Validation of Project-level Construction Cost Index Estimation Methodology

Draft Report

Prepared for:
Colorado Department of Transportation
and
Federal Highway Administration

Prepared By:
University of Colorado Denver
College of Engineering and Applied Science
Department of Civil Engineering

July 2017

TABLE of CONTENTS

ABSTRACT

Departments of transportation (DOTs) across the United States perform various estimating strategies and methodologies to gain an understanding of potential project costs. This process is undertaken in an attempt to predict project cost before going out to bid, and, by extension, predict the cost to the taxpayer. Within most state DOTs, construction cost indices (CCI) are used to determine the average movement of overall project costs over a specified time period. However, there is no standard nation-wide methodology for CCI calculation or implementation. Additionally, current estimation processes produce program or portfolio-wide forecasts, which, may not accurately represent the intricacies of individual projects within a DOT portfolio.

The Federal Highway Administration (FHWA) is attempting to develop an CCI based method to adjust the Engineer's Estimate at project advertisement. This draft methodology, titled "Index-Based Cost Estimation with Accuracy and Precision Analysis" by Weris, Inc., was published in July 2015, with a CCI approach based entirely on a specific project-level CCI methodology. In contrast to existing CCI processes, the calculated moving average and other forecasted metrics of the project-level CCI method are applied to DOT estimates in the interests of more closely approximating a potential low bid dollar value. This change in accuracy is influenced by adequacy of historical data, seasonal fluctuation within an individual state, the forecasted market condition of the local region, as well as the economic condition.

FHWA contracted University of Colorado Denver to validate the Index Based Cost Estimation Methodology and Tool developed in "Index-Based Cost Estimation with Accuracy and Precision Analysis" with the goal of testing the new process across multiple projects from Colorado, Montana, and Washingto. Generally, two projects were chosen from each state; one with a project value of greater than $50 million and one valued less than $10 million. The estimates using the new estimation method and tool are compared with the state DOTs final estimate prior to advertisement of project and the award amount.

Validation results have shown promise when applied to states with substantial historical data available. Data associated among states with high seasonal fluctuations in construction activity has been shown to increase variability within the results of the new CCI method. Additionally, the application of market conditions based on number of bidders shows promise when applied to projects considered to be standard, and which have no out of the ordinary external affecting factors.

INTRODUCTION

All transportation projects undergo a thorough estimation process for determining project cost; much the same as in the general construction industry. However, transportation projects are almost entirely taxpayer funded, and therefore incur high levels of scrutiny among program budgets, areas of spending, and resource allocations. Utilizing a uniform and step-by-step process, such as with CCI calculation, has allowed DOTs to standardize the estimation approach and reach a certain level of understanding with external stakeholders.

Historically, CCI methods have been applied to entire construction programs, with individual accuracy adjustments disseminated to projects within the program. This process provided estimators and program administrators a general idea of what end-result project costs may be. Unfortunately, the accuracy of program-wide CCIs occasionally led to swings of ±20 percent after projects had gone through the bidding process. Seasonal variability within the construction industry heavily influenced these swings of accuracy, with the slower winter seasons skewing the overall CCI results throughout the year. Additionally, no direct application of market or economic conditions existed in this conventional CCI process, which was theorized by FHWA to potentially be a significant influence on resulting project estimate accuracy.

FHWA developed the new project-level approach in the interest of reducing fluctuations in budget costs, as well as to develop the process for easier comparison from state-to-state and between types of projects. UCD was chosen as the collegiate environment for validating and testing this new methodology, in coordination with Colorado DOT (CDOT) officials. The UCD team worked closely with CDOT estimating experts to quickly familiarize with CCI theory, background, and calculation methods. Validation of the new FHWA method commenced only after CDOT experts were satisfied with the preparation of the UCD team and approved of the team ability to perform necessary CCI calculations.

The remainder of this report details research team organization, a literature review of the current and new CCI practices, an in-depth review of project-level methodology, results and discussion of testing, and a conclusion.

Research Team Organization

The Department of Civil Engineering at UCD was contracted as the primary investigators for the FHWA validation project. This team was led by two principle investigators (PIs); Dr. Chengyu Li, Associate Professor and Dr. Kevin Rens, Civil Engineering Department Chair and Director of Construction Engineering and Management. The UCD research team also includes three students; Dr. Xin Jiang, a postdoctoral at UCD, Jing Guo, a master student in UCD’s Construction

Engineering and Management program, and Corey Allison, also a master student in UCD's Construction Engineering and Management program.

The research was directly oversighted by two CDOT estimating experts; Shawn Yu, Program Manager for engineering estimates, and Roy Pallman, senior estimator. Mark Gabel and Mark Sujka of WSDOT and Lesly-Rae Tribelhorn of MDOT also provided data of test projects, participated in project progress meetings, and provided comments and input of the research.

Richard B. Duval, P.E., Construction & Project Management Research Engineer of FHWA, and Bryan Cawley, Construction Team Leader, Office of Infrastructure of FHWA, provided directions and oversight of the research.

Literature Review

Although FHWA is developing a new CCI methodology, a CCI process has existed in varying forms since 1933. Originally known as the Bid Price Index (BPI), FHWA published nation-wide construction cost data, price trends, and historical cost information. Historical data was collected all the way to 1922, when the US highway system was considered to be reasonably standardized from state-to-state, and representative of a substantial transportation network[1]. This initial BPI was entirely based on the awarded bid price of Federal-aid highway construction projects only and was dependent on individual state DOTs to document and report such collected data.

By 1977, the sheer number of Federal-aid projects requiring documentation had caused severe paperwork burdens on state DOTs. FHWA altered reporting requirements to only include contracts greater than $500,000 for National Highway System projects[1]. The change in documentation requirements was done to both lessen reporting burdens, as well as encourage state DOTs to continue reporting. One of the greatest issues with the BPI was a lack of reporting and adequate information to generate an accurate and comprehensive snapshot of the highway construction industry. The lack of information and data often led to severe percentage changes from one quarter to the next, creating a highly volatile spread on expected project costs.

The BPI system was increasingly criticized for the exclusion of any state DOT maintained cost databases. Though DOTs generally use similar materials in all construction projects, specific codes per pay item or group of pay items can be entirely different from one state to the next. For instance, the CDOT code for hot-mix asphalt (HMA) is 403-09221, while the code for a similar HMA type with the Washington DOT (WSDOT) is 5766. This coding difference was a major cause of paperwork burdens, and eventually led to DOTs simply not reporting most projects. Federal reporting forms also required the conversion to standard units, which were hard to convert or quantify in many cases. The search for a possibly solution or replacement for BPI began in 2000.

When contacted by the Government Accountability Office (GAO) for comment on the BPI system, it was found that 12 states did not report any projects to FHWA, since their own state data was more detailed and helpful[1]. With the lack of state data contributions and real-world use of the BPI system, it was determined in 2003 that the system itself was producing results that were not statistically significant and thereby to be considered inaccurate[2]. As a result, collection of data was discontinued in April 2007, and the final BPI report was issued for the fourth quarter of 2006.

Data collection officially began in 2003 for the replacement to BPI and would be known as the National Highway Construction Cost Index (NHCCI). This new database and analysis tool were developed in part by Oman Systems, Inc. (OSI) and FHWA. Essentially a web-based data aggregation tool, the NHCCI data mined state DOT websites for awarded contract postings and analyzed this data to produce a useable CCI[3]. This data could be formatted to pertain to the nation as a whole or individual states and could be published on a quarterly or yearly basis.

Captured contract data from DOT websites included: the state, awarded bid price, pay item name, pay item quantity, unit of measure, category of pay item, overall cost per pay item, and the date of contract award. NHCCI then analyzed and tracked this data to measure the overall percent change over time. Since no reporting was necessary from state DOTs, and data quality was maintained and standardized by OSI, the NHCCI became a substantially more reliable CCI estimate for transportation projects. Most importantly, this new aggregated CCI tool decreased the volatility in cost estimates from quarter to quarter (Figure 1).

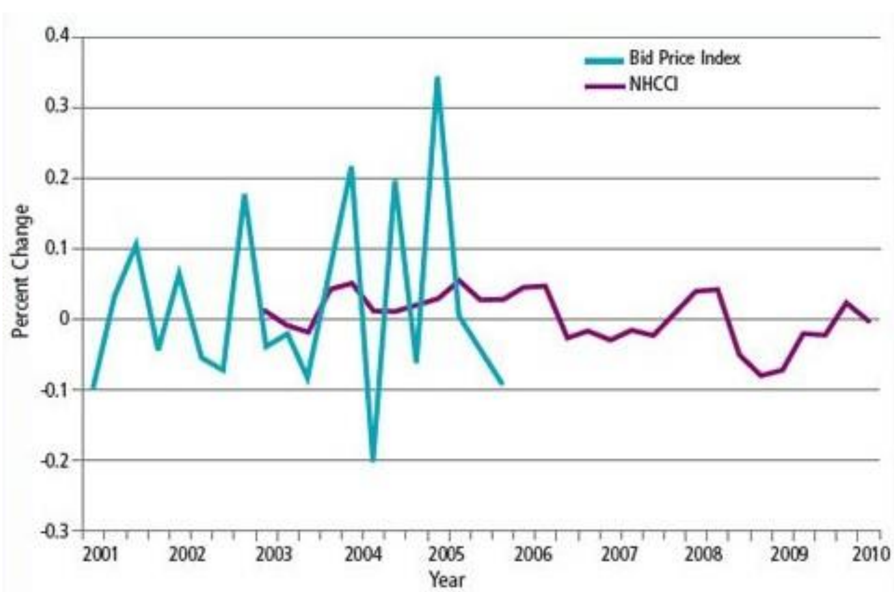


Figure 1: Comparison of NHCCI versus BPI on a moving quarterly basis[1]

After standardization by OSI, the analyzed data could not be reconverted into the units or standards of measure particular to specific state DOT estimating methods. Instead, the primary benefactors of this new estimation tool were subcontractors, suppliers, and related transportation construction businesses. This was well stated by the chief economist for the Associated General Contractors of America (AGC), Ken Simonson, when he said,

"...the NHCCI is valuable for demonstrating that highway costs may be escalating faster than consumer prices…some contractors may use the index to compare the change in their bid prices to the overall market[1]."

Though this index greatly aided members of the construction industry in improving their own bid accuracy, state DOTs could not share in this improvement. FHWA, alternatively, intended state DOTs to use the NHCCI as a comparison and check against the state developed CCI or estimating methods. Utilizing the NHCCI as a comparator tool was intentional, as FHWA recognized from the BPI years that state cost indices have two distinct advantages over a national index. First, state indices can more quickly represent changes in the local/regional construction environment, especially when unit costs rise rapidly. Second, statewide programs are better planned and budgeted as based on state-specific indices, instead of a national "average" index[1].

The NHCCI tool and system of reporting was regarded as highly successful in providing industry and state DOT estimating departments a snapshot of the transportation construction industry. However, as recent as 2012, individual state DOTs began creating and implementing state-based systems that mimicked the NHCCI methodology. In the interests of limiting a repeat of data inaccuracy from the BPI years, FHWA sought to create a standardized step-by-step methodology for calculating state CCIs.

Through discussions with state DOT representatives and statistics experts, it was determined that this new methodology would have a project specific basis; i.e. a CCI that is applied to engineer estimates in order to increase or decrease the price to fit historical trends. This CCI adjustment would be performed before a project goes out to bid and would ideally improve the accuracy of statewide budgeting practices. Essentially, the new project-level CCI methodology would allow state DOTs to adjust their own estimates before bidding, much in the same way as the NHCCI gave the construction industry an adjustment tool.

The new methodology was developed by FHWA and Weris, Inc. under the name of "Index-Based Cost Estimation with Accuracy and Precision Analysis," and was published in draft-final form on July 13th, 2015[4]. This report detailed current CCI methodologies of large state DOTs and laid-out the steps for producing a CCI. In addition to the conventional calculation of a CCI, the draft-final report proposed the inclusion of economic and market conditions to improve CCI accuracy.

The methodology in the Weris, Inc. report constitutes the validation and testing efforts performed by the UCD research team. As a stipulation of the contract between UCD and FHWA, the research team was required to follow each step of the methodology and was not permitted to alter the step-by-step process in any way. This contractual stipulation limits the UCD research team to testing and validating only; no new steps or interpretations were permitted.

CCI calculation background, methodology steps, and applications of market and economic conditions are detailed through the remainder of this report.

RESEARCH METHODOLOGY

The draft-final FHWA report laid out, in detail, the initial steps for calculating a CCI, and general guidelines for performing economic and market analyses. In order to adequately and clearly explain the project-level methodology process, this section of the report has been divided into the following sections: calculating the CCI overview, the seven steps of CCI calculation, future forecasting the CCI, and applications of market and economic conditions.

CCI Calculation Overview

There are numerous methods for calculating a cost index; with the chosen method depending on the accuracy required within a particular industry. Due to the high scrutiny of DOT projects, FHWA and many state DOTs have adopted the Fisher Price Index as the calculation method of choice. The Fisher Index is itself an average of two other indices: the Laspeyres and Paasche Price indices.

A mathematical guideline is provided on the FHWA website and is titled “The Mathematics of the National Highway Construction Cost Index.” This guideline separates CCI calculation into three general steps: 1) Defining the price index, 2) Calculating changes in aggregate price periods, and 3) Calculating the index time series[5].

In general, a price index of a project pay item is the result of comparing current costs and quantities to the costs and quantities of a previous reference period. Mathematically, this is represented by the following formula, where I_t is the price index, c_t is the pay item cost, and q_t is the pay item quantity.

Equation (1)[5]

$$I_t = \frac{(c_t/q_t)}{(c_0/q_0)}$$

In this way, a simple index is calculated by dividing costs and quantities from the current time period (t) by a predetermined reference time period (0). However, I_t represents direct cost of project pay items and is uncomparable to pay items measured with different unit costs. An index with the greatest use in the construction industry requires the application of weighted averages per pay item respective to the unit of measure. This relation is shown in the following formula, where individual indices using Equation 1 are multiplied by respective weighted averages (w).

Equation (2)[5]:

$$\mathrm{A} = \frac{w^1 I_t^1 + w^2 I_t^2 + \cdots + w^n I_t^n}{w^1 + w^2 + \cdots + w^n}$$

With the application of weighted averages, pay items of differing units of measure can be compared to one another to formulate a comprehensive construction cost index. This method of applying predetermined weights can be problematic and unstable, with resulting index values losing accuracy as longer time periods are grouped together.

For this reason, the currently accepted method for determining a price index specific to the construction industry, with statistically significant accuracy, is to utilize index formulas. Mathematically, this process is similar to equations 1 and 2, with the notable exception that price-quantity products are divided by each other. This is the point, at which, the FHWA approved method of CCI calculation can be differentiated from other methods. Aggregated pricing and related pay item quantities are multiplied and divided relative to a predetermined reference period. This is best shown by the Fisher Price Index below, where p is the pay item price and q is the pay item quantity.

