Advanced Methodology to Determine Highway Construction Cost Index (HCCI):

Task Reports - 1, 2, and 3

IOWA STATE UNIVERSITY
Institute for Transportation

Advanced Methodology to Determine Highway Construction Cost Index (HCCI)

Task Report: Task 1, 2, and 3

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1 INTRODUCTION

The accuracy of conceptual cost estimates in the planning level is crucial for successful construction project management (Migliaccio et al. 2013; Zhang et al. 2014). The underestimation of construction costs will result in reduced project scope, cancellation of the project, or forcing owners to secure additional funding. The overestimation of construction costs limits the number of projects that can be pursued in a given fiscal year. Inflation is one of the factors that affects the accuracy of cost estimates. Many highway agencies (e.g. California, Colorado, Montana, New York, Ohio, Wisconsin, etc.) use their in-house Highway Construction Cost Index (HCCI) and/or third party cost indexes for the planning stage as a rough but quick and useful indicator to measure the trend of cost escalation and its possible impact on the future construction projects (Weris, Inc. 2013).

The task report summarizes the findings from Phase I: Benchmark best practices, Phase II: Comparison and identification of national and regional trends, and Phase III: Review of current Montana Department of Transportation (MDT) HCCI process and data.

Phase I consists of literature review and nationwide survey of other state DOT's practices and process of calculating and utilizing HCCIs. As a part of Phase I, an on-site kick-off meeting was held in February 26 and 27, 2015 in the MDT headquarter. MDT staff shared their current HCCI practices and provided information about their available datasets for HCCI calculation. The research team conducted a literature search using Transportation Research Information Services (TRID) and the Google Scholar database to find studies regarding the HCCI calculation methodologies and its uses in state Departments of Transportation (DOTs).

For theoretical background on the various price index formulas, the research team briefly summarized the Fisher, Laspeyres, and Paasche index. Several manuals developed by International Labor Office et al. (2004), International Monetary Fund (IMF 2010), and United Nations (UN 2009) are studied. Other literature reviewed includes state DOTs' HCCIs published in their websites and academic research studies. The findings from the literature are discussed in Chapter 2.

As part of Phase I, a survey questionnaire was developed and submitted to MDT for review. The survey was conducted in the summer of 2015 using the Qualtrics system. The questionnaire is included in Appendix A of this report. The survey was developed to understand current practices and identify any innovative HCCI calculation techniques that can be adopted for MDT. Thirty-four state DOTs and the Federal Highway Administration (FHWA) responded to the survey. Louisiana, Minnesota, Mississippi, Wisconsin, Nebraska, Utah, Wyoming, Iowa, and Ohio provided their HCCI calculation manuals and/or spreadsheets. The results of the survey are presented in Appendix B.

Phase II consists of the comparisons of state DOTs' HCCI calculation methodologies and analysis of the HCCI trends in neighboring state DOTs. The methodologies are compared in Section 2.3 based on HCCI manuals and spreadsheets. State DOTs' HCCI calculation procedures were compared in terms of the item basket, price index formula used, base year, etc. The trends in neighboring state DOTs HCCIs and the FHWA HCCIs are compared with MDT HCCI trend using a regression analysis in Chapter 3. In the same chapter, the effective practices of calculating and utilizing HCCIs are identified and presented briefly based on the literature review and the survey.

Finally, MDT's current process of calculating and utilizing HCCIs along are reviewed under Phase III. Available and useful data attributes in MDT's bid data to develop an advanced multidimensional HCCI system are reviewed. The datasets were obtained from MDT's Program Project Management System (PPMS), SiteManager, and Geographic Information System (GIS). The findings of those tasks are presented in Chapter 4.

2 LITERATURE REVIEW

This section discusses theoretical aspects of HCCI formulas, a brief history of HCCIs in the U.S., and current practices of calculating and utilizing 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 categorized into several categories to calculate category level price indexes. Such categories are termed as "item category" in this report.

HCCIs are special types of price index that measure 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. Both Laspeyres and Paasche indexes are two special cases of Lowe index. This relationship is illustrated in Figure 1 and described in the following paragraphs. In the figure, p and q are the prices and quantities of the items.

