99%
2016	0.9100	0.9359	-2.85%
2017	0.9600	0.9268	3.46%
2018	1.0300	1.1071	-7.49%
2019	1.0509	1.0490	0.18%

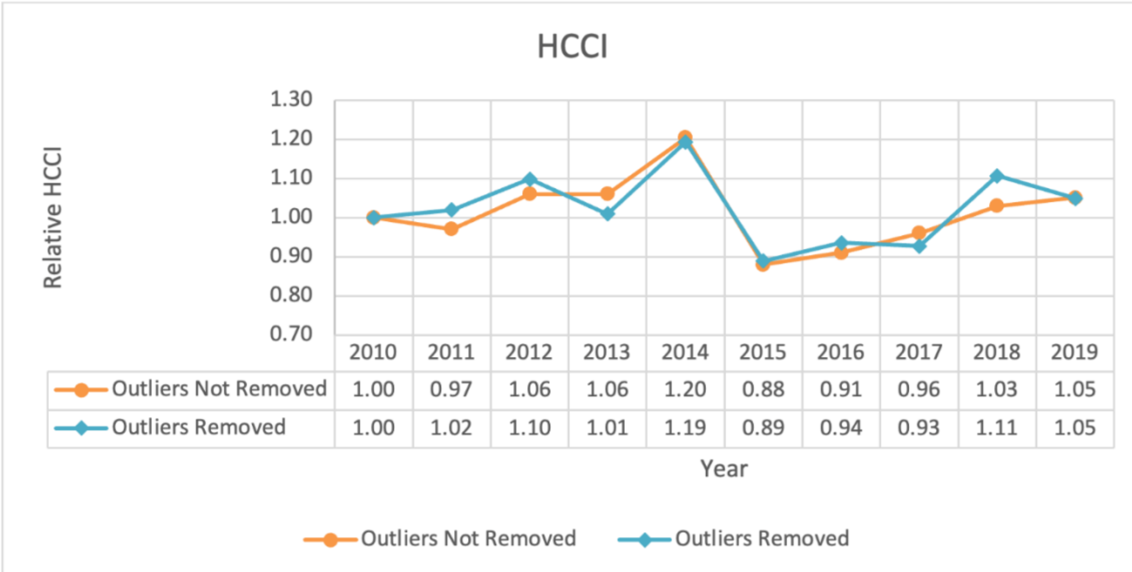


Figure 8 Relative HCCI Values with and Without Outliers

Once the chained HCCIs are calculated, they provide an interesting result. Since the relative HCCIs with outliers removed were generally higher and by larger percentages than the relative HCCIs calculated using all the data, the chained HCCIs are consistently higher if outliers are removed. Further, the smaller differences in the relative HCCIs continue to build up over years. In 2019, the two overall HCCIs are different by 10.54%.

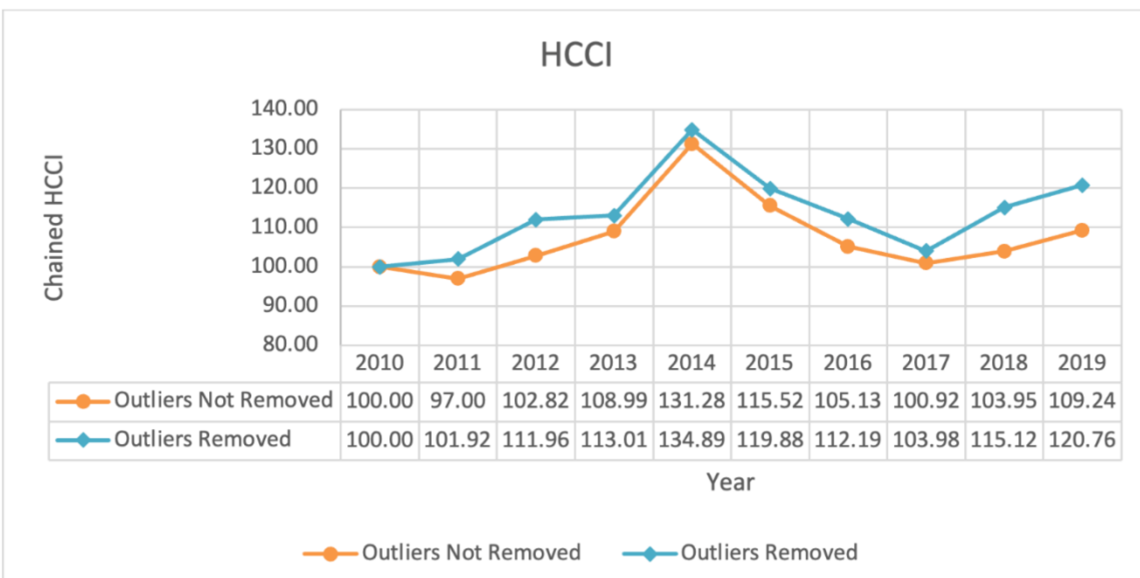


Figure 9 Chained HCCI Values with and Without Outliers

Since FHWA recommends removing outliers for cost index calculation, the dataset with outliers removed is used to calculate the remaining indexes.

5.6.3.2 Sub-HCCIs

The sub-HCCI values are tabulated in Appendix A: Sub-Highway Construction Cost Indexes (Sub-HCCIs). The values are visualized and discussed briefly in this section.

- Project and Contract Characteristics Based Sub-HCCIs

Five sets of sub-HCCIs are calculated and presented visually in this section (Figure 10, Figure 11, Figure 12, Figure 13, and Figure 14).

Figure 10 shows that the rural sub-HCCIs align closely with the overall HCCI compared to the urban sub-HCCI.