Equation (3)[5]:

$$F(p) = \sqrt{\frac{\sum_{j=1}^{N} p_{j,t} q_{j,0}}{\sum_{j=1}^{N} p_{j,0} q_{j,0}} * \frac{\sum_{j=1}^{N} p_{j,t} q_{j,t}}{\sum_{j=1}^{N} p_{j,0} q_{j,t}}}$$

As seen in equation 3, the summation product between pricing at the current time and quantity at the reference period is divided by the summation product between pricing at the reference period and quantity at the reference period. This quotient, representative of the Laspeyres Price Index, is multiplied by the adjacent quotient, representing the Paasche Price Index. The Paasche index is the summation product between price and quantity at the current time, divided by the summation product of reference period pricing and current time quantity. The square root of the two indices results in the Fisher index.

Stated previously, the Fisher index is a geometric average that essentially overcomes the shortcomings of the two indices within. The Laspeyres index usually overstates price increase impact, and understates decrease impacts; this issue is magnified as the reference period gets farther and farther away from the current time period. The Paasche index generally understates all results regardless of time period extension.

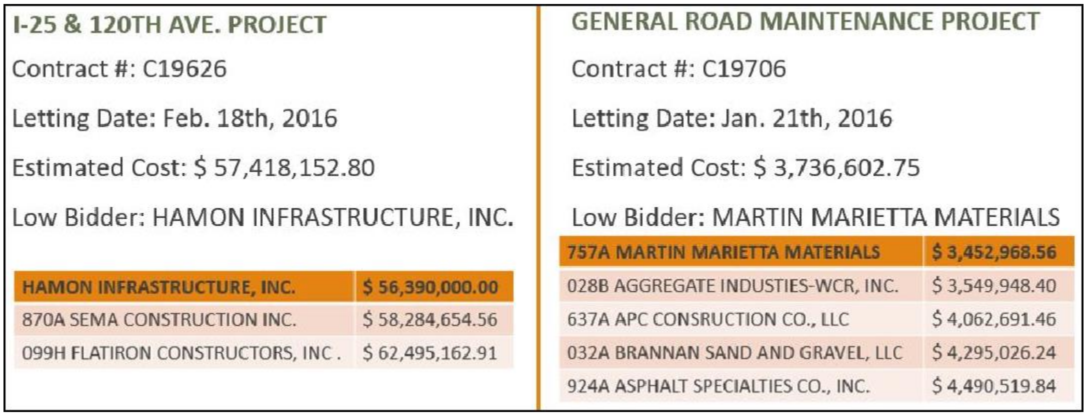
The Fisher index, through testing outside the scope of this project, has been proven as a statistically accurate means for calculating price indices over extended periods of time. For this reason, and as required by the FHWA report, CCIs will be calculated using the Fisher Ideal Index model and inherent mathematical processes.

CCI Methodology Process

Now that a general understanding of index calculation has been established, this section of the report will detail the various steps required to manipulate data for use in the Fisher index. Each of these steps has been developed by FHWA and the draft-final report from Weris Inc.. The seven steps in this section are included as direct references from the FHWA report and were strictly followed by the UCD research team.

Data was gathered from online DOT databases or directly from staff at CDOT, WSDOT, and Montana DOT (MDT). As agreed upon during initial team meetings with FHWA representatives, the methodology would be tested against two projects from each of the three DOTs. Generally, one project would be small at an awarded bid value of $10 million or less, and one project would be large at a value of $50 million or more. These projects were to be construction only type projects (non-maintenance), with a delivery method of design-bid-build (DBB).

Information provided by the various DOTs was collected and converted to usable formats for analysis in Microsoft Excel. Up-front information about the specific project to be validated included the following key pieces of information: contract name and number, DOT engineer's project estimate, awarded bid price, bid award date, and the number of bidders. An example of this information from the two CDOT projects is seen in Figure 2. This information was also collected from WSDOT and MDT and can be seen in the Appendix as A.2 and A.3 respectively.



I-25 & 120TH AVE. PROJECT

Contract #: C19626

Letting Date: Feb. 18th, 2016

Estimated Cost: $ 57,418,152.80

Low Bidder: HAMON INFRASTRUCTURE, INC.

HAMON INFRASTRUCTURE, INC.	$ 56,390,000.00
870A SEMA CONSTRUCTION INC.	$ 58,284,654.56
099H FLATIRON CONSTRUCTORS, INC .	$ 62,495,162.91

GENERAL ROAD MAINTENANCE PROJECT

Contract #: C19706

Letting Date: Jan. 21th, 2016

Estimated Cost: $ 3,736,602.75

Low Bidder: MARTIN MARIETTA MATERIALS

757A MARTIN MARIETTA MATERIALS	$ 3,452,968.56
028B AGGREGATE INDUSTIES-WCR, INC.	$ 3,549,948.40
637A APC CONSRUCTION CO., LLC	$ 4,062,691.46
032A BRANNAN SAND AND GRAVEL, LLC	$ 4,295,026.24
924A ASPHALT SPECIALTIES CO., INC.	$ 4,490,519.84

Figure 2: Initial information required of project data from two CDOT projects; figure as seen and created for team presentations to FHWA and DOT stakeholders

Once projects were identified and the necessary up-front information collected, validation of the FHWA methodology began. Each step will be described individually, with supporting visuals when necessary.

Step 1: Pay Item Organization

The first step of the project-level methodology calls for the collection and organization of pay item costs and quantities for each project. In this step, all pay items from a particular project are collected from the DOT-issued bid tabs and organized into the following Excel column format: Item Code, Description, Quantity, Unit of measure, unit Price, and total cost Amount.

Two additional columns were created for analysis progression; shown as Percentage and Cumulative Percentage. The Percentage column represents the quotient of a pay item's total cost divided by the total engineer's estimate for the project. The Cumulative Percentage column is simply the progressive sum of the percentage column, eventually leading to a 100% sum. This last column is used to check that all cost data has been accounted for.

Table 1: Sample of organized pay item data from methodology Step 1

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Cumulative Percentage
403-09221	Stone Matrix Asphalt (Fibers)(Asphalt)	70,133	TON	$97.00	$6,803,386	11.85%	11.85%
403-33841	Hot Mix Asphalt (Grading S) (100) (PG64-22)	81,292	TON	$74.00	$6,015,608	10.48%	22.33%
626-00000	Mobilization	1	LS	$3,750,000.00	$3,750,000	6.53%	28.86%
203-00010	Unclassified Excavation (Complete In Place)	287,329	CY	$10.00	$2,873,290	5.00%	33.86%
203-00065	Embankment Material (Complete In Place) (R20)	141,503	CY	$15.00	$2,122,545	3.70%	37.56%
607-15000	Fence Concrete (Sound Barrier)	49,500	SF	$38.00	$1,881,000	3.28%	40.83%
606-00745	Guardrail Type 7 (Style CE) *Concrete Glare)	16,570	LF	$100.00	$1,657,000	2.89%	43.72%
630-80370	Concrete Barrier (Temporary)	57,697	LF	$27.00	$1,557,819	2.71%	46.43%
601-03050	Concrete Class D (Wall)	2,400	CY	$600.00	$1,440,000	2.51%	48.94%

Each of the six DOT projects included hundreds of pay items. As a result, no full datasets will be included in this report; contact the report author for access to the original excel files.

Step 2: Pay Item Analysis

Once pay items are organized into a workable format, a certain number of pay items are chosen for further analysis as based on the cumulative percentage. Currently, state DOTs already perform this step in order to analyze high-costing pay items within projects. The percentage chosen, as explained in the FHWA draft-report, is entirely based on the standard operating procedures a particular state DOT operates under. This cut-off value is usually 80% of total costs or higher; even potentially including 100% of project pay items. For instance, CDOT generally chooses an 80% cut-off when performing estimation analysis as shown in Table 2.

Table 2: CDOT 80% cut-off pay items

Item Code	Description	Quantity	Unit	Price	Amount	Percentage
403-09221	Stone Matrix Asphalt (Fibers)(Asphalt)	70138.00	TON	$97.00	$6,803,386	11.85%
403-33841	Hot Mix Asphalt (Grading S) (100) (PG64-22)	81292.00	TON	$74.00	$6,015,608	10.48%
626-00000	Mobilization	1.00	LS	$3,750,000.00	$3,750,000	6.53%
203-00010	Unclassified Excavation (Complete In Place)	287329.00	CY	$10.00	$2,873,290	5.00%
203-00065	Embankment Material (Complete In Place) (R20)	141503.00	CY	$15.00	$2,122,545	3.70%
607-15000	Fence Concrete (Sound Barrier)	49500.00	SF	$38.00	$1,881,000	3.28%
↓	↓	↓	↓	↓	↓	↓
606-00301	Guardrail Type 3 (6-3 Post Spacing) (31 in. MGS)	13896.00	LF	$16.00	$222,336.00	0.39%
602-00000	Reinforcing Steel	258350.00	LB	$0.85	$219,597.50	0.38%
601-40400	Structural Concrete Stain	22291.00	SY	$9.50	$211,764.50	0.37%
630-85041	Mobile Attenuator	700.00	DAY	$300.00	$210,000.00	0.37%
206-00360	Mechanical Reinforcement of Soil	14492.00	CY	$13.00	$188,396.00	0.33%
614-00013	Sign Panel (Class III)	5349.00	SF	$35.00	$187,215.00	0.33%
					Total:	80.03%

For the purposes of following the standardized FHWA methodology, clarification was sought from FHWA representatives and Weris Inc. as to which percentage should be used during validation. It was determined that the UCD team should utilize at least 80% of project pay items at this stage of the methodology for every tested project; however, all pay items that constitute at least 1.00% of total project costs should also be included. If such a situation would occur that 1.00% or greater pay items were removed via the cut-off percentage, those pay items would be manually added back in and would continue through the analysis stages. This effort was made to ensure as much of a project's total costs were taken into account.

Step 3: Pay Item Classification and Cost Sensitivity

The process of Step 2 essentially began the "cleaning" of data for the overall CCI process. In Step 3, the remaining pay items are broken into three primary categories: Material, Labor, and Equipment (Table 3). These categories were defined by the FHWA draft-final report as a catch-all organization method to more closely identify the highest-costing pay items within a project. Only those pay items within the most cost sensitive category are used in subsequent steps of the project-level CCI methodology.

Pay items are manually classified as based on the description, elongated description within DOT code books, and advice from industry experts. This step, however, is the first instance of possible uncertainty, as most pay item pricing includes varying inherent ratios of material, labor, and equipment costs. For example, the price for 1 ton of HMA includes a specific ratio of the actual material HMA cost, as well as labor costs to install and the costs of installation equipment. These ratios normally do not change during the course of a project, yet can exhibit drastic relative changes when compared to historical pay item data.

Table 3: Sample of pay item classification from methodology Step 3

Material

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Classification
403-09221	Stone Matrix Asphalt (Fibers)(Asphalt)	70,138.00	TON	$97.00	$6,803,388	11.85%	Material
403-33841	Hot Mix Asphalt (Grading S) (100) (PG64-22)	81,292.00	TON	$74.00	$6,015,608	10.48%	Material
↓	↓	↓	↓	↓	↓	↓	↓
601-40400	Structural Concrete Stain	22,291.00	SY	$9.50	$211,764.50	0.37%	Material
613-00013	Sign Panel (Class III)	5,349.00	SF	$35.00	$187,215.00	0.33%	Material
					Total:	56.91%	

Labor

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Classification
626-00000	Mobilization	1	L S	$3,750,000.00	3750000	6.53%	Labor
203-00010	Unclassified Excavation (Complete In Place)	287,329.00	CY	$10.00	2873290	5.00%	Labor
↓	↓	↓	↓	↓	↓	↓	↓
208-00205	Erosion Control Supervisor	2,820.00	HOUR	$80.00	225600	0.39%	Labor
206-00360	Mechanical Reinforcement of Soil	14,492.00	CY	$13.00	188396	0.33%	Labor
					Total:	18.39%	

Equipment

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Classification
630-80370	Concrete Barrier (Temporary)	57,697.00	LF	$27.00	1557819	2.71%	Equipment
614-42400	Monotube Overhead Sign Bridge (24 Inch Diameter)	7	EACH	$100000.00	700000	1.22%	Equipment
614-10147	Variable Message Sign LED (Overhead)	10	EACH	$25000.00	250000	0.44%	Equipment
630-85041	Mobile Attenuator	700	DAY	$.00300	210000	0.37%	Equipment
					Total:	4.73%	

By way of general understanding of the construction industry, almost every project will be cost sensitive by material. That is, a majority of the project cost is embedded in material procured for a project, with significant impacts to be expected to the overall project budget should material costs rise or fall. Transportation construction projects are no different, and are virtually always heavily dependent on materials as the largest costing pay items.

As stated previously, only those pay items within the most cost sensitive category are analyzed in the remainder of the CCI methodology. This is a requirement of the FHWA draft-final report methodology.

Step 4: Application of Historical Occurrence Frequency

The most important aspect of this methodology is likely the completeness of historical datasets. In Step 4, historical instances are identified and collected for each of the remaining pay items from Step 3. Data is collected from a period going back four years from the fiscal quarter of the project award. For instance, the large project from Figure 2 was awarded in February 2016; i.e. quarter 1 of the fiscal calendar year. The historical period required by the FHWA methodology must then extend from quarter 4 of 2015 to quarter 1 of 2012.

However, as seen in Table 4, this four years of data is not a steadfast requirement. As stated in the FHWA draft-final report, if the state DOT CCI reference year is within the four-year period, historical frequency data is to be collected up to that specified year. This issue was only encountered with CDOT projects, whose reference time period starts in quarter 1 of 2012. Only one quarter of data loss was the result in Step 4 from the effects of the reference year.

Table 4: Sample of pay item frequency as aggregated from historical data

#	Frequency Item Code	2012 Q2	2012 Q3	2012 Q4	2013 Q1	2013 Q2	2013 Q3	2013 Q4	2014 Q1	2014 Q2	2014 Q3	2014 Q4	2015 Q1	2015 Q2	2015 Q3	2015 Q4
1	627-01010	4	2	3	2	4	2	1	3	2	2	3	5	3	2	2
2	207-00205	14	4	5	12	13	5	4	9	15	11	6	16	10	3	9
3	601-03040	8	3	1	8	6	2	2	5	6	11	4	10	3	1	4
4	403-00720	31	15	12	25	26	9	9	16	25	23	13	25	16	8	12
5	602-00020	15	8	6	10	13	3	4	15	14	18	8	18	8	4	7
6	613-01200	14	6	6	10	15	7	5	8	10	14	5	6	8	9	5
7	208-00002	32	15	15	27	28	11	12	20	31	21	10	29	26	14	10
8	503-00048	10	5	2	5	2	4	2	5	7	9	3	2	4	3	3
9	411-10255	20	5	9	18	27	5	5	16	26	10	6	27	17	5	7
10	606-00301	19	9	6	17	16	7	9	12	20	14	9	21	13	9	10
11	602-00000	9	2	6	5	8	4	4	4	12	10	6	6	7	3	7
12	614-00013	5	3	3	7	5	2	3	5	7	5	4	4	3	1	3

Individual instances within the four-year data sets are identified and summed. As the CCI is calculated on a quarterly basis, pay item frequency is broken down further into each quarter across the four-year period. It should be noted, that Table 4 represents the pay items with a complete four years of data instance. Any pay items with even a one quarter gap in frequency, as in there were no billed instances of that pay item, are eliminated and not analyzed for the remainder of the methodology.