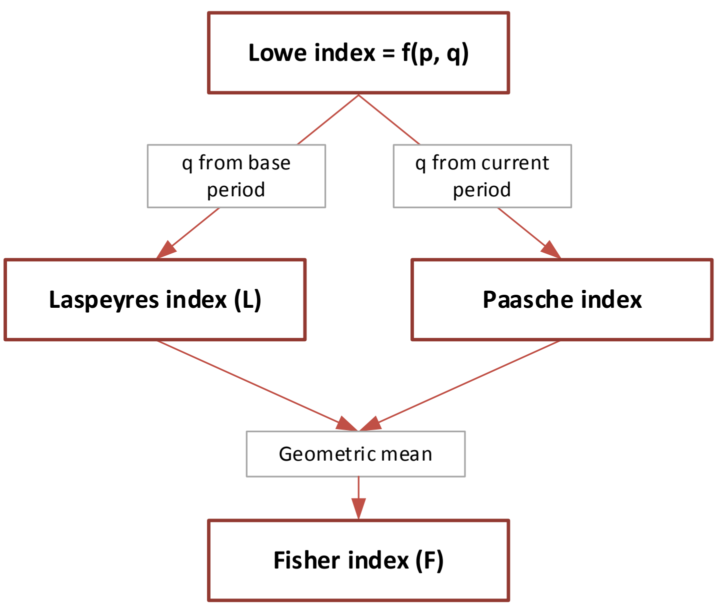

Figure 1 Relationship between Lowe, Laspeyres, Paasche, and Fisher Indexes

Lowe index is one of the popular class of price indexes (IMF 2010). For an item basket consisting of n items with price p_i and quantitie q_i, for the i^{th} item, the Lowe index comparing the periods t and 0 can be presented mathematically as

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

In Lowe index formula, any arbitrary quantity of the item, q_i, can be used. From a practical perspective, quantities from period t, 0 or in between can be used. Laspeyres and Paasche indexes are two special cases of Lower index where the quantities from the base period and current period are used respectively. If the item quantity of i^{th} item in the base period is $q_{i,0}$, the Laspeyres index can be mathematical expressed as

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

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

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 and 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 as explained in Appendix D.

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

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

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

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

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

The Fisher index accounts for the quantities from both periods symmetrically and provide a more accurate or representative measure of price change (UN 2009; International Labor Office (ILO) et al. 2004). Assuming that Lowe index is calculated using quantities from somewhere in between period 0 and period t, the values of the four indexes are ranked as

Lowe ≥ Laspeyres ≥ Fisher ≥ Paasche

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

The Fisher index is considered the best price index formula based on two established index formula evaluation methods (UN 2009; International Labor Office (ILO) et al. 2004). The detailed evaluation results are provided in Appendix D.

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 (International Labor Office (ILO) et al. 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 out of date 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

$$P_{t,0} = P_{1,0} \; X \; P_{2,1} \; X \; P_{3,2} \; X \ldots\ldots X \; P_{t,t-1} \tag{7}$$

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 using a chained index system, if there is a gradual economic transition, the spread between Laspeyres, Paasche, and Fisher indexes will be 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 prices and quantities of items fluctuate significantly within a year, then the monthly or quarterly chained price index calculation is not recommended. But, as year to year fluctuations of prices and quantities tend to be low, an annual chained index can be calculated.

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 contributes to 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 are 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.

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 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,
- 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.

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 inflation rates 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.

