ADVANCED METHODOLOGY TO DETERMINE HIGHWAY CONSTRUCTION COST INDEX (HCCI)

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prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

June 2017

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RESEARCH PROGRAMS

MDT

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16. Abstract

A highway construction cost index (HCCI) is an indicator of the purchasing power of a highway agency. Thus, it must reflect the actual construction market conditions. However, the current method used by MDT is not robust enough to meet this primary goal due to (1) a significantly insufficient sample size of bid items used in HCCI calculation and (2) inability to address the need to track cost trend of construction submarket segments such as, but not limited to, various project types, sizes, and locations. This study develops an advanced methodology to overcome these apparent limitations using two new concepts: (1) dynamic item basket; and (2) multidimensional HCCIs. The dynamic item basket process identifies and utilizes an optimum amount of bid-item data to calculate HCCIs in order to minimize the potential error due to a small sample size, which leads to a better reflection of the current market conditions. Multidimensional HCCIs dissect the state highway construction market into distinctively smaller sectors of interest and thus allow MDT to understand the market conditions with much higher granularity. A methodology is developed to integrate these two concepts and a standalone 'MDT HCCI Calculation and Bid Analysis System' is developed to automate the HCCI calculation process. The results show an eightfold increase in terms of the number of bid items used in calculating HCCIs and at least a 20% increase in terms of the total cost of bid items used. In addition, the multidimensional HCCIs reveal different cost-change patterns across different highway sectors. For example, the bridge construction market historically shows a very different trend compared with the overall highway construction market. The new methodology is expected to aid MDT in making more-reliable decisions in preparing business plans and budgets with more accurate and detailed information about the construction market conditions. Further, the system is expected to provide insights on the cost trends of a specific item; aid in identifying project types, locations, and sizes with higher construction cost growth; and aid in identifying hidden relationships such as cost-quality relationship.

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1 INTRODUCTION

Highway Construction Cost Index (HCCI) is an indicator of cost fluctuation in current market condition and hence the purchasing power of a highway agency. It allows the agencies to make early financial decisions based on the changing amount of financial resources and changing market conditions. It also helps determine the return on investment value of a new project. Higher budget and lower spending results in waste of remaining budget while lower budget and higher spending results in the cancellation or delay of projects. In addition, there is an inconsistency in the amount of federal funding available over years. Thus, quick and reliable conceptual cost estimation is very important for maximum utilization of available budget.

Montana Department of Transportation (MDT) currently uses eight groups of bid items – earthwork, aggregate, plant mix, asphalt, reinforcing steel, structural steel, concrete, and structural concrete – to calculate the Highway Construction Cost Index (HCCI) (Alavi and Tavares 2009). The items are selected based on the availability of unit prices for a predetermined number of time periods. Items with same units within each group are then used to calculate the weighted average unit prices and are combined to generate HCCI. However, a single composite HCCI has serious limitations. Specifically, the effects of item quantities, project size, project type, and spatial distribution of the project are neglected and it is in many cases difficult to estimate cost changes and differences for a wide range of construction projects. This can be specifically problematic when state Departments of Transportation (DOTs) shift their strategic focus from letting fewer larger projects to many smaller maintenance and rehabilitation projects. Thus, the high level of budget allocation decisions driven by current indexes can be significantly misleading in the current environment because of those limitations and unreliable analysis techniques used. As a result, many state DOTs are looking forward to updating their HCCIs (Walters and Yeh 2012). There has been a strong need to develop an advanced methodology to determine realistic and practical HCCIs and tools that MDT can use.

This project has developed a Montana specific Multi-dimensional Highway Construction Cost Index (HCCI) system using a newly developed concept of dynamic item basket. The new methodology and a computer software program developed in this study are expected to significantly improve the accuracy and reliability of HCCI for planning and budgeting for future fiscal years. The advanced HCCI system is expected to play a key role in maximizing the utilization of available budget.

2 LITERATURE REVIEW

This section discusses theoretical aspects of HCCI formulas, a brief history of HCCIs in the U.S., and current practices in terms of calculation and utilization of HCCIs.

2.1 Theoretical Aspects of Price Index

A price index represents the relative change in the price(s) of item(s) over time. In theory, the price indexes are calculated using unit prices (hereinafter referred to as “price”) and quantities of certain items from two periods. Those items and their quantities are called a market basket (“hereinafter referred to as “item basket”) (Dalton and Novak 2009). If the mix of items in the item basket does not change over time, it is called a fixed item basket. Otherwise, it can be termed as a dynamic item basket. The items in the item basket are generally organized into several categories to calculate category level price indexes. Such categories are termed as “item category” in this report.

An HCCI is a special type of price index that measures the relative price changes in the highway construction industry. The Laspeyres and Fisher indexes are two most common price index formulas used by state DOTs to determine their HCCIs. The Fisher index is based on the Laspeyres index and Paasche index (International Monetary Fund (IMF) 2010). Both the Laspeyres and Paasche indexes are two special cases of the Lowe index. This relationship is illustrated in Figure 1 and described in the following paragraphs. In Figure 1, p and q are the prices and quantities of the items, respectively.

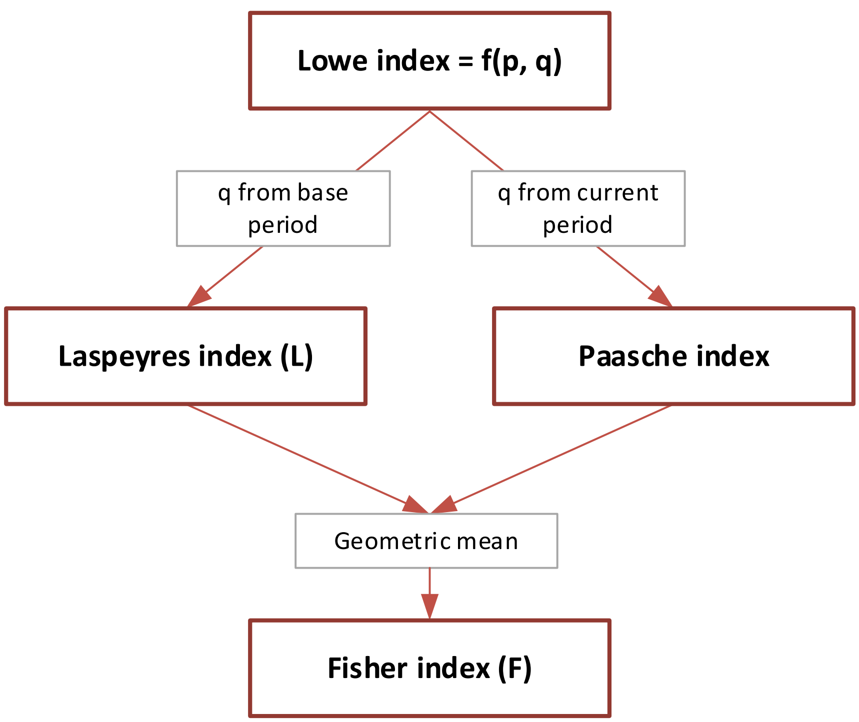

Figure 1 Relationship between Lowe, Laspeyres, Paasche, and Fisher Indexes

The Lowe index is one of the popular price indexes (IMF 2010). In an item basket consisting of *n* items with price p_i and quantity q_i, the Lowe index for the i^{th} item comparing the periods *t* and *0* can be presented mathematically as shown in equation (1).

$$\text{Lowe index} = \frac{\sum_{i=1}^{n} p_{i,t} q_i}{\sum_{i=1}^{n} p_{i,0} q_i} \qquad \textbf{\textit{(1)}}$$

In the Lowe index formula, any arbitrary quantity of the item, q_i, can be used, but, typically, the average quantity between the periods *t* and *0* is used. The Laspeyres and Paasche indexes are two special cases of the Lowe index where the quantities from the base period and current period are used, respectively. If the quantity of i^{th} item in the base period is $q_{i,0}$, the Laspeyres index can be mathematical expressed as equations (2) and (3).

$$\text{Laspeyres index}, L = \frac{\sum_{i=1}^{n} p_{i,t} q_{i,0}}{\sum_{i=1}^{n} p_{i,0} q_{i,0}} = \sum_{i=1}^{n} w_{i,0} \frac{p_{i,t}}{p_{i,0}} \qquad \textbf{\textit{(2)}}$$

$$\text{Where, weight, } w_{i,0} = \frac{p_{i,t} q_{i,0}}{\sum_{i=1}^{n} p_{i,0} q_{i,0}} \qquad \textbf{\textit{(3)}}$$

Generally, state DOTs use the second form of the Laspeyres index presented in the equation *(2)*. The term $w_{i,0}$ indicates the weight of the item in the base period. The ratio of the current period prices to the base period prices ($p_{i,t}/p_{i,0}$) is called the price relative. The Laspeyres index typically overestimates the impact of price increases and underestimates the impact of price decreases.

The Paasche index uses item quantities from the current period and has an exact opposite bias compared to the Laspeyres index (i.e.. it underestimates the impact of price increases and overestimates the impact of price decreases). The Paasche index can be modeled as shown in equations (4) and (5).

$$\text{Paasche index}, P = \frac{\sum_{i=1}^{n} p_{i,t} q_{i,t}}{\sum_{i=1}^{n} p_{i,0} q_{i,t}} = \left(\sum_{i=1}^{n} w_{i,t} \frac{p_{i,0}}{p_{i,t}}\right)^{-1} \qquad \textbf{\textit{(4)}}$$

$$\text{Where, } w_{i,t} = \frac{p_{i,t} q_{i,t}}{\sum_{i=1}^{n} p_{i,t} q_{i,t}} \qquad \textbf{\textit{(5)}}$$

The average of the Laspeyres and Paasche indexes is considered the best approach since it can theoretically cancel out the biases of the two methods. However, there are multiple ways to calculate an average of those two methods. The Fisher index is the geometric average of those two indexes and is generally considered the best price index formula as discussed later. It can be calculated as shown in equation (6).

$$\text{Fisher index}, F = \sqrt{\frac{\sum_{i=1}^{n} p_{i,t} q_{i,0}}{\sum_{i=1}^{n} p_{i,0} q_{i,0}} X \frac{\sum_{i=1}^{n} p_{i,t} q_{i,t}}{\sum_{i=1}^{n} p_{i,0} q_{i,t}}} = \sqrt{\sum_{i=1}^{n} w_{i,0} \frac{p_{i,t}}{p_{i,0}} \; X \; \left(\sum_{i=1}^{n} w_{i,t} \frac{p_{i,0}}{p_{i,t}}\right)^{-1}} \qquad \textbf{\textit{(6)}}$$

The Fisher index accounts for the quantities from both periods symmetrically and provides a more accurate or representative measure of price changes (UN 2009; International Labour Organization (ILO) et al. 2004). The Fisher index is also considered the best price index formula based on axiomatic and economic theory approaches of evaluating price index formulas (UN 2009; ILO 2004). Further discussion of those methods is out of the scope of this report, but readers may refer to manuals on price index formulas (UN 2009; ILO 2004) for additional information.

There are other price index formulas such as the Walsh, Young, Törnqvist, and Divisia indexes (IMF 2010). Currently, MDT uses the Young index and Wyoming DOT uses the Lowe index. Those indexes are not popular among state DOTs, but they use unique approaches to calculating price indexes. Those formulas are described briefly in Appendix C.

2.1.1 Chained Price Index

The price index formulas presented above can be used to calculate price indexes between two time periods. Traditionally, a base period is selected to calculate price indexes for all future periods. However, over time, the quantities from the base period become progressively out of date (ILO 2004). There are two possible solutions for overcoming this issue. First, the base period can be changed after a certain period (say 10 years). However, the quantities may become outdated before the base period is changed. The second and a preferred alternative is to use a chained price index, where price indexes are calculated for two consecutive periods only (i.e., only prices and quantities from current and previous periods are used to calculate the current index). A chained price index also accounts for the addition and removal of items over time from the item basket. For a chained price index, the base period *0* in the price index formulas is replaced by previous period *t-1*. The overall index between two periods (*0* and *t*) can be calculated by multiplying the consecutive price indexes between the periods. For example, the price index between *0* and *t* can be calculated as shown in equation (7).

$$P_{t,0} = P_{1,0} \; X \; P_{2,1} \; X \; P_{3,2} \; X \ldots\ldots \; X \; P_{t,t-1} \qquad \textbf{(7)}$$

The “index number spread” and “chain drift” are two important concepts that need to be understood when selecting chaining and price index calculation periods.

When a chained index system is used, if there is a gradual economic transition, the spread between the Laspeyres, Paasche, and Fisher indexes is less. However, if there is a significant fluctuation in prices and quantities, the Laspeyres, Paasche, and Fisher indexes will spread out and distort the measure of an overall price change between the first and last periods. Thus, if the prices and quantities of items fluctuate significantly within a year in the highway industry, then monthly or quarterly chained price index calculations may not be recommended. But, as year to year fluctuations may be relatively lower, an annual chained index is preferable.

Ideally, the value of a chained price index should return to one when the prices and quantities of items in the item basket return to their corresponding values in the base year. However, in reality, the value of the index will come close to one but not exactly to one because of the varying market condition fluctuations. This bias introduced in the chained price index is called "chain drift." Shorter interval and seasonal fluctuations contribute to a higher chain drift. Thus, an annual chained index is preferred to reduce the chain drift.

2.2 History and Review of HCCIs in the U.S.

This section discusses a brief history of the Federal Highway Administration (FHWA) HCCIs and state DOT HCCIs. The calculation and use of an HCCI in the U.S. highway construction industry started as early as 1987 when the FHWA developed a Laspeyres-index-based Bid Price Index (BPI) (FHWA 2011, FHWA 2014c). The BPI was calculated using prices and quantities of items from contracts that were larger than $500,000. The bid data were provided by state DOTs. The items were classified into six categories: common excavation, Portland cement concrete pavement, bituminous concrete pavement, reinforcing steel, structural steel, and structural concrete which were considered to be main cost items for typical highway projects. Data from multiple states were used in calculating BPI and hence it did not necessarily reflect the actual market conditions of a particular state DOT. State DOTs also started developing their state level HCCIs in late 1980s (Walters and Yeh 2012). Later, the FHWA discontinued publishing BPI in 2007 because of data quality and availability issues (FHWA 2014b).

In 2010, FHWA developed a chained Fisher-index-based National Highway Construction Cost Index (NHCCI) as a replacement for the BPI (White and Erickson 2011). The NHCCI was calculated for years dating back to 2003. The NHCCI is computed using bid data obtained from Oman System Bid-Tabs software (FHWA 2014b). The Oman System, Inc. collects bid data from all state DOTs but Hawaii (Oman Systems, Inc. 2013). The NHCCI item basket consists of items classified into 31 item categories. Some state DOTs have also adopted the Fisher index to replace their existing formulas while others are seeking guidance to develop and update their HCCIs (Walters and Yeh 2012). The following subsections discuss details about the FHWA NHCCI and state DOT HCCIs.

2.2.1 FHWA National Highway Construction Cost Index (NHCCI)

The NHCCI has been developed to keep track of the highway construction costs over time (FHWA 2014b). It is calculated to represent the changes in the costs of same quality of goods/services. The FHWA collects and processes bid data of multiple states to generate the NHCCI. The item categories used by NHCCI are listed in Table 1.

The inconsistencies in the units of measurements and the use of lump sum items are two major challenges to prepare a clean dataset to calculate the NHCCI (FHWA 2014b). The FHWA eliminates non-standard bid items (items with project specific specifications), lump sum items, and suspect categories (project specific items such as mobilization, bonuses, etc.). The FHWA further eliminates the items:

- Without data for at least 8 quarters,
- With adjusted R^2 value greater than 0.60 from a regression of the log change in price on the

log change in quantity (see Appendix D for a discussion of R^2 values),

- With maximum observed price that is more than 16 times the minimum observed price, and
- For which the coefficient of variation of 100 times the log change in price is greater than 42.

Table 1 Item categories used for NHCCI

1. Grading/Excavation	12. Grassing	23. Lighting
2. Bridge	13. Clearing	24. Buildings/Misc. Structures
3. Asphalt	14. Erosion Control	25. Mobilization
4. Base Stone	15. Retaining Wall	26. Concrete Pavement
5. Drainage-Pipe	16. Signalization	27. Misc. Stone/Riprap
6. Drainage-Inlets/Catch Basins	17. Signs-Permanent	28. Roadway Lighting/Electrical
7. Concrete-Culverts	18. Striping/Pavement Marking	29. Underdrain
8. Concrete-Misc.	19. Painting Structures	30. Equipment/Labor
9. Traffic Control	20. Utility-Water	31. Alternates/Bonus/Time
10. Guard Rail	21. Utility-Gas	
11. Fencing	22. Utility-Sewer	

The FHWA also eliminates data points in which the price is at least two standard deviations from the mean. Such data points are considered outliers. After cleaning the datasets, about 60% of the cost items remain and are used for the NHCCI calculation.

The chained Fisher index is used to calculate the NHCCI. Figure 2 shows the quarterly trend of NHCCI from 2003 to the second quarter of 2015. The base value of 1.00 is used in the first quarter of 2003. The chart captures the high construction cost inflation from 2003 to 2006 and a huge drop from September 2008 to December 2009 due to the U.S. economy recession. Compared to the first quarter of 2003, the current construction cost in the second quarter of 2015 is 14.36% higher.

Many state DOTs calculate their own HCCIs as the national economic condition does not necessarily reflect the economic condition of their states.

Some state DOTs have used a similar procedure for calculating HCCIs to the FHWA's new procedure with subtle differences relating to the bid items used. However, many DOTs have been looking forward to updating their cost indexing system based on the changes to the FHWA NHCCI procedure. The lack of guidance and/or human resources might be one of the challenges for state DOTs to update their HCCIs.

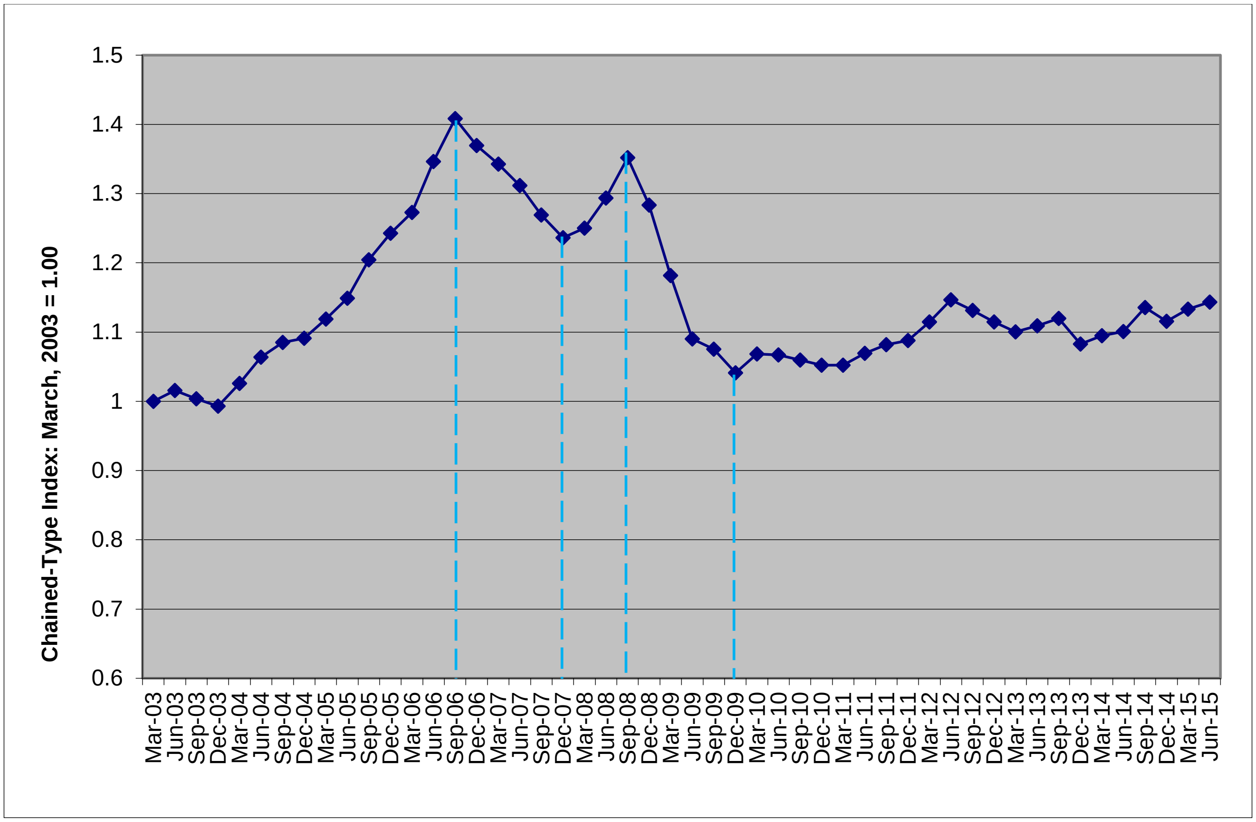

Figure 2 NHCCI trend from the first quarter of 2003 to the second quarter of 2015 (Source: FHWA (2015))

The FHWA (2014b) reports that there should be further research in the fields such as:

- Monitoring the performance of NHCCI after input substitution;
- Calculating and analyzing indexes for each state;
- Calculating sub-indexes for different categories like excavation, reinforcing steel, structural steel, etc.;
- Calculating indexes by project types like capital improvements, maintenance, etc.;
- Analyzing if pre-engineering cost should be included in NHCCI; and
- Identifying and analyzing the selected characteristics of the Oman and the Recovery Act dataset

2.3 State DOT HCCIs

HCCI methodologies of eighteen state DOTs are compared in this section based on the review of available literature, manuals, and results of the questionnaire survey conducted in summer 2015. The survey is attached in Appendix A and detailed survey results in Appendix B. First, the item categories of those states are listed in Table 2. The table shows that state DOTs have developed their own item categories to calculate their HCCIs (Table 2). Ohio and Texas DOTs have 20 and 16 item categories, respectively, while most of the other state DOTs have 10 or less categories.

More categories would enable tracking of sub-indexes for very specific item categories and are likely to cover more items. It would be generally easier to calculate indexes when fewer categories are used. Overall, the following seven item categories are the most common item categories from the 18 DOTs:

- Earthwork,
- Asphalt,
- Concrete pavement,
- Structural concrete,
- Reinforcing steel,
- Structural steel, and
- Aggregates.

Texas and Florida DOTs have two levels of item categorization. In Texas, the items are organized into 16 item categories, which are grouped under four higher level categories; earthwork, subgrade & base course, surfacing, and structures. In Florida DOT (FDOT), six item sub-categories are grouped under two higher level categories; surfacing and structural.

Table 2 Item categories used by state DOTs

1. Montana	2. Washington	3. South Dakota	4. Wyoming	5. Colorado	6. Utah
-excavation, -aggregate base, -surfacing, -drainage, -concrete, -reinforcing steel, -bridge, -traffic, -misc. item	-roadway excavation, -crushed surfacing, -hot mix asphalt, -portland cement concrete pavement, -structural concrete, -steel reinforcing bar, -structural steel	-unclassified excavation, -liquid asphalt, -asphalt concrete, -gravel cushion – sub-base and base, -portland cement concrete pavement, -class a concrete (structures), -reinforcing steel, -structural steel	-unclassified excavation -crushed base -hot plant mix -pg (non-modified) -pg (modified) -mc prime -concrete pavement -structural steel -class concrete -reinforcing steel (combined)	-earthwork, -hot mix asphalt, -concrete pavement, -structural concrete, -reinforcing steel	-roadway excavation, -bituminous surface mix, -bitumen, -portland cement concrete pavement, -reinforcing steel, -structural steel, -structural concrete
7. Nebraska	**8. Minnesota**	**9. Wisconsin**	**10. Iowa**	**11. Ohio**	**12. Texas**
-roadway excavation; -concrete pavement; -concrete for box culverts; -24” & 36” pipe, culvert, corrugated metal and plastic (cmp), reinforced; -concrete for bridges; -structural steel; -piling, concrete and steel; -asphalt concrete; -asphalt cement; -and emulsified asphalt for track coat	-excavation, -reinforcing steel, -structural steel, -structural concrete, -concrete pavement, and -plant-mix bituminous	-common excavation, -portland cement -concrete, -bituminous concrete pavement, -reinforcing steel, -structural steel, -structural concrete, -asphaltic material	-roadway excavation, -hot mix asphalt pavement, -portland concrete cement pavement, -reinforcing steel, -structural steel, -structural concrete	-asphalt, -aggregate base, -barrier, -bridge painting, -curbing, -drainage, -earthework, -erosion control, -guardrail, -landscaping, -lightining, -maintenance of traffic, -pavement marking, -pavement repair, -portland cement concrete pavement, -removal, -signalization, -structures, -traffic control, -unclassifiend construction items	earthwork -excavation -embankment subgrade and base course -lime treated subgrade or base -cement treated subgrade or base -asphalt treated base or foundation course -flexible base surfacing -surface treatment -bituminous mixtures -concrete pavement structures -structural concrete -metal for structures -prestructured concrete beams -foundations -drainage -riprap -retaining walls

13. West Virginia	**14. Mississippi**	**15. California**	**16. Florida**	**17. New Hampshire**	**18. Oregon**
-unclassified excavation; -class 1 aggregate base -course; -marshall hot-mix base course, stone; -marshall hot-mix wear course, stone, -class b concrete, -reinforcing steel bars; -type 1 guardrail	-unclassified excavation, -warm and hot mix asphalt pavement, -concrete pavement, -reinforcing steel, -structural steel, -class 'aa' bridge concrete	-roadway excavation, -aggregate base, -asphalt concrete pavement, -portland cement concrete pavement, -portland cement concrete structural, -bar reinforcing steel, -structural steel	surfacing: -earthwork, -portland cement concrete, and -bituminous concrete structural: -reinforcing steel, -structural steel, and -structural concrete	-roadway excavation, -crushed materials, -hot mix asphalt, -structural concrete, -rebar, -structural steel	-excavation, -crushed rock, -portland concrete cement, -mixed asphalt, -reinforcing steel, -structural steel, -structural concrete

In Table 3, state DOT HCCIs and the FHWA HCCIs are compared in terms of item categories, and major features such as base year, HCCI calculation interval, price index formula used, and other indexes monitored by state DOTs. The comparison shows that state DOTs use base years ranging from 1987 to 2012. Generally, a base year value of 100 or 1.00 is used. In Washington and New Hampshire DOTs, the base year of 1990 and 2000 are used with the base values of 110 and 145, respectively, to match with the FHWA BPI values for those years.