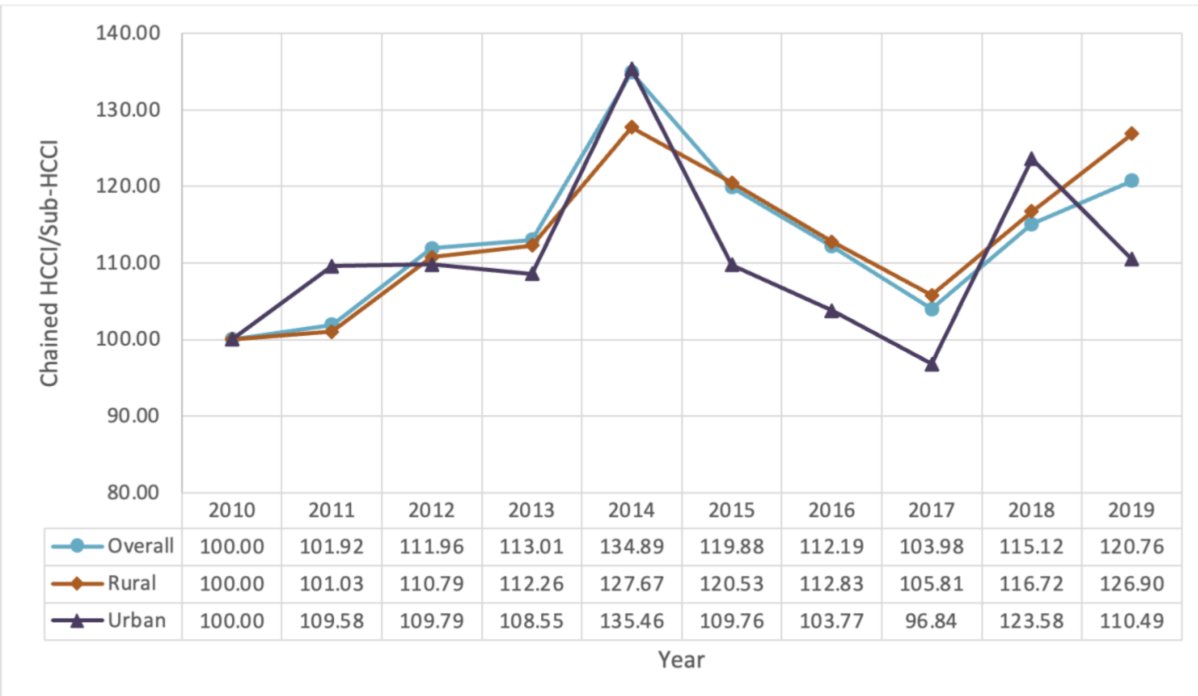
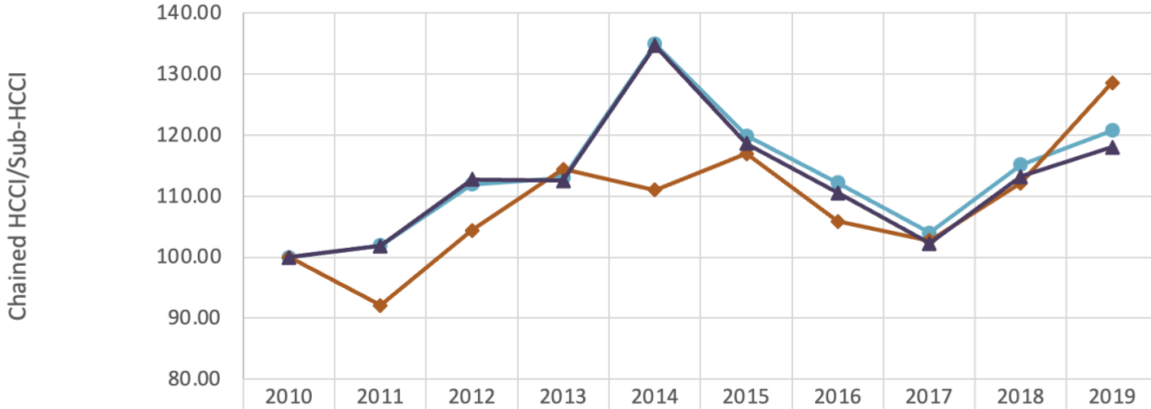


Figure 10 Rural and Urban sub-HCCIs

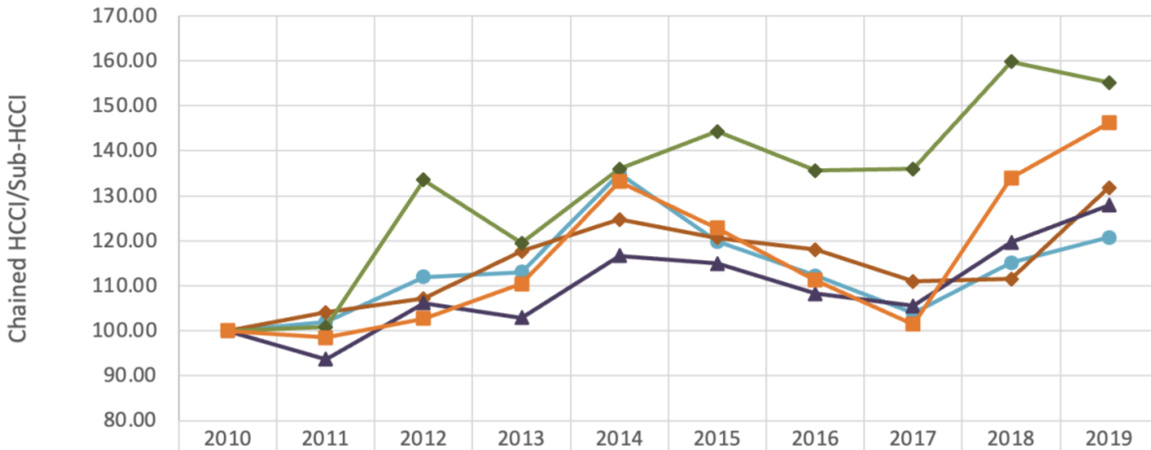
Figure 11 shows that the market conditions in the Indian reservation areas trend differently than the market conditions in the non-Indian reservation area when compared with the overall HCCIs.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Overall	100.00	101.92	111.96	113.01	134.89	119.88	112.19	103.98	115.12	120.76
Reservation	100.00	92.11	104.36	114.39	110.97	116.97	105.85	102.73	112.16	128.55
Non-Reservation	100.00	101.86	112.74	112.56	134.62	118.60	110.56	102.22	113.22	118.05