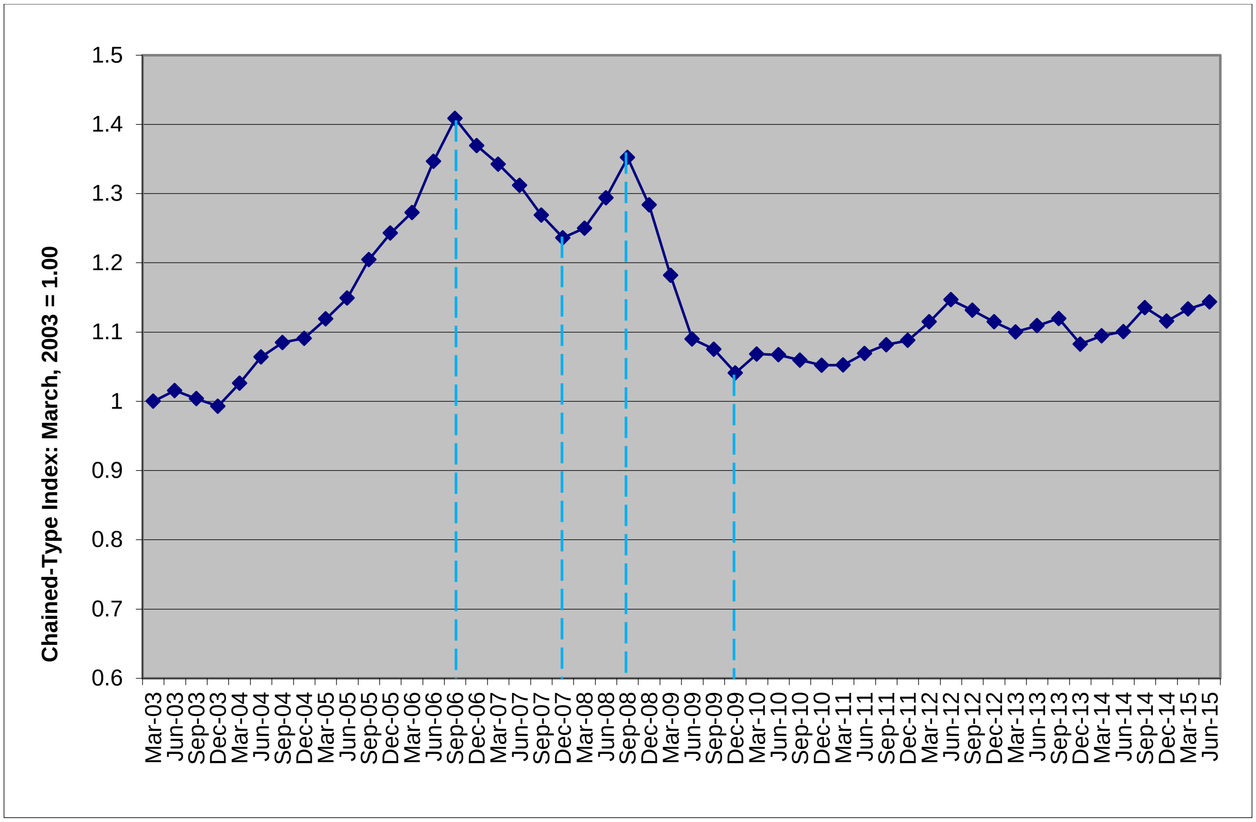

Figure 2 NHCCI trend from the first quarter of 2003 to the second quarter of 2015 (Source: FHWA (2015))

Many state DOTs calculate their own HCCIs as the national economic condition did 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.

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
- Identifying and analyzing the selected characteristics of the Oman and the Recovery Act dataset

2.3 State DOT HCCIs

Eighteen state DOT HCCI methodologies are compared in this section based on the review of available literature and manuals. First, the item categories of those states are listed in Table 2. The table shows that the state DOTs have developed their own item categories to calculate their HCCIs (Table 2). Ohio and Texas DOTs have 20 and 16 item categories 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, first the items in the items basket are classified into 16 item categories. Those categories are grouped into four item categories: earthwork, subgrade & base course, surfacing, and structures. In the Florida DOT, six item sub-categories are grouped into two item categories.

In Table 3, the state DOT HCCIs and the FHWA HCCIs are compared in terms of the above categories, 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 selected. In Washington and New Hampshire DOTs, the base year of 1990 and 2000 are used with base values of 110 and 145 to match 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 forecast its HCCI for 5 years based on the experience of the engineers. Montana and Oregon DOTs also forecasts 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 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 source are not known (and are indicated by “x” in the table).

Table 2 Item categories used by state DOTs to calculate their HCCIs

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

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	-	x	x	x	x	x	x
Concrete pavement	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	x
Structural concrete	x	x	x	x	x	x	x	x	x	x	-	x	x	x	x	x	x	x	x
Reinforcing steel	x	x	x	x	x	x	-	x	x	x	-	-	x	x	x	x	x	x	-
Structural steel	-	x	x	x	-	x	x	x	x	x	-	x	-	x	x	x	x	x	-
Aggregate	x	x	x	x	-	-	-	-	-	-	x	x	x	-	x	-	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	-	100
Interval	Annually	Qtrly	Qtrly	Annually	Qtrly	Qtrly	Annually	Annually	Qtrly	Qtrly	Qtrly	Monthly	Annually	Annually	Qtrly	Qtrly	Qtrly	Qtrly	Qtrly
Formula	Y	-	-	-	CF	ML	-	-	L	-	CF	-	-	-	Fi	Fi	-	-	CF
Forecast	10yrs										5yrs							10yrs	