This analysis is conducted for each of the six projects used during methodology validation. As this is a tedious and time consuming process per pay item, projects with a large number of surviving pay items from Step 3 will require a vast amount of time for frequency identification. In future applications of this methodology, an automated process would be ideal.

Step 5: Pay Item Outlier Elimination

At this stage of the methodology, a statistical “clean” of historical data is performed in order to remove outliers. Outliers in the data are generally defined as historical instances of a specific pay item that have per unit costs outside the statistical normal. Though no specific range is specified in the draft-final report methodology, approval was granted by FHWA to utilize a 5%-95% outlier normal range. This range, therefore, would eliminate pay item instances with unit costs greater than 95% and less than 5% of the normal. A sample result of this process is shown in Table 5.

Table 5: Sample effects of outlier elimination on frequency per quarter and total

Before Outlier Elimination																
#	Frequency Item Code	2012 Q2	2012 Q3	2012 Q4	2013 Q1	2013 Q2	2013 Q3	2013 Q4	2014 Q1	2014 Q2	2014 Q3	2014 Q4	2015 Q1	2015 Q2	2015 Q3	2015 Q4	
1	627-01010	4	2	3	2	4	2	1	3	2	2	3	5	3	2	2	Total 40
2	207-00205	14	4	5	12	13	5	4	9	15	11	6	16	10	3	9	Total 136
3	601-03040	8	3	1	8	6	2	2	5	6	11	4	10	3	1	4	Total 74

After Outlier Elimination																
#	Frequency Item Code	2012 Q2	2012 Q3	2012 Q4	2013 Q1	2013 Q2	2013 Q3	2013 Q4	2014 Q1	2014 Q2	2014 Q3	2014 Q4	2015 Q1	2015 Q2	2015 Q3	2015 Q4	
1	627-01010	4	2	1	2	4	2	1	2	2	1	3	4	3	2	2	Total 35
2	207-00205	13	4	4	11	12	5	2	7	13	8	6	12	9	2	9	Total 117
3	601-03040	6	2	1	7	6	2	1	3	6	9	4	6	1	1	3	Total 58

The 5%-95% range essentially helps to eliminate pay items instances that had exorbitantly low or high per unit costs. This is calculated by analyzing a rolling seven year period from the beginning of the initial four-year historical pay item time period. For example, outliers for quarter 2 of 2012, in Table 5, were calculated as based on historical pay item pricing from quarter 1 of 2012 all the way to quarter 2 of 2005. Outliers for quarter 3 of 2012 were calculated with a seven-year period from quarter 3 of 2005 to quarter 2 of 2012. This rolling outlier time frame continues until all quarters of the initial four-year historical period have been assessed.

Outlier elimination generally did not make cause for the elimination of entire pay item codes from further analysis. However, as seen in the totals of Table 5, the potential existed for the data pool moving forward to be substantially reduced. Each time a reduction in the data pool occurs, uncertainty increases and will affect the CCI calculation via the Fisher index.

Similar to Step 4, outlier calculation in Step 5 is a heavily time consuming process that requires focus and care so as not to miss important data. This process is exacerbated by projects with a large number of surviving pay items from Step 3 as well as Step 4.

Step 6: Calculation of Weighted Average Unit Pricing

Though potentially leading to CCI result issues, outlier elimination enables a more statistically accurate calculation of weighted average pricing. In Step 6, the weighted average unit price is calculated for all remaining pay items for each quarter of the four-year analysis period. The resulting unit pricing and related total quantities per pay item are direct inputs into the Fisher index formula, and represent the last major calculation step to be performed.

Weighted average unit pricing is calculated by taking the sum of historical pricing per unit, and dividing by the sum of historical quantities per unit. This is calculated for every pay item across each quarter in the four-year time period and is represented by the following formula.

Equation (4):

$$\text{Weighted Average} = \frac{Sum(Unit\ Cost)}{Sum(Unit\ Quantities)}$$

After all weighted averages have been calculated, the summed total of per unit quantities is adjacently situated (Table 6). In this configuration, the traditional CCI calculation table begins to take shape and is ready for the application of the Fisher index formula.

Table 6: Sample of a completed CCI data preparation table from methodology Step 6

Year	Quarter	627-01010		207-00205		601-03040		606-00301		602-00000		614-00013	
		Price	Qty	Price	Qty	Price	Qty	Price	Qty	Price	Qty	Price	Qty
2012	Q2	10.67	12268	10.44	43880	447.12	1973	17.76	21017	0.86	283970	28.96	505
2012	Q3	9.85	46100	6.98	9433	485.65	864	16.88	31381	1.83	8019	30.06	2732
2012	Q4	10.00	10000	8.77	9857	543.83	163	19.86	8252	0.81	228480	21.62	11772
2013	Q1	9.66	11190	20.68	5624	472.92	8336	18.71	36249	0.65	204053	22.27	5388
2013	Q2	11.76	23752	10.14	24285	387.67	2970	18.23	82760	0.81	261306	25.79	1077
2013	Q3	10.20	36800	7.19	51825	358.45	9399	16.58	46126	0.71	735522	28.00	8226
2013	Q4	13.00	1632	5.85	2682	508.89	243	19.25	38869	0.81	99415	26.23	4266
2014	Q1	13.11	35132	12.62	6930	363.94	1481	18.33	35469	0.87	227498	26.16	814
2014	Q2	8.82	176433	8.70	40531	472.72	4638	17.79	62846	0.86	288194	21.59	10729
2014	Q3	11.25	2569	9.04	22818	505.90	8123	19.99	12674	1.05	150209	25.21	928
2014	Q4	12.59	14390	8.14	80558	480.80	2652	21.58	36154	1.24	147293	25.16	1163
2015	Q1	9.18	127591	8.94	47388	592.11	1050	19.23	51028	1.55	65018	22.66	14108
2015	Q2	10.05	35391	11.35	20510	1400.00	9	23.92	19210	1.33	40580	29.49	444
2015	Q3	12.53	10142	27.95	203	1600.00	23	20.22	10805	0.85	37678	25.98	3505
2015	Q4	25.32	759	11.33	27163	772.56	1072	22.72	14956	0.70	389755	25.98	3505

A cursory check is performed at this stage to compare weighted averages across the four-year period. Generally, the weighted average value should not change drastically from quarter to quarter; this is, in part, due to outlier elimination from Step 5. Weighted averages also partially account for the effects of inflation, therefore any increasing trend towards the quarter of project award should not be seen as alarming.

Step 7: Consolidation of the CCI

The weighted averages and quantities of each pay item and quarter, depicted in Table 5, are direct inputs into the Fisher index formula. Care must be taken to correctly select reference period variables and respective current period variables throughout the four-year CCI calculation progression. In order to detail this process, the following example pertains to the complete data preparation table from the large CDOT project. This table in its entirety can be seen in the Appendix as A.4, however, Table 6 above may be used as reference.

First, the Laspeyres index is calculated; i.e. the left side quotient within the Fisher index (shown below).

Equation (5):

$$\frac{\sum_{j=1}^{N} p_{j,t} q_{j,0}}{\sum_{j=1}^{N} p_{j,0} q_{j,0}}$$

Using Table 6 or A.4 as the immediate reference, the reference period is defined as 2012 quarter 2, while the current period is 2012 quarter 3. The numerator portion of the Laspeyres formula, therefore, pulls weighted average data from quarter 3, and pulls quantity data from quarter 2. The denominator portion pulls both weighted average and quantity data from quarter 2. This operation is shown in the following sample calculation (SC).

SC (1):

$$\frac{(9.85*12268)+(6.98*43880)+...+(1.83*283970)+(30.06*505)}{(10.67*12268)+(10.44*43880)+...+(0.86*283970)+(28.96*505)} = 0.98$$

Next, the Paasche index is calculated; i.e. the right-side quotient within the Fisher index (shown below).

Equation (6):

$$\frac{\sum_{j=1}^{N} p_{j,t} q_{j,t}}{\sum_{j=1}^{N} p_{j,0} q_{j,t}}$$

Continuing with the previous example, the numerator portion of the Paasche formula pulls both weighted average and quantity data from quarter 3. The denominator portion pulls weighted average data from quarter 2, and pulls quantity data from quarter 3. Sample calculation 2 depicts this operation.

SC (2):

$$\frac{(9.85 * 46100) + (6.98 * 9433) + \cdots + (1.83 * 8019) + (30.06 * 2732)}{(10.67 * 46100) + (10.44 * 9433) + \cdots + (0.86 * 8019) + (28.96 * 2732)} = 0.96$$

When the results from the Laspeyres and Paasche formulas are input into the Fisher formula, a Relative CCI result is produced. This relative CCI pertains only to the two quarters assessed during any specific iteration of the index formulas. In order to monitor the change in CCI through all four years to the award date "current time" of a project, the relative CCI must be multiplied by the preceding Cumulative CCI result. Since 2012 quarter 2 is considered the overarching reference or base time for this project, the initial cumulative CCI is maintained as a constant of 1. Each successive iteration of the CCI calculation simply moves down the CCI data table, gaining and losing a quarter's data each time, with reference and current periods changing respectively.

As the final step of this example, the results from SC 1 and SC 2 are input into the Fisher formula to produce the relative CCI. This operation is shown in SC 3.

SC (3):

$$\sqrt{0.98 * 0.95} = 0.968{\sim}0.97(Relative\ CCI)$$

The relative CCI result is multiplied by the preceding cumulative CCI, and therefore results in the cumulative CCI that this entire methodology has been working up to. This is shown, for reference, in SC 4 below.

SC (4):

$$\sqrt{0.98 * 0.95} = 0.97(Cumulative\ CCI)$$

Calculation iterations continue until all quarters in the CCI data table have a resulting cumulative CCI. For the previous example from the large CDOT project, this result table is shown below.

Table 7: CCI calculation results from Steps 1-7 for the large CDOT project; contract # C19626

Year	Quarter	Fisher Ideal Index	
		Relative	Cumulative
2012	Q2	-	1.00
2012	Q3	0.97	0.97
2012	Q4	1.01	0.98
2013	Q1	0.94	0.92
2013	Q2	0.96	0.88
2013	Q3	1.05	0.92
2013	Q4	1.07	0.99
2014	Q1	0.96	0.95
2014	Q2	0.94	0.89
2014	Q3	1.09	0.97
2014	Q4	1.01	0.97
2015	Q1	1.01	0.98
2015	Q2	1.17	1.15
2015	Q3	1.12	1.29
2015	Q4	0.89	1.15

The highlighted cumulative CCI result in Table 7 indicates what is known as the CCI ratio. This value, using the current methodologies of some state DOTs, would be multiplied by the engineer's estimate. This adjusted Engineer's Estimate, essentially, provides the DOT with an educated guess as to what the upcoming results of the bidding process may be. The adjusted price also directly informs high-level budgeting concerns for the specific DOT locality, region, city, or entire state.

From this point on, however, the proposed project-level methodology delves into new processes that have not been used in any practical capacity among state DOTs. Though the previous CCI results are a strong educated guess at potential bid outcomes, Steps 1-7 do not capture the full variability of seasonal change or economic and market influences. The next two sections, *CCI Forecasting* and *Applying Market & Economic Conditions*, comprise the bulk of new research contributions to the transportation construction industry.

CCI Forecasting Process

A common issue within DOT estimating departments is the forecasting of a project estimate into a future time. DOTs, and often the construction industry in general, will put together engineer estimates for a project that may not be built for a year or more. This practice, though efficient in keeping DOTs prepared for future projects, often encounters changes to material, labor, and equipment rates, as well as potential difficulties associated with the particular calendar season of construction start.

The proposed FHWA methodology employs a procedure of forecasting the CCI results from the previous seven steps, into the next four quarters after the initial project award date. These forecasted CCI ratios can then be applied to the engineer's estimate to gain perspective on any increases or decreases to be expected in the overall project budget. As the UCD team was strictly tasked with validation, testing utilized the same forecasting tools as stated in the draft-final report; R software and the ARIMA model.

R software, essentially, is an open source statistical analysis software package downloadable for free from the internet. ARIMA, which is an abbreviation for "autoregressive integrated moving average," is the tool within R software that aggregates the historical CCI ratios developed in Step 7, and predicts future ratios within a specified timeframe. Though understanding the exact statistical operations of this software package are outside the scope of this UCD validation project, the following steps were followed in order to continue the validation process.

The first step in using R software is to organize the historical CCI ratios into a format usable by the ARIMA model. Basically, this constitutes reformatting CCI ratios into a matrix format, with the following Table 8 used as an example. The below CCI data was used during the initial CDOT approval process of the UCD team's ability to replicate published results from the FHWA draft-final report.

Table 8 CCI for input into the ARIMA model in R

Year	Q1	Q2	Q3	Q4
Year 1	-	1.000	1.319	1.298
Year 2	1.024	1.042	1.312	1.118
Year 3	1.147	1.148	1.229	1.214
Year 4	1.089	1.078	1.178	1.204

In this example, "Year 1" corresponds to 2012, while quarters 1-4 are positioned horizontally. As the sample CCI ratios were taken from a CDOT project with a base time period of 2012 quarter 2, there is no CCI data available for 2012 quarter 1.

Once CCI ratio data is input into R software, the time series function must be set to the number 4. The time series function both determines the format of inputs as well as the format of outputs. Since CCI data is quarterly, a setting of 4 will result in four complete quarters of forecasted CCI ratios.

Without the ARIMA model tools, the next stage of forecasting would entail the manual determination of the best fit model with respect to data quality. Thankfully, the ARIMA model performs this task automatically, and simply states the resulting best fit model to the software user. This can be seen in the following Figure 3 as published in the FHWA draft-final report, where various coefficient variables are also automatically calculated.

```
> fit=auto.arima(train,stepwise=FALSE,approximation=FALSE)
> fit
Series: train
ARIMA(1,0,0)(0,1,0)[4]

Coefficients:
         ar1
      0.5989
s.e.  0.1374

sigma^2 estimated as 0.07568:  log likelihood=-4.33
AIC=12.65   AICc=13.07   BIC=15.59
```

Figure 3: Outputs from the ARIMA model, with best fit model and coefficients auto-populated[4]

After each iteration of the ARIMA software, results are first checked for statistical outliers. This process entails running the "tsdiag()" function in R, and results in a bounded time series chart concerning the quality of data operations. Essentially, if all data falls within the upper and lower bounds of the generated charts, then no actions must be taken. The following Figure 4 is an example of a successful test, where time zero is disregarded as it is representative of CDOT data for 2012 quarter 1 which does not exist.