Figure 11 Indian Reservation and Non-Indian Reservation Sub-HCCIs

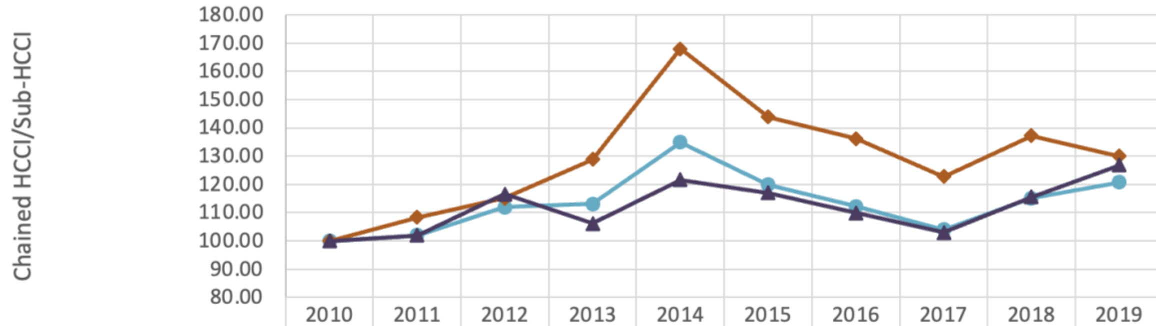
Figure 12 shows the region-specific HCCIs. Pierre Region has a much different cost trend in the market conditions than in other regions.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Overall	100.00	101.92	111.96	113.01	134.89	119.88	112.19	103.98	115.12	120.76
Aberdeen	100.00	104.11	107.20	117.68	124.72	120.68	118.06	110.95	111.51	131.86
Mitchell	100.00	93.66	106.14	102.90	116.67	114.96	108.26	105.55	119.67	127.93
Pierre	100.00	100.77	133.55	119.42	135.98	144.28	135.65	135.95	159.80	155.23
Rapid City	100.00	98.48	102.69	110.46	133.14	122.86	111.25	101.44	133.94	146.20

Figure 12 Regional Sub-HCCIs

Figure 13 shows that the cost of construction projects with federal oversight grew more rapidly than the cost of construction projects without federal oversight.

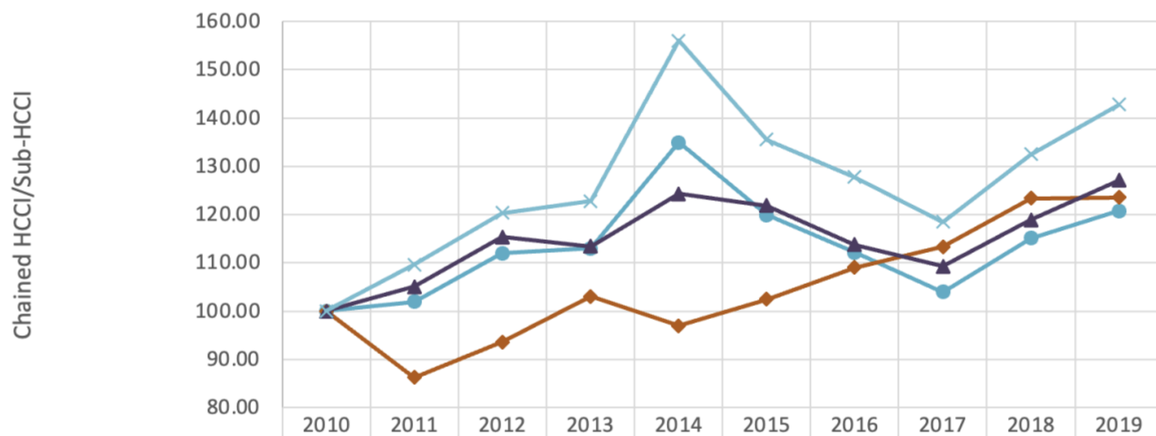


	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Overall	100.00	101.92	111.96	113.01	134.89	119.88	112.19	103.98	115.12	120.76
Federal Oversight	100.00	108.27	115.04	128.84	167.98	143.79	136.16	122.73	137.22	129.93
No federal Oversight	100.00	101.93	116.53	106.20	121.64	117.05	109.99	103.05	115.61	126.81

Year

Figure 13 Federal Oversight Based Sub-HCCIs

Figure 14 shows that the cost of large-sized projects grew more rapidly than the cost of mid-sized projects until 2014. Afterward, the cost of small-sized projects continued to inflate while that of medium and larger sized project deflated till 2017.



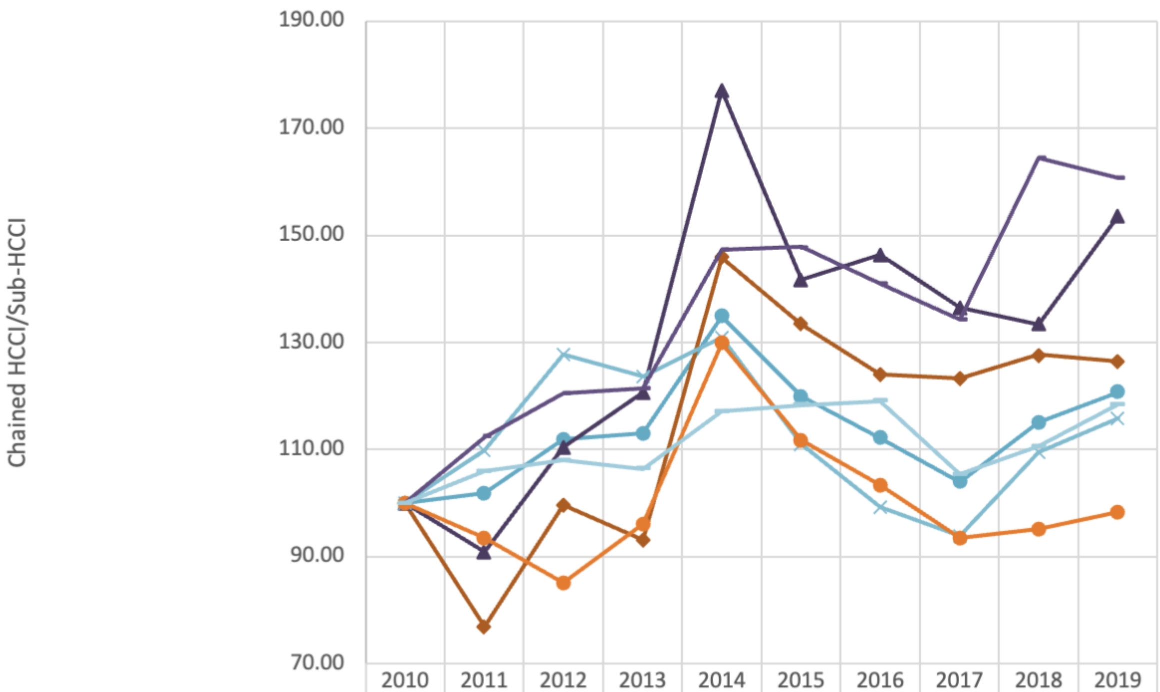
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Overall	100.00	101.92	111.96	113.01	134.89	119.88	112.19	103.98	115.12	120.76
Small Sized Contract	100.00	86.25	93.56	103.00	96.93	102.46	109.02	113.37	123.35	123.52
Mid Sized Contract	100.00	105.03	115.40	113.43	124.31	121.88	113.72	109.29	118.94	127.11
Large Sized Contract	100.00	109.58	120.35	122.75	156.04	135.50	127.75	118.46	132.45	142.77