Most state DOTs calculate HCCIs quarterly and/or annually. Texas DOT calculates the index monthly as well. Based on the comparison, the Fisher index (with or without chaining) is the most popular index formula and is used by four state DOTs (Colorado, Ohio, California, and Florida DOTs) and the FHWA. Ohio DOT (ODOT) forecasts its HCCI for 5 years based on the experience of the engineers. Montana and Oregon DOTs also forecast their HCCIs or inflation rates for 10 years. Several DOTs, such as Ohio and Florida DOTs, also track and publish the fuel and asphalt price indexes. Some state DOTs also track external indexes, such as the Regional Economic Models (REMI), Producer Price Index (PPI), and Gobal Insights (GI) to monitor overall market conditions. Some state DOTs also monitor fuel index, asphalt index, etc. from Department of Energy (DOE), Chevron, and Exon Mobil. Some other state DOTs do monitor those indexes, but their data sources are not known (indicated by “x” in the table).

Table 3 Comparison of state DOT HCCIs and the NHCCI

Item	Montana	Washington	South Dakota	Wyoming	Colorado	Utah	Nebraska	Minnesota	Wisconsin	Iowa	Ohio	Texas	West Virginia	Mississippi	California	Florida	New Hampshire	Oregon	NHCCI
Item categories																			
Earthwork	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Asphalt	x	x	x	x	x	x	x	x	x	x	x	x	n/a	x	x	x	x	x	x
Concrete pavement	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	n/a	n/a	x
Structural concrete	x	x	x	x	x	x	x	x	x	x	n/a	x	x	x	x	x	x	x	x
Reinforcing steel	x	x	x	x	x	x	n/a	x	x	x	n/a	n/a	x	x	x	x	x	x	n/a
Structural steel	n/a	x	x	x	n/a	x	x	x	x	x	n/a	x	n/a	x	x	x	x	x	n/a
Aggregate	x	x	x	x	n/a	n/a	n/a	n/a	n/a	n/a	x	x	x	n/a	x	n/a	x	x	x
Features																			
Base year	1987	1990	1987	1997	2012 Q1	2003	1987	1987	2010	1987	2012 Q1	1997	2006	1987	2007	2000	2000	1987	2003
Base year value	100	110	100	100	1	1	100	100	100	100	100	100	100	100	100	80.7	145	n/a	100
Interval	Annually	Qtrly	Qtrly	Annually	Qtrly	Qtrly	Annually	Annually	Qtrly	Qtrly	Qtrly	Monthly	Annually	Annually	Qtrly	Qtrly	Qtrly	Qtrly	Qtrly
Formula	Y	n/a	n/a	n/a	CF	ML	n/a	n/a	L	n/a	CF	n/a	n/a	n/a	Fi	Fi	n/a	n/a	CF
Forecast	10yrs	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5yrs	n/a	n/a	n/a	n/a	n/a	n/a	10yrs	n/a

Item	Montana	Washington	South Dakota	Wyoming	Colorado	Utah	Nebraska	Minnesota	Wisconsin	Iowa	Ohio	Texas	West Virginia	Mississippi	California	Florida	New Hampshire	Oregon	NHCCI
Additional indexes																			
Fuel	n/a	DOE	OPIS	n/a	DOE	WSJ	n/a	n/a	n/a	OPIS	x	n/a	n/a	n/a	Ch, EM, U76	x	x	OPIS	n/a
Asphalt/ Bitumen	n/a	PP	n/a	n/a	x	x	n/a	n/a	n/a	n/a	x	n/a	n/a	n/a	Ch, EM, CP	x	PP	PP	n/a
Steel	n/a	ENR	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	PPI	n/a	n/a	n/a	n/a	n/a	n/a	PPI	n/a
Cement	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	x	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
External HCCIs	REMI	PPI, GI	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	ENR CCI, CPI, UCLA	PPI, ECI		PPI, DOE, Oregon wage index	n/a
Miscellaneous																			
Tool used	Excel	n/a	n/a	Excel	n/a	Excel	Excel	n/a	n/a	Excel	SAS	n/a	n/a	Excel	n/a	n/a	n/a	n/a	Proprietary

Note:

n/a – not available
Fi – Fisher
CF – Chained Fisher
L – Laspeyres
ML – Modified Laspeyres
Y – Young
Qtrly – Quarterly

DOE – Department of Energy
Ch – Chevron
EM – Exon Mobil
U76 – Union 76
CP – ConocoPhilips
OPIS – Oil Price Information Service
ENR – Engineering News-Record

WSJ - Wall Street Journal
ECI – Employment Cost Index
BLS – Bureau of Labor Statistics
PPI – Producer Price Index
CPI – Consumer Price Index
REMI - Regional Economic Models Incorporated
UCLA – University of California, Los Angeles
GI – Gobal Insights

2.4 State DOT Practices

Notable state DOT practices in terms of HCCI calculation methodologies and utilization are discussed in this section. Some unique approaches used by ODOT and Louisiana Department of Transportation and Development (LDOTD) are also discussed.

2.4.1 Indexing Formula

State DOTs are switching to the Fisher index: State DOTs in California, Colorado, South Dakota, and Ohio have switched from the Laspeyres-based HCCIs to Fisher-based HCCIs while other state DOTs such as Wisconsin and North Dakota are switching to Fisher-based HCCIs (Mills 2013; Collins and Pritchard 2013; Walters and Yeh 2012).

Besides the Laspeyres and Fisher indexes, the Lowe and Young indexes are also in use: Most state DOTs only use the Laspeyres or Fisher index. However, MDT is using the Young index, while Wyoming DOT is using Lowe index. MDT's current practices are described in Chapter 4. The average quantities ($q_{i,avg}$) from 1997 to 2008 is used as the quantity in the Lowe's formula in the Wyoming DOT HCCI (see equation (8)).

$$WYDOT\ HCCI = \frac{\sum_{i=1}^{n} p_{i,t} q_{i,avg}}{\sum_{i=1}^{n} p_{i,0} q_{i,avg}} \qquad \textbf{\textit{(8)}}$$

Where p_t and p_0 are average prices of the items in the current period and base period.

Two stage aggregation: Many state DOTs sort their bid items into several item categories. Thus, sub-indexes, such as the concrete pavement index and earthwork index, can be calculated for the categories. Those sub-indexes are then aggregated to calculate an overall HCCI. State DOTs, such as Mississippi and Florida, also calculate additional intermediate level sub-indexes: surfacing and structural sub-indexes (Davis 2013b). In Mississippi DOT, the surfacing sub-index is composed of hot mix asphalt pavement and concrete pavement sub-indexes. The structural sub-index is composed of reinforcing steel, structural steel, and bridge concrete sub-indexes.

Single overall HCCI: State DOTs generally compute a single HCCI to represent the diverse construction market throughout the state. However, highway construction costs are heavily affected by availability of local materials, equipment, and even specialty contractors. In addition, the project size and quantity of work significantly affect construction methods and their productivities which are directly associated with project costs. Moreover, many DOTs are forced to shift their highway project portfolio from new construction to maintenance and rehabilitation projects due to aging roadway systems. These unique characteristics of highway construction and changing business environments require DOTs to customize HCCIs to better understand specific market conditions and trends based on local regions, project sizes and project types. Some state DOTs do compute sub-indexes, partially meeting the needs, but those sub-indexes are based on fixed bid item categories. They fail to reflect the changing project characteristics.

2.4.2 Market Basket

Some state DOTs are using an outdated item basket: State DOTs such as Nebraska DOR and Wyoming DOT are using fixed weight indexes such as the Laspeyres and Lowe indexes. They have not updated their base year in a reasonable frequency, which results in outdated quantities and hence less accurate HCCIs. Nebraska DOR last updated their base year in 1997 (NDOR 2015). Colorado DOT (CDOT) has not changed their base year since 1987, until 2012, when it switched from the Laspeyres index to the Fisher index (CDOT 2015). Utah and New Hampshire DOTs are some of the exceptions that update their item basket annually (Walters and Yeh 2012; New Hampshire DOT (NHDOT) 2013).

Limited Coverage of Items in HCCI: DOTs choose a few important bid items from each category such as asphalt, concrete, and earthwork with a rationale that those selected items can represent all items in the category (Hanna et al. 2011). In this process, most DOTs consider items with high unit costs and/or high frequency as the important items. Non-frequent items and/or items with low unit costs are excluded from HCCI calculation (Shrestha, Jeong, and Gransberg 2016). Such sampling process is common in general inflation calculation such as consumer price index as it requires a significant amount of effort to use more items, and it is practically impossible to use the entire product items in general inflation calculation (Bureau of Labor Statistics (BLS) 2016; IMF 2010). However, for HCCI calculation, the entire bid dataset is readily available in an electronic format, which provides an opportunity to potentially eliminate any *sampling error*. Currently, HCCI is representative of only a select number of bid items. State level HCCIs are calculated using bid items that cover as low as 14% of total construction cost and as few as seven bid items (Table 4). The highest cost coverage is 60% in FHWA's NHCCI. The coverage of 271 bid items in Utah DOT may appear to be large, but considering that DOTs typically use more than 2,000 bid items, it may not be significantly large.

Table 4 Comparison of items covered in HCCI calculation

DOT	Item coverage	
	Number of bid items	% of total construction costs
West Virginia	7	14%
Wisconsin	91	n/a
Colorado	n/a	45%
Nebraska	101	46%
Ohio	n/a	48%
Mississippi	116	n/a
Iowa	190	n/a
Utah	271	n/a
FHWA	n/a	60%

n/a – not available

2.4.3 Data Cleaning and Data Preparation

Some data cleaning steps may be necessary before calculating HCCI: Data from projects delivered through alternate project delivery methods other than the design-bid-build method are typically removed as they can introduce bias in the index. Minnesota DOT (MnDOT) removes data from projects delivered through Construction Manager General Contractor (CMGC), design-build, Indefinite Delivery Indefinite Quantity (IDIQ), Emergency Relief (ER), urgent, and negotiated contracts (MnDOT 2009). CDOT removes data from projects delivered with design-build, hybrid/modified/streamlined design build, construction manager/general contractor, and emergency contracts. Lump sum items are typically removed from HCCI calculation because these items are mostly unit-less and their costs do not have consistent relationships with their quantities, if there were quantities assigned. These data cleaning processes substantially reduce the cost coverage of the items used for HCCI calculation, but are necessary steps to ensure a reliable HCCI calculation.

Outlier removal: Minnesota, California, and Wisconsin DOTs remove data from projects smaller than $100,000 in value (Hanna et al. 2011; Lacho 2015; MN DOT 2009). Similarly, Iowa DOT removes concrete items with quantities less than 96 cubic meters (125 cubic yards) (Iowa DOT (IADOT) 2013) and Colorado DOT removes excavation items less than 765 cubic meters (1,000 cubic yards) (CDOT 2015). CDOT removes bid data outside 5 to 95 percentile as outliers (Yu 2012). They also utilize various outlier detection techniques to remove items whose unit costs appear to be significantly different from most of the unit costs.

Missing data imputation: If bid data is not available for certain item categories, data from previous periods can be used as an option. Utah DOT uses this simple missing data imputation method (Njord 2013).

Manual steps to prepare data for HCCI calculation: In MnDOT, if excavation and embankment are both used in the same project, MnDOT uses the costs of both items, but only the larger quantity among the two is used for both items (MnDOT 2009). CDOT normalizes the quantities (SY) of multiple concrete items of varying thickness into 9-inch thickness to calculate an average price of concrete items ($/SY).

2.4.4 Other Findings

Not all state DOTs calculate HCCIs: Some DOTs such as Oklahoma DOT (OKDOT), LDOTD, and Kansas DOT (KDOT) monitor an item level trend for items such as asphalt binder, but they do not calculate a combined index representing an overall market condition (OKDOT 2016; KDOT 2014).

Regional HCCIs: California Department of Transportation (Caltrans) construction districts calculate their district-level HCCIs. FDOT also keeps track of indexes for 12 regions for earthwork, base, asphalt, concrete, structural steel, and reinforcing steel (FDOT 2013).

Charts and Tables Online: Some state DOTs such as IADOT, FDOT, and CDOT calculate tabulated HCCI data and/or visualized HCCIs. Some of them also publish those data online as pdf files. State DOTs also compare their HCCIs with the FHWA indexes and other state DOTs HCCIs. For instance, Washington DOT (WSDOT) compares its HCCI with FHWA BPI and combined HCCIs of nearby state DOTs (California, Colorado, Oregon, South Dakota, and Utah DOTs) (WSDOT 2015). The combined HCCI is a single HCCI calculated to approximate the market conditions of the neighboring states.

Moving averages: Iowa and Florida DOTs calculate quarterly HCCIs and also compute three-quarterly moving averages to visualize smoother trend of their HCCIs (IADOT 2013; Davis 2013a). Three-quarterly moving average for the current quarter is calculated as an average of the current and two previous quarters.

State DOTs have a varying level of automation: State DOTs have a varying level of automation to calculate HCCIs. FHWA uses a proprietary system and ODOT is using a SAS based program, while most other state DOTs are using an Excel based tool.

Third party indexes: Many state DOTs monitor third party indexes in addition to their own HCCIs. Those indexes include ENR CCI, BLS PPI, and REMI.

2.4.5 Unique Approaches used by Ohio DOT (ODOT)

ODOT has automated its HCCI calculation process using the Statistical Analysis System (SAS) software (ODOT 2013b). It has introduced three unique approaches in calculating its HCCI that are presented below.

Outlier detection. ODOT uses the Median Absolute Deviation (MAD) outlier detection method. First, the MAD value is calculated as MAD = median ($|p_i - \tilde{p}|$) where p_i is the unit price of the data point and $\tilde{p}$ is the median unit price of the item. The unit prices that deviate from the median by at least two times the MAD value are replaced with the median unit price.-Median values are not affected by the extreme outliers as opposed to mean values and standard deviations; hence a MAD based outlier is considered to be a better outlier detection method than standard deviation based outliers.

Missingness factor. ODOT introduced a concept of the "missingness factor (δ)" to identify frequently used items to develop item basket. The missingness factor of an item is defined mathematically as shown in equation (9) (Collins and Pritchard 2013).

$$\delta = \frac{nmiss + \sum x_j^{\theta_j}}{n} * 100 \qquad \textbf{(9)}$$

Where *nmiss* is the number of missing observations, x_j is the number of consecutive missing periods, θ_j is the number of times the item is not purchased for x_j consecutive periods, and n is the total number of periods for which an item has been used. The items with the missingness value of at least 75 are considered as infrequent items and are eliminated.

Use of lump sum items. In order to include as many items as possible when calculating HCCIs, ODOT has developed a methodology to incorporate Traffic Control, which is a lump sum item. Lump sum items are usually ignored when calculating HCCIs as their unit prices fluctuate widely because of the nature of the item. ODOT has used lump sum items under a "maintenance of traffic control" item with a unique approach. It calculates total cost of traffic control items divided by the total contract amount and uses it as the quantity of the item.

ODOT also publishes construction cost outlook and forecast (ODOT 2013a). The DOT tracks and forecasts the trend of key construction inputs like labor, contractor & suppliers' margins, oil & diesel, liquid asphalt, steel, ready mix concrete, and aggregate for five years.

2.4.6 Unique Approach used by Louisiana Department of Transportation and Development (LDOTD)

LDOTD has developed a linear regression technique to model the construction costs of various items (Nickel 2014). It keeps track of items like asphalt and concrete by developing polynomial equations that fit the 5-year bid price data (Weris, Inc. 2013). The indexes of major items calculated from the equations are combined with weights based on the percentages of the construction costs to calculate its HCCI. It further uses the model to predict the cost fluctuation (Nickel 2014). It does not calculate an overall HCCI as other state DOTs do.

2.5 Use of HCCIs

HCCIs are used to monitor the current market conditions, preliminary estimation of construction costs, and for long term financial planning of state DOTs (Erickson 2010; White and Erickson 2011). State DOTs use HCCIs to keep track of the changes in highway construction cost over time (Erickson 2010). HCCIs are also used to inflate the construction cost estimates to the midpoint of construction for long-term projects and hence is a cost estimation tool (White and Erickson 2011). They are used to convert current dollar expenditures on highway construction to constant dollar expenditures which can then be used to compare the costs of similar projects completed at different time periods (FHWA 2014a; Office of the Under Secretary of Defense for Acquisition, Technology and Logistics 2007).

HCCIs serve as a tool to determine the expected purchasing power of the agency's available financial resources (White and Erickson 2011). The index can also be used as an indicator to compare the cost changes in different states. HCCIs allow highway agencies to make more informed decision for writing contracts (FHWA 2014b; Weris, Inc. 2013). Item level HCCIs and category level sub-HCCIs for steel, asphalt, concrete, and fuel have been used for price adjustment clauses (Pierce, Huynh, and Guimaraes 2012). Price adjustment clauses allow contractors to be compensated when the unit prices of volatile items such as fuel, asphalt, etc.

change above a certain threshold value, say 5%. Those clauses shift the risks of price volatility from contractors to the state DOTs and thus, it is likely to result in lower bid amounts. If the trend of the market is known, decisions can be made about purchasing the materials earlier or later depending upon the trend (Toplak 2013). Michigan previously determined the fuel tax rate that is directly proportional to its HCCI, but changed it later as the revenue decreased by 36% (Slone 2009). Slone (2009) and the Institute on Taxation and Economic Policy (2013) still recommend that adjusting fuel tax rate based on a HCCI as a possible option to stabilize user-based revenue growth for the increasing highway construction expenditures. Other applications of HCCI include forecasting HCCIs, life cycle cost analysis, budgeting, and feasibility study (UK Department for Business Innovation & Skills 2013).

2.6 Forecasting of HCCIs

Although cost escalation is a very important issue in developing a tentative construction program (TCP) for future fiscal years, very little attention has been given to generating and predicting HCCIs (Wilmot and Mei 2005). In this section, various uses of HCCIs and methodologies developed to forecast HCCIs are discussed.

Mills (2013) developed an HCCI forecasting model for CDOT based on the macroeconomic and demographic forecasts. The model is developed with the objective of predicting the changes in the Colorado HCCI due to the changes in the input prices. It uses a multiple regression model to make the prediction based on the concept of lagging variables (i.e., the construction market in a quarter is determined to be a function of indicators in a prior quarter). The number of lagging periods can be determined by the users. For example, the value '1' indicates that the HCCI (output variable) for a given quarter is dependent on the input prices (input variables) of the previous quarter. The input prices used in the model are the prices of oil, cement, steel, equipment, and the average wage rate for the Colorado construction industry. The study does not provide details on the performance of the models in terms of errors and accuracies. The study found that the Colorado asphalt pavement index closely followed the trend of BLS PPI for Asphalt and PPI for Crude Petroleum.

Williams (1994) applied an Artificial Neural Network to predict changes in HCCIs. It concluded that a multiple number of complex macroeconomic factors affected highway construction costs and HCCIs and thus it was difficult to apply Artificial Neural Networks to predict the changes. Wilmot and Mei (2005) also used an Artificial Neural Network to forecast LADOTD's HCCI. The study concluded that the predicted HCCIs were not significantly different from the observed HCCIs. Wilmot and Cheng (2003) developed a multiplicative model to predict the LADOT's HCCI and construction costs. The study found that the contract size, duration, location, and the quarter in which the contract is let had a significant impact on contract cost.

A study by Caltrans shows that an auto-regression formula could be used to predict construction cost changes based on historical indexes (Luo 2009). ODOT forecasts high, most likely, and low value of construction inflation forecast based on expert opinions. Some third parties such as Engineering News-Records (ENR) and Global Insight also provide HCCI forecasts.

2.7 Spatial Interpolation of HCCIs

Highway Construction cost varies depending on the project location because of the level of development in surrounding area, accessibility to materials and resources, type of geology, etc. State DOTs mostly calculate state level HCCIs, but some third parties such as Engineering News-Record (ENR) provide CCIs for various cities across the nation. When a new construction is to be executed in a location outside the cities for which the value of CCI is given, such CCI values can be interpolated for the new location. Zhang et al. (2014) developed surface interpolation methods using nearest neighborhood, conditional nearest neighborhood, and inverse distance weighted to estimate CCIs for such locations. Those tools utilize the Geographic Information System (GIS) platform. The study concluded that the conditional nearest neighborhood was the best rough surface interpolation and the Inverse Distance Weighted (IDW) was the best smooth surface interpolation method. Both methods are better than the nearest neighborhood method. Migliaccio et al. (2013) conducted a similar study earlier to model location cost factors for the locations for which location cost factors are not available. The study concluded that geographically weighted regression analysis resulted in the most appropriate results to model the location cost factor.

2.8 Forecasting of Third Party Cost indexes

Several studies have been conducted to predict the third party cost indexes by academics. Ashuri and Lu (2010) developed a methodology to forecast the ENR CCI using several time series analyses. It found that the autoregressive integrated moving-average model and Holt-Winters exponential smoothing model were two most-accurate time series approaches for forecasting the ENR CCI. Some of the forecasting models also provided better forecast than the forecasts from ENR's subject matter experts. Later, Shahandashti and Ashuri (2013) conducted another study and concluded that multivariate time series models provided more accurate prediction results than the autoregressive integrated-average model and the Holt-Winters exponential smoothing model.

Another study by Ashuri et al. (2012) looked into the applicability of various economic, energy, and construction market variables to explain the variations in ENR CCI. The study found that those variables such as BLS CPI, gross domestic product, crude oil price, housing starts (number of new housing projects that started in a given period), and employment level in construction were useful in explaining the variations of CCI.

Xu and Moon (2013) developed a cointegrated vector autoregression model to forecast ENR CCI. The model developed was found to be accurate forecasts for short terms. The study cautions that the level of accuracy may not hold true for the medium- and long-term forecasts.

2.9 Third Party Indexes

This section reviews some of the third party cost indexes and other indexes available in the market. Most indexes are more relevant to the vertical construction than the horizontal. Most of those third party indexes are input cost indexes (i.e., they are calculated using costs of material, labor, and equipment). Some of those indexes such, as PPI and CPI, are used by state DOTs to track the general market conditions. Other indexes such as the Parsons Brinckerhoff cost index and Turner construction company cost index are developed by construction companies to monitor the market from the contractors' perspectives.

2.9.1 Engineering News-Records (ENR) BCI and CCI

Engineering News-Records (ENR) started to publish its CCI since 1921 and Building Cost Index (BCI) since 1938 (Grogan 2008). The indexes are calculated using item baskets consisting of material and labor components. Both indexes use cement, steel, and lumber as the material component of the item basket as they were considered to have a stable relationship with the U.S. economy and were available readily for timely calculation of the indexes. For the labor component, the ENR CCI uses common labor rates while the ENR BCI uses skilled labor rates.

ENR CCI is one of the widely quoted indexes and is calculated for 20 cities in the U.S. (Weris, Inc. 2013). The ENR CCIs have been used by public and private organizations as an inflation factor to adjust contract procurement, estimate nonresidential building construction costs, adjust connection fee of water supply lines, etc. (Lewis and Grogan 2013). However, the use of ENR CCI for highway construction projects is questionable because of the material composition (Weris, Inc. 2013). The index does not take account of price of asphalt that is one of the most commonly used materials in transportation construction projects. At the same time, it takes account of lumber, skilled labor, and unskilled labor that are more suited for the vertical construction.

2.9.2 RS Means City Cost Index

The Reed Construction, Inc. publishes RS means city cost indexes for 731 U.S. and Canadian cities (Reed Construction Data 2012). The indexes are used to estimate the construction costs of vertical projects for the current year (or any other years) based on the construction costs of previous projects. It can also be used to generate estimates based on the construction data from other states. The national average for the U.S. is calculated from cost data of 30 major U.S. cities and has a base value of 100 in 1993. The indexes are computed using material, labor, and equipment costs for nine different types of buildings which are most often constructed in the U.S. and Canada (Reed Construction Data 2012).

Specific quantities of 66 commonly used construction materials, specific labor-hours for 21 building construction trades, and specific days of equipment rental for 6 types of construction equipment are used for calculating the cost index. The cost data for material and equipment are collected quarterly from 318 cities in the U.S. and Canada. The labor wage rates are obtained from 21 different building trades. The materials, labor, and equipment are given weights based on their expected usage.

2.9.3 Bureau of Labors Statistics (BLS) PPI

The Bureau of Labor Statistics (BLS) publishes a number of Producer Price Indexes (PPIs) and Consumer Price Indexes (CPIs). The PPIs measure the trend of selling prices received by domestic producers of goods and services (BLS 2012). One of the PPIs relevant to the highway construction industry is the PPI for Other Nonresidential Construction (BONS) (BLS 2013). The BLS also publishes the Nonresidential maintenance and repair construction (BMNR) index. Those PPIs represent the overall nonresidential construction market. Some state DOTs monitor those PPIs to keep track of the construction market.