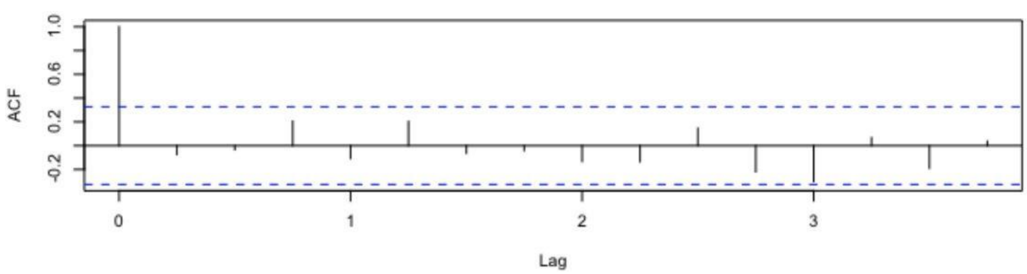


Figure 4: Upper & lower bound check of time series data[4]

Once appropriate checks have occurred, the actual forecasting of CCI ratios may proceed.

This operation was performed by inputting the following command into the ARIMA model software: "forecast.Arima()" to initiate the actual forecast, "level=c(95)" to produce a result with 95% confidence, and with a frequency value of 4 to result in four quarters of CCI forecasted[4].

ARIMA provides results in two formats, tabular and graphical. Tabular results look similar in format to the initial CCI ratio input table, but must be further analyzed in order to reach a useable format. The graphical results depict the final forecasted CCI values, as well as the seasonal (or lack thereof) variability of historical and forecasted CCI values. As such, the graphical outputs and associated CCI result values were utilized by the FHWA methodology and the UCD team.

An example of forecasted CCI results is shown below in Figure 5, with associated CCI values depicted in Table 9. It should be noted that graphical results must be added to the base year value of 1 in order to truly represent CCI values in the traditional DOT format.

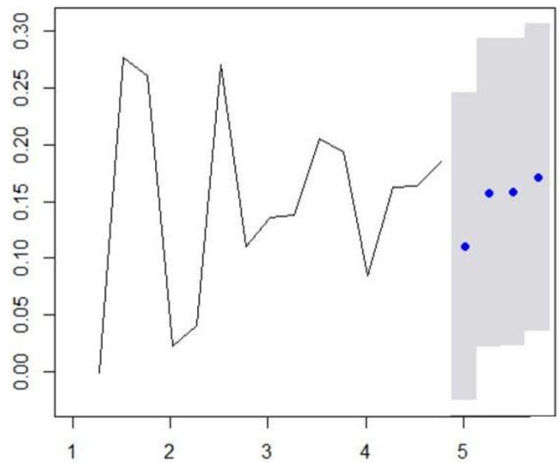


Figure 5: Forecasted CCI output from ARIMA software; as seen and created for team presentations to FHWA and DOT stakeholders

Table 9 Forecasted CCI output values

Year	Q1	Q2	Q3	Q4
2016	1.120	1.170	1.170	1.190

Directly following the guidelines of the project-level methodology, the four forecasted CCIs from Table 9 are then averaged, and then divided by the most current non-forecasted CCI value. This results in an adjusted CCI ratio that can then be applied to an engineer's estimate. A sample calculation using the values from Table 9 and the last CCI value from Table 8 is shown below.

SC (5):

$$\frac{1.12 + 1.17 + 1.17 + 1.19}{1.20} = 0.964$$

The above result from SC 5 is the final culmination of Steps 1-7 and the forecasting process. A forecasted CCI ratio is calculated for each of the six DOT projects, and is multiplied by the engineer's estimate to adjust the overall project estimate. The final stage of the FHWA methodology is to apply market and economic condition adjustments, to further refine the engineer's estimate.

Applying Market & Economic Conditions

It was theorized in the FHWA draft-final report that market and economic conditions were not fully captured by the traditional CCI calculation methods outlined previously.

Primarily, FHWA expressed interest in applying more distinct and measurable effects of the specific locality or region that a project was to be built within. This follows the well understood characteristic of specific market regions having different conditions than the overall state or nation.

The FHWA report, however, did not lay out a standardized process for applying market and economic conditions to projects across all states and used unit in its draft-final report. The reasoning behind this absence of standardization is that each state and its subsequent regions are unique, and, therefore, cannot utilize a standardized national methodology. While intuitive, this created an issue for the UCD team with regards to validating the proposed methodology. Specifically, if each state is to have a separate market and economic assessment methodology, there is no way to compare one project to another within the same state, let alone to projects in different states.

Through discussions between FHWA representatives, CDOT estimating staff, and the UCD team, it was decided that validation would test the market condition impacts of the total number of bidding contractors. This would take the form of assessing the total number of bidders on each of the six tested projects, as well as assessing historical bidding contractor numbers. No consensus could be reached on a validation method for economic conditions, and it was decided that this aspect would not be directly included in validation.

<u>Market Conditions Analysis</u>

The market conditions of a city, locality, region, or entire state can greatly affect the overall costs and budgeting for a project. Drastic changes can occur in project costs in especially volatile or competitive markets. After consulting estimation experts from CDOT, the market factor with the greatest impact on a project's cost is the total number of bidding contractors competing to win a project.

Generally, project award amount is inversely related to the number of bidders; more bidders results in lower award amounts, while fewer bidders result in higher award amounts. The effects of bidding contractors is seen throughout the construction industry, where any project or scope area of a project ideally has at least three bidding contractors. Reasoning behind the "at least three" stance, is that three bid proposals provide a high, middle of the road, and low contractor estimate of the project cost. High, middle, and low estimate proposals allow an owner or general contractor to determine where the true project cost may be, as based on their experience and knowledge of the project.

For the purposes of validation, the total number of bidders was accounted for from each of the six projects, as well as from five years of historical data. This historical data would be analyzed to determine the percent difference between the engineer's estimate and the low-bid amount. These percent differences were then tied to the number of bidders for each project analyzed within the five year period.

Similar to Step 4 and 5 of the initial CCI methodology, this process is highly time intensive as each project requires a five year dataset as based on its award date. However, due to both CDOT projects having an award date in quarter 1 of 2016 and both WSDOT projects with an award date in quarter 2 of 2015, only four datasets were required. Datasets were assessed on a statewide basis, as individual project regions did not have enough historical projects awarded to create a statistically significant dataset. The time periods for these datasets are as follows:

- CDOT
    - Large and Small Projects: Q1 2011 to Q4 2015
- MDT
    - Large Project: Q4 2011 to Q3 2016
    - Small Project: Q1 2010 to Q4 2014
- WSDOT
    - Large and Small Projects: Q2 2010 to Q1 2015

Collected data is organized into the following Excel format: award date, contract #, low bid amount, engineer's estimate, and the number of bidders. The percent difference is then calculated between the low bid and engineer's estimate. A sample of this data can be seen in Table 10, as it pertains to the CDOT five-year dataset.

Table 10 Sample of five-year bidder data for CDOT projects

Award Date	Contract #	Low Bid	Engineer's Estimate	# of Bidders	% Difference
7/7/2011	18446	$1,591,680.00	$1,546,400.00	2	2.93%
7/7/2011	18125	$852,377.00	$715,845.00	3	19.07%
7/14/2011	18412	$224,420.50	$179,804.75	4	24.81%
7/14/2011	17495	$3,046,312.28	$3,048,363.00	5	-0.07%
7/14/2011	18193	$2,012,860.54	$1,641,785.60	6	22.60%
7/14/2011	18141	$310,000.00	$294,998.50	7	5.09%
7/21/2011	17647	$1,945,004.18	$2,125,469.00	3	-8.49%

Percent differences are then aggregated by the associated number of bidders. This results in a statistical average percent difference for each magnitude of bidders on a project. Averages were calculated for one bidder projects, two bidder projects, and so on until reaching eight bidder projects. Percent difference breakout by number of bidders stopped at eight, primarily due to the fact that any more than eight bidders on a project is extraordinarily rare. Therefore, any historical projects with eight or more bidders were lumped under the "greater than or equal to eight bidders" category, as seen in Table 11 below.

Table 11 Percent difference b/w low bid and engineer's estimate as associated with number of bidders (#)

Difference	# Of Bidders
-0.90%	1
-2.53%	2
1.78%	3
-0.22%	4
-5.23%	5
-4.32%	6
-5.48%	7
-8.13%	≥8

The data from Table 11 was then graphed in Excel, with a linear trendline analysis applied. The trendline allowed the calculation of the adjustment factor to be applied to the overall engineer's estimate of a project. The CDOT example of this percentage difference and bidder data is seen in Figure 6.

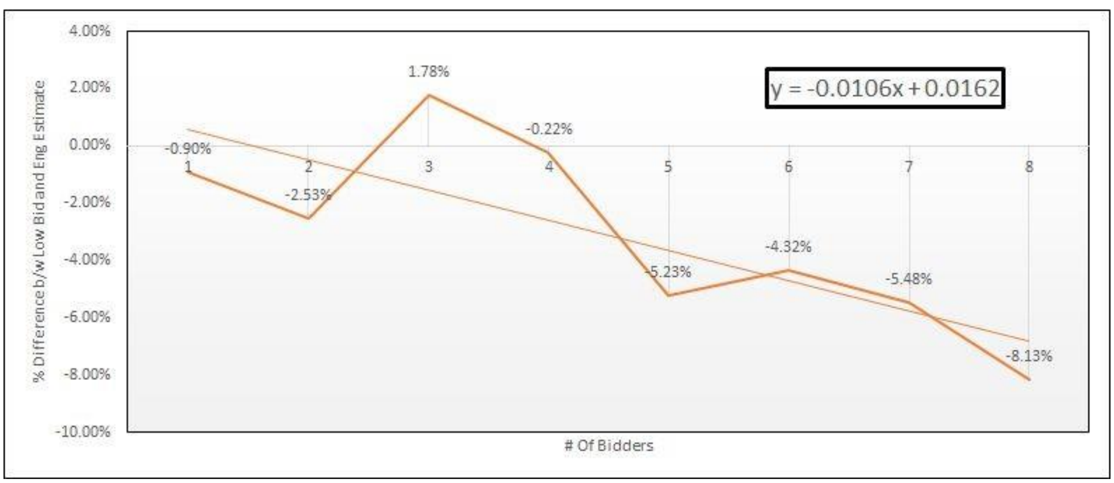


Figure 6: Historical percent difference data for CDOT projects with trendline analysis

With the historical analysis completed, any project with an award date within the quarter before the five year period could have a market conditions index (MCI) value calculated. Using Figure 6 as an example, a Colorado project awarded in quarter 1 of 2016 with 4 bidders would have the following MCI adjustment.

SC (6):

$$-0.0106 * 4 + 0.0162 = -0.0262 \text{ MCI Adjustment}$$

This MCI adjustment value, along with the forecasted CCI ratio, is multiplied against the engineer's estimate to finally obtain the fully adjusted estimate. The difference in dollar amount and percentage is then calculated between the adjusted estimate and the winning low bid.

RESULTS AND DISCUSSION

The primary determinant of success for this proposed project-level methodology rests on any improvement in percentage and dollar amount difference as compared to the real-world results. For instance, if the percent difference between one of the tested projects was 15%, and the FHWA methodology produced an improved 8% difference, then the validation for that particular project would be deemed a success.

This validation Results & Discussion section has been separated by way of the three states tested: CDOT, WSDOT, and MDT.

CDOT Validation

CDOT projects were the first to be validated by the UCD team. Information about the two projects is shown below in Figure 7, with the large project on the left and the small project on the right.

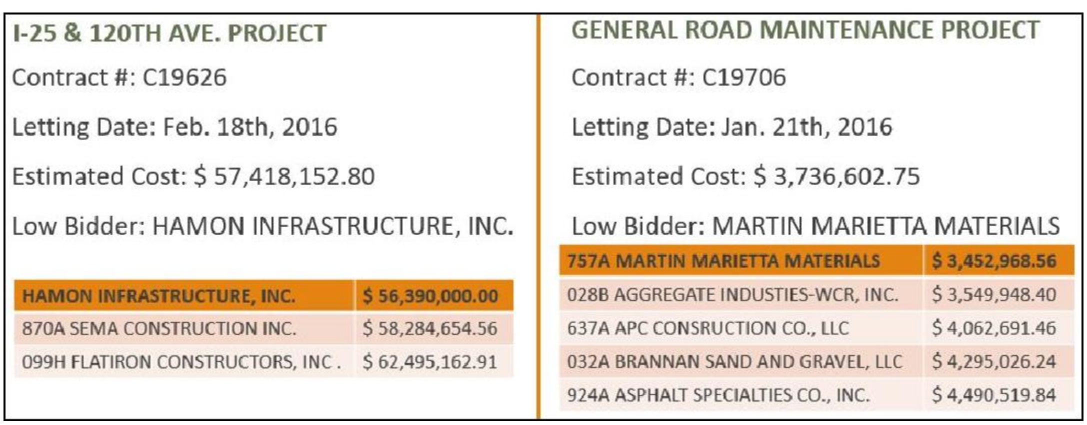


Figure 7: CDOT project information; figure as seen and created for team presentations to FHWA and DOT stakeholders

Large CDOT Project: I-25 & 120th Ave. Project

The large project was found to be cost sensitive by the Material category, with materials representing 57%, labor at 18%, and equipment at 5%. These percentages correspond to the 80% cut-off applied to all pay items for analysis on this particular project. A total of twelve pay items had sufficient data for further analysis; however, these remaining pay items only represented 7.72% of the entire project costs. Remaining pay items can be seen in Table 12.