Year

Figure 14 Contract Size Based Sub-HCCIs

➢ Bid Item Characteristics Based Sub-HCCIs

This section presents the results for work type specific sub-HCCIs (Figure 15). Most of the sub-HCCIs had similar trends except for a) granular bases and surfacing and b) structure.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Overall	100.00	101.92	111.96	113.01	134.89	119.88	112.19	103.98	115.12	120.76
Earthwork	100.00	76.95	99.61	93.17	145.89	133.43	124.05	123.28	127.68	126.42
Granular Bases and Surfacing	100.00	90.85	110.49	120.69	177.08	141.66	146.38	136.47	133.37	153.60
Asphalt Construction	100.00	109.87	127.72	123.69	130.94	111.10	99.26	93.85	109.48	115.80
Rigid Pavement	100.00	93.48	85.09	96.21	129.87	111.69	103.40	93.49	95.13	98.31
Structure	100.00	112.36	120.43	121.39	147.28	147.78	140.94	134.30	164.52	160.69
Incidental Construction	100.00	106.04	107.95	106.43	117.10	118.28	119.10	105.42	110.56	118.49

Year

Figure 15 Item Part Based Sub-HCCIs

Figure 16 shows Traffic control HCCIs and erosion control HCCIs. Both sub-HCCIs have increased at a slower pace than the overall HCCI. Erosion control construction costs have decreased from 2010 to 2019.

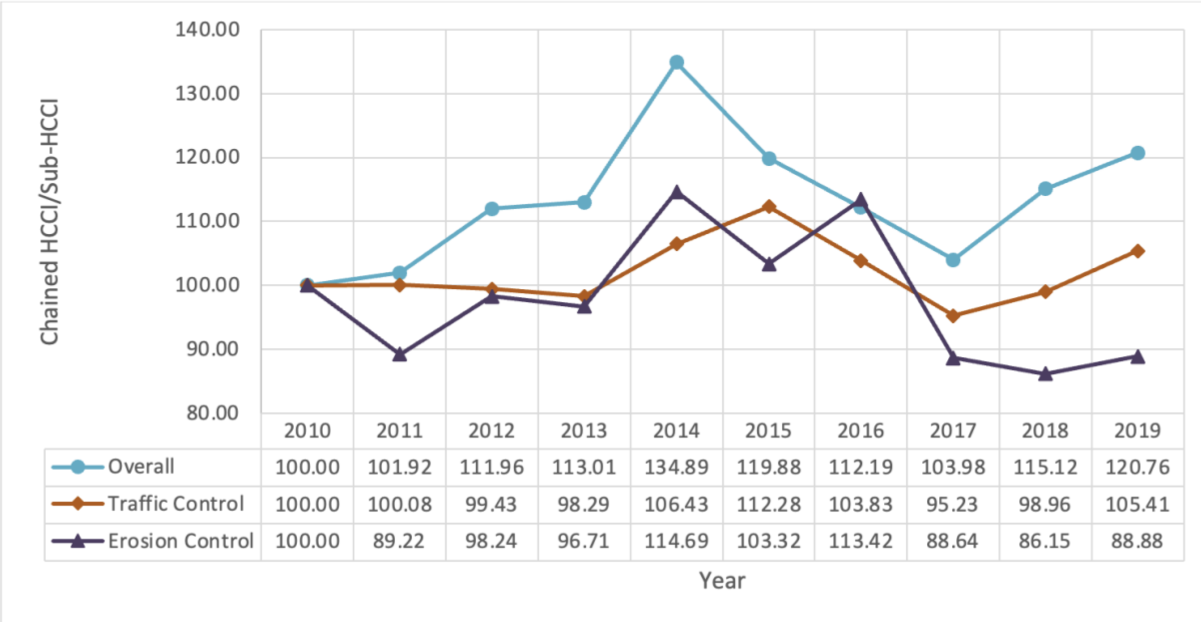


Figure 16 Item Sub-Part Based Sub-HCCIs

➢ Custom Item Basket Based Sub-HCCI

In this section, results for sub-HCCIs based on the top 10 largest items are compared with the overall HCCI (Figure 17). The two indexes fluctuated differently from 2010 to 2013, but, since 2013, the trend appears to be very similar.

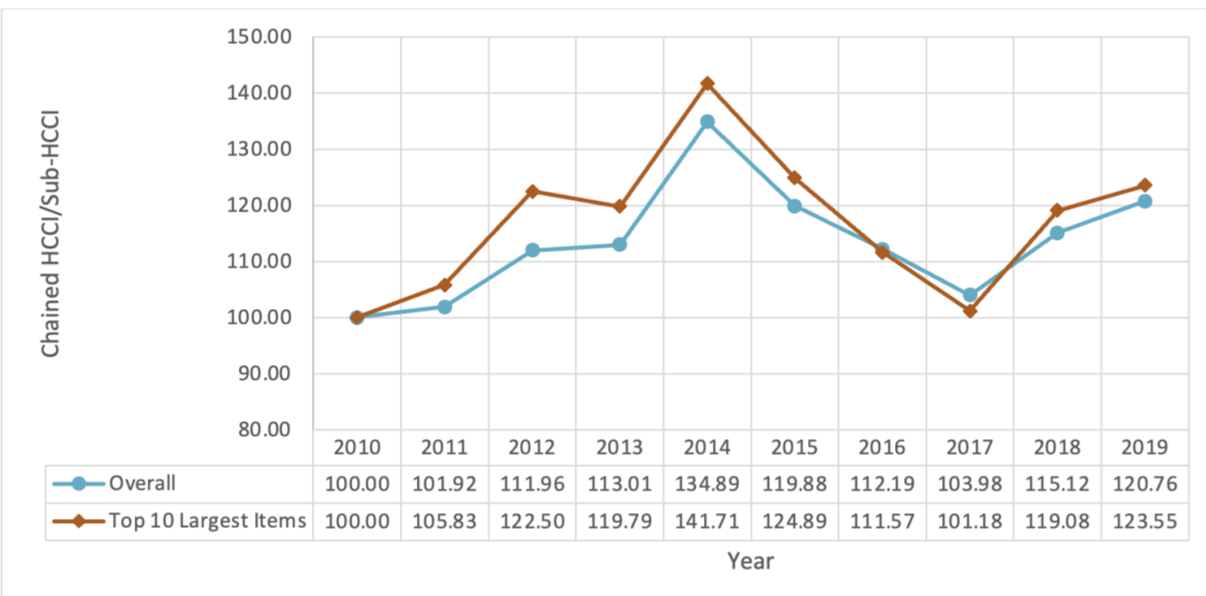


Figure 17 Custom Item Basket Based Sub-HCCI

5.7 Forecasting

5.7.1 Fine Tuning Time Series and Linear Regression Models

The historical HCCI values were split into a training dataset and a testing dataset. The forecasted values of HCCIs were compared against the actual HCCI values to compute errors. For example, HCCI values up to 2014 were used to develop forecasting models. This model is used to compute HCCI values from 2015 to 2019. Since the actual HCCI values of years from 2015 to 2019 are already known, the difference between the actual and forecasted values indicates the error in the forecasting model.