The BLS publishes a Consumer Price Index for All Urban Consumers (CPI-U) for the West Region which comprises thirteen states, including Montana (BLS 2016d). Other states included in the region are Alaska, Arizona, California, Colorado, Hawaii, Idaho, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. The CPI-U represents the general inflation in the market; a higher CPI is likely to result in a higher construction inflation or cost index.

CPI-U for Gasoline and CPI-U for Energy are two other sub-indexes that are applicable and relevant to study the regional market trend relevant for the construction industry. However, those indexes are posted after about seven months from the actual date. For example, May 2014 CPI-U was published in December 2015 (BLS 2015b, 2015c, 2015d). Thus, its value may be limited to comparing how general market conditions and construction market conditions have changed.

The BLS also publishes economic summaries for Billings, Great Falls, and Missoula area which include unemployment rates, average weekly wages, employment, PPI, and average annual spending (BLS 2016c, 2016b, 2016a).

The BLS also publishes item specific PPIs that represent the price trends of specific items such as asphalt, cement, fuel, and construction equipment. Some of the relevant item specific BLS PPIs are listed in Table 5. The PPI data can be obtained from the BLS website (http://data.bls.gov/pdq/querytool.jsp?survey=wp).

The BLS collects more than 100,000 price quotations monthly by mail survey from more than 25,000 establishments to calculate PPIs (Dalton and Novak 2009). The BLS PPIs are fixed weight indexes unlike FHWA NHCCI. It is published monthly as well as annually (BLS 2012).

Some state DOTs also keep track of the BLS CPIs to track general inflation. "The Consumer Price Index (CPI) is a measure of the average change in price over time in a fixed market basket of goods and services" (BLS 2016d). The CPI is the most widely used measure of the inflation (BLS 2008) and it is used as an economic indicator, as a deflator of other economic series, and as a measure of adjusting dollar values.

Table 5 Producer Price Indexes relevant to the construction industry

Item code	Item name
058102	Asphalt
133301	Ready-mix concrete
1322	Cement, hydraulic
133	Concrete products
1331	Concrete block and brick
132101204	Construction sand and gravel, West
1321	Construction sand, gravel, and crushed stone
0571	Gasoline
05320104	Propane
0531	Natural gas
0576	Finished lubricants
072106	Plastic construction products
081	Lumber
108303	Commercial, institutional and industrial electric lighting fixtures
0651	Mixed fertilizers
1017	Steel mill products
112	Construction machinery and equipment
3012	Truck transportation of freight

The CPI is calculated using the prices of food, clothing, shelter, and fuels; transportation fares; charges for doctors' and dentists' services; drugs; and other goods and services that people buy for day-to-day living (BLS 2016d). The price data for the national-level CPI is collected in 87 urban areas from 6,000 housing units and approximately 24,000 retail establishments (BLS 2016d). The CPI value is set as 100.0 for base period of 1982-1984.

2.9.4 REMI Index

Regional Economic Models Incorporated (REMI) PI+ indexes are calculated based on material (e.g., stone, gravel, asphalt, etc.), equipment, and labor price data from sources including BLS Employment Outlook, Bureau of Economic Analysis (BEA) State Personal Income (SPI) and Local Area Personal Income (LAPI) series, Energy Information Administration's State Price and Expenditure Report, and Census of Housing (Regional Economic Models, Inc. 2015). Based on the REMI index, Montana has 17% higher construction costs compared to the national average. The higher costs are the result of higher material and equipment costs that are 55% higher than the national average. The lower costs of labor offset high material and equipment costs resulting in lesser overall costs difference (17% rather than 55%).

REMI also publishes an index called TranSight that is used to evaluate state transportation plans, new and expanded highway corridors, toll roads, airports, seaports, rail, freight, and multimodal developments (Regional Economic Models, Inc. 2008).

2.9.5 Global Insight

Global Insight uses statistical material, econometric modeling, and industrial expertise to analyze and forecast the construction market (IHS Global Insight 2013). It publishes a Highway and Street Construction Cost Index based BLS data for material, labor, and equipment costs. It uses fixed weight formula with 60% weight to materials, 28% to labor, and 12% to capital equipment.

2.9.6 Parsons Brinckerhoff (PB)'s Highway Construction Cost Index

PB's Highway CCI uses cost of construction labor, construction equipment, steel, asphalt and asphalt binder, aggregate, and concrete from BLS data for calculating the index (Weris, Inc. 2013). The company estimates the relative weight of the items. PB's analysis shows that the highway construction cost depends on the public spending on transportation and local contractors' competition. The monthly PB's index is published in its semi-annual publication of the Economic Forecast Review.

2.9.7 Turner Construction Company Cost Index

The Turner Construction Company Cost Index focuses on the non-residential building construction market and is widely used by the construction industry, federal governments, and state governments (Weris, Inc. 2013). The index takes account of labor rates, productivity, material prices, and the competitive condition of the marketplace.

2.10 Summary

This chapter provides a theoretical background on price index calculation, reviews the history of state DOT HCCIs in the U.S, identifies the current practices of calculating and utilizing HCCIs, and reviews relevant third party indexes. Chained Fisher index is identified as the best price index formula and will be used for MDT HCCI calculation. State DOTs uses similar methodology with different item baskets to compute quarterly and/or annual HCCIs. State DOTs are using outdated item baskets that cover as low as 14% of the total construction cost. Thus, the reliability of such HCCIs in reflecting the actual construction market condition can be questionable. Further, state DOTs mostly computes HCCIs manually using spreadsheet based solution. In Chapter 4.4, an advanced HCCI calculation methodology and system will be developed to overcome the issue.

3 COMPASION OF HCCIs BETWEEN MDT AND NEIGHBORING STATES

In this section, the HCCI values from neighboring state DOTs and the FHWA are compared and evaluated to identify any correlations.

3.1 Comparison of MDT HCCIs with HCCIs from Neighboring State DOT and FHWA

MDT has calculated two sets of HCCIs: original HCCIs and modified HCCIs. The original HCCI uses item category weights from the current year and the modified HCCI uses constant weights throughout the years. Detailed descriptions of the current MDT HCCIs are presented in Chapter 3.2. Both HCCIs are used for comparison purposes. The HCCI data used for the analyses performed in this section are presented in Appendix E. It includes HCCI data from North Dakota, South Dakota, Wyoming, and the FHWA. Idaho is not included in this comparison as Idaho HCCIs are not available. The MDT HCCI data are available from 1987 to 2013. HCCI data of other state DOTs and the FHWA after 2013 are removed as MDT HCCIs are not available after 2013.

First, South Dakota, North Dakota, and Wyoming DOTs and the FHWA HCCIs are compared in a chart with MDT HCCIs. The HCCIs from neighboring states are expected to have similar trends because of the regional similarities. The comparisons with the FHWA HCCIs show the relative changes in the Montana market conditions with the U.S. market conditions. Statistical correlations between the HCCIs are calculated to identify the states that have the most similar HCCI trend with the MDT HCCIs. A brief theoretical background about correlation coefficients is provided in Appendix D.

3.1.1 HCCIs of Neighboring State DOTs

South Dakota DOT (SDDOT) and MDT have an almost identical HCCI trend (Figure 3). Those HCCIs have base value of 100 for 1987. The SDDOT HCCI values are slightly lower than MDT HCCIs until 1994. From 1997 to 2000 and in 2004, the SDDOT HCCIs are higher than MDT HCCIs. Afterwards, it has been lower than the MDT's original HCCIs. The FHWA BPI has almost always been lower than the MDT HCCIs from 1987 to 2006 with the exceptions of 1997, 1999, 2000, and 2002. The change in the MDT's base years in 1997 and 2000 might have affected these different behaviors in 1997 and 2000.

The North Dakota DOT HCCI, Wyoming DOT HCCI, and FHWA NHCCIs have different base years than the MDT HCCIs. As such, direct comparisons cannot be made. However, Wyoming and North Dakota DOT HCCIs appear to have sharper peaks from 2005 to 2009 and sharper drops than MDT HCCIs during the recession period from 2009 to 2010. The recession officially lasted from December 2007 to June 2009 (Economic Policy Institute 2016).

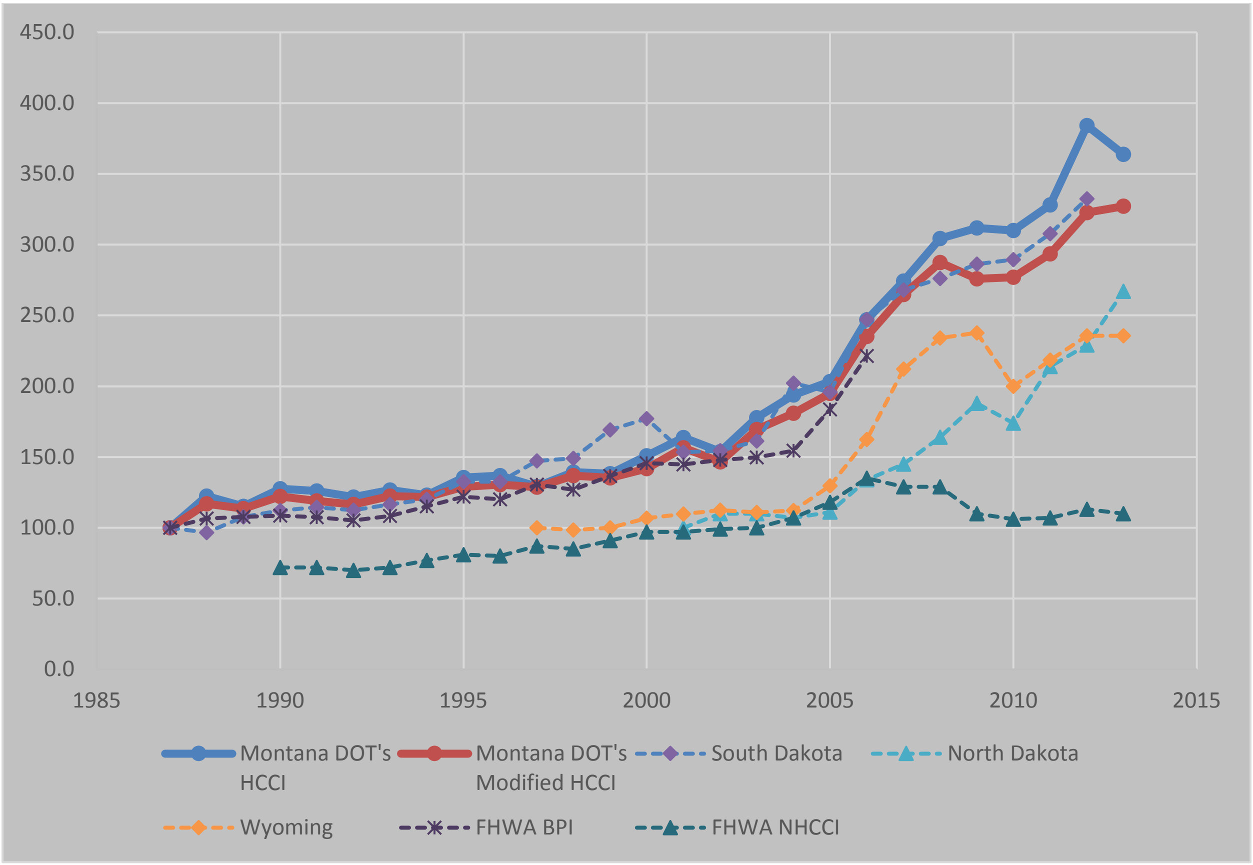

Figure 3 Comparison of HCCIs

3.1.2 Correlation Analysis

The results of the correlation analyses are presented in Table 6. Correlation coefficients measure the statistical relationship between two variables. Correlation coefficients can have values ranging from 0 to 1–higher values indicate a stronger relationship (i.e., increase (or decrease) in the first variable is likely to be accompanied by increase (or decrease) in the second variable).

Five sets of correlations are performed to identify any relationships that might exist between the HCCIs. The values are color coded to indicate the highest correlation (green) and lowest correlations (red). First, HCCI values of MDT, other state DOTs, and the FHWA of same years are compared for the correlation. Practically, this indicates the level of similarities in market conditions and the changes in the market conditions of those states in same years. Those correlations are presented in the table in “No lag” columns. In other four sets, some year lag between the HCCIs are used. For example, in MDT 1 year ahead, MDT HCCI values (say 1998) are compared with the other state DOT HCCIs from the previous year (1997). Such analyses can be used to identify the states whose previous year’s market condition changes are representative of this year’s Montana market condition changes. Consequently, this year’s market condition changes in those states could indicate the market condition changes in the next year in Montana. This analysis assumes that historical trends will continue in the future. It is important to note that the overall market condition can be affected by many other factors that are not considered in this analysis. As such, the results of the analysis should be used carefully.

The analyses show that SDDOT has the most similar HCCI trend with MDT, with correlation coefficients ranging from 0.95 to 0.98. The SDDOT HCCI's correlation with the MDT HCCIs (original, modified) are highest with the "no lag" (correlation coefficients 0.98 and 0.98 for the original and modified MDT HCCIs, respectively) and "MDT 1 year ahead" (correlation coefficients 0.98 and 0.98 for the original and modified MDT HCCIs, respectively). Thus, MDT HCCIs can be predicted using SDDOT's previous year's HCCI values. Although the MDT HCCIs also have very strong correlations to predict future SDDOT HCCIs, this correlation is weaker than the correlation for predicting the MDT HCCIs using SDDOT HCCI. As such, SDDOT HCCIs are more suitable for predicting MDT HCCI than the opposite.

The MDT HCCIs have the weakest correlation with the FHWA NHCCI, with the correlation coefficients of 0.86 or less in all datasets. Thus, the national construction market seems to have a limited effect on the Montana's market conditions.

It appears that MDT's original HCCI trend is followed by North Dakota DOT HCCI with one and two year lags, respectively. Thus, MDT's original HCCIs can be used to predict the North Dakota HCCIs with one or two year's lag. Statistically, this analysis result may indicate that the effect of the regional construction market conditions is first observed in South Dakota. This effect is then transferred to Montana and finally to North Dakota. However, the state DOT HCCIs are calculated using varying methods and hence those indications should be taken with high caution.

Table 6 Correlation coefficients of MDT HCCIs with other state DOT's and FHWA HCCIs

HCCI	**Correlation coefficients with MDT HCCIs**									
	No lag		MDT 1 year ahead (predict MDT HCCI)		MDT 2 years ahead (predict MDT HCCI)		MDT 1 year behind (predict using MDT HCCI)		MDT 2 years behind (predict using MDT HCCI)	
	Original	Modified	Original	Modified	Original	Modified	Original	Modified	Original	Modified
North Dakota	0.94	0.92	0.93	0.89	0.86	0.84	0.97	0.94	0.95	0.93
South Dakota	0.98	0.98	0.98	0.98	0.97	0.96	0.97	0.98	0.95	0.96
Wyoming	0.97	0.97	0.94	0.93	0.88	0.86	0.95	0.97	0.92	0.93
FHWA NHCCI	0.75	0.79	0.81	0.84	0.83	0.86	0.68	0.72	0.64	0.66

3.1.3 Frequency of Calculating HCCI

Many DOTs calculate the HCCIs either “annually” or “annually and quarterly.” The quarterly HCCI allows to observe the seasonal effect on the construction market, but can result in the “chain drift” for chained indexes. The decision is also dependent on the time and effort DOTs want to spend on calculating the HCCIs.

3.1.4 Selection of Base Year and Base Year Value

The base year value is generally selected as 100 or 1.00 by most of the state DOTs and the FHWA. However, there are instances where different base year values are used–mostly so that the value matches with the FHWA HCCI for that period. Adopting such base year value eases the comparison of the state DOT HCCI with the FHWA HCCI. Many state DOTs have also selected 1987 as their base year–mostly likely for the same reason of easing the comparison. State DOTs that have updated the methodologies have adopted recent base years such as 2012, 2010, and 2007.

3.1.5 Automating HCCI Calculation

HCCI calculations are generally done in Excel by many state DOTs. ODOT and the FHWA are two agencies who have automated the HCCI calculation process. Such automation would ease the use of more items in the item basket for calculating HCCIs.

3.1.6 Utilizing HCCIs

State DOTs reported that they use their HCCIs as a cost inflation factor for future contracts, monitor the current market conditions, and as a tool for project cost estimation in early stages of project development. It also indicates the purchasing power of agencies and can be used for budgeting purposes.

3.1.7 Publishing HCCIs

Some state DOTs also publish their HCCI values and charts over time in their websites. HCCI charts can include the HCCI trend of the state DOT as well as other state DOTs and/or the U.S. Construction companies and consultants in the state can use such information to understand the market conditions and generate their own estimates.

3.1.8 Monitoring other HCCIs

State DOTs also monitor HCCIs of other state DOTs and other third party HCCIs. The comparison with other state DOT HCCIs enable them to observe the relative changes in the market conditions of the states.

3.2 Summary

This chapter compares the current MDT HCCI values and calculation methodologies with that of the neighboring state DOTs. The correlation analysis of the HCCI values shows that SDDOT has the most similar HCCI trend with MDT, with correlation coefficients ranging from 0.95 to 0.98. The MDT HCCIs have the weakest correlation with the FHWA NHCCI, with the correlation coefficients of 0.86 or less.

4 REVIEW OF CURRENT MDT HCCI PROCESS

In this section, current practices of calculating MDT HCCIs are discussed followed by current utilization of MDT HCCIs. Also, available datasets for calculating an advanced HCCI are discussed briefly.

4.1 Current MDT Practices of Calculating HCCIs

MDT developed an Excel based tool "MDT Master.xlsm" to calculate its HCCIs. The HCCIs were calculated from year 1987 to 2013. The first step in calculating the MDT HCCI is to obtain necessary bid data. MDT uses item number, item description, unit, average unit price, and current total dollar amount to calculate HCCI. MDT used bid data of 52 items in 1987 which were organized under 9 categories.

Over the years, MDT has added, removed, and replaced a number of items from the item basket. The total number of items increased over time: 54 items were used in 1995 and 56 items were used in 1997. In 2013, the number of items increased to 71 items – 35 of which were also used in 1987. Item numbers of some of those items have changed from 1987 to 2013. The complete lists of items used in 1987 and 2013 are presented in Appendix F. MDT has updated the base years in 1995, 1997, 2000, 2003, and 2006. The base year change was made when there were changes in the item basket. However, the base year value was not reset to 100 in those years. Thus, the MDT HCCI represents the inflation compared to the original base year (1987).

An overall MDT HCCI is calculated through two stages. First, item price relatives are calculated, which are combined to calculate category level HCCIs. Then, the category level HCCIs are aggregated to determine an overall HCCI.

A price relative of an individual item is calculated as the ratio of the current year average price to the last year's average price for that item. Weights of the items in a category are used as the weights (s_i) for calculating category level HCCI. This formula is a form of Young index formula where the weights are taken from the current period. The Young index can be mathematically presented as in equation (10) (ILO 2004):

$$\text{Young index}, Y = \sum_{i=1}^{n} s_i \left(\frac{p_{i,t}}{p_{i,0}}\right) \tag{10}$$

Where s_i (equation 11) is the weight calculated as the shares of expenditure of the item in an arbitrary period.

$$s_i = \frac{p_{i,t} q_{i,t}}{\sum_{i=1}^{n} p_{i,t} q_{i,t}} \tag{11}$$

The period can be anywhere from period *0* to period *t*. In the MDT HCCI, the weights are obtained from the current period. If the weights are taken from the base period instead of the current period, the Young index becomes the Laspeyres index.

To calculate an overall HCCI, the price relatives ($p_{t,t}/p_{i,0}$) in Eq. *(10)* is replaced by the category level HCCIs and the weights of the items are replaced by the weights of the categories. The weights of the 9 categories of the item basket in 1998 and 2013 are presented in Table 7.

The weights of aggregate base, concrete, reinforcing steel, bridge, and “miscellaneous items” categories have increased over time, while the weights of excavation, surfacing, and traffic categories have decreased. The weight of the drainage category practically remained constant.

The decrease in the weight of excavation might indicate the decreased cost of excavation works resulting from the economic construction methods or the decreased excavation works as more works have focused on repair and maintenance of existing highways rather than construction of new highways. The increase of the weight of the aggregate base might indicate the increased cost of quality aggregate production as readily available sources of aggregates were depleted.

The Excel file also calculates a modified composite index using a constant weight for the categories throughout the years rather than using the weights based on the expenditure in the current period. The methodology used to generate the weights for the modified index is not presented in the spreadsheet.

Table 7 Weights of item categories for aggregated indexes

Item categories	Weights (1988)	Weights (2013)	Constant weights
Excavation	26.86%	21.18%	16.00%
Aggregate Base	4.48%	11.95%	10.00%
Surfacing	52.32%	46.38%	32.00%
Drainage	2.57%	2.57%	7.00%
Concrete	1.39%	3.18%	5.00%
Reinforcing Steel	0.42%	1.24%	2.00%
Bridge	0.36%	2.85%	6.00%
Traffic	9.66%	7.57%	7.00%
Misc. Items	1.93%	3.08%	15.00%
TOTAL	**100.00%**	**100.00%**	**100.00%**

4.2 Current MDT HCCI Utilization Practices

The American Association of State Highway and Transportation Officials’ (AASHTO) Technical Committee on Cost Estimation realized the importance of tracking the current market conditions using in-house and third party HCCIs (AASHTO 2009). MDT understands the challenge of developing budgets for a long term financial planning and considers HCCIs as important tools to make such predictions.

MDT compares its HCCI values with five other indexes: ENR, CPI - Urban, PPI - All, PPI Road and Highway, and PPI-Construction (Figure 4). The comparison based on the base year of 1997 shows that MDT has higher HCCI values compared to cost indexes obtained from other sources.

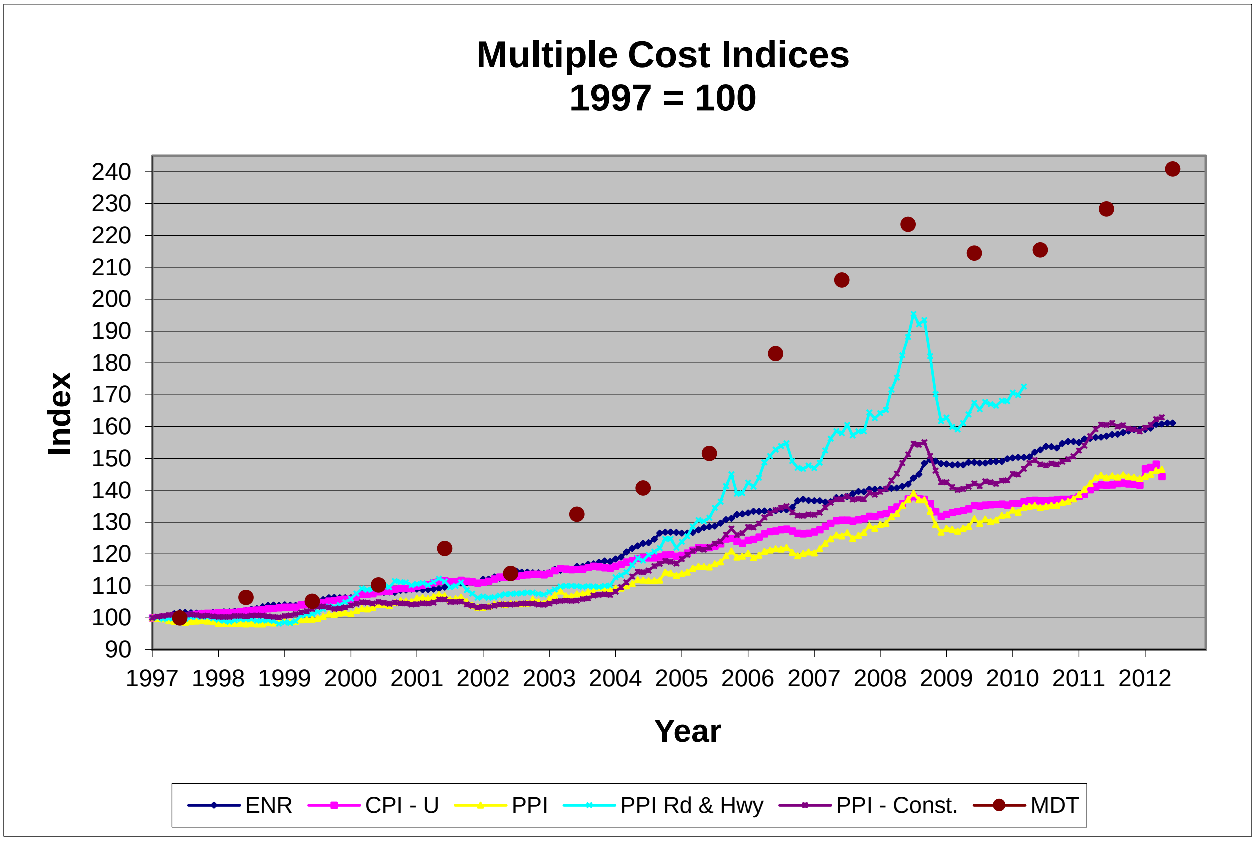

Figure 4 MDT HCCI vs other indexes

4.3 Available and Useful Data Attributes in MDT Systems

This project is to develop multidimensional HCCIs with sub-HCCIs for project type, size, and location. The research team reviewed 163 data attributes from MDT PPMS system and AASHTOWare SiteManager for their applicability in calculation of advanced HCCIs for MDT. The important datasets are bid dataset (Research_Bidder_Info_II_v2_042715.xlsx), item list datasets (Item_List.xlsx and Bid_Item_List_042815.xlsx), MDT project classification systems (Project_Work_Types.xlsx), and GIS features class files. Appendix G shows the complete list of data attributes available in MDT that were analyzed for this study. The following sections present the results of the analyses focusing on data attributes relevant to calculating the overall HCCI and three other sub-HCCIs.