Table 12: Pay items remaining for analysis after methodology Steps 1-5

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Classification
627-01010	Preformed Plastic Pavement Marking (Type I)(Inlaid)	81,928.00	SF	$11.00	$901,208.00	1.57%	Material
207-00205	Topsoil	50,430.00	CY	$14.00	$706,020.00	1.23%	Material
601-03040	Concrete Class D (Bridge)	702	CY	$650.00	$456,300.00	0.79%	Material
403-00720	Hot Mix Asphalt (Patching) (Asphalt)	2,961.00	TON	$120.00	$355,320.00	0.62%	Material
602-00020	Reinforcing Steel (Epoxy Coated)	383,398.00	LB	$0.90	$345,058.20	0.60%	Material
613-01200	2 Inch Electrical Conduit (Plastic)	28,940.00	LF	$10.00	$289,400.00	0.50%	Material
208-00002	Erosion Log Type 1 (12 Inch)	54,460.00	LF	$5.00	$272,300.00	0.47%	Material
503-00048	Drilled Caisson (48 Inch)	773	LF	$320.00	$247,360.00	0.43%	Material
411-10255	Emulsified Asphalt (Slow-Setting)	52,753.00	GAL	$4.50	$237,388.50	0.41%	Material
606-00301	Guardrail Type 3 (6-3 Post Spacing) (31 in. MGS)	13,896.00	LF	$16.00	$222,336.00	0.39%	Material
602-00000	Reinforcing Steel	258,350.00	LB	$0.85	$219,597.50	0.38%	Material
614-00013	Sign Panel (Class III)	5,349.00	SF	$35.00	$187,215.00	0.33%	Material
					Total	7.72%	

Across these twelve pay items, the cumulative CCI values were calculated and formatted for use in the R software ARIMA model; seen in Table 13. To reiterate, CDOT projects have a base year of 2012 quarter 2, and therefore do not have data to analyze for 2012 quarter 1.

Table 13 CCI calculation results from Steps 1-7 as organized for use in ARIMA

Year	Q1	Q2	Q3	Q4
2012	-	1.000	0.968	0.980
2013	0.918	0.876	0.924	0.986
2014	0.947	0.891	0.968	0.975
2015	0.982	1.153	1.287	1.147

Forecasting operations were performed with ARIMA model results staying in bounds during model validation. Historical data for the remaining pay items did not represent high seasonal variability, and therefore caused ARIMA to choose a best fit model without variance; model ID ARIMA(0,1,0). This model continued the trend of no seasonal variance by calculating all forecasted CCI values as constant over the four quarter period (Figure 8 and Table 14).

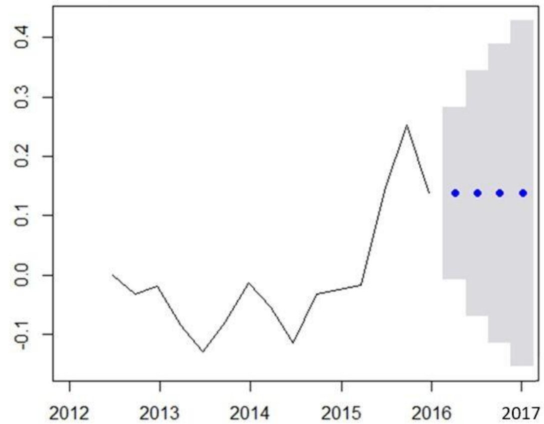


Figure 8: Forecasted CCI output from ARIMA software, with no seasonal variance

Table 14 Forecasted CCI output values

Year	Q1	Q2	Q3	Q4
2016	-	1.147	1.147	1.147
2017	1.147	-	-	-

The CCI ratio, therefore, for the large project was the average of four quarters valued at 1.147, and then divided by the most recent real-world CCI value of 1.147. Naturally, this resulted in an ultimate forecasted CCI ratio of 1.000.

With regards to the MCI results, both CDOT projects utilized the same bidder percentage difference dataset. This is allowable due to both CDOT projects starting within the same quarter; quarter 1 of 2016. The corresponding table and figure from the Market Conditions Analysis section of the report has been reproduced on the next page as Figure 9 and Table 15.

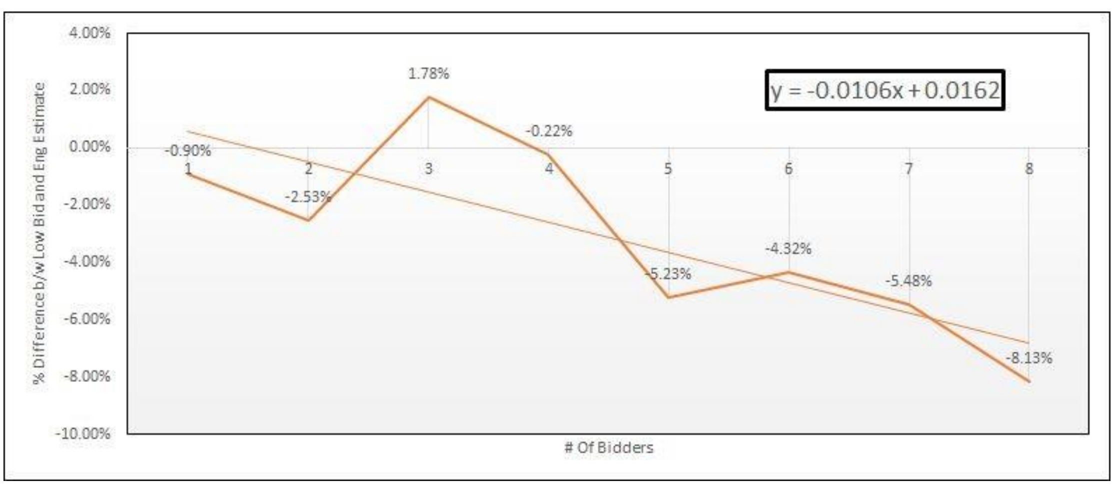


Figure 9: Historical percent difference data for CDOT projects with trendline analysis

Table 15 Percent difference for CDOT projects

Difference	# Of Bidders
-0.90%	1
-2.53%	2
1.78%	3
-0.22%	4
-5.23%	5
-4.32%	6
-5.48%	7
-8.13%	≥8

The large project was bid on by three contractors. As such, inputting three as the slope variable in the trendline formula resulted in MCI of -0.0156. This value, as well as the forecasted CCI ratio were input into the following result Table 16.

Table 16: Final adjusted result for the large CDOT project

Adjustment Method	Winning Bid	Estimate	CCI Ratio	MCI Ratio	Adjusted Estimate	Difference	
						Dollars	Percent
None	$56,390,000.00	$57,418,152.80	N/A	N/A	$57,418,152.80	$1,028,152.80	1.82%
CCI	$56,390,000.00	$57,418,152.80	1	N/A	$57,418,152.80	$1,028,152.80	1.82%
CCI& MCI	$56,390,000.00	$57,418,152.80	1	-0.0156	$56,522,429.62	$132,429.62	0.23%

As shown, the initial percent difference between the engineer's estimate and the awarded low bid contractor was 1.82%, or $1,028,152.80. After applying CCI ratio and MCI adjustments, the percentage difference decreases to 0.23%, or $132,429.62. The main benefit for this analysis came from the use of an MCI, as there was no improvement by solely using the CCI ratio.

Small CDOT Project: General Road Maintenance Project

The small project was material cost sensitive, with 67% material costs, 26% labor, and 2% equipment. These percentages correspond to a 95% cut-off percentage of all project pay items. Seven project pay items remained for analysis after Steps 1-5, and are seen in the below Table 17. Unlike the percentage issue of the remaining pay items for the large project, remaining pay items for the small project represent 58.53% of the entire project cost.

Table 17: Pay items remaining for analysis after methodology Steps 1-5

Item Code	Description	Quantity	Unit	Unit Price	Ext Amount	% of Total	Class
403-34871	Hot Mix Asphalt (Grading SX) (100) (PG 76-28)	24423.62	TON	75	1831771.5	49.02%	Material
627-01010	Preformed Plastic Pavement Marking (Type I)(Inlaid)	17377	SF	12	208524	5.58%	Material
613-10000	Wiring	1	L S	50000	50000	1.34%	Material
411-10255	Emulsified Asphalt (Slow-Setting)	8777	GAL	3.75	32913.75	0.88%	Material
608-00010	Concrete Curb Ramp	255	SY	125	31875	0.85%	Material
609-21010	Curb and Gutter Type 2 (Section I-B)	975	LF	18	17550	0.47%	Material
613-00206	2 Inch Electrical Conduit (Bored)	800	LF	18	14400	0.39%	Material
					Total	58.53%	

Corresponding CCI values were calculated for the remaining seven pay items and were formatted into a useable ARIMA format (Table 18).

Table 18 CCI calculation results from Steps 1-7 as organized for use in ARIMA

Year	Q1	Q2	Q3	Q4
2012	-	1.000	1.319	1.298
2013	1.024	1.042	1.312	1.118
2014	1.147	1.148	1.229	1.214
2015	1.089	1.178	1.178	1.204

ARIMA model validation results stayed within bounds, and forecasting continued. For the small project, however, the ARIMA tool chose a seasonally variant forecast model; ARIMA (0,0,0)(1,0,0) with non-zero mean. This is an indicator that the historical data associated with the remaining small project pay items are highly seasonal. Forecasted CCI values were therefore calculated as seasonally dependent, and are shown by Figure 10 and Table 19.

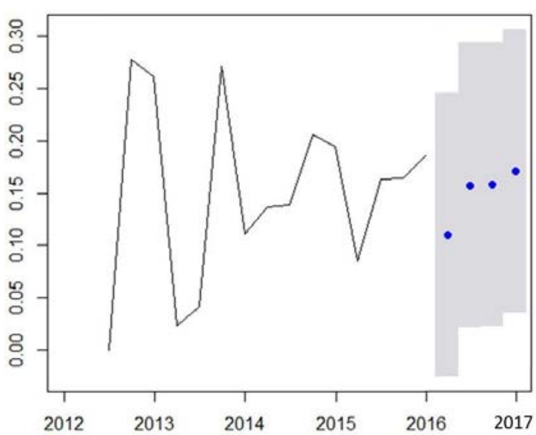


Figure 10: Forecasted CCI output from ARIMA software, with seasonal variance

Table 19 Forecasted CCI output values

Year	Q1	Q2	Q3	Q4
2016	-	1.116	1.170	1.171
2017	1.186	-	-	-

The average of the values from Table 19 were divided by the current period CCI of 1.204 to result in the small project forecasted CCI ratio of 0.964.

With regards to MCI, the small project had a total of five bidding contractors. When input into the trendline formula from Figure 9, the adjusted MCI is -0.0368. This value, as well as the forecasted CCI ratio were input into the following result Table 20.

Table 20 Final adjusted result for the small CDOT project

Adjustment Method	Winning Bid	Estimate	CCI Ratio	MCI Ratio	Adjusted Estimate	Difference	
						Dollars	Percent
None	$3,452,968.56	$3,736,602.75	N/A	N/A	$3,736,602.75	$283,634.19	8.21%
CCI	$3,452,968.56	$3,736,602.75	0.964	N/A	$3,602,085.05	$149,116.49	4.32%
CCI& MCI	$3,452,968.56	$3,736,602.75	0.964	-0.0368	$3,469,528.32	$16,559.76	0.48%

The initial percent difference between the engineer's estimate and low bid was 8.21%, or $283,634.19. A substantial improvement resulted after applying the CCI ratio and MCI adjustments, with the percent difference down to 0.48%, or $16,559.76. Both the CCI ratio and the MCI adjustment assisted in reducing the engineer's estimate and bringing it closer to the actual awarded low bid amount.

WSDOT Validation

WSDOT projects were next to be validated by the UCD team. Information about the two projects is shown below in Figure 11.

Figure 11: WSDOT project information; figure as seen and created for team presentations to FHWA and DOT stakeholders

Large WSDOT Project: I-90 Lanes and Wildlife Bridges

Continuing the trend, this first project from the Washington DOT was material cost sensitive, with 40% material costs, 10% labor, and 14% equipment. These pay items represent 64% of the overall project, as well as a slight shift in methodology. As mandated by FHWA during progress meetings concerning UCD team validation efforts, only pay items that constituted 1.00% or more of total project costs were to be analyzed further.

This was in stark contrast to the methods applied to CDOT projects, where all pay items were included within a specified cut off point. With this reduction in available pay items for analysis, only four pay items had enough historical data to remain (Table 21). Mimicking an issue encountered with the large CDOT project, the remaining pay items only constituted 8.69% of total project costs.

Table 21: Pay items remaining for analysis after methodology Steps 1-5

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Class
4322	CONC. CLASS 4000 FOR BRIDGE	4348	C.Y.	$550.00	$2,413,950.00	3.52%	Material
5100	SURFACING CRUSHED SURFACING BASE COURSE	114290	TON	$12.00	$1,371,450.00	2.00%	Material
4269	PRESTRESSED CONC. GIRDER WF95G	2790	L.F.	$400.00	$1,116,000.00	1.63%	Material
470	EMBANKMENT COMPACTION	560910	C.Y.	$1.88	$1,054,510.80	1.64%	Material
					Total	8.69%	

From the remaining pay items, CCI values were calculated and formatted for use in the ARIMA model (Table 22). It should be noted that the initial WSDOT base year for their CCI calculation purposes was well outside the four years of data necessary. As a result, quarter 1 of 2011 was set as the base time period for the purposes of the FHWA methodology.

Table 22: CCI calculation results from Steps 1-7 as organized for use in ARIMA

Year	Q1	Q2	Q3	Q4
2011	-	1.000	1.189	0.945
2012	0.883	0.841	0.839	0.989
2013	0.827	0.693	0.895	1.066
2014	1.091	1.282	1.409	1.324
2015	1.058	-	-	-

Again, similar to the large CDOT project, an ARIMA best fit model without seasonal variance was auto-selected as the most optimal model. This was a result of low seasonal variance within the historical data of all remaining pay items. The ARIMA forecast model chosen was ARIMA(0,1,0), which continues the no variance trend with the resulting forecasted CCI values. These are shown by Figure 12 and Table 23 respectively.

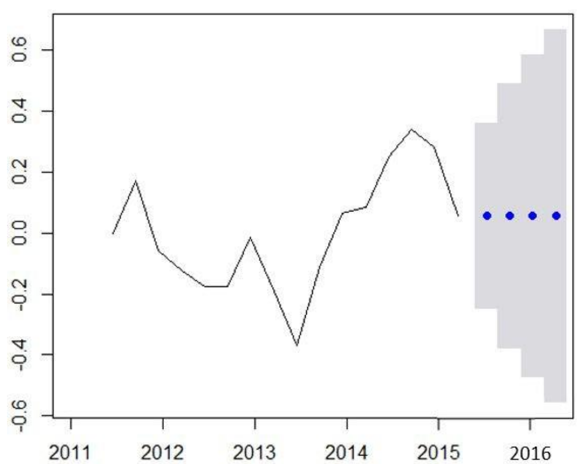


Figure 12: Forecasted CCI output from ARIMA software, with no seasonal variance

Table 23 Forecasted CCI output values

Year	Q1	Q2	Q3	Q4
2015	-	-	1.058	1.058
2016	1.058	1.058	-	-

Since all four quarters of forecasted CCI values were the same, the average was 1.058, divided by the most current CCI value of 1.058 to equal a CCI ratio of 1.000.

The five year MCI time period is the same for both the large and small WSDOT projects; with the period extending from quarter2 of 2010 to quarter 1 of 2015. The corresponding graph and table of data is seen below.