Figure 18 and Figure 19 shows the MAPE (%) and RMSE values when a varying number of historical HCCI values are used to predict future HCCI values. For both time series and linear regression, the errors decreased when the highest number of historical data available was used. Further, the linear regression model performs better than the time series. Thus, further results are presented using linear regression and the highest number of years of available data.

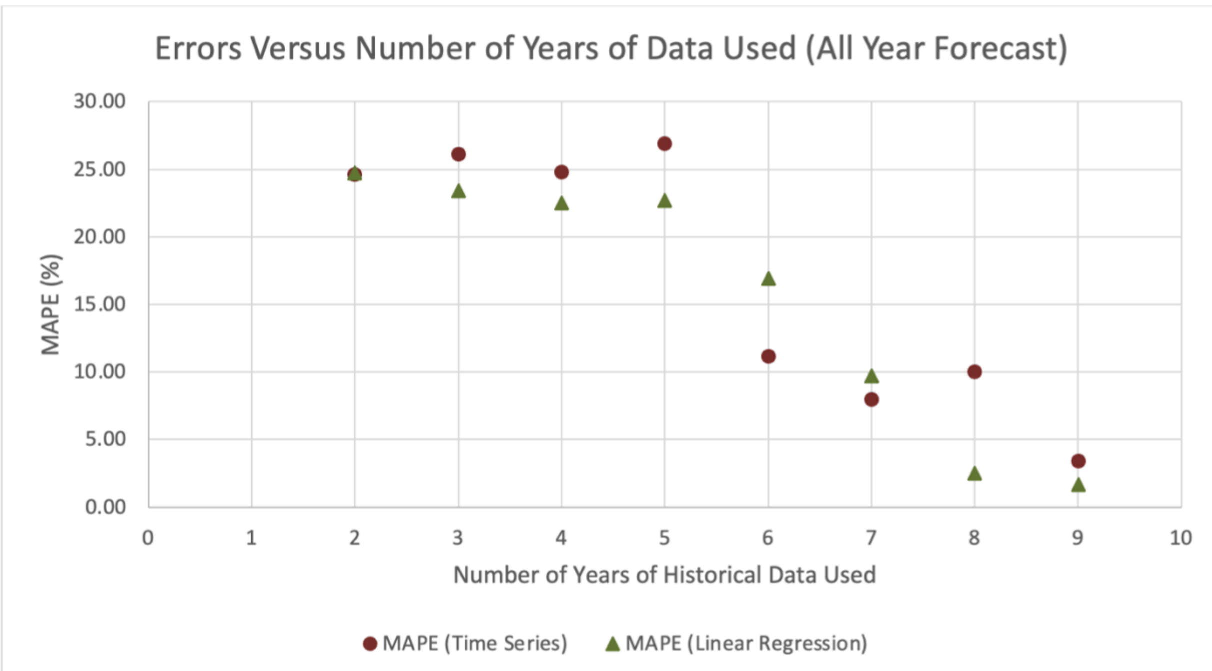


Figure 18 Change in MAPE (%) With the Number of Years of Historical Data Used

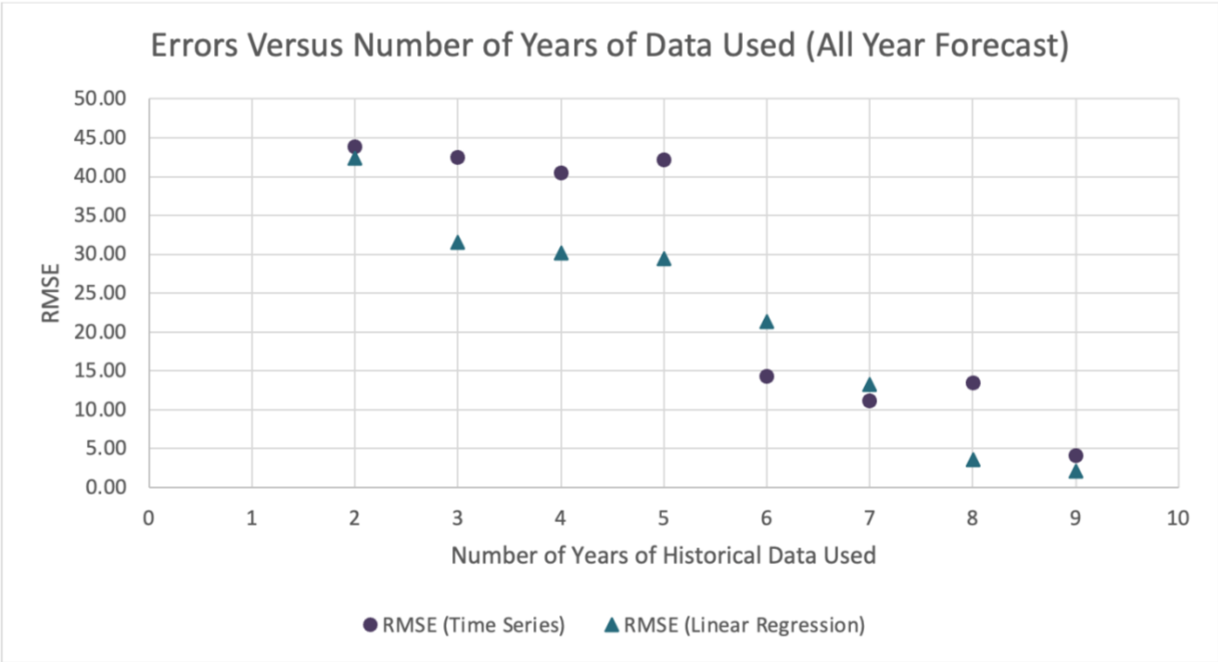


Figure 19 Change in RMSE With the Number of Years of Historical Data Used

5.7.2 Forecasted HCCI and Sub-HCCI Values

Forecasts were made for the next 15 years (2020 – 2034) based on historical data and the linear regression using the highest number of years of available data. Figure 20 shows the forecasted overall HCCI values based on the model. Forecasts for other sub-HCCIs are presented in Appendix C Appendix B: Forecasted Values of HCCIs.