4.3.1 Overall HCCI Calculation

An overall HCCI calculation requires two major datasets: a) project level information, 2) item level information. The project level dataset should include the project id, project total amount, and let date. The item level dataset should include item number, item description, item quantity, item price, item unit, and item total. Those project level and item level data attributes are available in bid dataset (research_bidder_info_ii_v2_042715.xlsx). Those data attributes are illustrated in Figure 5. The dashed line indicates that the project level dataset and the item level dataset should be connected with a project number so that the item level data of each project can be included or excluded from the calculations as required.

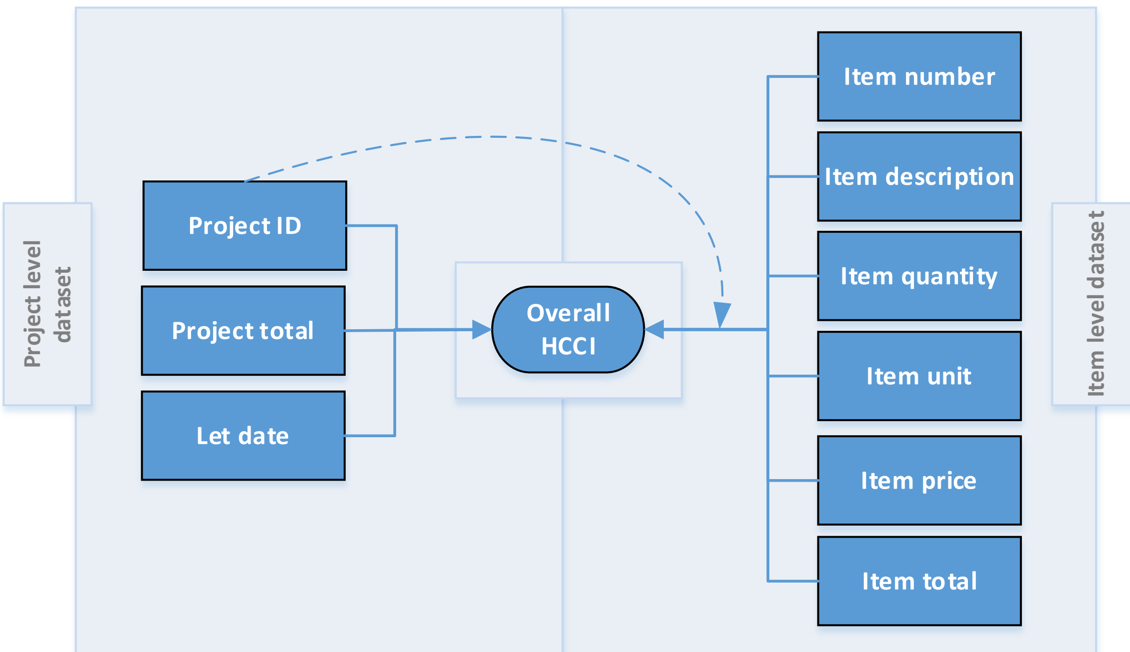

Figure 5 Project level and item level dataset required to calculate an overall HCCI

The project ID and project contract amount are required if small projects should be removed as some other state DOTs and the FHWA do. The let date is required to identify the year in which the project was let so that the item level data from each year can be isolated programmatically or manually to calculate the indexes.

4.3.2 Sub-HCCIs Calculations

The data attributes for location, project type classification, and size are available in the bid datasets provided by MDT. Those data attributes can be used to develop HCCIs that are more granular. To calculate size-based sub-HCCI (SHCCI), the total project cost data is required. The project construction cost data can be classified using K-means clustering technique. A clustering technique classifies similar projects into a number of clusters. In this case, the projects with similar project costs are classified together into three categories indicating small, average, and large size project.

To calculate location-based sub-HCCIs (LHCCIs), several alternatives are available. MDT divided the state into financial districts, maintenance districts, administrative & construction districts, and counties. The technical panel at the meeting in February 2016 indicated that the administrative and construction district was considered to be better location divisions for LHCCI calculation. The administrative and construction district borders do not overlap perfectly with the county borders (Figure 6). The bold lines represent administrative and construction district borders; the faint lines represent county borders. Based on the location, five LHCCIs can be developed. The dataset includes a data attribute titled “admin_dists” that represents the administrative and construction districts.

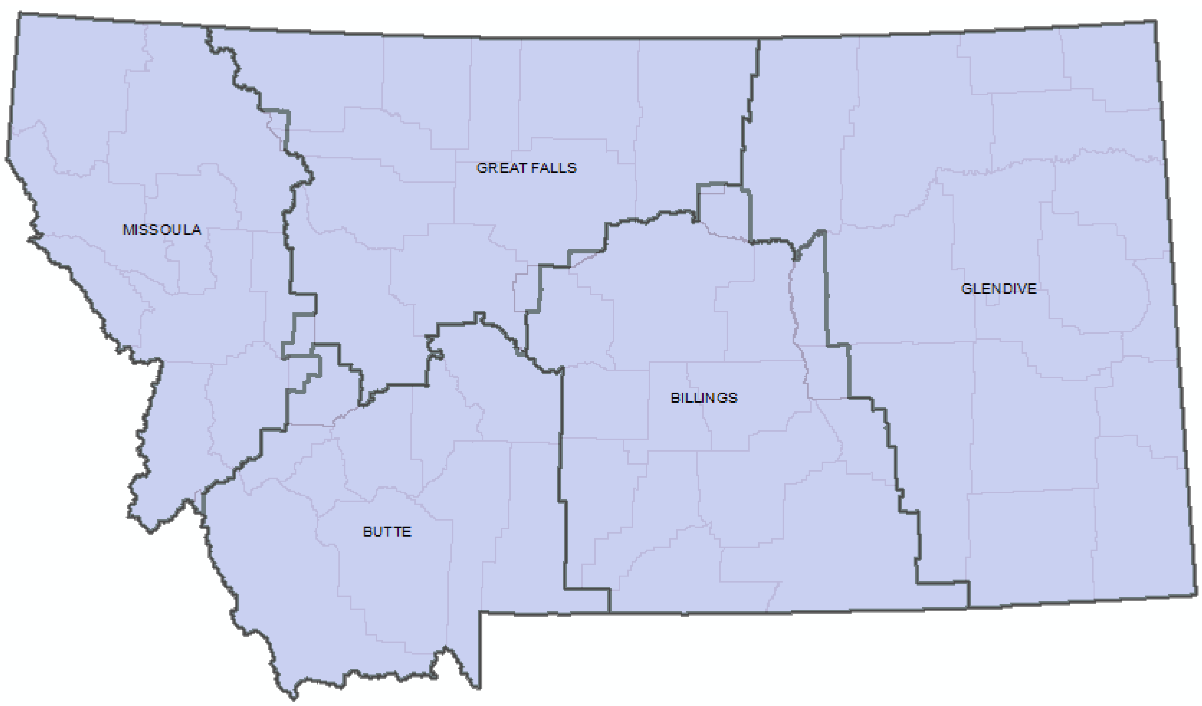

Figure 6 Administrative and construction district and county borders

For type-based classification, six major work types based on MDT’s project classification are used. The six work types under this system are construction, resurfacing, bridge, spot improvement, miscellaneous, and facilities. The details of those data attributes are presented in Appendix G.

4.4 Summary

This chapter reviews the current practices of calculating HCCIs at MDT. The researchers recommend to use the Fisher index formula—rather than the current Young index formula—to computer HCCIs. Currently, MDT uses bid data of 71 items organized under 9 categories. The research team identified the data attributes available in MDT PPMS and AASHTOWare systems that can be used to develop an advanced HCCI. The most important data attributes are classified into two datasets: project level datasets and item level datasets. Project level datasets include project ID, cost, and let date. Item level dataset include item number, description, quantity, unit, price, and total cost. Further, MDT GIS database is available to perform spatial analysis of bid data.

5 DEVELOPMENT OF MULTIDIMENSIONAL HIGHWAY CONSTRUCTION COST INDEXES USING DYNAMIC ITEM BASKET

In Chapter 3, three major limitations were identified from the current approaches used by state DOTs in computing HCCIs. First, most state DOTs have not yet updated their methodologies to reflect the changes in the NHCCI methodology primarily due to lack of appropriate guidance. Second, current HCCI calculation methods adopted by most DOTs are not sophisticated enough to assure that an HCCI can be used as a reliable indicator of the changing market conditions. This is primarily because only a small number of items representing 60% or less construction costs are used in calculating HCCIs. Third, state DOTs use a single overall HCCI to represent a diverse construction industry throughout the state, which fail to provide more granular information. To overcome those major limitations, this study develops an advanced HCCI methodology with new concepts of dynamic item basket and multi-dimensional HCCIs. This chapter a) discusses a methodology to generate a *Dynamic Item Basket* (DIB) with a higher coverage of bid items, b) discusses multidimensional HCCIs that can show construction market conditions with a higher granularity, c) discusses the automation process to reduce efforts required to compute multi-dimensional HCCIs, and d) evaluates the performance of the new HCCI methodology.

5.1 Concept of Dynamic Item Basket

An item basket (IB) should contain all items used in the market if the costs and quantities of the items are available for both base and current periods. If that is not possible, an IB should still be a good representative of actual items used in the market to ensure that the cost index is a good reflector of the current market conditions (BLS 2015a; IMF 2010). Since highway project bid data are now available in a digital format in DOT's contracts office, it is practically possible to use the entire population of bid items for HCCI calculation.

In dynamic IB (DIB), the items in the IB, and corresponding cost and quantity vectors are updated automatically based on the current purchasing behavior of DOTs. The DIB generation process identifies the largest IB that can be generated from the bid data and hence increases the coverage of the items to the maximum possible value. To explain the DIB generation process, consider a universal set 'U' consisting of all standard bid items used by DOTs (Figure 7).

Some of those items will be used in the current period (B), some in the previous period (A), and others will not be used in either period (C). The items that are not used in either period or the items used for only one of the two periods cannot be mathematically included in the HCCI calculation. But, all items that were used in both periods (D) can be used in HCCI calculation and DIB consists of these items (D). The use of this DIB with those items instead of a small-sampled IB that is currently used by most DOTs, can significantly improve the HCCI calculation process with higher accuracy and reliability by removing the sampling error.

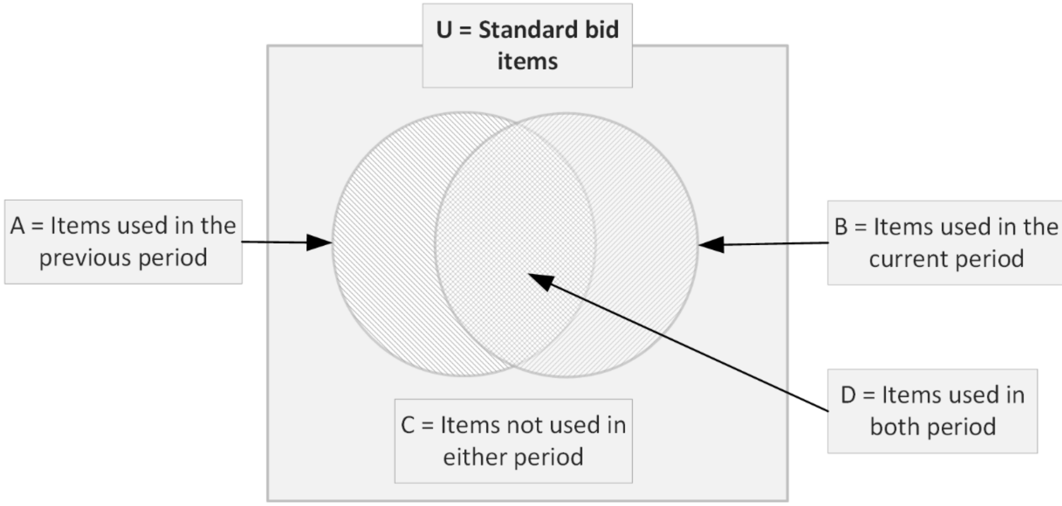

Figure 7 Dynamic Item Basket

5.2 Concept of Multidimensional HCCIs

The concept of multidimensional HCCIs is to develop cost indexes for highway construction market sectors defined by factors such as project size, project type, and location. Thus, in addition to an overall HCCI that is used to indicate the state level market conditions, three-dimensional sub-HCCIs are developed: project size specific HCCIs (S-HCCIs), project type specific HCCIs (T-HCCIs), and location specific HCCIs (L-HCCIs) which are visually depicted as HCCI cubes in Figure 8. Those three factors are selected as they are well known factors affecting the construction costs as well as availability of required data to classify projects into those categories. State DOTs may add and/or remove various project characteristics to develop other multidimensional HCCIs.

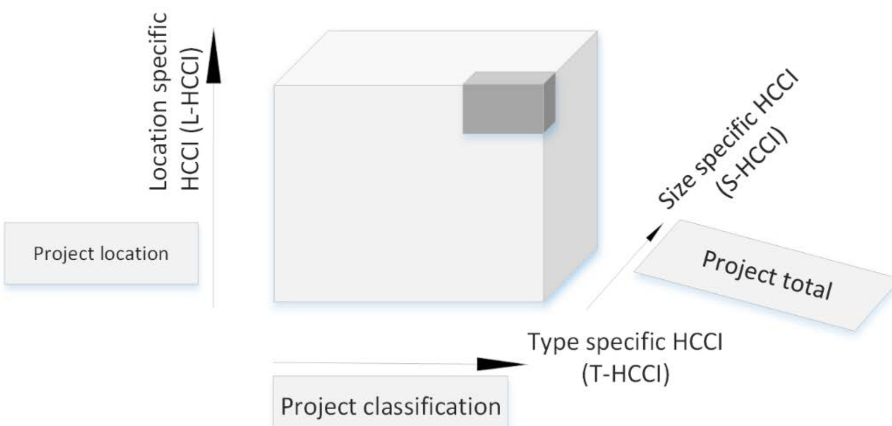

Figure 8 HCCI Cubes

The size specific sub-HCCIs (S-HCCIs) are necessary because of the effect on costs by the economies of scale. The unit cost of an item is less when purchased in bulk. As such, larger projects that would contain larger quantities of items are likely to have a different market trend than that of smaller projects. Further, the level of competition for projects of different sizes also varies because contractors often need to be prequalified to perform larger projects. Similarly, contractors are often specialized to perform a certain type of projects. In addition, work items for different types of projects also vary. Those reasons necessitate a project type specific HCCI (T-HCCI) (Erickson and White 2011; Rueda and Gransberg 2015). One may argue that DOTs already calculate item category specific HCCIs (I-HCCIs) for different work categories such as structures, pavements, etc. However, a typical highway project consists of various work items from different item categories. Thus, T-HCCIs are different from I-HCCIs. The traditional T-HCCIs, while not the focus of this study, are also calculated and analyzed in this study. Further, while developing programming budgets, DOTs have information regarding the number of bridge and highway construction projects of particular types rather than the amount of specific material category (say, asphalt and aggregate) required for such construction. Thus, such multidimensional HCCIs can be used for making budgeting decisions.

Existing literature also recognizes the importance of developing location specific sub-HCCIs (L-HCCIs) (Anderson, Molenaar, and Schexnayder 2007; Erickson and White 2011; Ghosh and Lynn 2014; Gransberg and Diekmann 2004; S. M. Shahandashti 2014). The rationale behind L-HCCI can be explained with the Tobler (1970)'s First Law of Geography which states that "everything is related to everything else, but near things are more related than distant things." Specifically, in highway construction, the availability of resources and their hauling distances to the jobsite such as qualified materials, equipment, and labor significantly affect the total construction cost and hence the market trend. Also, the market trend is likely to vary differently in mountainous areas and plain areas.

5.3 Framework for Multidimensional HCCI with DIB

The framework to integrate DIB into multidimensional HCCI calculation process is illustrated in Figure 9. The framework can be divided into four components: a) database development, b) project filtering, c) DIB generation, and d) multidimensional HCCI calculation.

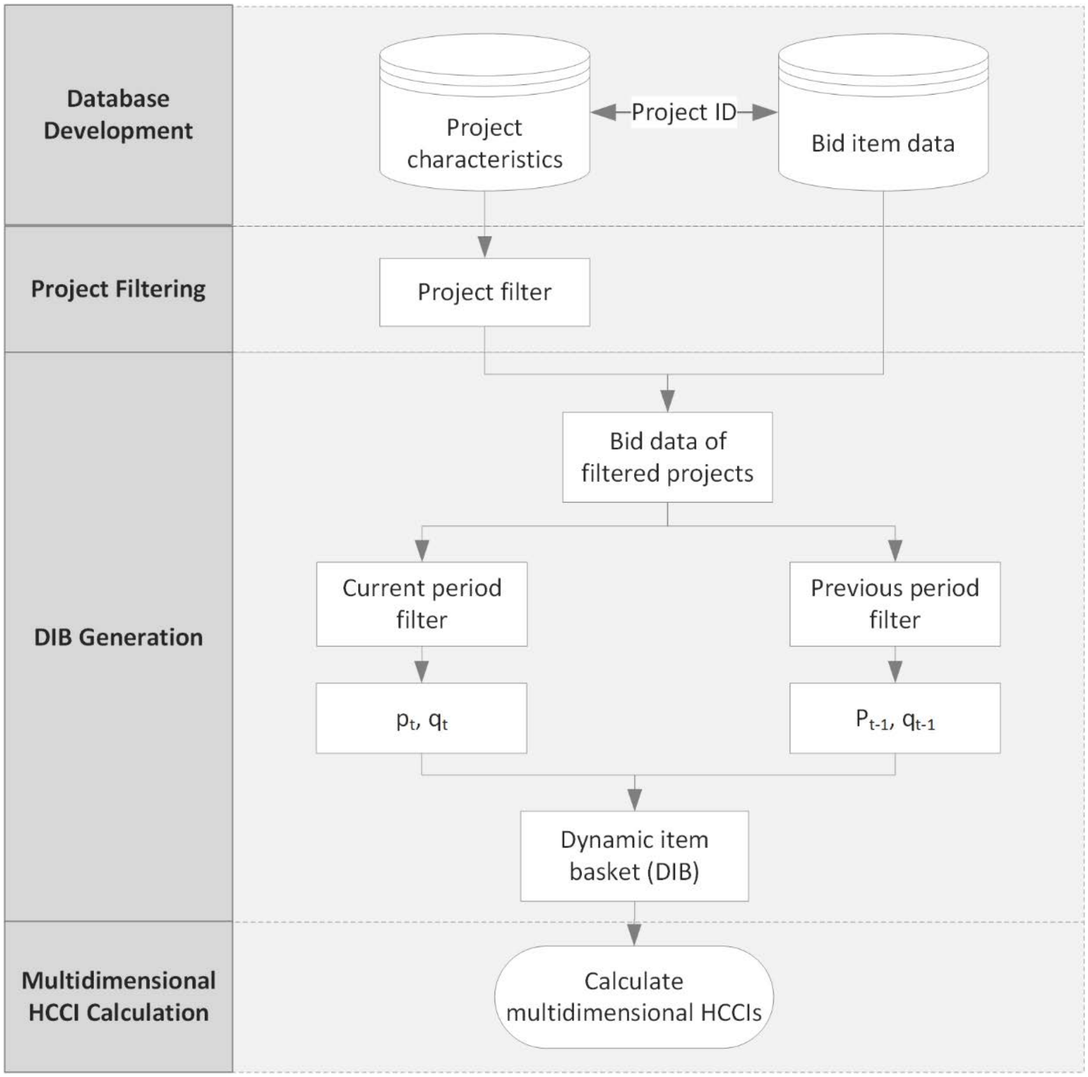

Figure 9 Framework for advanced multidimensional HCCI calculation using DIB

In the first component, bid item data and project characteristics data required for calculating multidimensional HCCIs with DIB are collected from MDT's Oracle database and systematically compiled in a structured MS Access database. *Project filtering* is a process to clean and filter project data in three stages to obtain a list of projects relevant to a particular sub-HCCI. In this component, projects relevant to calculating sub-HCCIs are selected in three phases as illustrated in Figure 10: a) removal of non-design-bid-build projects, b) selection of projects from the current and previous or base periods, and c) selection of projects of a particular category corresponding to the selected sub-HCCI. Further, each sub-HCCI consists of multiple sub-HCCI values (i.e., S-HCCIs for small sized projects, medium sized projects, and large sized projects). The list of projects for each of the sub-HCCI value calculation is filtered separately and each list is sent to the DIB generation component one at a time. The third phase (c) is required only to generate sub-HCCIs and is skipped for an overall HCCI calculation. For an overall HCCI calculation, data from all project sizes, types, and locations are used.

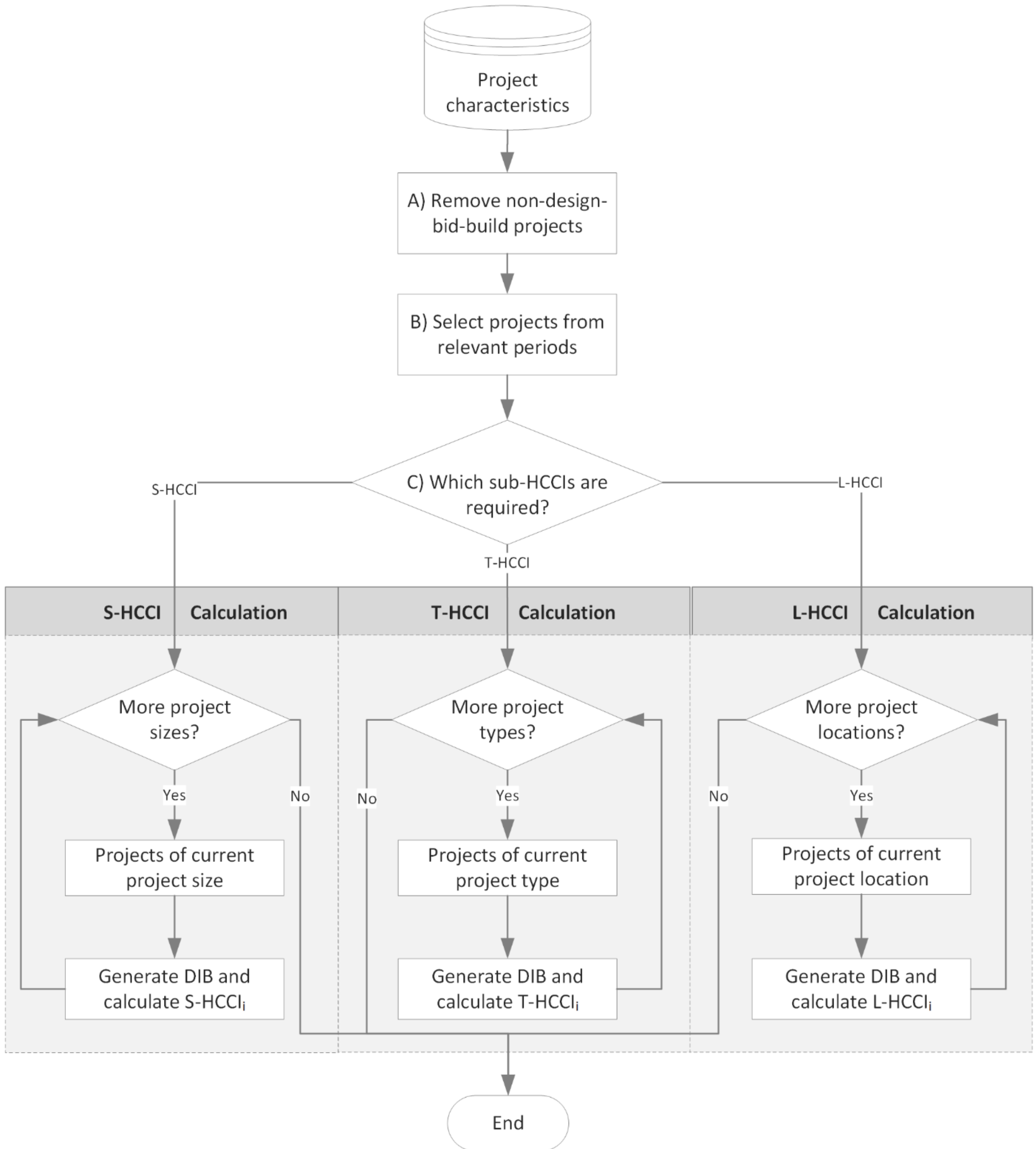

Figure 10 Project Filtering Component

In *DIB generation*, two sets of cost and quantity data from previously selected projects are generated in three phases: a) extraction of relevant bid data, b) splitting the data into current and previous period data, c) generation of initial cost and quantity data, and d) removal of irrelevant items to generate the final cost and quantity data. In the first phase, bid data of previously filtered projects are extracted for the current and previous period. In the second phase, those data are separated for the current and previous period. The quantity for each item is computed as the total quantity of the item used in various projects. Similarly, an average price is calculated as the quantity-weighted-average of the unit prices of the corresponding item. The mathematical formulas for those computations are presented in equations *(12)* and *(13)*.

$$\text{Total quantity of an item } (q_i) = \sum Quantity\ of\ the\ item \qquad \textbf{\textit{(12)}}$$

$$\text{Weighted average price of an item } (p_i) = \frac{\sum(\text{Price of the item X Quantity of the item})}{\sum Quantity\ of\ the\ item} \qquad \textbf{\textit{(13)}}$$

As the unit price data of only those items that are used in both periods can be used for HCCI calculation, unit price data of all other bid items are removed. In addition, all the lump sum bid items are removed. The remaining dataset forms the largest IB that can be generated from a given bid item and project characteristic datasets. Further, the process updates IB dynamically based on the project characteristics and bid item data, current period selection, and sub-HCCI that is calculated. Thus, this IB is the *Dynamic Item Basket (DIB)* and can also be called an *optimum IB*. Unlike traditional methods where smaller and/or less frequent items are ignored and only larger and more frequent items are used, this method utilizes all items if they are used in both the current and previous periods. This DIB and corresponding final cost and quantity vectors are transferred to the next component for multidimensional HCCI calculation.