Figure 13: Historical percent difference data for WSDOT projects with trendline analysis

Table 24 Percent difference for WSDOT projects

Difference	# Of Bidders
25.39%	1
0.66%	2
-2.83%	3
-10.12%	4
-11.82%	5
-14.48%	6
-18.53%	7
-9.10%	≥8

A total of six bidding contractors submitted proposals on the large WSDOT project. Using the trendline formula from Figure 13, the resulting MCI adjustment factor is -0.1182. This value and the forecasted CCI ratio were input into the following result Table 25.

Table 25: Final adjusted result for the large WSDOT project

Adjustment Method	Winning Bid	Estimate	CCI Ratio	MCI Ratio	Adjusted Estimate	Difference	
						Dollars	Percent
None	$72,777,532.41	$68,584,834.08	N/A	N/A	$68,584,834.08	-$4,192,698.33	-5.76%
CCI	$72,777,532.41	$68,584,834.08	1	N/A	$68,584,834.08	-$4,192,698.33	-5.76%
CCI& MCI	$72,777,532.41	$68,584,834.08	1	-0.1182	$60,478,106.69	-$12,299,425.72	-16.90%

The final result for the large WSDOT project was the first negative result encountered using the FHWA methodology. The initial difference between the winning bid and engineer's estimate was -5.76%, or -$4,192,698.33. After applying the CCI ratio and MCI adjustment factors, the difference widened to -16.90%, or -$12,299,425.72.

More than likely, this negative result came about from three factors: the exclusion of pay items less than 1.00% of total project costs (within a specified total percentage cut-off), the lack of strong historical datasets, and the large number of bidders. As was seen in the large project test from CDOT, remaining pay items constituted less than 8% of total project costs. However, of that 8%, there were twelve pay items to analyze, many of which were below the 1.00% cut-off applied to the WSDOT and MDT projects. The additional trend data from the twelve pay items likely assisted in saving the final result of the large CDOT project.

Even with the inclusion of less than 1.00% pay items, a serious issue with continuous historical data exists within the WSDOT databases. Of the four pay items analyzed for the large WSDOT project, all exhibited low frequency instances throughout the four year historical period, as well as in the further seven year period for outlier calculation. During a discussion with WSDOT estimating experts, it was revealed that many of their project pay items utilize "lump sum" units of measure. Lump sums are impossible to compare between projects and years, and are immediately eliminated in Step 4 of the traditional CCI calculation methodology.

Lastly, the number of bidders had a heavy influence worsening adjusted estimate results. Within the construction industry, large projects of $50 million or more tend to have three or fewer bidders. The fact this large WSDOT project had six is rare, with WSDOT experts in agreement that this project represented an extraordinary situation with a large number of big contracting companies bidding. Simply by nature of the inverse relationship between the number of bidders and percentage differences, this project was assured to have a less than ideal adjusted result.

With all these potential factors in play, it was determined that the large WSDOT project tested was not a standard project or one without external affecting factors. To ensure a standard project was chosen for validation testing, a second large WSDOT project was chosen for analysis. The results of this project are shown in the next section.

Second Large WSDOT Project: EB Nalley Valley - HOV

In the interest of standardization, the additional large WSDOT project encompassed the construction of HOV lanes; an activity considered well-within the standard projects of a DOT. With an engineer's estimate of approximately $92.5 million, and with an awarded low bid of approximately $74.7 million, this project presented a good test-case for the new CCI method.

Information about this HOV lane construction project can be see in Figure 14 below.

EB NALLEY VALLEY - HOV

Region NO: 3

Letting Date: Sep. 22th, 2011

Estimated Cost: $ 92,457,289.59

Low Bidder:

MOWAT CONSTRUCTION COMPANY

MOWAT CONSTRUCTION COMPANY	$ 74,687,777.28
TRI-STATE / SCARSELLA JV	$ 76,171,657.09
GRAHAM CONSTRUCTION	$ 76,917,871.70
MAX J. KUNEY COMPANY	$ 77,266,965.80
WADSWORTH ICON JV	$ 79,950,890.69
HAMILTON CONSTRUCTION	$ 81,284.000.05
PCL CIVIL CONSTRUCTORS, INC.	$ 81,934,993.70
GRANITE CONSTRUCTION COMPANY	$ 83,335,335.00
GUY F. ATKINSON CONSTRUCTION,	$ 83,941,588.17
FLATIRON CONSTRUCTORS, INC.	$ 86,447,067.12
WALSH CONSTRUCTION COMPANY DBA	$88,408,339.95

Figure 14: WSDOT project information for the additional large project

Of the project pay-items representing 1.00% or more of project costs, 69% of the project costs were captured; with 49% material, 14% labor, and 6% equipment. As such, only material pay-items were analyzed further. The five-remaining pay-items, after analysis in Steps 1-5, are shown in Table 26 below.

Table 26: Pay items remaining for analysis after methodology Steps 1-5

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Class
4269	PRESTRESSED CONC. GIRDER (WF100G)	16484	L.F.	$350.00	$5,769,400.00	7.55%	Material
4322	CONC.CLASS 4000 FOR BRIDGE	8076	C.Y.	$500.00	$4,038,000.00	4.37%	Material
0310	ROADWAY EXCAVATION INCL.HAUL	197310	C.Y.	$8.90	$1,756,059.00	1.90%	Material
5767	HMA CL.1/2 IN.PG 58-22	14330	TON	$76.31	$1,093,522.30	1.18%	Material
0431	GRAVEL BORROW INCL.HAUL	93309	TON	$10.35	$965,748.15	1.04%	Material
					Total	10.05%	

CCI values were calculated based on these five remaining pay items and were formatted for use in the ARIMA model (Table 27).

Table 27: CCI calculation results from Steps 1-7 as organized for use in ARIMA

Year	Q1	Q2	Q3	Q4
2007	-	-	1.000	1.243
2008	1.363	1.385	1.254	1.172
2009	1.114	1.057	1.332	1.632
2010	1.251	1.349	1.244	1.317
2011	1.380	1.430	-	-

An ARIMA best fit model without seasonal variance was auto-selected as the most optimal model. This was a result of low seasonal variance within the historical data of all remaining pay items. The ARIMA forecast model chosen was ARIMA(0,0,0), which continues the no variance trend with the resulting forecasted CCI values. These are shown by Figure 15 and Table 28 respectively.

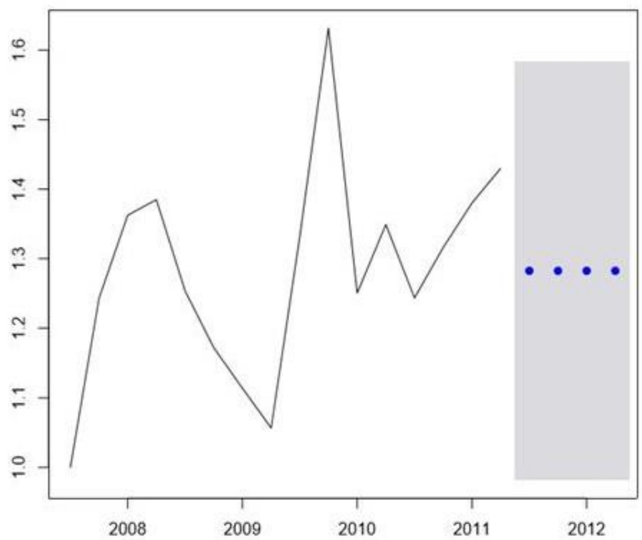


Figure 15: Forecasted CCI output from ARIMA software, with no seasonal variance

Table 28 Forecasted CCI output values

	Q1	Q2	Q3	Q4
2011	-	-	1.283	1.283
2012	1.283	1.283	-	-

Since all four quarters of forecasted CCI values were the same, the average was 1.283, divided by the most current CCI value of 1.430 to equal a CCI ratio of 0.897.

Since this additional WSDOT project was from an entirely different time period as the others, separate MCI data and analysis were conducted. The corresponding graph and table of data is seen below.

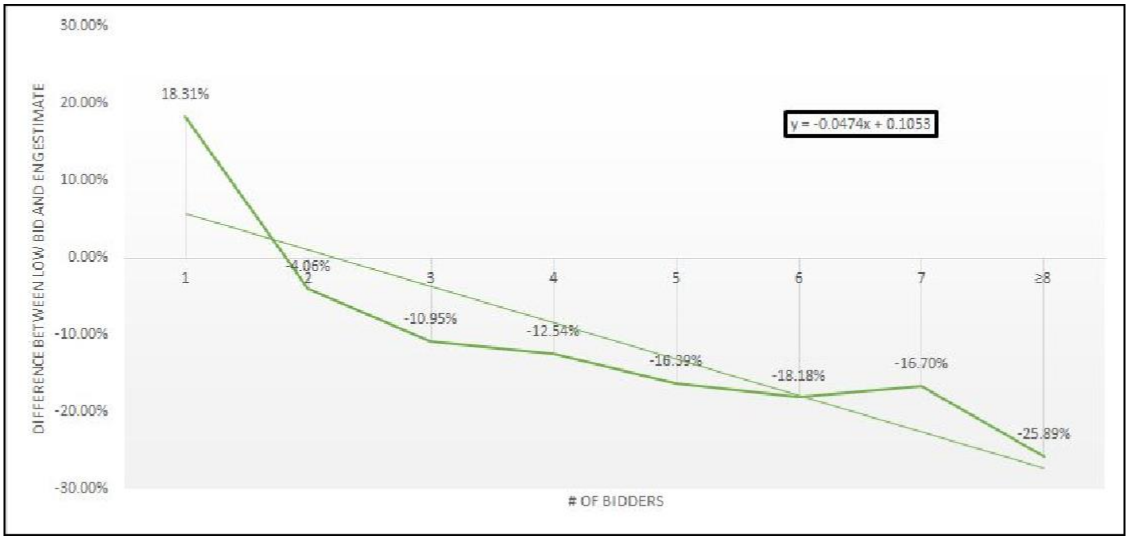


Figure 16: Historical percent difference data for WSDOT projects with trendline analysis

Table 29 Percent difference for WSDOT projects

Difference	# Of Bidders
18.31%	1
-4.06%	2
-10.95%	3
-12.54%	4
-16.39%	5
-18.18%	6
-16.70%	7
-25.89%	≥8

A total of eleven bidding contractors submitted proposals on this WSDOT project. Using the trendline formula from Figure 16, the resulting MCI adjustment factor is -0.259. This value and the forecasted CCI ratio were input into the following result Table 30.

Table 30 Final adjusted result for the second large WSDOT project

Adjustment Method	Winning Bid	Estimate	CCI Ratio	MCI Ratio	Adjusted Estimate	Difference	
						Dollars	Percent
None	$74,687,777.28	$92,457,289.59	N/A	N/A	$92,457,289.59	$17,769,512.31	23.79%
CCI	$74,687,777.28	$92,457,289.59	0.895925	N/A	$82,834,797.18	$8.147,019.90	10.91%
CCI& MCI	$74,687,777.28	$92,457,289.59	0.895925	-0.25888	$61,458,926.24	-$13,228,851.04	-17.71%

As seen in the results table, the CCI applied alone resulted in a substantial improvement in accuracy. When the MCI ratio was factored in, an improvement in accuracy remained but was not as significant as the CCI-only case. This result, however, shows the importance of selecting standard projects for analysis when validating the project-level CCI method.

Small WSDOT Project: I-90 Bridge Replace & Concrete Rehab

The small WSDOT project was unsurprisingly material sensitive when assessed within an 80% total pay item cut-off, with 67% material cost, 13% labor, but with 0% equipment. Understandably, there is of course equipment cost built into the various pay items of the 80% project costs represented. However, as per the mandates of the FHWA methodology, the pay items making up the 80% are each a majority material or a majority labor.

Similar to the large WSDOT project, material pay items that were at least 1.00% or more were manually added back in for further analysis. This resulted in the increase of the material percentage to 71% of total project costs. Unfortunately, after analyzing pay items for their historical frequency and outliers, only four pay items remained for further analysis. These pay items amounted to 18.13% of entire project costs, and are depicted below in Table 31.

Table 31 Pay items remaining for analysis after methodology Steps 1-5

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Class
5100	SURFACING CRUSHED SURFACING BASE COURSE	47080	TON	$13.00	$612,040.00	7.35%	Material
310	GRADING ROADWAY EXCAVATION INCL.HAUL	47900	C.Y.	$10.00	$479,000.00	5.75%	Material
6757	TRAFFIC BEAM GUARDRAIL TYPE 31	8512.5	C.Y.	$25.00	$212,812.50	2.56%	Material
6751	TEMPORARY CONC.BARRIER	13687.5	L.F.	$15.00	$205,312.50	2.47%	Material
					Total	18.13%	

The CCI values were calculated based on the four remaining pay items and were formatted for use in the ARIMA model (Table 32).

Table 32 CCI calculation results from Steps 1-7 as organized for use in ARIMA

Year	Q1	Q2	Q3	Q4
2011	-	1.000	1.418	1.174
2012	1.228	1.190	0.689	1.232
2013	1.002	1.971	1.319	1.178
2014	1.002	1.971	1.535	2.016
2015	1.505	-	-	-

As based on the variability of historical data, the ARIMA best fit model chosen incorporated seasonal variability; ARIMA(2,1,0). The forecast results are depicted in Figure 17 and Table 33.

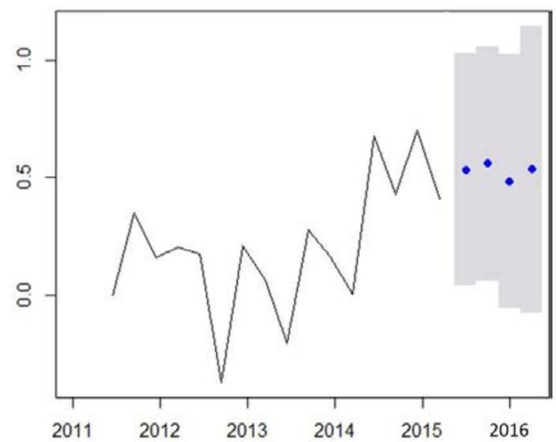


Figure 17: Forecasted CCI output from ARIMA software, with seasonal variance

Table 33 Forecasted CCI output values

Year	Q1	Q2	Q3	Q4
2015	-	-	1.702	1.747
2016	1.620	1.705	-	-

When the forecasted CCI values are averaged and divided by the current 1.505 CCI value, the final CCI ratio is 1.125. The MCI adjustment value, as based on three project bidders and the trendline formula from Figure 13, was calculated to be 0.0156. The combined CCI ratio and MCI adjustment resulted in the final adjusted engineer's estimate seen in Table 34.