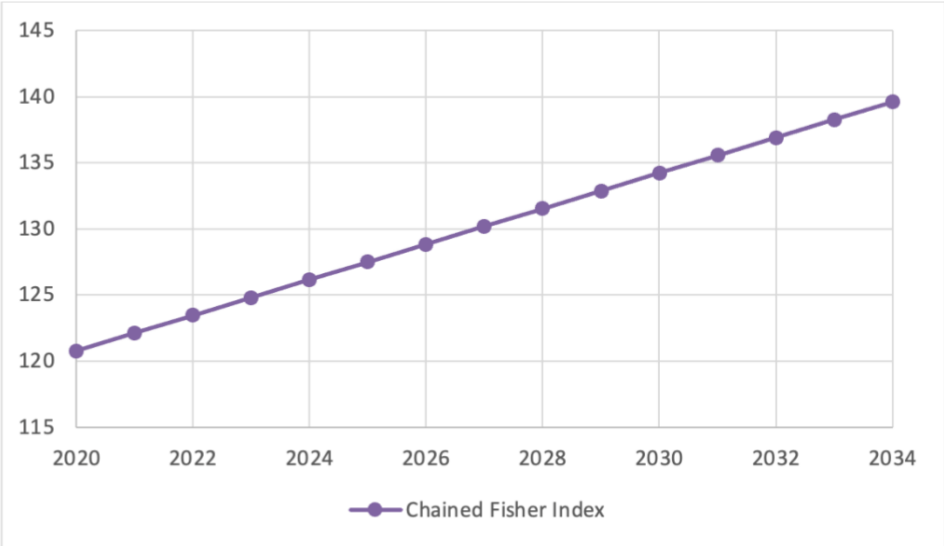


Figure 20 Forecasted Overall HCCI Values

5.8 Conclusions

An HCCI is an important indicator of the current market conditions. Although SDDOT currently has a methodology to compute HCCI, it has not been updated for several decades. Many SDDOT engineers were concerned that the current HCCIs do not accurately reflect the current market conditions as the market conditions vary within the state. Further, only eight bid items are currently used to compute HCCIs, which is a small fraction of all the bid items used by SDDOT. Further, SDDOT did not have a methodology to forecast HCCIs. The interviews conducted for this study showed that the use of SD HCCIs is currently limited despite being useful for multiple applications such as life cycle cost analysis, cost estimating, monitoring the construction market trend.

To address these issues, the research team developed an enhanced framework to compute and forecast multidimensional HCCIs using dynamic item baskets. The major improvements of the new solution developed by the researchers include a) multidimensional HCCIs that provides more granular market conditions, b) dynamic item basket and chained Fisher index that ensures the use of data from the maximum number of bid items, c) forecasting methodology that can be used for planning future projects, and d) automation of the HCCI calculation and forecasting to reduce the burden of manually calculating and forecasting HCCIs. In addition to an overall statewide HCCI, the framework and automation tool enable SDDOT engineers to compute multiple sub-HCCIs including sub-HCCIs for rural/urban, federal reservation/non-federal reservation, various administrative regions, various contract sizes, various bid-item characteristics. The HCCI values were forecasted using linear regression and weighted time series. The error analysis showed that linear regression predicted HCCIs with higher accuracies compared to the weighted time series.

Noticeable differences were observed when all data was used and when outliers were removed. However, since FHWA recommends removing outliers, all HCCIs except for the overall HCCIs were calculated using the dataset with outliers removed. SDDOT can continue to utilize HCCIs with outliers removed.

Linear regression and time series analysis both performed better when more data was used to predict future values. Between the two methods, linear regression performed better overall. Thus, future values of overall HCCI and sub-HCCIs were calculated using the linear regression with the highest number of data for the next 15 years.

The research team expects that the increased reliability of an overall HCCI, sub-HCCIs, and ease of computing them would aid in improved accessibility to the HCCIs among SDDOT users and consequently increased use of the HCCIs and sub-HCCIs.

6 RECOMMENDATIONS

The following ideas are recommended for SDDOT to benefit from the results of this research.

6.1 Use the SDDOT HCCI Tool

In this project, the SD DOT HCCI tool was developed to automate the computation process of multidimensional highway construction cost indexes using the C# programming language and MS SQL Server Database. This independent software tool is immediately available for implementation.

6.2 Compute and Distribute HCCI Values Annually

The HCCI values should be computed and saved in a portable format annually and distributed to the relevant personnel. The portable format might be an MS Excel, PDF, or web-based information-sharing page. The potentially relevant personnel may include SDDOT employees responsible for STIP and LRTP, city planners, contractors, consulting companies, and state legislature. An annual meeting among the users of HCCIs is recommended where all the users can share their perspectives on the HCCI trends and how it might affect SDDOT's financial resource planning and management. The meeting can also discuss various areas to further improve the HCCI calculation methodologies and/or tools to obtain more benefits from the available data.

6.3 Monitor Potential Warning Signs

Any sudden changes in the market conditions as indicated by widely fluctuating HCCI values should be investigated to identify the potential reasons behind the fluctuation. Such changes could be a result of reduced competition or increased cost of labor, material, or equipment.

6.4 Develop a Clean Dataset to Recompute All HCCIs and Sub-HCCIs

SDDOT should develop an automatic data extraction tool to extract and store data that will be used to compute HCCIs. This database should be automatically updated at least once a year after the results of the bids let in the previous year are available.

6.5 Train Current and New Users of the Software Tool

The computer software tool developed in this project connects to a shared network database by default. Proper training for new users using the user's manual that is available as part of the final products from this project is needed for continuous use of the software tool in case of the main users' retirement or rotation to a different position.

7 RESEARCH BENEFITS

The new HCCI calculation and forecasting tool developed as a part of this study will enable SDDOT to accurately track the current construction market conditions and reliably forecast HCCIs. For example, the HCCI values can be used as an inflation factor to improve the accuracy of programming level construction cost estimates for STIP and LRTP. The HCCI values may also be used as an inflation factor for LCCA and Benefit-Cost analysis. It can also be used to improve the accuracy of an engineer's estimate by using specific HCCIs directly relevant to a project's location, type, size, etc.