Finally, the Chained Fisher index formula is applied in the final component to generate sub-HCCIs. The project-filtering component and the following components are repeated to generate various sub-HCCIs (such as small, medium, and large sized S-HCCIs). The HCCIs are calculated on an annual basis. A base year of 2010 is selected after discussion with MDT team. The base year value is set as 1.00.

5.4 MDT HCCI Calculation and Bid Analysis System

MDT HCCI Calculation and Bid Analysis System is developed with MS Access database (Figure 11) and Visual C#.NET frontend (Figure 12) to implement the framework. The Graphical User Interface (GUI) has menu items on top to calculate various sub-HCCIs and perform some additional bid data analysis. The system is capable of generating sub-HCCIs using the raw bid data in a single click. Users can select a year as the current year to calculate sub-HCCIs for that particular year. A user manual is developed for the system and is attached in Appendix H. Next section discusses the analysis of the results regarding the performance of this new methodology generated using this system.

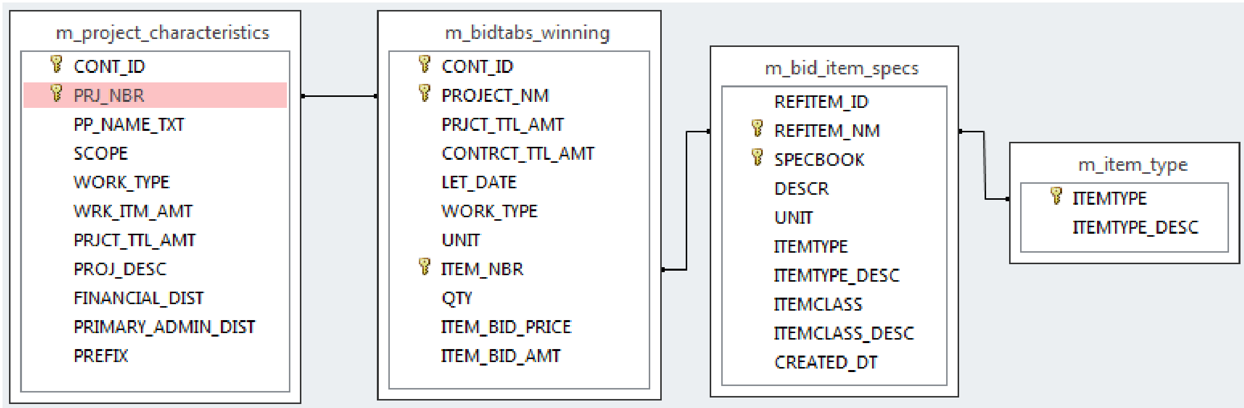

Figure 11 MS Access Database

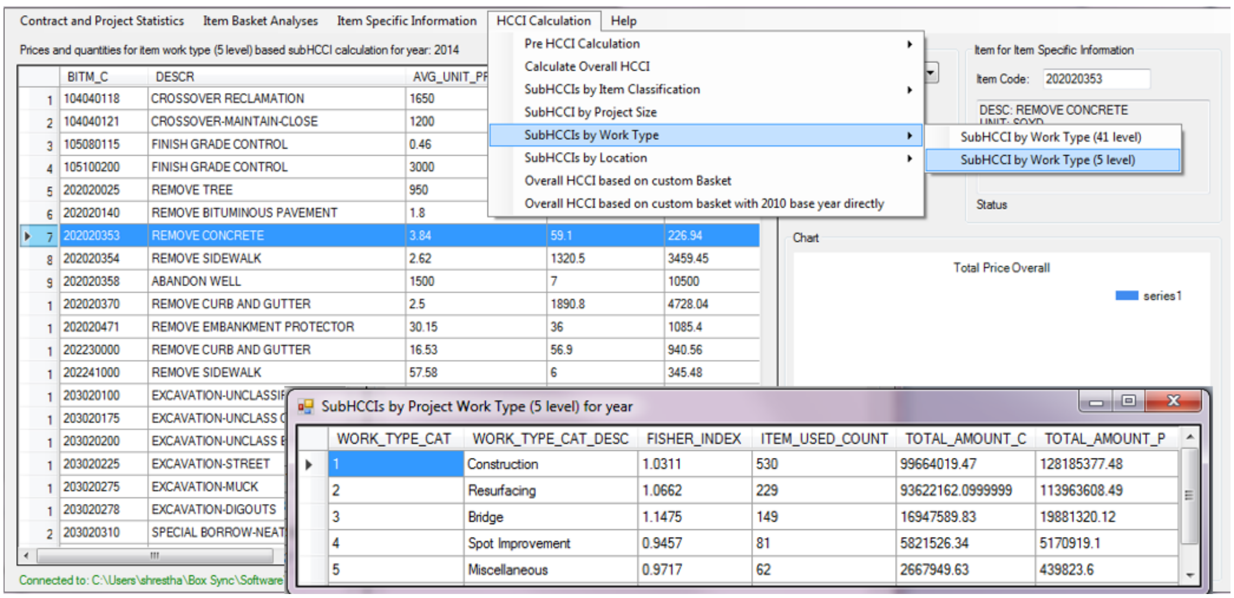

Figure 12 Visual C#.NET Frontend

5.5 Performance Evaluation of MDT HCCI and Bid Analysis System

Historical bid data from MDT are collected and analyzed to evaluate improvements in the IB coverage using the DIB. This section further discusses the results on the fluctuation of specific segments of the highway construction market using the multidimensional HCCI approach by comparing the sub-HCCIs with the overall HCCIs.

5.5.1 Data Collection

The researchers obtained the historical bid data from MDT in an excel format which was imported into the database. The database consists of bid data of 687 projects let from 2010 to

2014 that represent more than $1.8 billion of construction projects. The dataset consists of 33,975 lines of items based on 2,529 standard bid items from MDT's specification. MDT has developed a list of 3,681 unique bid items in its 2014 specification manual (MDT 2014). The obtained bid data was imported into the MDT HCCI and Bid Analysis System.

5.5.2 Improvements in IB using DIB

To evaluate the effect of the DIB, overall HCCIs are calculated using DIB ($HCCI_{DIB}$) and the current IB used by MDT ($HCCI_{current\ IB}$). MDT's current item basket includes 71 high cost items handpicked by MDT. In the DIB, items are selected automatically using the framework developed in this study. The number of items in the DIB ranges from 610 to 735 items in various years (2010 – 2014). This indicates that DIB consists of items more than eight times the number of items in the original IB. In terms of the cost coverage, the current MDT's item basket represents less than 50% of the total project costs. The DIB improves the cost coverage to over 70% of the total project costs indicating at least 20% increase in the coverage. The overall HCCI values calculated from year 2011 to 2014 are presented in Table 8. Year 2010 is assigned as the base year with the base cost index of 100. The difference in terms of percentage ranges from 2.34% up to 5.98%.

Table 8 Comparison of overall HCCI calculated using DIB and current IB

Current year	$HCCI_{DIB}$	$HCCI_{current\ IB}$	% difference
2010	100.00	100.00	0%
2011	110.46	114.37	-3.54%
2012	111.12	117.77	-5.98%
2013	113.06	115.70	-2.34%
2014	115.46	119.92	-3.86%

A correlation coefficient is calculated to compare the trend of the two series. The correlation coefficient (R) is a statistical factor used to access the linear relationship between two variables (say x and y) (Taylor 1990). Mathematically, the correlation coefficient can be calculated as in equation (14):

$$Correlation\ coefficient\ (r) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}}. \quad \textbf{\textit{(14)}}$$

The value of R can vary from -1 to +1. A positive value indicates that both variables have similar trends, i.e. increase in one variable is associated with the increase in another variable. The higher the value is, the stronger the correlation is. Negative values indicate that an increase in one variable is associated with a decrease in the other. The R-value calculated for these two HCCIs series is 0.98, which indicates a very similar trend between the two series.

Further, an overall error between the two HCCI series is calculated using Mean Absolute Percentage Error (MAPE) (equation *(15)*). The higher MAPE indicates more variation between the two series. Generally, one may expect to have a higher MAPE value associated with a lower R-value and vice-versa.

$$MAPE = \sum_{i=2011}^{2014} \frac{\frac{|HCCI_{DIB,i} - HCCI_{current\ IB,i}|}{HCCI_{DIB,i}} * 100}{n} \quad \textbf{\textit{(15)}}$$

The results show a MAPE value of 3.93%. While 3.93% may seem to be a small error, this is a large error considering that an average inflation itself is recommended as 4% by the FHWA (Mack 2012). In addition, the absolute percentage difference between the two series is as high as 5.98% in 2012. This implies that the use of the current IB may result in an erroneous decision-making on highway construction market evaluation, preliminary transportation budgeting and planning, etc.

5.5.3 Fluctuations of multidimensional HCCIs

MDT uses several project characteristics to classify their highway projects (Table 9). It uses a six-level project type classification system, which is further sub-divided into 41 types. MDT also divides the state into five administrative and construction districts and five financial districts. These two types of districts overlap closely. MDT also uses three different bid item classification systems: division, class, and type. However, no project size classification is found in the current MDT business practices. For this study, MDT projects are classified using a clustering algorithm known as Simple Expectation Maximization that resulted into three clusters (Figure 13). Based on the clusters, project sizes are divided into three ranges representing small (0 - $3,500,000), medium ($3,500,000 - $10,500,000), and large ($10,500,000 - $50,000,000) construction projects.

Table 9 Sub-HCCI calculation parameters and number of sub-HCCIs

Sub-HCCI type			Number of sub-HCCIs	Sub-HCCIs	Number of continuous sub-HCCIs
Project characteristics based	Project Type	Project Type	6	Construction; Resurfacing; Bridge; Spot Improvement; Miscellaneous; Facilities	5
		Extended Project Type	41	New Construction; Reconstruction – with added capacity; Reconstruction – without added capacity; Resurfacing – Crack Sealing; New Bridge; Bridge Replacement with added capacity; etc.	13
	Project Location	Administrative and Construction District	5	Glendive; Billings; Great Falls; Missoula; Butte	5
		Financial District	5	Glendive; Billings; Great Falls; Missoula; Butte	5
	Project Size		3	Small (0 - $3,500,000) Medium ($3,500,000 - $10,500,000) Large ($10,500,000 - $50,000,000)	3
Item characteristics based		Item Division	6	General Provisions; Earthwork; Aggregate Surfacing and Base Courses; Bituminous Pavements; Rigid Pavement and Structures; Miscellaneous Construction	6
		Item Class	31	Liquid Asphalt; Base Course; Concrete Paving; Crushing; Drainage; Earthwork; Removals; Signing; Structures; Surface Treatment, etc.	24
		Item Type	10	Grading/ Drainage; Paving; Structures/ Buildings; Materials; Equipment; Traffic Control; Landscaping; Other, misc.; Trucking; Unknown	7

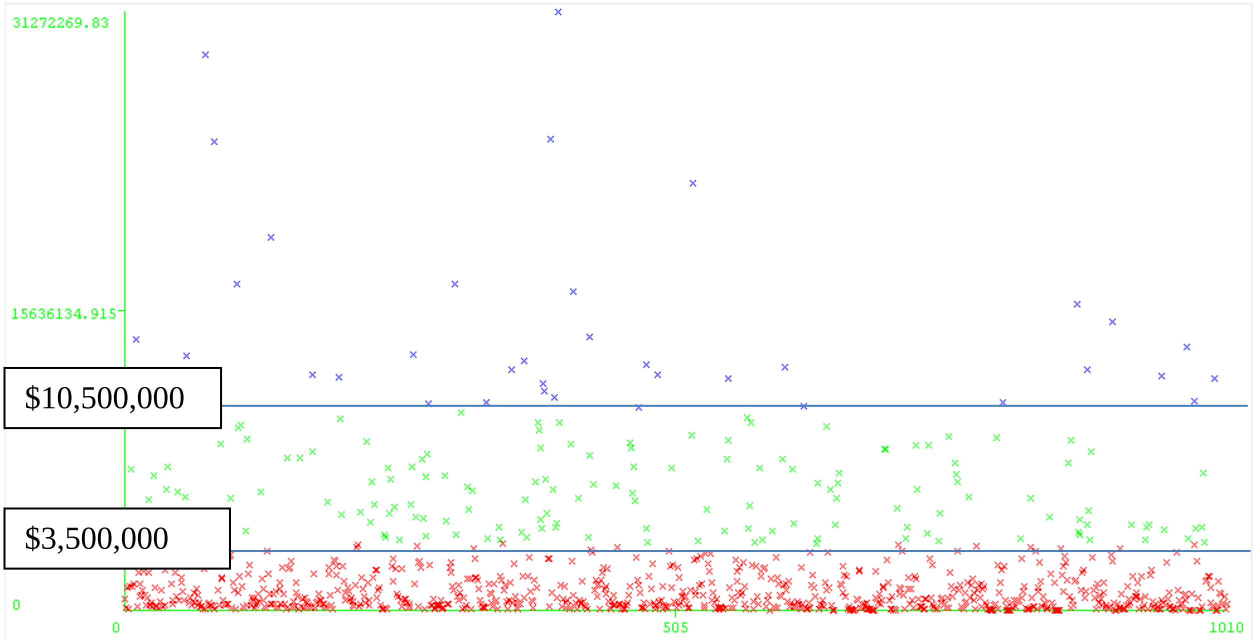

Figure 13 Clustering of projects based on construction cost data

With those classification systems, 107 series of chained sub-HCCIs can be calculated. For chained sub-HCCIs, their continuity over time is very important to utilize them. Sixty-eight sub-HCCIs have continuous values from 2010 to 2014. Continuous values for other sub-HCCIs are not available because of the lack of items in the DIB. Such scenarios can occur when projects in a particular category are not let frequently. For example, a type of project -'facilities', is not very frequent in MDT and hence very limited data points are available. In addition, some item categories such as 'unknown' are used for lump sum items. Thus, it is not possible to calculate sub-HCCIs for such categories as the system removes all lump sum items. In addition, as the number of classification levels in a given category increases, the possibility of generating a non-empty DIB for that specific classification level decreases causing a discontinuity in sub-HCCIs. The extended project type T-HCCIs (41 levels) and item class IHCCI (31 level) have many non-continuous sub-HCCIs and are hence not included for further analysis.

The values of overall HCCIs and all continuous sub-HCCIs are presented in Table 10. Correlation coefficients and MAPE values are calculated for the two series to quantify the similarities and differences between them. Most of the bituminous pavement and paving sub-HCCIs have a very high correlation (r = 0.94 and 0.96) with the overall HCCI. However, T-HCCI for bridges has an R-value of -0.04 indicating slightly negative correlation. It might be because a large portion of bridge costs are associated with concrete and steel, but the majority of construction projects are asphalt intensive roadway projects. Concrete and steel costs do not necessarily follow the cost movement of asphalt items. This weak relationship is also visible in structures/buildings I-HCCI (r = 0.10) and rigid pavement & structures I-HCCI (r=0.02). One may assume that the T-HCCI for bridges should match closely with I-HCCI for rigid pavement and structures. However, this is not the case. For example, in 2012, T-HCCI for bridges is 89.94 while I-HCCI for rigid pavement and structures is 110.47. Thus, the multi-dimensional HCCIs give additional insights than the existing I-HCCIs.

Table 10 Overall HCCIs, sub-HCCIs, and their correlation coefficients (R)

Sub-HCCI Type		sub-HCCI	2010	2011	2012	2013	2014	R	MAPE
	Overall	Overall HCCI	100.00	110.46	111.12	113.06	115.46	-	-
Project characteristics based	Project Size	Small (0 - $3,500,000)	100.00	106.76	109.01	107.73	109.15	0.96	4%
		Medium($3,500,000-$10,500,000)	100.00	107.73	115.50	117.29	112.81	0.86	3%
		Large ($10,500,000-$50,000,000)	100.00	114.15	113.50	116.87	115.55	0.97	2%
	Project Type	Construction	100.00	112.03	106.90	109.24	112.64	0.91	3%
		Resurfacing	100.00	106.83	114.12	109.57	116.83	0.89	3%
		Bridge	100.00	104.89	89.94	91.50	105.00	**-0.04**	13%
		Spot Improvement	100.00	169.33	162.56	219.01	207.12	**0.94**	**68%**
		Miscellaneous	100.00	91.68	42.72	72.10	70.06	-0.60	39%
	Financial District	**Glendive**	100.00	114.55	113.11	115.41	121.58	**0.99**	3%
		Billings	100.00	106.73	104.62	105.42	114.30	0.83	4%
		Great Falls	100.00	107.25	101.06	114.44	119.12	0.77	4%
		Missoula	100.00	118.07	125.21	123.67	113.64	0.76	8%
		Butte	100.00	102.94	117.79	110.81	128.74	0.76	7%
	Primary Administrative and Construction District	**Glendive**	100.00	114.98	113.11	116.75	119.19	**0.99**	3%
		Billings	100.00	106.85	104.20	106.67	112.95	0.88	4%
		Great Falls	100.00	107.61	103.11	122.66	121.28	0.77	6%
		Missoula	100.00	109.97	127.49	125.46	118.39	0.78	7%
		Butte	100.00	101.98	118.29	119.62	130.99	0.81	8%
Item characteristics based	Item Division	General Provisions	100.00	154.91	95.02	144.04	131.14	0.51	24%
		Earthwork	100.00	124.64	106.80	115.40	116.02	0.68	5%
		Aggregate Surfacing and Base Courses	100.00	107.50	103.08	116.36	107.96	0.68	5%
		Bitu. Pavements	100.00	109.83	116.76	118.91	117.80	**0.94**	3%
		Rigid Pavement and Structures	100.00	109.51	110.47	90.39	103.06	**0.02**	8%
		Miscellaneous Construction	100.00	104.12	104.04	104.36	113.45	0.79	5%
	Item Type	Grading/ Drainage	100.00	117.93	100.23	108.21	111.98	0.54	6%
		Paving	100.00	109.69	113.96	116.59	115.62	**0.96**	2%
		Structures/ buildings	100.00	106.46	112.92	93.69	103.52	**0.10**	8%
		Materials	100.00	107.44	107.79	110.42	111.11	0.99	3%
		Traffic Control	100.00	117.94	122.83	121.00	119.56	0.92	7%
		Landscaping	100.00	93.25	91.93	106.51	124.36	0.45	12%
		Other, misc.	100.00	99.59	105.05	102.75	121.73	0.61	7%

From L-HCCI perspective, Glendive district has the strongest correlation (R = 0.99 for both financial district and administrative & construction district) while others have lesser correlation but still strong correlation. In terms of project sizes, the overall HCCI was a better representative of small and large sized projects rather than medium sized projects.

MAPE confirms correlation analysis results and provides additional insights. For instance, in most cases such as T-HCCI for resurfacing projects and S-HCCI for large projects, MAPEs are less than 5%, which is in accordance with the strong correlations observed with higher R-values.

The MAPE and R-value for the T-HCCI for spot improvement might seem contradictory at first sight. The T-HCCI has the highest MAPE value (68%) as well as a high R-value (0.94). This indicates that spot improvement projects do have a similar trend to an overall HCCI, but their rates of change (i.e. inflation rates) are very different. Specifically, while the overall HCCI increased from 100 in 2010 to only 115.46 in 2014, the spot improvement project T-HCCI increased to 207.12 during the same period.

Finally, project characteristics based sub-HCCIs provide more granular insights than the item based sub-HCCIs. For example, while paving HCCI has a strong correlation (R-value = 0.96) and small error (MAPE = 2%), construction and resurfacing T-HCCIs shows relatively weaker correlations (R-values = 0.91 and 0.89, respectively) and higher errors (MAPE = 3% each). Further, construction and resurfacing projects have varying sub-HCCIs, while construction T-HCCI grew from 100 in 2010 to 112.64 in 2014, resurfacing T-HCCI grew only to 116.83 during the same period indicating 3.52% MAPE value between the two types of paving projects.

Overall, T-HCCIs have the highest deviations from the overall HCCIs while S-HCCIs have the lowest. However, S-HCCI might have varying deviations based on the different range of size categories developed.

5.6 Summary

This chapter develops a multidimensional HCCI computation methodology using dynamic item basket. The methodology overcomes the limitations of the current HCCI computation methodologies including the use of outdated item basket, use of a small item basket, and lack of granularity in the current HCCIs. The dynamic item basket ensures that the item baskets used to compute an overall HCCI and sub-HCCIs are current, relevant, and covers maximum percentage of the construction cost. The HCCIs computed using the new methodology covers eight times more items and 20% more construction costs compared to the current MDT HCCI process.

The project size specific HCCIs, project type specific HCCIs, and location specific HCCIs provides more granular information on the construction market conditions. An overall HCCI and 31 sub-HCCIs are computed using the new methodology. The correlation coefficient of the sub-HCCIs with the overall HCCI is computer to compare the trend of the overall construction market to a specific construction market. The result shows that a specific construction market does not necessarily follow the trend of the overall construction market. For example, T-HCCI for bridges has a negative correlation with an overall HCCI with R-value of -0.04. Similarly, in terms of magnitude of the cost trend, some specific construction market such as spot improvement has a MAPE value as high as 68% in comparison to the overall HCCI. This indicates that the specific construction market does not fluctuate at the same pace as the overall construction market.

Finally, the MDT HCCI and Bid Analysis System is developed using Visual C#.NET frontend and MS Access database to automate the HCCI computation process.

6 CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the major conclusions of the study along with the recommendations to improve the current MDT HCCI calculation and utilization practices.

6.1 Conclusions

This research project identified the gaps in the knowledge on the Highway Construction Cost Index (HCCI) calculation methodology, introduced two new concepts of Dynamic Item Basket (DIB) and multidimensional HCCI, and integrated those concepts in a six-component-framework to improve the coverage of Item Basket (IB) and enable more granular overview of the market conditions. The framework consists of database development, project filtering, DIB generation, and multidimensional HCCI calculation. To reduce the time and effort required to calculate the advanced HCCI, an automated prototype system was developed using Visual C#.NET frontend and MS Access database.

Analysis of Montana Department of Transportation (MDT) data using the framework shows improvements in the HCCI calculation methodologies and presented insights about MDT's highway construction cost market that cannot be obtained from the existing HCCIs. The framework increased the coverage of the bid items by more than 8 times in terms of the number of bid items used and by at least 20% in terms of the total construction costs covered.

Although the current HCCI and the advanced HCCI values change in the same direction (as indicated by a high correlation of 0.98), Mean Absolute Percentage Error (MAPE) of 3.93% is very high considering an average recommended inflation rate of 4%. Thus, the HCCI values obtained by existing methodology is not reliable and may mislead the decisions.

Further, the multidimensional HCCI provided additional insights. For example, T-HCCI for bridges has a negative correlation with the overall HCCI indicating that a single HCCI cannot explain market conditions of a specific construction segment. In addition, some sub-HCCIs have high MAPE errors when compared with an overall HCCI, indicating a differences in the changes in specific market conditions compared to the overall market conditions. For example, T-HCCIs for spot improvement and miscellaneous construction have 68% and 39% MAPE values, respectively. These granular and more accurate HCCIs are expected to aid MDT in assessing their market condition accurately and developing more reliable budget plans for different project types and sizes in different locations. Thus, the advanced HCCI methodology and system developed in the project was able to provide additional insights on the fluctuation of the market conditions with a higher accuracy and lower effort.

6.2 Recommendations

The researchers recommend that MDT implement the new system, observe the HCCI values over time, and compare the values with the perceived market conditions. Further, MDT may compare the HCCI values computed using the new methodology and inflation indexes obtained from third parties such as Regional Economic Models, Inc. MDT may utilize the system to analyze bid data cost trends; identify project types, locations, and sizes with higher construction cost growth; and identify hidden relationships such as cost-quantity relationship.

The current system lacks a component that can visualize the bid item cost in a colorful heat map indicating the varying cost. Such tool can be used to analyze the effect of location on the cost of a particular bid item. The researchers recommends MDT to develop such visualization tool that can also be used to visually communicate item specific market fluctuation over location. Further, the current system relies on MS Access database: users need to export data from MDT's Oracle database and import it to the system. A direct connection of the system to Oracle database would eliminate the need of data export and import.

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APPENDIX: A QUESTIONNAIRE USED FOR NATIONWIDE SURVEY

Cover Letter

The Montana Department of Transportation (MDT) and Iowa State University are conducting a nationwide survey to identify the current practices of calculating and utilizing Highway Construction Cost Indexes (HCCIs). HCCIs are commonly used to assess current market conditions and possibly to determine the approximate budget for future construction projects. Other terms used for HCCIs include "highway cost index" and "construction & maintenance index."

You have been contacted for the survey because of your current position in your agency. We would like you to participate in this survey and provide us with your valuable opinions. If you feel that you are not the right person to fill out this questionnaire, please forward the email to an appropriate person in your agency. The time required to complete this survey is approximately **20 minutes**. Please complete the survey by **July 04, 2015**.

If you have any questions about the survey, please feel free to contact us via email or telephone.