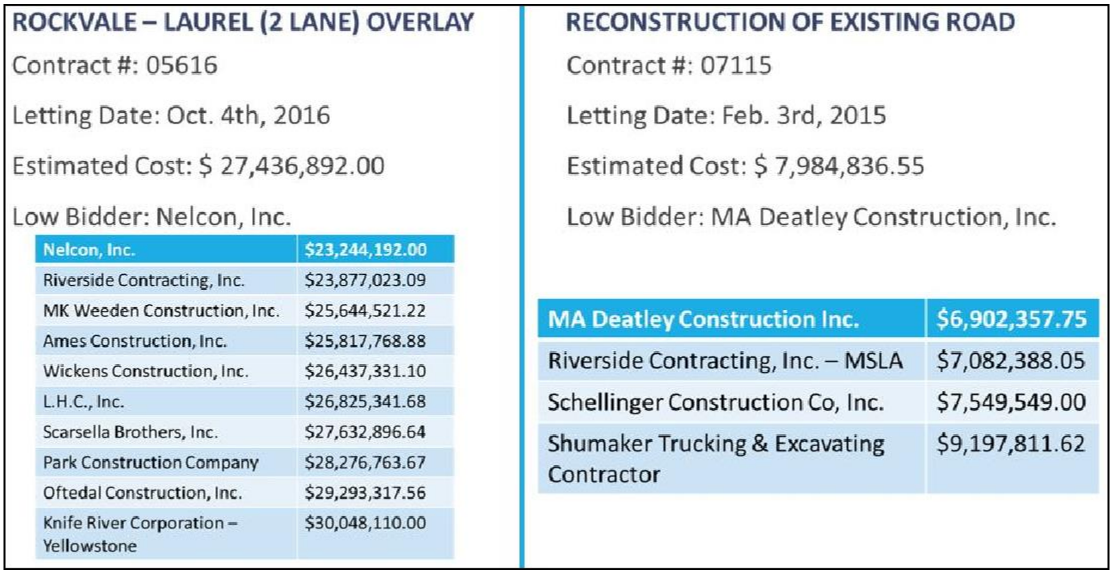
Table 34 Final adjusted result for the small WSDOT project

Adjustment Method	Winning Bid	Estimate	CCI Ratio	MCI Ratio	Adjusted Estimate	Difference	
						Dollars	Percent
None	$10,632,683.70	$8,325,728.00	N/A	N/A	$8,325,728.00	-$2,306,955.70	-21.70%
CCI	$10,632,683.70	$8,325,728.00	1.125	N/A	$9,366,444.00	-$1,266,239.70	-11.91%
CCI& MCI	$10,632,683.70	$8,325,728.00	1.125	0.0156	$9,512,560.53	-$1,120,123.17	-10.53%

The initial percent difference between the engineer's estimate and low bid was -21.70%, or -$2,306,955.70. A substantial improvement resulted after applying the CCI ratio and MCI adjustments, with the percent difference down to -10.53%, or $1,120,123.17. Both the CCI ratio and the MCI adjustment assisted in reducing the engineer's estimate, and bringing it closer to the actual awarded low bid amount.

MDT Validation

MDT projects were the last to be validated by the UCD team. Project information is depicted below in Figure 18.



ROCKVALE – LAUREL (2 LANE) OVERLAY

Contract #: 05616

Letting Date: Oct. 4th, 2016

Estimated Cost: $ 27,436,892.00

Low Bidder: Nelcon, Inc.

Nelcon, Inc.	$23,244,192.00
Riverside Contracting, Inc.	$23,877,023.09
MK Weeden Construction, Inc.	$25,644,521.22
Ames Construction, Inc.	$25,817,768.88
Wickens Construction, Inc.	$26,437,331.10
L.H.C., Inc.	$26,825,341.68
Scarsella Brothers, Inc.	$27,632,896.64
Park Construction Company	$28,276,763.67
Oftedal Construction, Inc.	$29,293,317.56
Knife River Corporation – Yellowstone	$30,048,110.00

RECONSTRUCTION OF EXISTING ROAD

Contract #: 07115

Letting Date: Feb. 3rd, 2015

Estimated Cost: $ 7,984,836.55

Low Bidder: MA Deatley Construction, Inc.

MA Deatley Construction Inc.	$6,902,357.75
Riverside Contracting, Inc. – MSLA	$7,082,388.05
Schellinger Construction Co, Inc.	$7,549,549.00
Shumaker Trucking & Excavating Contractor	$9,197,811.62

Figure 18: MDT projects information; figure as seen and created for team presentations to FHWA and DOT stakeholders

<u>Large MDT Project: Rockvale to Laurel (2 Lane) Overlay</u>

Initially, an attempt was made to get to an 80% total pay item cut off for the large MDT project. However, with the agreed-upon methodology change to utilize 1.00% and greater pay items, only 77.30% of total project cost was initially captured. From this quantity, material costing pay items were 71%, labor was 7%, and equipment was 0%. Similar to the small WSDOT project, equipment costs are built into the pricing for labor and material classified pay items.

MDT projects were intentionally left as the last to assess by the UCD team for validation. Through database searches and discussions with MDT estimation experts, it was found that not enough historical data existed to complete outlier elimination processes. In total, only six years of data was available; other historical data existed, but covered only high-level aspects of project costs, and otherwise did not have the detail required for analysis at this level of detail. Once pay items were assessed for historical frequency, seven pay items remained for further analysis (Table 35).

Table 35: Pay items remaining for analysis after methodology Steps 1-5

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Class
203020100	EXCAVATION-UNCLASSIFIED	2120618	C.Y	$2.50	$5,301,545.00	23%	Material
401020045	PLANT MIX SURF GR S-3/4 IN	102540	TON.	$35.00	$3,588,900.00	15%	Material
301020340	CRUSHED AGGREGATE COURSE	112773	C.Y	$14.50	$1,635,208.50	7%	Material
402020092	ASPHALT CEMENT PG 64-28	5538.5	TON	$240.00	1,329,240.00	6%	Material
551020030	CONCRETE-CLASS GENERAL	406.6	C.Y	$1,200.00	$487,920.00	2%	Material
203080100	TOPSOIL-SALVAGING AND PLACING	114238	C.Y	$4.17	$476,372.46	2%	Material
203023010	SPECIAL BORROW-NEAT LINE	97487	C.Y	$3.50	$340,854.50	1%	Material
					Total	57%	

Since only six years of data was available, CCI values were calculated across all available years of data. Calculations using the remaining seven pay items resulted in the following table of CCI values, as formatted for use in the ARIMA model (Table 36).

Table 36 CCI calculation results from Steps 1-7 as organized for use in ARIMA

Year	Q1	Q2	Q3	Q4
2010	-	-	-	1.000
2011	0.930	0.940	1.120	1.086
2012	1.047	0.909	1.073	0.829
2013	1.114	1.089	1.041	1.002
2014	1.062	1.221	0.929	0.964
2015	0.865	1.162	0.985	0.792
2016	0.833	0.828	0.821	-

The ARIMA software tool determined that input CCI values and embedded historical data represented a no seasonal variation. Therefore, the specific model auto-selected was ARIMA(0,0,0) with non-zero mean. Forecast results are shown in Figure 19 and Table 37.

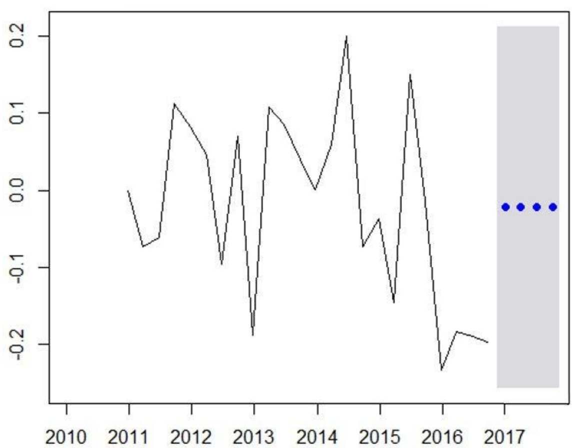


Figure 19: Forecasted CCI output from ARIMA software, with seasonal variance

Table 37 Forecasted CCI output values

Year	Q1	Q2	Q3	Q4
2017	0.978	0.978	0.978	0.978

Averaged forecasted CCI values were divided by the current CCI value of 0.821, which equated to a final CCI ration of 1.190.

Each of the two MDT projects were awarded in different time periods, and therefore require separate MCI datasets and analyses. The time period for the large project was set from quarter 4 of 2011 to quarter 3 of 2016. The corresponding graph and table for this project are depicted below.

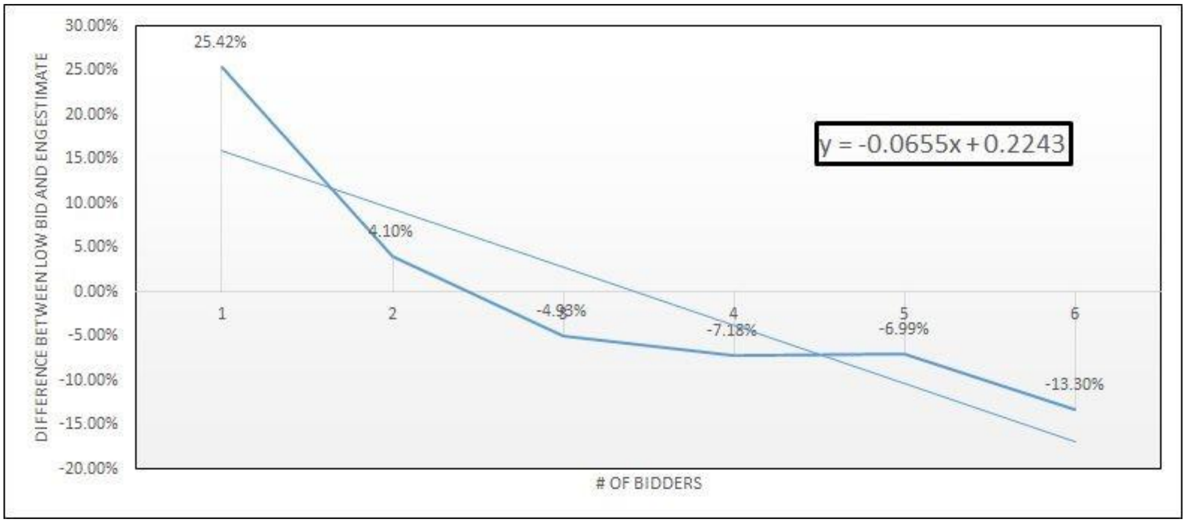


Figure 20: Historical percent difference data for the large MDT project with trendline analysis

Table 38 Percent difference for the large MDT project

Difference	# Of Bidders
25.42%	1
4.10%	2
-4.93%	3
-7.18%	4
-6.99%	5
-13.30%	≥6

In what is considered to be a rare occurrence, ten contractors bid on the large MDT project. However, due to limitations in available data, percent differences were only calculated for projects with one to five bidders. Projects with six or more bidders were grouped together into a greater than or equal to six bidder group. As such, the ten-bidder variable was input in the trendline formula from Figure 20 and resulted in an MCI adjustment of -0.4307.

The forecasted CCI ratio and MCI adjustment were then applied to the original engineer’s estimate to produce the final adjusted project estimate. This is seen in the following Table 39.

Table 39: Final adjusted result for the large MDT project

Adjustment Method	Winning Bid	Estimate	CCI Ratio	MCI Ratio	Adjusted Estimate	Difference	
						Dollars	Percent
None	$23,244,192.00	$27,436,892.00	N/A	N/A	$27,436,892.00	$4,192,700.00	18.04%
CCI	$23,244,192.00	$27,436,892.00	1.19	N/A	$32,649,901.48	$9,405,709.48	40.46%
CCI& MCI	$23,244,192.00	$27,436,892.00	1.19	-0.4307	$18,587,588.91	-$4,656,603.09	-20.03%

Initially, the application of the CCI ratio resulted in a drastic overshoot of the awarded bid amount. MCI adjustment, unfortunately, caused a swing in the other direction, with roughly the same magnitude of difference to the original engineer's estimate and winning bid percent difference.

This lack of improvement is similar to the issues faced by the large WSDOT project. These include: limitations of available historical data, using only 1.00% or greater pay items by cost, and the effects of high numbers of project bidders.

Small MDT Project: Reconstruction of Existing Road

Conveniently, the 85% cut-off point lands on the last 1.00% or greater pay item by cost for the small MDT project. This project was initially declared as well suited to the proposed FHWA methodology as it fulfilled both the cut-off and 1.00% or greater requirements. Within this 85%, material pay items constituted 68.5% of costs, labor at 12.5%, and equipment at 4%. Seven pay items remained for analysis after assessing historical frequency (Table 40).

Table 40: Pay items remaining for analysis after methodology Steps 1-5

Item Code	Description	Quantity	Unit	Price	Amount	Percentage	Class
203020100	EXCAVATION-UNCLASSIFIED	434236	C.Y.	$3.05	$1,324,419.80	19%	Material
301020340	CRUSHED AGGREGATE COURSE	54393	C.Y.	$17.00	$924,681.00	13%	Material
402020092	ASPHALT CEMENT PG 64-28	1085.4	TON	$635.00	$689,229.00	10%	Material
401020045	PLANT MIX SURF GR S-3/4 IN	20066	TON.	$27.00	$541,782.00	8%	Material
203080100	TOPSOIL-SALVAGING AND PLACING	47604	C.Y.	$3.50	$166.614.00	2%	Material
622011084	GEOTEXTILE STABILIZATION	119026	SQYD	$1.25	$148,782.50	2%	Material
402020368	EMULSIFIED ASPHALT CRS-2P	173.3	TON	$600.00	$103,980.00	2%	Material
					Total	56%	

CCI values were calculated for the six years of available data, and formatted for use in ARIMA (Table 41).

Table 41: CCI calculation results from Steps 1-7 as organized for use in ARIMA

Year	Q1	Q2	Q3	Q4
2010	-	-	-	1.000
2011	0.936	0.935	1.123	1.114

2012	1.116	0.967	1.100	0.905
2013	1.120	1.070	1.036	1.126
2014	1.188	1.323	1.055	1.121

Once again, the ARIMA tool determined that there was not enough seasonal variability in the CCI values to utilize a seasonal best fit model. Therefore, the model chosen by the software was ARIMA(0,1,0). Forecasted results are shown in Figure 21 and Table 42.

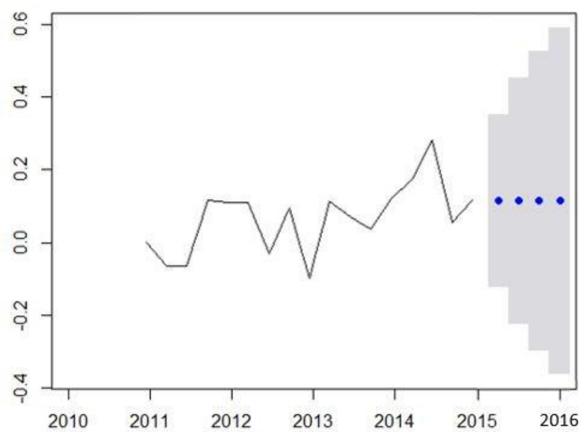


Figure 21: Forecasted CCI output from ARIMA software, with seasonal variance

Table 42: Forecasted CCI output values

Year	Q1	Q2	Q3	Q4
2015	-	1.121	1.121	1.121
2016	1,121	-	-	-

By averaging these forecasted CCI values and dividing by the current period CCI value of 1.121, the resulting final CCI ratio is 1.000.