Sub-HCCIs can be monitored to understand varying market conditions for a specific work type in a specific region to capture an warning sign on any unexpected or different cost trend so that the agency can properly be prepared and respond. The new methodologies and the software tool developed in this study are expected to aid SDDOT in making more reliable data-driven decisions in planning, programming, and managing construction budgets.

8 REFERENCES

Chiulli, Roy M. 1999. *Quantitative Analysis: An Introduction*. CRC Press.

Federal Highway Administration (FHWA). 2011. "Price Trends for Federal-Aid Highway Construction." U.S. Department of Transportation, Federal Highway Administration. April 7, 2011. http://www.fhwa.dot.gov/programadmin/pt2006q1.cfm.

———. 2017. "The Mathematics of the National Highway Construction Cost Index." November 14, 2017. https://www.fhwa.dot.gov/policy/otps/nhcci/math.cfm.

Guerrero, Peter. Letter to Peter G. Fitzgerald and Daniel K. Akaka. 2003. "Comparison of States' Highway Construction Costs," November 3, 2003. http://www.gao.gov/assets/100/92296.pdf.

Huntsman, Brent, Brianne Glover, Samir Huseynov, Tengxi Wang, and Jacqueline Kuzio. 2017. "Highway Cost Index Estimator Tool Huntsman Estimating Tool Index." PRC 17-73. Texas A&M Transportation Institute. https://rosap.ntl.bts.gov/view/dot/35587.

International Monetary Fund (IMF). 2010. *Export and Import Price Index Manual: Theory and Practice*. OECD Publishing.

Jeong, H. David, Douglas D. Gransberg, and K. Joseph Shrestha. 2017. "Advanced Methodology to Determine Highway Construction Cost Index (HCCI)." Final Report FHWA/MT-17-006 / 8232-001. Montana Department of Transportation. http://www.mdt.mt.gov/other/webdata/external/research/DOCS/RESEARCH_PROJ/CONSTRUCT_COST_INDEX/Final_Report.pdf.

Mills, Peter. 2013. "Construction Cost Forecast Model - Model Documentation and Technical Notes," May. http://trid.trb.org/view/2013/M/1250687.

Minnesota Department of Transportation. 2018. "Highway Construction Costs and Cost Inflation Study." Saint Paul, Minnesota: Minnesota Department of Transportation.

Nassereddine, Hala, Gary C. Whited, and Awad S. Hanna. 2016. "Developing a Chained Fisher Construction Cost Index for a State Highway Agency." In . Washington, D.C.

Ohio Department of Transportation (ODOT). 2019. "January 2019 Construction Cost Outlook and Forecast." http://www.dot.state.oh.us/Divisions/ConstructionMgt/Estimating/TrendsAndForecasts/Construction%20Cost%20Outlook%20Archive/Jan2019_Construction_Cost_Forecast.pdf.

Ott, R. Lyman, and Micheal T. Longnecker. 2015. *An Introduction to Statistical Methods and Data Analysis*. Cengage Learning.

Shrestha, K. Joseph, H. David Jeong, and Douglas D. Gransberg. 2016. "Current Practices of Highway Construction Cost Index Calculation and Utilization." In , 351–60. San Juan, Puerto Rico. http://ascelibrary.org/doi/abs/10.1061/9780784479827.036.

———. 2017. "Multidimensional Highway Construction Cost Indexes Using Dynamic Item Basket." *Journal of Construction Engineering and Management* 143 (8): 04017036. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001307.

South Dakota Department of Transportation (SDDOT). 2015. "Standard Specifications for Roads and Bridges."

US Census Bureau. 2020. "Urban and Rural." The United States Census Bureau. February 24, 2020. https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural.html.

Walters, JonAnne, and Daniel Yeh. 2012. "Transportation Literature Search & Synthesis Report: Research and State DOT Practice on Construction Cost Indices." Wisconsin Department of Transportation (WisDOT). http://wisdotresearch.wi.gov/wp-content/uploads/WisDOT-

TSR-Construction-Cost-Index-2012.pdf.
White, Karen, and Ralph Erickson. 2011. “New Cost Estimating Tool.” *Public Roads*, 2011. http://www.fhwa.dot.gov/publications/publicroads/11julaug/02.cfm.
Yaffee, Robert Alan, and Monnie McGee. 2000. *An Introduction to Time Series Analysis and Forecasting: With Applications of SAS® and SPSS®*. Academic Press.
Yu, Shawn. 2012. “Colorado Construction Cost Index Report: Calendar Year 2012: Second Quarter.” Colorado Department of Transportation. http://www.coloradodot.info/business/eema/documents/2012/2012Q2CCI.pdf.

APPENDIX A: SUB-HIGHWAY CONSTRUCTION COST INDEXES (SUB-HCCIS)

Project and Contract Characteristics Based Sub-HCCIs

Year	Overall HCCI	Rural/Urban		Reservation/Others		Region				Federal Oversight		Contract Size		
		Rural HCCI	Urban HCCI	Reservation HCCI	Non-Reservation HCCI	Aberdeen HCCI	Mitchell HCCI	Pierre HCCI	Rapid City HCCI	Federal Oversight HCCI	No Federal Oversight HCCI	Small Sized Contract HCCI	Mid-Sized Contract HCCI	Large Sized Contract HCCI
2010	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2011	101.92	101.03	109.58	92.11	101.86	104.11	93.66	100.77	98.48	108.27	101.93	86.25	105.03	109.58
2012	111.96	110.79	109.79	104.36	112.74	107.20	106.14	133.55	102.69	115.04	116.53	93.56	115.40	120.35
2013	113.01	112.26	108.55	114.39	112.56	117.68	102.90	119.42	110.46	128.84	106.20	103.00	113.43	122.75
2014	134.89	127.67	135.46	110.97	134.62	124.72	116.67	135.98	133.14	167.98	121.64	96.93	124.31	156.04
2015	119.88	120.53	109.76	116.97	118.60	120.68	114.96	144.28	122.86	143.79	117.05	102.46	121.88	135.50
2016	112.19	112.83	103.77	105.85	110.56	118.06	108.26	135.65	111.25	136.16	109.99	109.02	113.72	127.75
2017	103.98	105.81	96.84	102.73	102.22	110.95	105.55	135.95	101.44	122.73	103.05	113.37	109.29	118.46
2018	115.12	116.72	123.58	112.16	113.22	111.51	119.67	159.80	133.94	137.22	115.61	123.35	118.94	132.45
2019	120.76	126.90	110.49	128.55	118.05	131.86	127.93	155.23	146.20	129.93	126.81	123.52	127.11	142.77