Sincerely,

David Jeong, PhD
Associate Professor
Iowa State University
Email: djeong@iastate.edu
Phone: 515-294-3845

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PhD Student
Iowa State University
Email: shrestha@iastate.edu
Phone: 702-518-1175

Contact Information

Please provide your contact information below:

1. Name: ____

2. Position: ____

3. Bureau/Division within the agency: ____________________________

4. State highway agency: ______________________________________

5. Email: ____

6. Phone number: ____

Screening Questions

7. Does your agency calculate a HCCI?

[ ] Yes [ ] No

8. (Only if no in #7) Does your agency have a plan to calculate and use HCCIs in the near future?

[ ] Yes [ ] No [ ] I do not know

9. Does your agency use any third party HCCIs or other cost indexes?

[ ] Yes [ ] No

(If no in both #8 and #9, go to #20 for general comment.)

Methodology of Computing the HCCI (If Yes in #7)

10. What time interval is used for updating the HCCIs?

[ ] Monthly [ ] Quarterly [ ] Every six month [ ] Yearly

11. How does your agency determine which pay-items are to be used for calculating the HCCIs?

[ ] Items with higher total costs
[ ] Items with higher unit costs
[ ] Items that are more frequent
[ ] Items that are more volatile

[ ] Others: ____

12. Does your agency use any lump sum items for calculating HCCIs?
[ ] Yes [ ] No

13. Which mathematical methodology is used to calculate the HCCI?

[ ] Laspeyres index (quantities from base period/year is used $L = \frac{\sum_{j=1}^{N} p_{j,t} q_{j,0}}{\sum_{j=1}^{N} p_{j,0} q_{j,0}}$)

[ ] Paasche index (quantities from current period/year is used $P = \frac{\sum_{j=1}^{N} p_{j,t} q_{j,t}}{\sum_{j=1}^{N} p_{j,0} q_{j,t}}$)

[ ] Fisher index (combination of Laspeyres and Paasche $F = \sqrt{\frac{\sum_{j=1}^{N} p_{j,t} q_{j,0}}{\sum_{j=1}^{N} p_{j,0} q_{j,0}} X \frac{\sum_{j=1}^{N} p_{j,t} q_{j,t}}{\sum_{j=1}^{N} p_{j,0} q_{j,t}}}$)
[ ] I do not know
[ ] Others (mention)

14. Does your agency use the chained or the non-chained indexing?

[ ] Chained [ ] Non-chained [ ] Not applicable [ ] I do not know

External HCCIs Tracked by Your Agency (If Yes in #9)

15. Which of the following cost indexes (besides the HCCIs developed by your own agency) are monitored by your agency? Please also rate (on a scale of 1 to 5, 1 being the least and 5 being the most relevant) their relevancy to your agency applications.

Index	**Monitored? (Yes/No)**	**Relevant (Rate from 1 to 5)**
National Highway Construction Cost Index (NHCCI)		
HCCIs from other states		
Bureau of Labor Statistics (BLS) Consumer Price Index		
BLS Producer Price Index (PPI) for Other Nonresidential Construction (BONS)		
BLS PPI for Nonresidential Maintenance and Repair Construction (BMNR)		
Engineering News-Records (ENR) Construction Cost Index (CCI)		
ENR Building Cost Index (BCI)		
RS Means Cost Index		
Other BLS PPIs (mention all) ___		
Other cost indexes (mention all) ______________		

16. (If any of the previously mentioned indexes are tracked by the agency, skip logic) How does your agency utilize the indexes you mentioned in the previous question?

[ ] Side by side comparison of the indexes with the in-house HCCI
[ ] Third party index is used to determine an inflation rate of construction projects
[ ] As an indicator of overall market conditions
[ ] Others (mention) ____

Importance and Utilization of HCCIs (If Yes in #7)

17. Who are the current users of HCCIs calculated by your agency?

[ ] Planning and programming departments [ ] Design departments
[ ] Contract department [ ] Consultants [ ] Contractors
[ ] Others (mention all)

____

18. What are the current uses of the HCCIs calculated by your agency?

[ ] As an indicator of purchasing power of your agency
[ ] Calculating current dollar value of historical projects
[ ] Cost inflation factor for future contracts
[ ] Cost estimation tool for project cost estimation in early stages (project level)
[ ] Budgeting construction projects for upcoming fiscal year(s) (program level)
[ ] Monitoring the construction market fluctuation for predicting future market condition
[ ] Comparing the construction market with other states and national construction market
[ ] Calculating the gas tax percentage by the state
[ ] Others (mention all)

Miscellaneous

19. Would you please provide your agency's a) HCCI calculation and/or utilization manual, b) a spreadsheet tool developed for calculating the HCCI, and c) the most recent publication of HCCIs of your agency?

Yes) then, (upload up to three attachments in Qualtrics)

No) would you briefly explain why you cannot provide the above?

20. Please provide any additional comments about the survey and/or the calculation and utilization of HCCIs.

____

21. Can we contact you for further information about the information you provided in the questionnaire?

[ ] Yes [ ] No

APPENDIX B: NATIONWIDE SURVEY RESULTS

This section discusses the results of the questionnaire survey (Appendix A) conducted in summer 2015. The findings of the survey confirm the findings of the literature review.

Thirty-four state DOT representatives and a FHWA (DC) representative responded to the questionnaire, i.e. 67% response rate (Figure 14). The questionnaire survey was conducted to determine the current status of state DOTs regarding HCCI calculation, frequency of HCCI calculations, practices of choosing the basket of items, indexing formula used, use of third party indexes, and utilization of HCCIs.

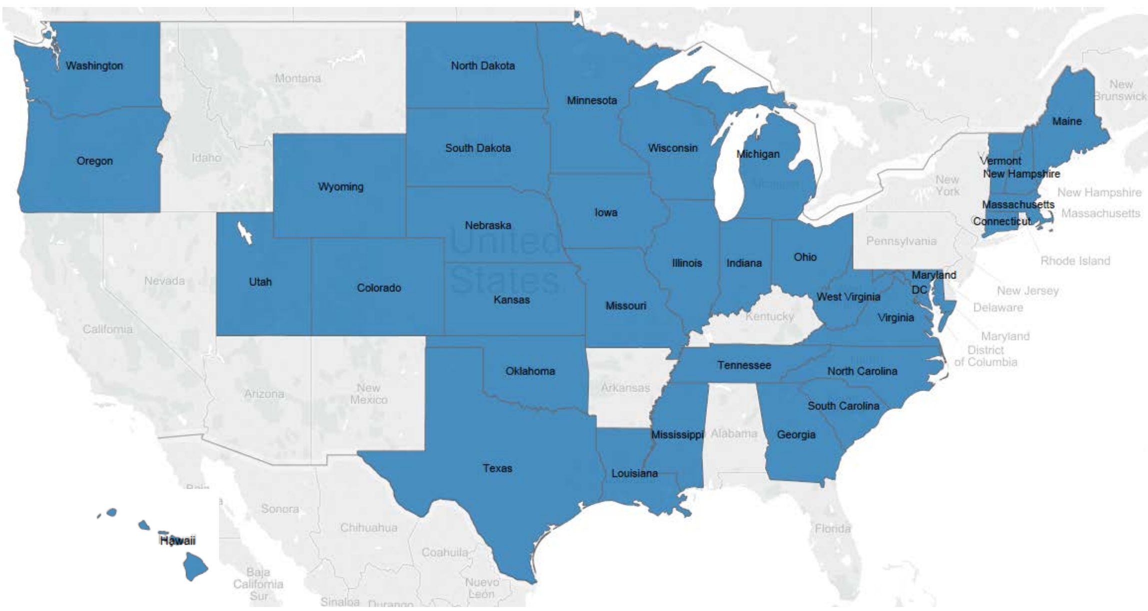

Figure 14 State DOTs that responded to questionnaire survey

State DOTs that Calculate HCCIs

Although the concept of a HCCI has evolved for many years, only 20 of the 34 state DOTs that responded calculate their HCCIs (Figure 15). Vermont and Maryland DOTs do not calculate composite HCCIs but are planning to develop one in the near future. This is possibly because of the lack of resources or guidance to calculate HCCIs. Some state DOTs are tracking external HCCIs to keep track of those construction markets.

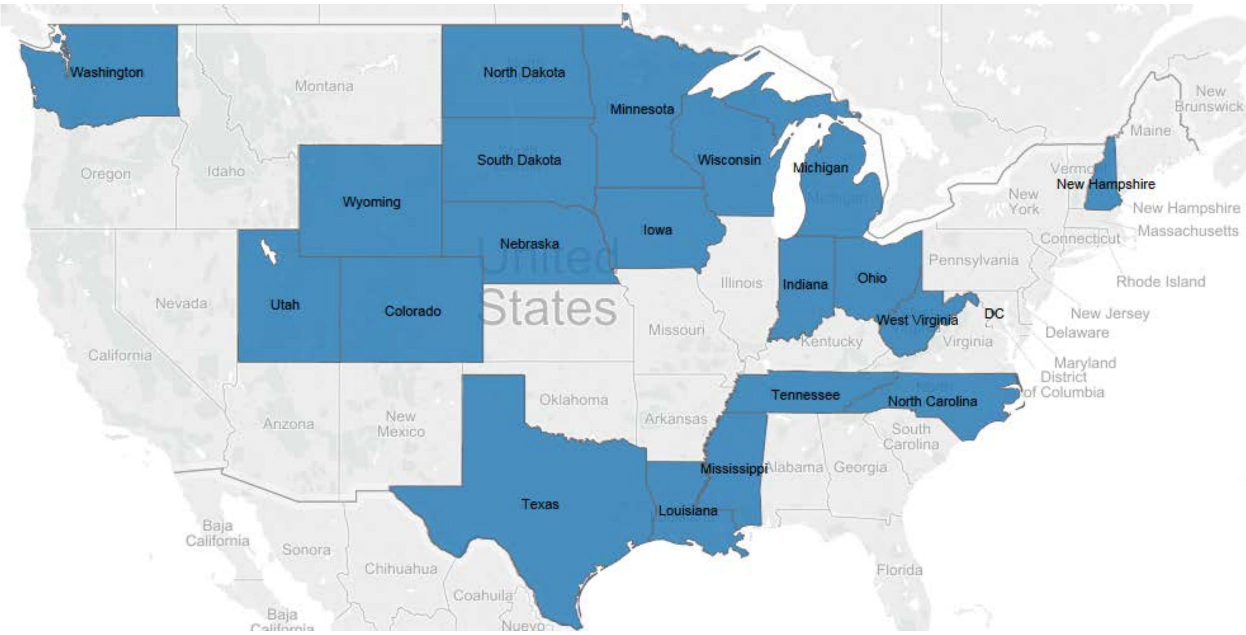

Figure 15 State DOTs that calculate HCCIs

Frequency of HCCI Calculation

In terms of the frequency of calculating HCCIs, 12 respondents are calculating their HCCIs at least once in a quarter (three months) (Figure 16). Five state DOTs calculate their HCCIs only once a year. State DOTs may not have a sufficient number of items being used every quarter to generate quarterly HCCIs. Some state DOTs calculate HCCIs quarterly as well as yearly. The quarterly HCCIs may reflect the seasonal effects in the construction market. But, high seasonal fluctuation in the construction market can also result in the "chain drift" discussed in Section 2.1.1.

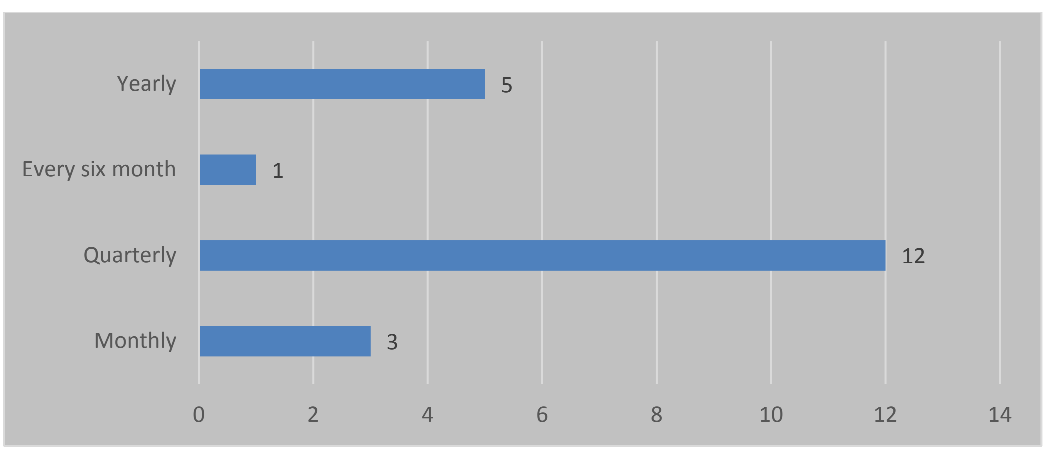

Figure 16 Frequency of calculating HCCIs

Item Basket

State DOTs use various methods to determine an item basket for calculating HCCIs. The HCCI documents provided by state DOTs show that the bid items used for HCCI calculation cover as low as 14% and as high as 96% of the total construction costs. Many state DOTs further categorize the item basket into item categories which have both pros and cons as discussed later in this section.

An item basket should be selected so that the fluctuation in the construction market and construction costs are reflected properly in the HCCI. Ten respondents reported that they use more frequent items as the items for their HCCI calculation (Figure 17). The likely reason behind selecting more frequent items is that the unit price and quantity data for the selected basket of items are required to calculate the HCCIs. ODOT has defined and utilized a missingness factor to identify the items that meet a minimum threshold value of being frequent enough to be included in HCCI calculation (Collins and Pritchard 2013). The details of the missingness factor is provided in Chapter 2.

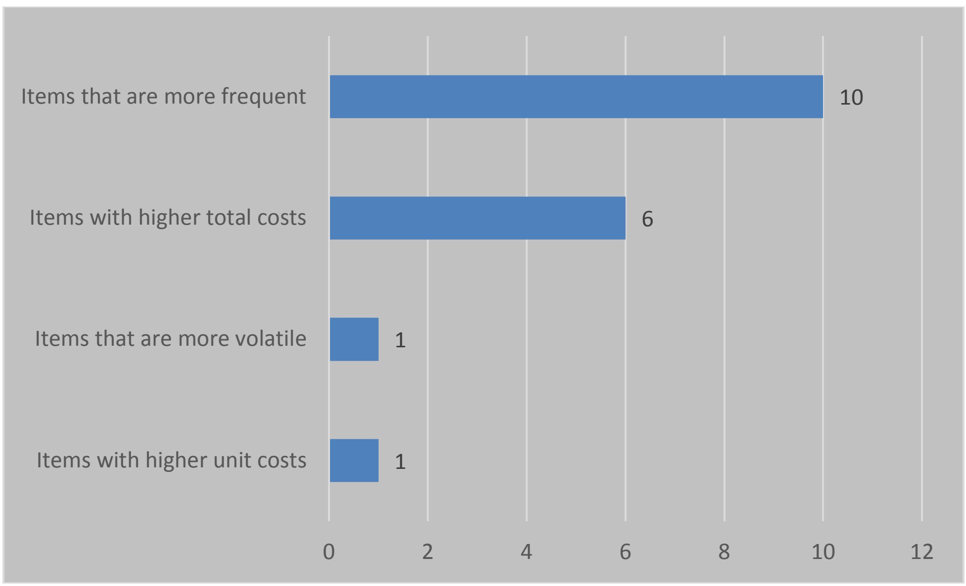

Figure 17 Item identification for HCCI

If only frequent items are included, some large but not-so-frequent items may be missing. As such, some state DOTs also consider the items with higher costs even when those items are not used frequently. When data for those items are not available for a given period of time, the data from previous periods can be used. Similarly, the costs of the items that are volatile can play a role in the overall construction costs. But, if those items are neither large nor frequent, including those items would possibly create more complications without much benefit. This might be the reason that many state DOTs have not considered volatility alone as a factor for identifying the market basket. The lack of in-house human resources and methodologies to analyze the volatility of the items might be another reason for not considering the volatility as a factor.

Once the item basket is identified, most state DOTs classify the items into several item categories like excavation, asphalt concrete, concrete pavement, structural concrete, and structural steel and calculate overall HCCIs in two stages. The two stage HCCI calculation process has pros and cons. For instance, items that are not actually used in highway projects, one of the two periods are used to calculate weights of the categories. In other words, the less frequent items will have some effect on the index calculation. For example, even if "Asphalt Binder PG 58-28" is not a frequent item, its total price can be used when calculating the weight for the Asphalt concrete category. Thus, more items are included in the HCCI calculation and hence the HCCI will possibly better reflect the actual market conditions. However, the accuracy with which the market condition is reflected in the overall HCCI may degrade when two-stage HCCI calculation is used.

The price trend of items for which data are available governs the category level sub-HCCI, i.e. if the price of only one item in the category increases, it will increase the category level index. If the prices of other items that are included in the category are decreasing but price data is not available for the current period, it will not decrease the category level HCCI. To reduce such bias, the items in a given item category should have a similar unit price trend. For example, all concrete items are likely to have a similar price trend and can be included in an item category, but concrete items and steel items may have different trends and should not be combined into a single item category.

In an alternative approach, some state DOTs do not categorize items nor calculate category level sub-HCCIs before calculating an overall HCCI. They use an item basket consisting of several items to calculate the overall HCCI directly. The West Virginia DOT (WVDOT) uses only seven specific bid items: unclassified excavation; class 1 aggregate base course; Marshall hot-mix base course, stone; Marshall hot-mix wear course, stone; class B concrete; reinforcing steel bars; and type 1 guardrail to calculate its HCCI. Such indexes are easier to calculate as only few items are used and it is a one-step aggregation process, but as the dollar amount represented by the items would be low, it may not be an accurate indicator of the construction market conditions.

Price Index Formulas

Based on the survey results, the Laspeyres index is still being used by more states (7) than the Fisher index (4 states) (Figure 18). However, North Dakota and Wisconsin DOTs are currently using Laspeyres index but are switching to the Fisher index. It appears that state DOTs were using the Laspeyres index when FHWA was using the Laspeyres index for its Bid Price Index (BPI)–the predecessor of NHCCI. After the FHWA started using the Fisher index in 2011 for the NHCCI, state DOTs have been switching to the Fisher index. Utah DOT uses both Laspeyres and Paasche to calculate two different indexes. The LADOTD has developed its own customized polynomial regression model to calculate its HCCI. The WYDOT uses a form of the Lowe index where average quantities from several years are used.

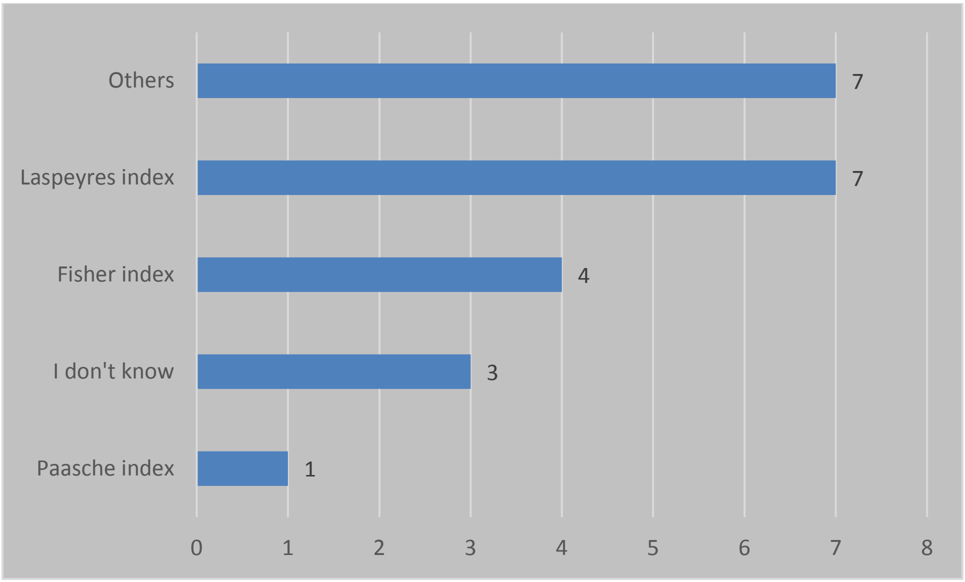

Figure 18 Indexing formulas used by state DOTs

Four states indicated that they used chained HCCIs and four others stated they used non-chained HCCIs (Figure 19). Ten state DOT representatives did not know whether they were using a chained index or non-chained HCCI.

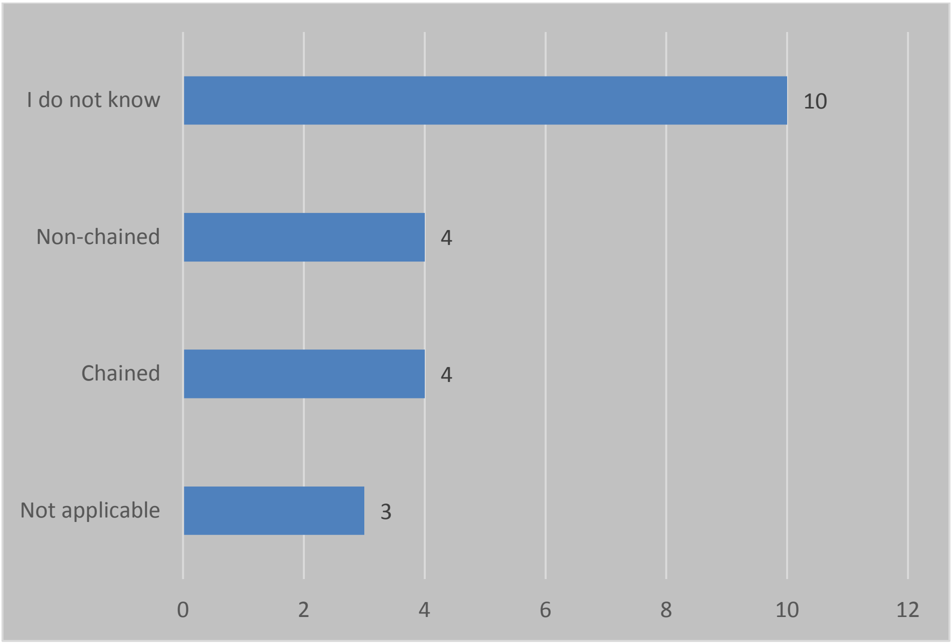

Figure 19 Chaining of indexes

Third Party HCCIs

State DOTs are monitoring many third party cost indexes to keep track of the construction market. Twelve state DOTs (39%) obtain and utilize third party HCCIs from the BLS and Engineering News-Records (ENR) sources. But, the majority of the respondents (61%) do not use third party indexes.

External cost indexes were rated to be relevant to their state to different extents. The National Highway Construction Cost Index (NHCCI) is the most popular third party HCCI (Figure 20). The NHCCI is monitored by 8 respondents and its relevance to their state DOT is rated an average of 2.6 out of 5. The NHCCI is calculated using bid data from state DOTs and is, hence, reflective of the overall condition of state DOTs. The BLS Consumer Price Index (CPI) is rated to be the most important third party index with an average relevance rating of 3.5 out of 5. The BLS CPI is monitored by five respondents. Other indexes monitored by state DOTs include the ENR CCI, RS Means Cost Index, BLS PPI BONS, ENR BCI, BPI PPI BMNR. ENR is a private company that provides construction cost indexes for 20 U.S. cities (ENR 2013). Some state DOTs also monitor HCCIs from neighboring state DOTs to compare the trend with their states.

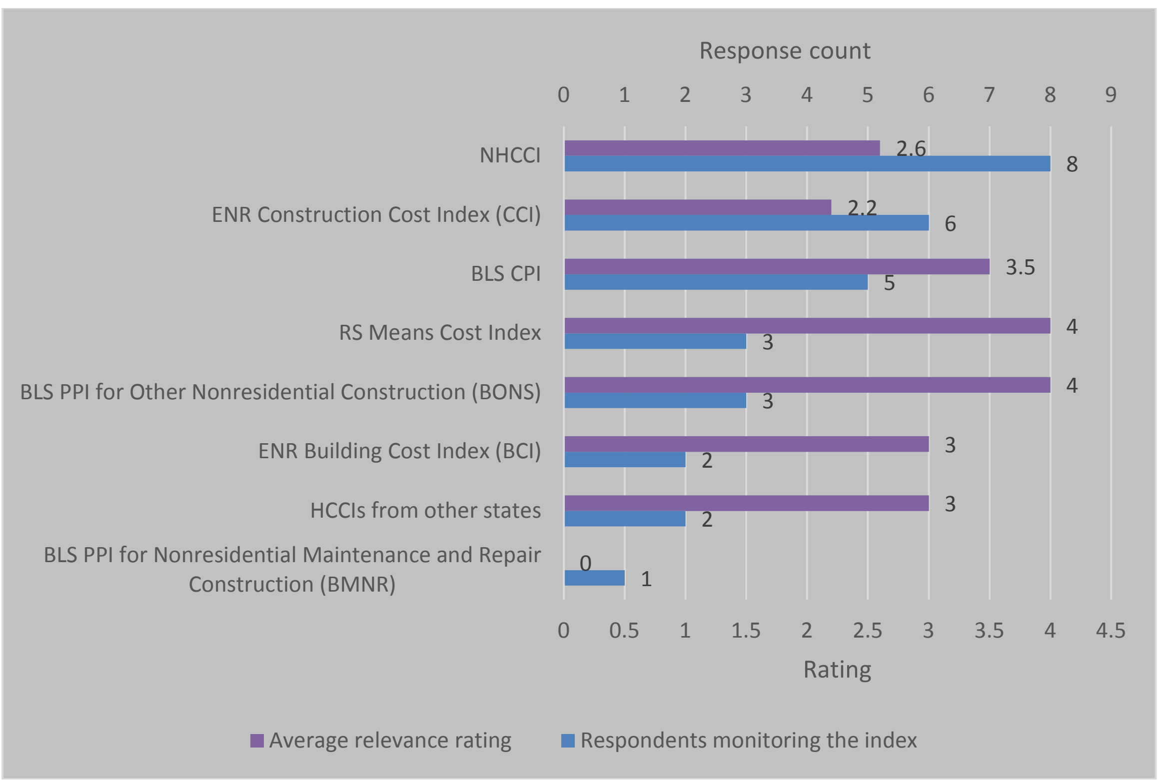

Figure 20 Various indexes being monitored and their relevance

The third party indexes are mostly (7 respondents) used as an indicator of overall market conditions. Some state DOTs (5) use it for side-by-side comparison with their in-house HCCIs and others (2) used it to determine an inflation rate of construction projects. When making comparisons, state DOTs should compare the percentage change in the index rather than the absolute value of the index (FHWA 2014c).