As for MCI analysis, the five year time period for the small project covers quarter 1 of 2010 to quarter 4 of 2014. The corresponding graph and table are shown on the next page.

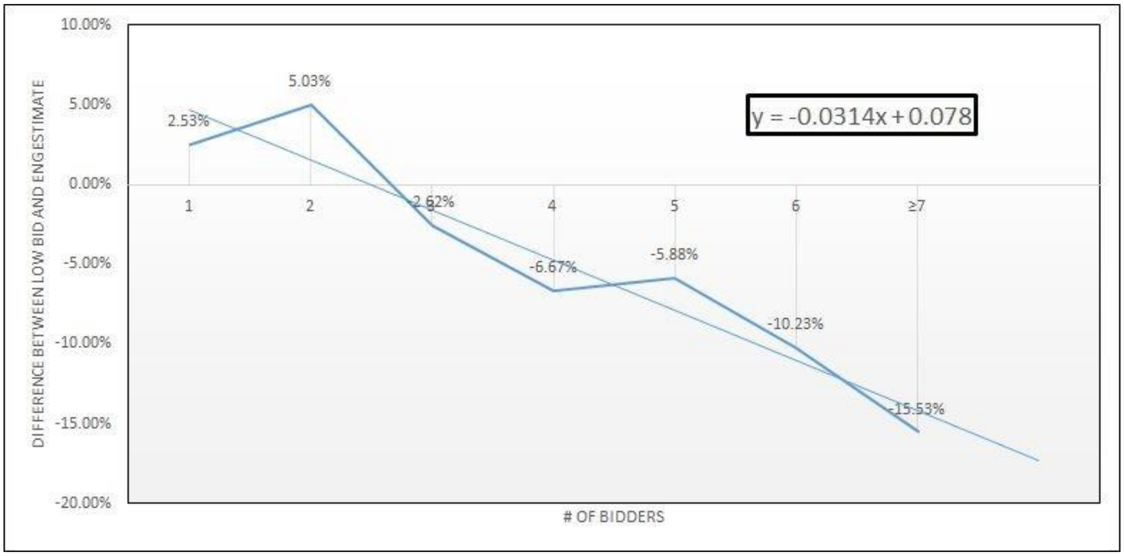


Figure 22: Historical percent difference data for the small MDT project with trendline analysis

Table 43: Percent difference for the small MDT project

Difference	# Of Bidders
2.53%	1
5.03%	2
-2.62%	3
-6.67%	4
-5.88%	5
-10.23%	6
-15.53%	≥7

The four bidders on the small project were input into the trendline formula, where an MCI adjustment of -0.0476 was output.

The forecasted CCI ratio and the MCI adjustment were combined and multiplied against the original engineer's estimate to arrive at the final adjusted estimate (Table 44).

Table 44: Final adjusted result for the small MDT project

Adjustment Method	Winning Bid	Estimate	CCI Ratio	MCI Ratio	Adjusted Estimate	Difference	
						Dollars	Percent
None	$6,902,357.75	$7,984,836.65	N/A	N/A	$7,984,836.65	$1,082,478.90	15.68%
CCI	$6,902,357.75	$7,984,836.65	1	N/A	$7,984,836.65	$1,082,478.90	15.68%
CCI& MCI	$6,902,357.75	$7,984,836.65	1	-0.0476	$7,604,758.43	$702,400.68	10.18%

The initial percent difference between the engineer's estimate and low bid was improved from 15.68%, or $1,082,478.90, to a percent difference of 10.18%, or $702,400.68.

Summary of Results

The following Table 44 is a summary of the results of this validation effort.

Table 44: EE compared to Winning Bid, percent difference

State	Project Size	No Adjust to EE	W/ both CCI & MCI Adj to EE
CDOT	Large	1.82%	0.23%
CDOT	Small	8.21%	0.48%
WSDOT	Large	-5.76%	-16.90%
WSDOT	Large	23.79%	-17.71%
WSDOT	Small	-21.70%	-10.53%
MDT	Large	18.04%	-20.03%
MDT	Small	15.68%	10.18%

FUTURE WORK

There are opportunities for knowledge growth on any future validation iterations for this methodology in both pay item selection and applications of economic conditions. Mentioned throughout the methodology and results sections, an alteration was made to selecting pay items for further analysis by selecting only 1.00% or greater items by total project cost. Now knowing the results of all three states, CDOT with only an 80% and 95% cut-off, and with WSDOT and MDT using the 1.00% limit, it is quite possible that this methodology change led to the mixed results for WSDOT and MDT. A future analysis should test the effectiveness of the 1.00% or greater rule, as well as statistically compare the 1.00% or greater rule to the simple cut-off percentage by total project cost.

Intuitively, the application of an economic conditions index (ECI) adjustment factor, similar to the use of the MCI, should improve adjusted estimates further. As was mentioned within the MCI explanation previously, economic indicators cannot be compared easily from region to region, or even state to state. A future analysis should have its entire focus spent on the impacts of market and economic indicators from the perspective of, at least, a statewide perspective.

CONCLUSIONS

The proposed project-level methodology is a robust analysis method that aims to close the gap between an engineer's project estimate and that of the awarded low bid. This methodology is generally successful in its application, however, is heavily dependent on a large and detailed historical dataset. As shown, validated CDOT projects resulted in positive outcomes, more than likely due to the detailed nature of state historical databases. WSDOT and MDT projects, on the other hand, were continuously hampered by issues with data continuity.

Problems within the methodology, unfortunately, will continue to arise as standardized estimation tools simply cannot account for the unique characteristics of individual states. Specifically, the seasonal variations, or lack thereof, from one state to the next will require consistent monitoring of the methodologies results.

References

[1] Erickson, Ralph, and Karen White. "New Cost Estimating Tool." New Cost Estimating Tool. FHWA, July-Aug. 2011. Web. <https://www.fhwa.dot.gov/publications/publicroads/11julaug/02.cfm>.

[2] "Guide to Good Statistical Practice in the Transportation Field." BTS Publications. Bureau of Transportation Statistics, May 2003. Web. <https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/guide_to_good_statistical_practice_in_the_transportation_field/index.html>.

[3] "BidTABS.NET." Oman Systems - Your Civil Construction Software Partner. Oman Systems,
Inc., 2017. Web. <http://omanco.com/index.php/product/bidtabs/>.

[4] "Research and Development (R&D) Project Sites." Research and Development (R&D) Project Sites. FHWA, 30 Aug. 2015. Web. <https://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=FHWA-PROJ-12-0035>.

[5] "The Mathematics of the National Highway Construction Cost Index (NHCCI)." Policy and Government Affairs | Office of Highway Policy Information. FHWA, 7 Nov. 2014. Web. <https://www.fhwa.dot.gov/policyinformation/nhcci/math.cfm>.

Appendix

I-25 & 120TH AVE. PROJECT

Contract #: C19626

Letting Date: Feb. 18th, 2016

Estimated Cost: $ 57,418,152.80

Low Bidder: HAMON INFRASTRUCTURE, INC.

HAMON INFRASTRUCTURE, INC.	$ 56,390,000.00
870A SEMA CONSTRUCTION INC.	$ 58,284,654.56
099H FLATIRON CONSTRUCTORS, INC .	$ 62,495,162.91

GENERAL ROAD MAINTENANCE PROJECT

Contract #: C19706

Letting Date: Jan. 21th, 2016

Estimated Cost: $ 3,736,602.75

Low Bidder: MARTIN MARIETTA MATERIALS

757A MARTIN MARIETTA MATERIALS	$ 3,452,968.56
028B AGGREGATE INDUSTIES-WCR, INC.	$ 3,549,948.40
637A APC CONSRUCTION CO., LLC	$ 4,062,691.46
032A BRANNAN SAND AND GRAVEL, LLC	$ 4,295,026.24
924A ASPHALT SPECIALTIES CO., INC.	$ 4,490,519.84

A1: CDOT projects used for methodology validation; figure as seen and created for team presentations to FHWA and DOT stakeholders

I-90 PROJECT – LANES & WILDLIFE BRIDGES

Contract #: 008715

Letting Date: Apr. 20th, 2015

Estimated Cost: $ 68,584,834.08

Low Bidder: Guy F Atkinson Construction

Guy F. Atkinson Construction	$72,777,532.41
Midmountain Contractors, Inc.	$76,060,572.20
Max J. Kuney Company	$76,094,181.85
Scarsella Bros., Inc	$84,614,029.51
Walsh Construction Co II LLC	$90,324,160.81
Kiewit Infrastructure West	$106,489,601.37

I-90 – BRIDGE REPLACE & REHAB CONCRETE

Contract #: 008740

Letting Date: May 7th, 2015

Estimated Cost: $ 8, 325,728.00

Low Bidder: Midmountain Contractors, Inc.

Midmountain Contractors, Inc.	$10,632,683.70
Gary Merlind Construction Co.	$10,879,778.50
Granite Construction Company	$12,516,615.00

A.2: WSDOT projects used for methodology validation; figure as seen and created for team presentations to FHWA and DOT stakeholders

ROCKVALE – LAUREL (2 LANE) OVERLAY

Contract #: 05616

Letting Date: Oct. 4th, 2016

Estimated Cost: $ 27,436,892.00

Low Bidder: Nelcon, Inc.

Nelcon, Inc.	$23,244,192.00
Riverside Contracting, Inc.	$23,877,023.09
MK Weeden Construction, Inc.	$25,644,521.22
Ames Construction, Inc.	$25,817,768.88
Wickens Construction, Inc.	$26,437,331.10
L.H.C., Inc.	$26,825,341.68
Scarsella Brothers, Inc.	$27,632,896.64
Park Construction Company	$28,276,763.67
Oftedal Construction, Inc.	$29,293,317.56
Knife River Corporation – Yellowstone	$30,048,110.00

RECONSTRUCTION OF EXISTING ROAD

Contract #: 07115

Letting Date: Feb. 3rd, 2015

Estimated Cost: $ 7,984,836.55

Low Bidder: MA Deatley Construction, Inc.

MA Deatley Construction Inc.	$6,902,357.75
Riverside Contracting, Inc. – MSLA	$7,082,388.05
Schellinger Construction Co, Inc.	$7,549,549.00
Shumaker Trucking & Excavating Contractor	$9,197,811.62

A.3: MDT projects used for methodology validation; figure as seen and created for team presentations to FHWA and DOT stakeholders

Year	Quarter	627-01010		207-00205		601-03040		403-00720		602-00020		613-01200		208-00002	
		Price	Qty	Price	Qty	Price	Qty	Price	Qty	Price	Qty	Price	Qty	Price	Qty
2012	Q2	10.67	12268	10.44	43880	447.12	1973	121.10	8091	1.03	549131	9.69	19470	4.08	59446
2012	Q3	9.85	46100	6.98	9433	485.65	864	115.89	3733	1.02	464551	7.80	6148	3.94	40410
2012	Q4	10.00	10000	8.77	9857	543.83	163	147.91	1535	1.32	81827	8.25	52245	3.95	30310
2013	Q1	9.66	11190	20.68	5624	472.92	8336	109.19	6813	0.91	1514373	8.76	32278	3.93	30836
2013	Q2	11.76	23752	10.14	24285	387.67	2970	126.36	9423	0.94	787455	9.76	18634	3.85	35889
2013	Q3	10.20	36800	7.19	51825	358.45	9399	160.83	2902	0.79	1614769	15.16	100855	4.66	16450
2013	Q4	13.00	1632	5.85	2682	508.89	243	174.82	2210	0.86	387376	7.09	14755	4.33	18763
2014	Q1	13.11	35132	12.62	6930	363.94	1481	144.71	5700	1.04	401748	9.05	7725	7.00	36930
2014	Q2	8.82	176433	8.70	40531	472.72	4638	145.78	12263	0.91	1180001	11.39	15017	4.46	57024
2014	Q3	11.25	2569	9.04	22818	505.90	8123	168.51	2771	1.01	2798831	9.01	61240	4.57	14031
2014	Q4	12.59	14390	8.14	80558	480.80	2652	202.26	3888	0.99	800736	8.31	12378	4.12	35335
2015	Q1	9.18	127591	8.94	47388	592.11	1050	144.15	10576	1.68	303158	12.26	2689	4.37	30562
2015	Q2	10.05	35391	11.35	20510	1400.00	9	184.07	3655	1.71	164665	9.71	17421	4.55	19264
2015	Q3	12.53	10142	27.95	203	1600.00	23	184.59	3237	1.55	46070	12.93	9705	4.18	15632
2015	Q4	25.32	759	11.33	27163	772.56	1072	197.07	3449	1.39	346258	13.90	22016	5.13	14282

503-00048		411-10255		606-00301		602-00000		614-00013		Fisher Ideal Index	
Price	Qty	Price	Qty	Price	Qty	Price	Qty	Price	Qty	Relative	Cumulative
481.12	1054	2.63	140802	17.76	21017	0.86	283970	28.96	505		1.00
364.46	325	2.35	28954	16.88	31381	1.83	8019	30.06	2732	0.97	0.97
451.87	187	1.60	70659	19.86	8252	0.81	228480	21.62	11772	1.01	0.98
342.29	1080	2.61	146374	18.71	36249	0.65	204053	22.27	5388	0.94	0.92
376.10	51	2.76	261842	18.23	82760	0.81	261306	25.79	1077	0.96	0.88
320.00	761	5.27	130716	16.58	46126	0.71	735522	28.00	8226	1.05	0.92
634.93	201	3.31	28382	19.25	38869	0.81	99415	26.23	4266	1.07	0.99
398.14	662	3.23	208388	18.33	35469	0.87	227498	26.16	814	0.96	0.95
400.15	1393	3.03	225961	17.79	62846	0.86	288194	21.59	10729	0.94	0.89
333.32	4466	4.71	29532	19.99	12674	1.05	150209	25.21	928	1.09	0.97
407.74	486	3.30	50057	21.58	36154	1.24	147293	25.16	1163	1.01	0.97
464.76	84	3.35	329450	19.23	51028	1.55	65018	22.66	14108	1.01	0.98
488.31	89	3.07	107080	23.92	19210	1.33	40580	29.49	444	1.17	1.15
390.00	23	5.08	32510	20.22	10805	0.85	37678	25.98	3505	1.12	1.29
719.95	200	3.02	25270	22.72	14956	0.70	389755	25.98	3505	0.89	1.15

A.4 Completed CCI data-table for the large CDOT project; contract # C19626