Bid Item Characteristics Based Sub-HCCIs

Year	Overall HCCI	Specification Part					
		Earthwork HCCI	Granular Bases and Surfacing HCCI	Asphalt Construction HCCI	Rigid Pavement HCCI	Structure HCCI	Incidental Construction HCCI
2010	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2011	101.92	76.95	90.85	109.87	93.48	112.36	106.04
2012	111.96	99.61	110.49	127.72	85.09	120.43	107.95
2013	113.01	93.17	120.69	123.69	96.21	121.39	106.43
2014	134.89	145.89	177.08	130.94	129.87	147.28	117.10
2015	119.88	133.43	141.66	111.10	111.69	147.78	118.28
2016	112.19	124.05	146.38	99.26	103.40	140.94	119.10
2017	103.98	123.28	136.47	93.85	93.49	134.30	105.42
2018	115.12	127.68	133.37	109.48	95.13	164.52	110.56
2019	120.76	126.42	153.60	115.80	98.31	160.69	118.49

Custom Item Basket Based Sub-HCCIs (Top 10 Largest Cost Items)

Year	Overall HCCI	Top 10 Largest Items
2010	100.00	100.00
2011	101.92	105.83
2012	111.96	122.50
2013	113.01	119.79
2014	134.89	141.71
2015	119.88	124.89
2016	112.19	111.57
2017	103.98	101.18
2018	115.12	119.08
2019	120.76	123.55

APPENDIX B: FORECASTED VALUES OF HCCIS

Forecasted Values of Overall HCCI and Project and Contract Characteristics Based Sub-HCCIs

Year	Overall HCCI	Sub-HCCIs												
		Urban/Rural		Reservation/Non-Reservation		Region				Federal Oversight		Contract Size		
		Rural	Urban	Reservation	Non-Reservation	Aberdeen	Mitchell	Pierre	Rapid City	Federal Oversight	No Federal Oversight	Small Sized	Mid-Sized	Large Sized
2020	120.77	124.17	113.70	121.13	118.02	126.49	124.40	164.70	137.71	145.94	121.09	124.95	125.22	144.24
2021	122.11	126.12	114.23	123.37	119.03	128.64	127.10	170.64	141.64	149.02	122.77	128.55	127.09	147.45
2022	123.45	128.07	114.77	125.61	120.05	130.79	129.80	176.57	145.58	152.10	124.45	132.15	128.97	150.66
2023	124.80	130.02	115.30	127.84	121.06	132.94	132.49	182.51	149.52	155.18	126.12	135.75	130.84	153.87
2024	126.14	131.97	115.83	130.08	122.08	135.08	135.19	188.44	153.46	158.26	127.80	139.35	132.71	157.09
2025	127.49	133.91	116.36	132.32	123.09	137.23	137.89	194.38	157.40	161.34	129.47	142.95	134.59	160.30
2026	128.83	135.86	116.89	134.56	124.11	139.38	140.58	200.31	161.34	164.42	131.15	146.55	136.46	163.51
2027	130.18	137.81	117.42	136.80	125.12	141.53	143.28	206.24	165.28	167.50	132.82	150.15	138.34	166.72
2028	131.52	139.76	117.95	139.04	126.13	143.67	145.97	212.18	169.21	170.58	134.50	153.75	140.21	169.94
2029	132.87	141.71	118.49	141.28	127.15	145.82	148.67	218.11	173.15	173.66	136.17	157.35	142.09	173.15
2030	134.21	143.66	119.02	143.52	128.16	147.97	151.37	224.05	177.09	176.74	137.85	160.95	143.96	176.36
2031	135.55	145.61	119.55	145.76	129.18	150.12	154.06	229.98	181.03	179.82	139.52	164.55	145.83	179.57
2032	136.90	147.56	120.08	148.00	130.19	152.27	156.76	235.92	184.97	182.90	141.20	168.15	147.71	182.79
2033	138.24	149.50	120.61	150.24	131.21	154.41	159.46	241.85	188.91	185.98	142.87	171.75	149.58	186.00
2034	139.59	151.45	121.14	152.48	132.22	156.56	162.15	247.79	192.85	189.06	144.55	175.35	151.46	189.21

Forecasted Values of Overall HCCI and Item Part Based Sub-HCCIs and Custom Item Basked Based Sub-HCCI

Year	Overall HCCI	Item Part						Item Sub-Part		Custom Item Basket
		Earthwork	Granular Bases and Surfacing	Asphalt Construction	Rigid Pavement	Structures	Incidental Construction	Traffic Control	Erosion Control and Water Pollution Control	Top 10 Largest Items
2020	120.77	141.43	162.78	108.07	102.06	169.63	118.42	103.4046	93.5688	122.23
2021	122.11	146.23	168.55	107.32	102.31	175.93	119.78	103.6611	92.7763	123.18
2022	123.45	151.02	174.31	106.58	102.56	182.24	121.14	103.9176	91.9839	124.13
2023	124.80	155.82	180.08	105.83	102.81	188.54	122.50	104.1741	91.1914	125.08
2024	126.14	160.62	185.85	105.08	103.07	194.84	123.87	104.4306	90.399	126.03
2025	127.49	165.41	191.62	104.34	103.32	201.14	125.23	104.6871	89.6065	126.98
2026	128.83	170.21	197.38	103.59	103.57	207.45	126.59	104.9436	88.8141	127.93
2027	130.18	175.01	203.15	102.85	103.83	213.75	127.95	105.2002	88.0216	128.88
2028	131.52	179.80	208.92	102.10	104.08	220.05	129.31	105.4567	87.2292	129.83
2029	132.87	184.60	214.69	101.36	104.33	226.35	130.67	105.7132	86.4367	130.77
2030	134.21	189.40	220.45	100.61	104.58	232.65	132.03	105.9697	85.6443	131.72
2031	135.55	194.19	226.22	99.86	104.84	238.96	133.39	106.2262	84.8518	132.67
2032	136.90	198.99	231.99	99.12	105.09	245.26	134.75	106.4827	84.0594	133.62
2033	138.24	203.79	237.76	98.37	105.34	251.56	136.11	106.7392	83.2669	134.57
2034	139.59	208.58	243.52	97.63	105.59	257.86	137.47	106.9958	82.4745	135.52