Users of HCCIs

HCCIs can be used by various offices within state DOTs. Planning and programming offices are the primary users of the HCCIs (Figure 21). During the early phase of project planning, state DOTs have very limited information about projects under consideration. At this stage, they utilize methodologies such as per lane mile cost estimation to come up with estimates for those projects. The HCCIs are used with those methodologies to improve the estimates by taking account of the inflation. Consultants use HCCIs to estimate the construction costs for the projects they are designing. Contractors can possibly benefit from the index to better position themselves for the next bid.

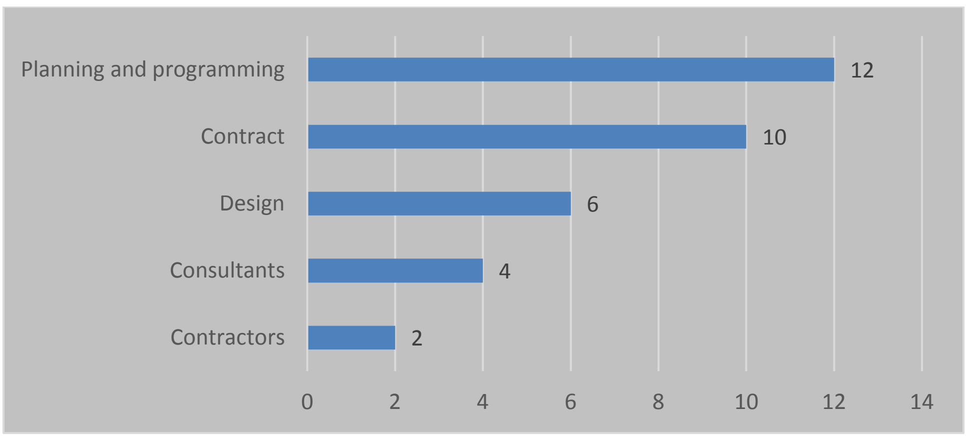

Figure 21 Current users of HCCIs

Use of HCCIs

State DOTs use their HCCIs for multiple purposes (Figure 22). Most respondents use HCCIs as a tool to forecast inflation rates for future contracts. It is used as a general construction market indicator. From a high-level perspective, it indicates the purchasing power of the agency. State DOTs also use it to compare their construction market with the national market and that of nearby states. Montana DOT mentioned that MDT HCCI follows the HCCI trend of Colorado with some lag (i.e., Colorado DOT's historical HCCI trend is followed by Montana after a year or two). Michigan DOT has previously used its HCCI to calculate fuel tax (Slone 2009). The fuel tax was proportional to the HCCI and inversely proportional to the state fuel consumption. A project level HCCI can be calculated to estimate the inflation rates for a particular type of project.

Some state DOTs use material specific indexes (such as fuel, asphalt cement, steel, cement indexes) calculated from prices of those materials in the open market to adjust payments to the contractors (Skolnik 2011). The purpose of such adjustment is to obtain lower bids by shifting the market volatility risks from the contractors to the state DOTs.

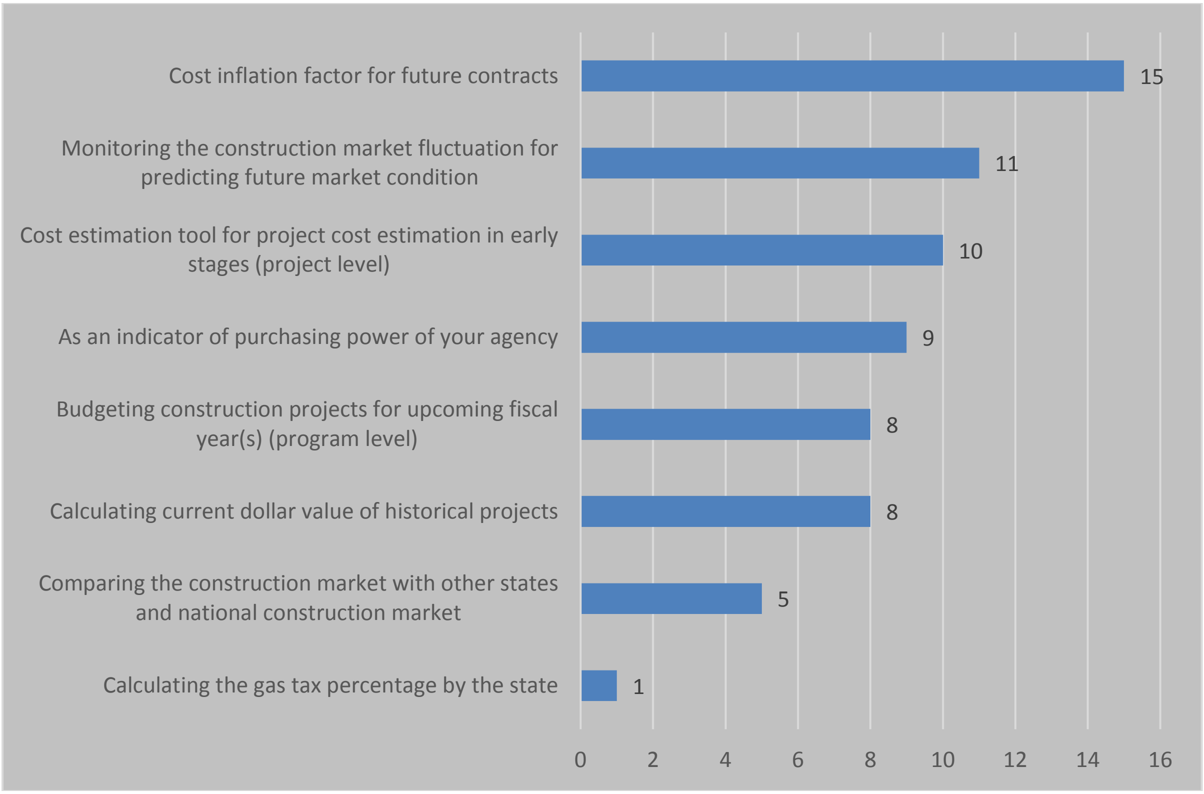

Figure 22 Current uses of HCCIs

State DOTs use third party HCCIs mostly as an indicator of an overall market condition (Figure 23). Five respondents reported that their agencies used third party HCCIs for side-by-side comparison with their in-house HCCI. Two respondents stated that their agency relied on third party HCCIs to determine an inflation rate for their construction projects.

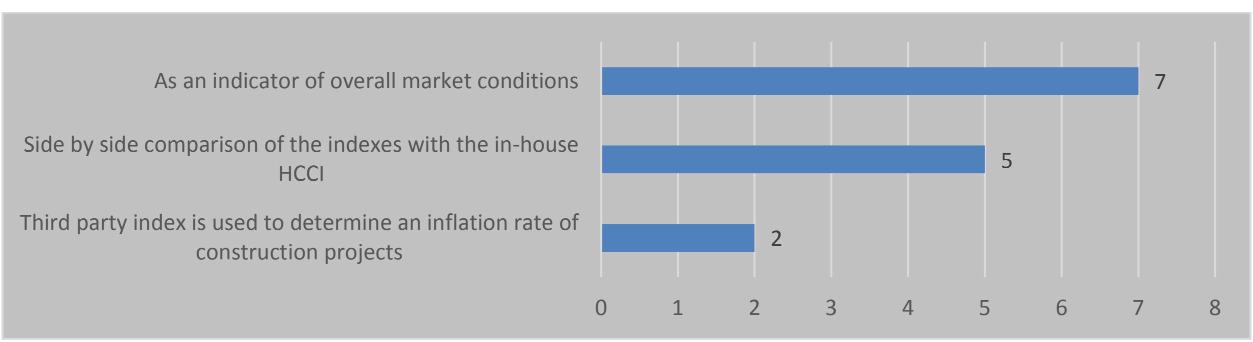

Figure 23 Current uses of third party HCCIs

Other Findings

A survey respondent noted that the costs of major items were highly sensitive to changes in quantities. If quantities are larger, the price tends to stabilize. In larger projects, asphalt prices tend to decrease. In smaller maintenance projects, asphalt prices tend to increase. Similarly, if there are more bidders for the same project, unit prices tend to go down. Different project locations and project types also affect the unit prices. Theoretically, the effect of those factors should be reflected on the HCCI.

Some state DOTs are looking forward to updating their HCCI methodology or developing one. Others are unsure about the reliability of their current HCCI methodology.

Based on the communication with a state DOT representative, the data cleaning is a very challenging and time-consuming step for a HCCI calculation. A data cleaning and selection of item basket should be automated with proper algorithms.

APPENDIX C OTHER INDEXING FORMULAS

This section presents brief mathematical definitions of Walsh, Young, Törnqvist, and Divisia index. Those indexes have their unique approaches to calculating cost indexes and are, hence. possible candidates for HCCI calculation for MDT.

The Walsh index uses the geometric averages of the quantities as shown in equation (16) below. Equal weight is given to the relative quantities in both periods by using a geometric rather than an arithmetic mean.

$$\text{Walsh index}, W = \frac{\sum_{i=1}^{n} p_{i,t}\sqrt{q_{i,0}q_{i,t}}}{\sum_{i=1}^{n} p_{i,0}\sqrt{q_{i,0}q_{i,t}}} \quad \textbf{\textit{(16)}}$$

The superlative indexes such as the Fisher index and the Walsh index that use quantities of both periods symmetrically provide more accurate or representative measure of price change and is preferred over other indexes (UN 2009; ILO 2004).

The Young index is calculated as the weighted arithmetic average of the individual price relatives as shown in equation (17) (ILO 2004).

$$\text{Young index}, Y = \sum_{i=1}^{n} s_i \left(\frac{p_{i,t}}{p_{i,0}}\right) \quad \textbf{\textit{(17)}}$$

Where s_i (equation 18) is the weight calculated as the shares of expenditure of the item in an arbitrary period. As in the Walsh index, the period can be anywhere from period 0 to period t.

$$s_i = \frac{p_i q_i}{\sum_{i=1}^{n} p_i q_i} \quad \textbf{\textit{(18)}}$$

In the Törnqvist index, a geometric average of the price relatives (ratio of prices in two periods) weighted by the average expenditure shares in the two period is calculated as presented in equation (19) below (ILO 2004).

$$\text{Törnqvist index}, T = \prod_{i=1}^{n} \left(\frac{p_{i,t}}{p_{i,0}}\right)^{\sigma_i} \quad \textbf{\textit{(19)}}$$

Where σ_i (equation 20) is the arithmetic average of the shares of expenditure on product *i* in the two period.

$$\sigma_i = \frac{1}{2}\left[\frac{p_{i,0}\ q_{i,0}}{\sum_{j=1}^{n}(p_{j,0}\ q_{j,0})} + \frac{p_{i,t}\ q_{i,t}}{\sum_{j=1}^{n}(p_{j,t}\ q_{j,t})}\right] \qquad \textbf{\textit{(20)}}$$

The Divisia index assumes a continuous change in price and quantity data. If *V(t)* is a total expenditure in time *t* as defined in equation (21) below

$$V(t) = \sum_{i=1}^{n} p_i(t)\ q_i(t) \qquad \textbf{\textit{(21)}}$$

The Divisia index can be obtained by differentiating the expenditure with respect to time as shown in equation (22):

$$V'(t) = \sum_{i=1}^{n} p_i{}'(t)\ q_i(t) + \sum_{i=1}^{n} p_i(t)\ q_i{}'(t) \qquad \textbf{\textit{(22)}}$$

However, in most cases, economic data are not collected in continuous time. For example, construction bid letting takes place approximately once a month and hence the prices change once a month from the DOT's perspectives. Thus, Divisia index can be considered a theoretical index which has less practical value.

APPENDIX D CORRELATION COEFFICIENT

The correlation coefficient or Pearson's product-moment (R) is a statistical factor used to access the linear relationship between two variables (say x and y) (Taylor 1990). Mathematically, the correlation coefficient can be calculated as in equation (23).

$$Correlation\ coefficient\ (R) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \qquad \textbf{(23)}$$

The range of R-value is from -1 to +1. If R-value is:

- Positive: both variables have similar trend, i.e. increase in x-value increases y-value while decrease in x-value decreases y-value
- Negative: increase in one-variable (say x) is associated with the decrease in another value (y)
- Zero: there is no relationship between the two variables

Based on the absolute R-value (| R |), the correlation can be interpreted for its strength as presented in the Table 11.

Table 11 Interpretation of R-values

Absolute R-value (| R |)	Interpretation
0.90 to 1.00	Very high correlation
0.70 to 0.89	High correlation
0.50 to 0.69	Moderate correlation
0.30 to 0.49	Low correlation
0.00 to 0.29	No correlation or Little if any correlation

The R^2 value, known as the coefficient of determination, represents the strength of the linear association between x and y, i.e. if R^2 value is 0.98, then 98% of the variation in y can be explained by the linear relationship between x and y.

APPENDIX E STATE DOT HCCI VALUES

Table 12 State DOT and the FHWA HCCI values

Year	Montana DOT's HCCI	Montana DOT's Modified HCCI	North Dakota	South Dakota	Wyoming	FHWA BPI	FHWA NHCCI
1987	100.0	100.0		100.0		100.0	
1988	122.3	116.9		96.6		106.6	
1989	115.2	113.5		107.7		107.7	
1990	127.6	122.1		112.3		108.5	72.0
1991	125.9	118.9		114.4		107.5	72.0
1992	121.8	116.4		112.4		105.1	70.0
1993	126.6	122.4		116.5		108.3	72.0
1994	123.1	121.8		120.0		115.1	77.0
1995	135.5	129.0		132.5		121.9	81.0
1996	136.8	130.6		132.6		120.2	80.0
1997	129.2	128.6		147.1	100.0	130.6	87.0
1998	139.3	136.8		149.1	98.5	126.9	85.0
1999	138.2	135.2		169.3	99.9	136.5	91.0
2000	150.8	141.8		177.0	106.7	145.6	97.0
2001	163.8	156.6	100	153.3	109.7	144.8	97.0
2002	153.9	146.5	110	154.4	112.4	147.9	99.0
2003	177.8	169.4	110	161.3	110.9	149.8	100.0
2004	193.7	181.0	107	202.2	112.3	154.4	107.0
2005	203.3	194.9	111	195.7	129.5	183.6	118.0
2006	246.9	235.2	134	247.2	162.5	221.3	135.0
2007	274.3	264.8	145	268.0	212.2		129.0
2008	304.4	287.4	164	276.1	234.0		129.0
2009	311.8	275.8	188	286.4	237.7		110.0

Year	Montana DOT's HCCI	Montana DOT's Modified HCCI	North Dakota	South Dakota	Wyoming	FHWA BPI	FHWA NHCCI
2010	310.1	277.0	174	289.5	200.0		106.0
2011	328.0	293.5	214	307.8	218.4		107.0
2012	384.1	322.7	229	332.4	235.6		113.0
2013	363.8	327.1	267		235.6		110.0

APPENDIX F BID ITEMS USED IN MDT HCCI CALCULATION

The items used under each category in 2013 and 1987 are presented in Table 13. The items that are used in both years are placed on the top of each category in the same row. Other non-matching items are placed afterwards and are separated by an empty row. The number of items used to calculate MDT HCCI increased from 52 in 1987 to 71 in 2013. Out of the 52 items used in 1987, same 35 items or their replacements were used in 2013.

Table 13 Bid items used in MDT HCCI calculation in 2013 and 1987

Year 2013			Year 1987		
Item #	**Item Description**	**Unit**	**Item #**	**Item Description**	**Unit**
		EXCAVATION			
203020100	Ex – Unclassified	CY	111010000	Ex - Unclassified	CY
203020200	Ex- Unclass. Borrow	CY	111030000	Ex- Unclass. Borrow	CY
203020250	Special Borrow- Ex	CY	111050000	Ex- Special Borrow	CY
203020375	Embankment In Place	CY	111102000	Embankment In Place	CY
203020225	Ex- Street	CY			
203020310	Special Borrow- Neat Line	CY			
203080100	Topsoil- Salvaging and Placing	CY			
		AGGREGATE BASE			
301020416	Shoulder Gravel	CY	941394101	Shoulder Gravel	Ton
301020268	Traffic Gravel	CY	231150001	Base Course 1.5"/2" GR 5A	Ton
301020340	Crushed Aggregate Course	CY	231300001	Base Course 3"/4" GR 2A	Ton
304010000	Portland Cement	TON			
304010005	Base-Cement Treated	CY			
		SURFACING			
401020042	Plant Mix Grade D - Commercial	TON		PMBS GR D	Ton
402020305	Emulsified Asphalt SS-1	Gal	313016003	Emulsified Asphalt CRS-2	Ton
501010125	PCCP 9"	SY	501010125	PCCP 9in	SY
401020045	Plant Mix Bit Surf GR S - 3/4 in	TON	251000001	Cover Material Grade 4A	Ton
301020718	Cover - Type 1	SY	301000001	PMBS GR A	Ton
301020735	Cover - Type 2	SY	301000002	PMBS GR B	Ton
401020300	Hydrated Lime	TON	311008500	A/C 85-100	Ton
402020089	A/C PG 58-28	TON	311012000	A/C 120-150	Ton
402020092	A/C PG 64-28	TON	312007002	Liquid A/C MC-70	Ton
402020093	A/C PG 64-34	TON	313002001	Emulsified Asphalt SS-1	Gal
402020095	A/C PG 70-28	TON		Plant Mix Polymer Mod. Asphalt	Ton
402020368	Emuls. Asphalt CRS-2P	TON			
		DRAINAGE			
551020030	Concrete Class DD Road	CY	401030000	Concrete Class DD	CY
207010010	Excavation Culvert	CY	521005000	Excavation Culvert	CY

Year 2013			Year 1987		
Item #	**Item Description**	**Unit**	**Item #**	**Item Description**	**Unit**
207010200	Bedding Material	CY	541005000	Bedding Material	CY
603010040	Drainage Pipe - 18"	LF	660018000	Drainage Pipe - 18"	LF
603010048	Drainage Pipe - 24"	LF	660024000	Drainage Pipe - 24"	LF
603010522	CSP - 18"	LF	561018060	CSP - 18"	LF
603010532	CSP - 24"	LF	561024060	CSP - 24"	LF
603012530	RCP - 18" Class 2	LF	621018020	RCP - 18" Class 2	LF
603012555	RCP - 24" Class 2	LF	621024070	RCP - 24" Class 2	LF
603012645	RCP - 36" Class 2	LF	621036020	RCP - 36" Class 2	LF
609010200	Curb and Gutter - Conc.	LF	753100010	Curb and Gutter - Conc.	LF
602010010	Remove Pipe Culverts	LF	561015060	CSP - 15"	LF
CONCRETE					
616183000	Foundation Concrete	CY	616183000	Foundation Concrete	CY
551020035	Concrete - Class DD	CY	401020000	Concrete - Class AD	CY
551020105	Concrete - Latex Modified	CY	401080000	Concrete - Class BD	CY
551020107	Concrete - Class SD	CY			
552010066	Drilled Shaft Concrete	CY			
REINFORCING STEEL					
555010100	Reinforcing Steel	LB	471000000	Reinforcing Steel	LB
555010200	Reinforcing Steel - Epoxy	LB	471000001	Reinforcing Steel - Epoxy	LB
BRIDGE					
553010151	Prestressed Beam - Type MTS-36	LF	553010010	Prestressed Beam - Type A	LF
553010152	Prestressed Beam - Type MTS-45	LF	553010090	Prestressed Beam - Type 4	LF
557010012	Bridge Rail - T 101	LF	557010012	Bridge Rail - T 101	LF
559010026	Anchor Post	EA		Anchor Post	EA
301020251	Bridge End Backfill	CY		Class A Bridge Deck Repair	SY
553010155	Prestressed Beam - Type MTS-54	LF		Class B Bridge Deck Repair	SY
553010161	Prestressed Beam - Type MTS-72	LF		Bridge Deck Treatment	SY
553010300	Prestressed Beam-Bulb Tee	LF			
557010542	Revise Bridge Rail - Conc Barrier	LF			
559050075	Furn Stl Pile HP 12x53	LF			
559060075	Drive Stl Pile HP 12x53	LF			
561020080	Prepare Deck	SY			
TRAFFIC					
618030005	Traffic Control Devices CB	Unit	42001000	Traffic Control - Devices	Unit
620013000	Striping - White Paint	Gal	891070001	Striping - White Paint	Gal
620013960	Striping - White Epoxy	Gal		Striping - White Epoxy	Gal
620014000	Striping - Yellow Paint	Gal	891070000	Striping - Yellow Paint	Gal
620014960	Striping - Yellow Epoxy	Gal		Striping - Yellow Epoxy	Gal

Year 2013			Year 1987		
Item #	**Item Description**	**Unit**	**Item #**	**Item Description**	**Unit**
			42002000	Traffic Control - Flagging	Hour
MISC. ITEMS					
608010020	Sidewalk - Concrete 4"	SY	608010020	Sidewalk - Concrete 4"	SY
606010030	Guard Rail – Steel	LF	901106251	Guard Rail – Steel	LF
617183054	Stnd. Stl. Type 10-A-500-4	EA	871301053	Stnd. Stl. Type 10-A-500-3/4	EA
616323120	Conduit Steel 2" Rigid	LF	851012001	Conduit Steel 2" Rigid	LF
202020140	Remove Bitum. Pavement	SY			
210200000	Obliterate Roadway	STA			
551020126	Flowable Fill	CY			
608010050	Sidewalk - Concrete 6"	SY			
606010040	Guard Rail - Steel Box Beam	LF			
609010030	Curb - Conc Median Type A	LF			
613100030	Rip Rap Class 1 Random	CY			

Table 14 lists four items replaced in 2013 for calculating MDT HCCI. The item numbers as well as the item descriptions are changed in 2013.

Table 14 Item number changes and replacements

Year	Previous item number	Previous item name	New item number	New item name
2013	553010010	Prestressed Beam - Type A	553010151	Prestressed beam-type MTS-36
2013	553010090	Prestressed Beam - Type 4	553010152	Prestressed beam-type MTS-45
2013	553010160	Prestressed Beam - Type M72	553010155	Prestressed beam-type MTS-54
2013	553010170	Prestressed Beam - Type MT-28	553010161	Prestressed beam-type MTS-72

APPENDIX G AVAILABLE DATASETS AND DATA ATTRIBUTES

Table 15 lists the bid data attributes available in research_bidder_info_ii_v2_042715.xlsx file.

Table 15 Data attributes in bid dataset (research_bidder_info_ii_v2_042715.xlsx)

SN	Data attribute	Description	Remarks on use for HCCI
1	CONT_ID	Contract id	
2	PROJECT_ID	Project id	
3	PROJECT_NM	Project number	
4	AWD_VENDOR_NAME	Vendor name	
5	PRJCT_TTL_AMT	Project total amount	
6	CONTRCT_TTL_AMT	Contract total amount	
7	LATITUDE	Latitude	Location specific sub-index
8	LONGITUDE	Longitude	Location specific sub-index
9	LET_DATE	Let date	Identify items for a given HCCI period
10	CONT_DESC	Contract description	
11	WORK_TYPE	Work type	Project type specific sub-index
12	CNTY_NM	County name	
13	CNTY_CNT	County count	
14	LENGTH	Length	
15	BIDS_RECEIVED	Number of bids received	Competition factor that may be introduced to the HCCI
16	AWARD_DT	Contract award date	
17	BIDDER	Bidder id	
18	BIDDER_NAME	Bidder name	
19	UNIT	Unit of measurement	
20	LINE_NBR	Line item number	
21	ITEM_NBR	Bid item number	Identify market basket
22	QTY	Quantity	Essential to use any indexing formula
23	ITEM_BID_PRICE	Unit price	Essential to use any indexing formula
24	ITEM_BID_AMT	Total amount for the item	

Mr. Antonick provided an “Item_List.xlsx” file followed by an updated version of the file named “Bid_Item_Lists_042815.xlsx.” The updated file has more data attributes, but are missing two data attributes (ITEMCLASS_DESC, ITEMTYPE_DESC); those data attributes are not much important for the initial data analysis. Table 16 lists potentially useful and important data attributes and their uses for HCCI calculation. A short description of each bid item is presented in the file, but details of the items might be required to understand the items. Those details are available in the *MDT Standard Specifications for Road and Bridge Construction* (MDT 2014). The data attributes listed in the table can be used to remove lumpsum items, and develop categories for the category level indexes, etc. There are 6,176 unique bid items in the updated file. Thirty different units are used for the bid items.

Table 16 Data attributes in item_list.xlsx and bid_item_list_042815.xlsx

SN	Data attribute	Updated Data attribute	Description	Use for HCCI
1	Item	REFITEM_NM	Item code, e.g. "501000000"	To identify items for the market basket
2	IDESCR	DESCR	Description of items, e.g. "PORT CEM CONC PAVEMENT"	
3	ISPECYR	SPECBOOK	Specification year, e.g. "06"	Items are added, removed, and/or replaced in updated specifications which should be considered for HCCI calculation
4	IUNITS	UNIT	Unit of measurement, e.g. M2, LS	Lumpsum items will likely be removed
5	ITEMCLASS	ITEMCLASS	Categorization of items, e.g. "CONC"	Useful to develop category-level indexes
6	ITEMCLASS_DESC	-	Description of the item category, e.g. "Concrete Paving"	
7	ITEMTYPE	ITEMTYPE	"02"	Useful to develop category-level indexes
8	ITEMTYPE_DESC	-	Categorization of items, e.g. "02"	
9	OBSOLETE_INDICATOR	-	Indicates obsolete items, (Y/N)	Obsolete items will not be used in HCCI calculation for future years
10	OBSOLETE_DT	OBSOLETE_DT	Obsolete date, e.g. "29-JAN-15 12.00.00.000000 AM"	
11	-	FUELADJUSTMENT	Fuel adjustment for the item (all 0 for some reason)	
12	-	CREATED_DT	Date item was introduced/created	
13	-	LASTUPDATED_DT	Last updated date	

The lists of bid item classes and bid item types are tabulated in Table 17 and Table 18. Either of those classifications can be used to develop sub-indexes. However, bid item classes seem to be more aligned with the sub-indexes developed by other state DOTs (earthwork index, surfacing index, etc.). Only a few select categories are used to calculate the sub-indexes. For HCCI calculation, the design build (DB) projects and corresponding items are removed.

Table 17 Bid item classes

SN	Item class	Item class description
1	ERTH	Earthwork
2	STRC	Structures
3	CLRG	Clearing
4	RMVP	Remove Pavement
5	RMVL	Removals
6	MISC	Miscellaneous
7	DRNG	Drainage
8	ENVT	Environmental
9	BASE	Base Course
10	SURF	Surface Treatment
11	CRSH	Crushing
12	PMS	Plant Mix Surfacing
13	RCYL	Recycling
14	ASLQ	Liquid Asphalt
15	CONC	Concrete Paving
16	RMVB	Removal of Structures
17	WTMN	Water Mains
18	GRDL	Guardrail
19	FNC	Fencing
20	CGS	Curbs, Gutters, and Sidewalks
21	LSCP	Landscaping
22	REST	Rest Stop Construction
23	SIGN	Signing
24	LTNG	Lighting
25	PVMK	Pavement Marking
26	TRAF	Traffic Control
27	DB	Design Build
28	MOBL	Mobilization
29	NA	Not available
30	PAIN	Painting
31	PRP	Pavement Repair
32	SGNL	Signalization

Table 18 Bid item types

Item type code	Item type description
00	Unknown
01	Grading/Drainage
02	Paving
03	Structures/Bldgs
04	Materials
05	Equipment
06	Trucking
07	Traffic Control
08	Landscaping
09	Other, misc.

The divisions used in the MDT specification can also be used to develop category level indexes. The categories used in the specification are presented in Table 19.

Table 19 Item divisions used in MDT's specification manual

Division	Description
100	General Provisions
200	Earthwork
300	Aggregate Surfacing And Base Courses
400	Bituminous Pavements
500	Rigid Pavement And Structures
600	Miscellaneous Construction
700	Materials

The MDT projects are classified into 28 categories based on the work types, which can also be used in developing project type specific indexes. The list of MDT work types is presented in Table 20.

Table 20 Project work types (project_work_types.xlsx)

1. Bike And Pedestrian	15. Pavement Markings
2. Bridge Construction,Rehab And Removal	16. Portland Cement Concrete Pavement
3. Buildings (Scales, Rest Areas)	17. Reconstruction, Grading
4. Crack Seal	18. Rehab (Minor Grade and Overlay)
5. Drainage	19. Rumble Strips
6. Environmental And Wetland	20. Safety
7. Fencing	21. Scour Projects
8. GR S-PL Mix Wear Course	22. Seal and Cover
9. Guardrail	23. Sidewalk
10. Landscaping	24. Signals
11. Lighting	25. Signing
12. Microsurfacing	26. Slides Or Slope Stabilization
13. Miscellaneous	27. Utilities
14. Overlays	28. Warm Mix Bit Surf

MDT projects are also classified into 40 categories based on the work types as presented in Table 21.

Table 21 Project classification based on work type

Construction 110 New Construction 120 Relocation 130 Reconstruction – with added capacity 140 Reconstruction – without added capacity 141 Reconstruction – remove and replace culverts 150 Major Rehabilitation-with added capacity 151 Major Rehabilitation-without added capacity 222 Bridge Replacement with a culvert with no added capacity 223 Bridge Replacement with a Culvert while adding capacity **Resurfacing** 160 Minor Rehabilitation 170 Restoration and Rehab – PCCP 172 Restoration and Rehab - Facilities 180 Resurfacing – Asphalt (thin lift<=60.00mm) (including safety improvements) (Pavement Preservation) 181 Resurfacing – Asphalt (thin lift<=60.00mm) (Scheduled Maintenance) 182 Resurfacing – PCCP 183 Resurfacing – Seal and Cover 184 Resurfacing – Gravel 185 Resurfacing – Crack Sealing	**Bridge** 210 New Bridge 220 Bridge Replacement with added capacity 221 Bridge Replacement with no added capacity 230 Bridge Rehabilitation with added capacity 231 Major Bridge Rehabilitation without added capacity 232 Minor Bridge Rehabilitation 233 Bridge Preservation **Spot Improvement** 234 Bridge Protection 310 Roadway and Roadside Safety Improvements 311 Railroad/Highway Crossing Safety Improvements 312 Structure Safety **Miscellaneous** 313 Pedestrian and Bicycle Safety 410 Traffic Signals and Lighting 411 Signing, Pavement Markings, Chevrons, Etc.. 412 Miscellaneous Electronic Monitoring or Information Services 510 Environmental 520 Landscaping, Beautification 610 Maintenance Stockpiles 620 Bicycle and Pedestrian Facilities 660 Historic Preservation 710 Pedestrian and Bicycle Facilities CTEP **Facilities** 111 New Construction – Facilities

APPENDIX H MDT HCCI CALCULATION AND BID ANALYSIS SYSTEM: USER MANUAL

The MDT HCCI Calculation and Bid Data Analysis System is a powerful tool. Once the historical bid data and project characteristics data are imported to the system, it can calculate overall HCCI and eight different types of Sub-HCCIs. The system can also perform various bid data analyses such as computation of price fluctuation of a selected bid item, identification of frequent items and their frequencies. Further, tabular data are automatically visualized in trend line, bar chart, and histogram in a few clicks. This manual provides step-by-step guide to perform various analyses.

Overview of the System

Figure 24 below highlights five areas of the main screen of the system. In Area 1, the tabular results of the analysis are presented which is sometimes accompanied by chart is Area 4. Tabular data can be exported to an excel file using 'Export Data to Excel' button in Area 4.

In Area 2, the two input parameters are entered; a) year and b) item code. The year selected here is used for an analysis such as calculation of HCCI while the item code is used for bid item level analysis. In Area 3, basic information about the item is displayed. The bottom of the screen shows the full path of the current database used by the system. The system uses MS Access (*.accdb) based database.

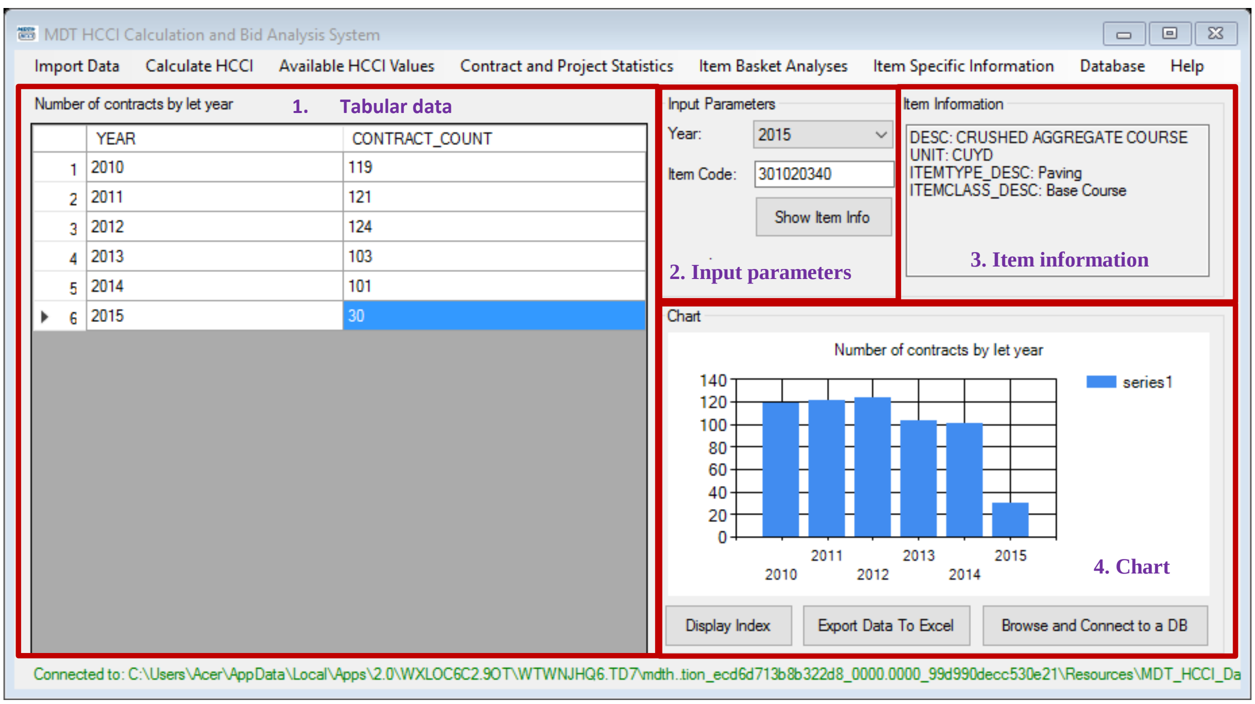

Figure 24 Overview of MDT HCCI Calculation and Bid Data Analysis System

Importing New Data

The database used in the system is preloaded with the historical bid data and project characteristics data which can be used to compute the historical HCCI values. As more data is collected every year, those new data need to be imported into the system to compute recent HCCIs. The system can import data from MS Excel files. A sample bid data and project characteristics data can be found in the 'Resources' folder, which is one of the installation folders of the software. A screenshot of the sample project characteristics and bid data are provided in Figure 25 and Figure 26. The project characteristics data must be stored in a sheet titled 'e_project_characterstics' to enable the data import. Similarly, bid data must be stored in 'e_bidtabse_winning.' The headers must appear in the same order as in the sample file for the import to work properly. Ensure that no values are empty. The system replaces an empty value with '-1' in the database.

CONT_ID	PRJ_NBR	WORK_TYPE	PP_LET_DTE	PRJCT_TTL_AMT	PROJ_DESC	ADMIN_DISTS	FINANCIAL_DIST	PRIMARY_ADMIN_DIST
07115	4051065000	140	1/22/2015	244618.16	PENDROY - N & S	3	3	3
04115	8041018000	310	1/22/2015	0	SF 129 SFTY IMPR GIFFEN	3	3	3
04115	8161110000	180	1/22/2015	0	KINGS HILL-NEIHART	3	3	3
06115	7282017000	221	1/22/2015	0	NELSON CREEK - 13M S SCOBEY	4	4	4
03115	7911017000	140	1/22/2015	19306.26	OLD DIVIDE RD APPROACH	5	5	5
08115	7912031000	620	1/22/2015	0	HARLOWTON SIDEWALKS	5	5	5

e_project_characteristics

Figure 25 Sample Project Characteristics Data for Importing

CONT_ID	PROJECT_ID	PROJECT_NM	LET_DATE	LINE_NBR	ITEM_NBR	QTY	ITEM_BID_PRICE	ITEM_BID_AMT	UNIT	PRJCT_TTL_AMT	CONTRCT_TTL_AMT	LATITUDE_DEGREE	LONGITUDE_DEGREE
02315	1316	7857050000	3/26/2015	0010	104030010	10000	1	10000	UNIT	0	0	45.87444444	-110.8863889
02315	1316	7857050000	3/26/2015	0020	109200005	1	8400	8400	LS	0	0	45.87444444	-110.8863889
02315	1316	7857050000	3/26/2015	0030	606010038	4562.5	20.5	93531.25	LNFT	0	0	45.87444444	-110.8863889
02315	1316	7857050000	3/26/2015	0040	606010140	4	300	1200	EACH	0	0	45.87444444	-110.8863889
02315	1316	7857050000	3/26/2015	0050	606010642	4	2500	10000	EACH	0	0	45.87444444	-110.8863889
02315	1316	7857050000	3/26/2015	0060	618030015	500	1	500	UNIT	0	0	45.87444444	-110.8863889
02315	1316	7857050000	3/26/2015	0070	618030080	1	14000	14000	LS	0	0	45.87444444	-110.8863889
02315	1316	7857050000	3/26/2015	0080	619010086	43.4	25.3	1098.02	SQFT	0	0	45.87444444	-110.8863889

e_bidtabs_winning

Figure 26 Sample Bid Data for Importing

The system allows for importing data for one year at a time. First, choose the year in Area 2 for which the data is to be imported. To import project characteristics data, click on 'Import data' menu and then 'Import Project Characteristics Data (Figure 27).' Then browse an appropriate MS Excel file.

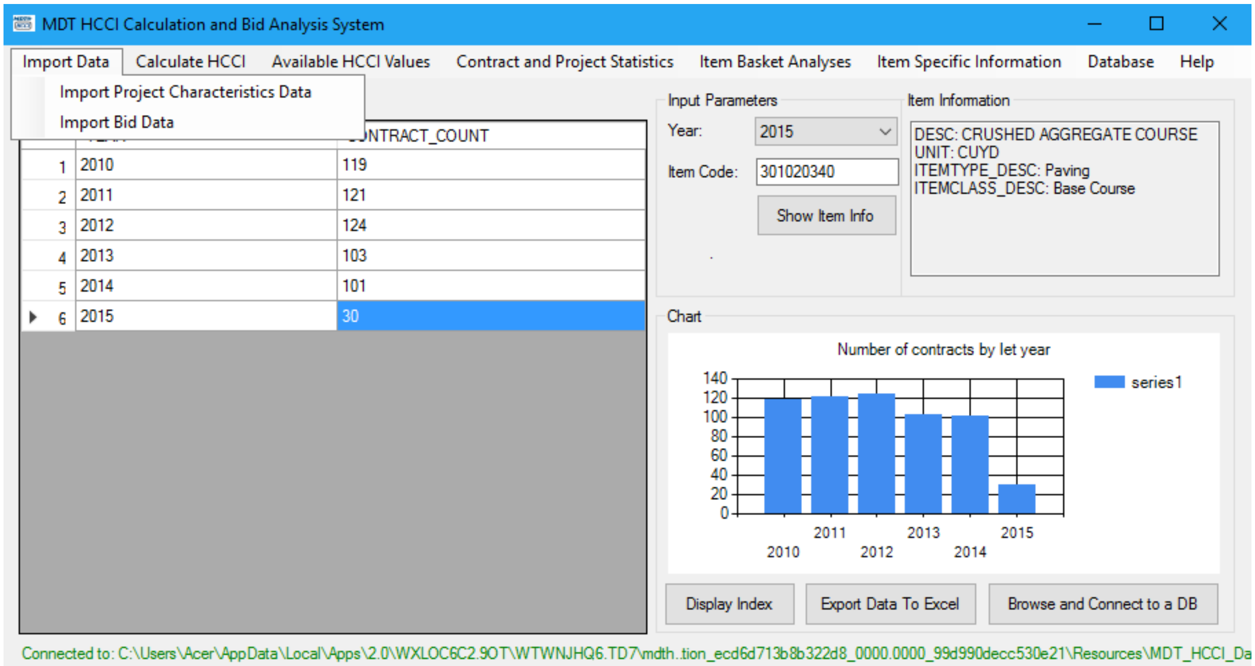

Figure 27 Importing Project Characteristics Data and Bid Data

The system checks for existing project characteristics data in the database for the selected year. If data exists, it will delete the existing data for the selected year before importing the new data. It will show some information about the import process which can be used to verify that all the data are imported. New bid data can be imported in the same fashion.

Note: Importing large file can take several minutes. Please be patient.

Calculating HCCIs and Sub-HCCIs

First, select the year in Area 2 for which HCCI or Sub-HCCIs are to be calculated. Each HCCI and Sub-HCCI can be calculated using 'Calculate HCCI' menu (Figure 28). In this step, the HCCI and Sub-HCCI are calculated for the selected year with respect to the previous year. The chained HCCI is calculated in the next step.

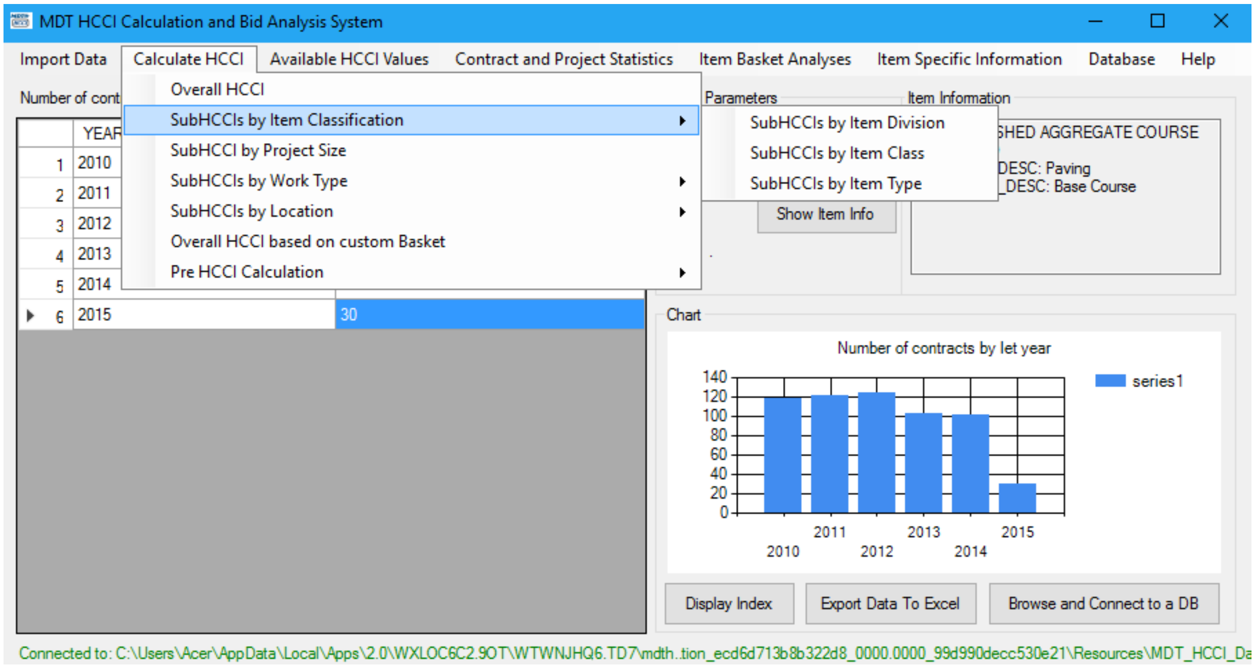

Figure 28 Calculating HCCI and Sub-HCCIs

The overall HCCI and most of the Sub-HCCI computations will be completed within several minutes. However, some complex Sub-HCCIs with higher number of categories can take half an hour or more depending on the processing power of the computer. Once the computation is completed, it will display the result in another window (Figure 29). The column titled 'Fisher_Index' contains the calculated HCCI for the selected year with respect to the previous year. The 'Item_Used_Count,' 'Total_Amount_C,' and 'Total_Amount_P' represents the number of bid items used to calculate the values, the total dollar amount of the items in the current year, and the total dollar amount of the items in the previous year. The 'NaN' is displayed when the value cannot be computed as no common item is used in the current and previous year.

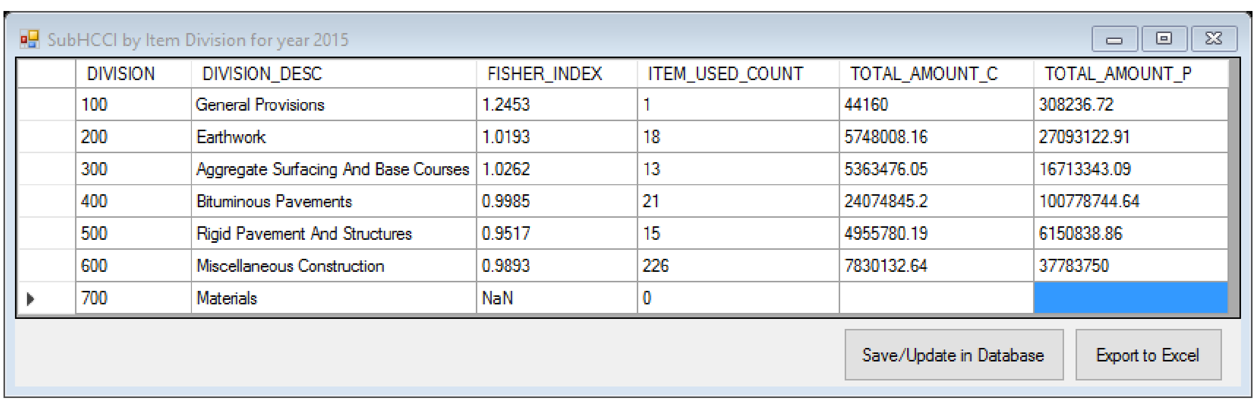

Figure 29 Sub-HCCI Window

The results can be stored in the database by clicking on the 'Save/Update in Database' button. It will first check any existing data. If data exists for the same year and same Sub-HCCI type, it will update the existing data. If not, it will insert the new data. It will show some information about the save/update operation.

Calculating Chained HCCIs and Sub-HCCIs and Viewing the Values

The ‘Available HCCI Values’ menu will list the various HCCIs and Sub-HCCIs that the system is capable of computing. Select desired Sub-HCCI type and click on ‘Display Index’ button in Area 4. It will show the tabular and graphical values of the selected HCCIs or Sub-HCCIs (Figure 30). In the tabular data, the Chained HCCI is presented in the last column ‘Chained_Fisher_Index.’

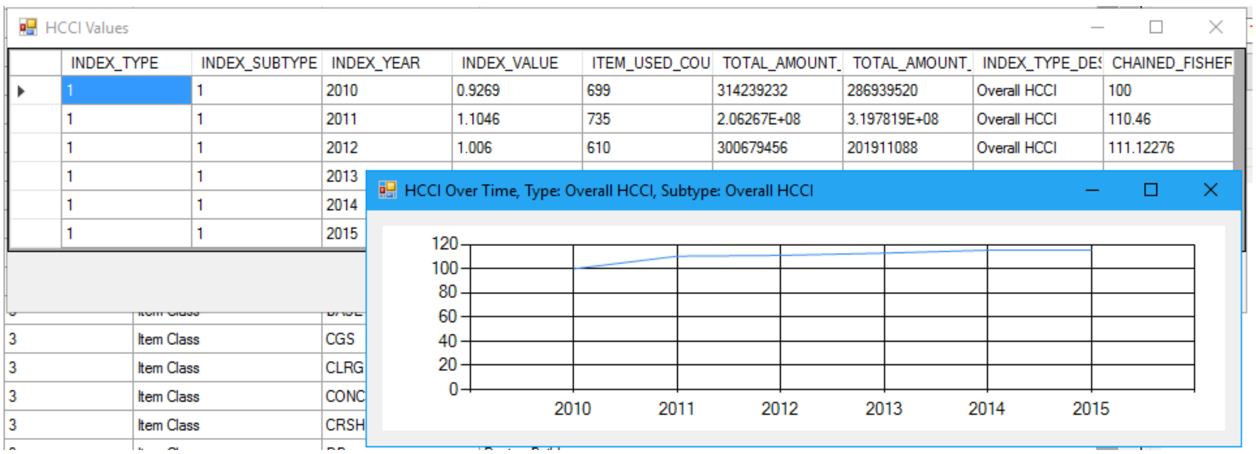

Figure 30 Viewing HCCIs and Sub-HCCIs

The system attempts to compute the chained HCCIs to the current year. For that, relative HCCIs must be computed for all year from the base year to the current year in the previous step. If there are missing HCCI values for any year in between, then the chained HCCI is computed only up to the date for which relative HCCIs are already computed. For example, if the base year 2010 and relative HCCIs are computed for 2011, 2012, 2014, and 2015; the year 2013 is missing. As such, the chained HCCI will be calculated from 2010 up to 2012.

Note: The system assigns 100 as the base year HCCI.

Other Features

Other features of the system include the computation and visualization of the contact and project statistics by year (‘Contact and Project Statistics’ menu), analysis of item basket that generates the list of items by frequency of use and total dollar values (‘Item Basket Analyses’).

If the Area 1 (tabular data) contains a bid item column, any value of the bid items can be double clicked to copy it to the ‘Item Code’ text box in the Area 2 (Input Parameters). Item code in this text box is necessary to perform item level analysis using any menu in ‘Item Specific Information.’

Backing up and Restoring Database

The ‘Database’ menu can be used to back up or restore the database. It is a good practice to back up the database in a safe location anytime new computations are performed. In MDT’s case, this would may just be once a year. By default, the filename in the back up file will end with the current date in YYYY-MM-DD format (e.g. 12-23-2016). If the existing database is corrupted or lost, the backup file can be used to restore all the information that are previously imported and computed.