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	-	DOE	OPIS	-	DOE	WSJ	-	-	-	OPIS	x	-	-	-	Ch, EM, U76	x	x	OPIS	-
Asphalt/ Bitumen	-	PP	-	-	x	x	-	-	-	-	x	-	-	-	Ch, EM, CP	x	PP	PP	-
Steel	-	ENR	-	-	-	-	-	-	-	-	PPI	-	-	-	-	-	-	PPI	-
Cement	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-
External HCCIs	REMI	PPI, GI	-	-	-	-	-	-	-	-	-	-	-	-	ENR CCI, CPI, UCLA	PPI, ECI		PPI, DOE, Oregon wage index	-
Miscellaneous																			
Tool used	Excel	-	-	Excel	-	Excel	Excel	-	-	Excel	SAS	-	-	Excel	-	-	-	-	Proprietary

Note:

Fi – Fisher
CF – Chained Fisher
L – Laspeyres
ML – Modified Laspeyres
Y - Young

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

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 Findings of State DOT Practices

The findings from the literature review are discussed in the following four sections followed by unique approaches of Ohio DOT and Louisiana Deparmtent of Transporatation and Development (DOTD).

2.4.1 Indexing Formula

State DOTs are switching to the Fisher index: State DOTs in California, Colorado and Ohio have switched from 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).

Lowe and Young indexes are also in use: Most of the literature on HCCI indicates that state DOTs only use the Laspeyres or Fisher index. MDT is using the Young index while Wyoming DOT is using Lowe index. The average quantities (*qi,avg*) from 1997 to 2008 is used as the quantity in the Lowe's formula in the Wyoming DOT HCCI.

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

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 first categorize their bid items into item categories. First, sub-indexes such as concrete pavement index and earthwork index are calculated for the categories. Those sub-indexes are then combined to calculate an overall HCCI. Other 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.

2.4.2 Market Basket

Some state DOTs are using outdated item basket: State DOTs such as Nebraska DOR and Wyoming DOT that are using fixed weight indexes such as Laspeyres and Lowe index have not updated their base year frequently, which results in the outdated quantities and hence less relevant HCCIs. Nebraska DOT 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. Utah and New Hampshire DOTs are some of the exceptions that update the item basket annually (Walters and Yeh 2012; New Hampshire Department of Transportation (NHDOT) 2013).

Items covered in HCCI calculations vary widely: West Virginia DOT started to calculate its HCCI in 2008 and uses only seven specific bid items covering 14.30% of all bid items in 2014. Nebraska Department of Roads (NDOR) uses item basket that covers 46.31% of all bid items. Ohio DOT uses item basket that have the highest cost coverage of 96% of all bid items in fourth quarter of 2012.

2.4.3 Data Cleaning and Data Preparation

Several data cleaning steps necessary before calculating HCCI: Data from various types of contract procurement other than design bid build should be removed as it can introduce bias in the index. Minnesota DOT (MnDOT) removes data from Construction Manager General Contractor (CMGC), design-build, Indefinite Delivery Indefinite Quantity (IDIQ), Emergency Relief (ER), urgent, and negotiated contracts (MnDOT 2009). MnDOT also removes data from projects that are $100,000 or less. Colorado DOT (CDOT) removes data from design build, hybrid/modified/streamlined design build, construction manager/general contractor, and emergency contracts. It also removes bid data outside 5 to 95 percentile as outliers (Yu 2012).

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).

Some manual steps used to prepare data for HCCI calculation: If excavation and embankment are both used in the same project, the MnDOT uses the costs of both items, but only the larger quantity among two (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), Louisiana Department of Transportation and Development (LDOTD), and Kansas DOT (KDOT) monitor an item level trend for items such as asphalt binder, but do not necessarily generate 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. Florida DOT also keeps track of sub-indexes for 12 areas for earthwork, base, asphalt, concrete, structural steel, and reinforcing steel (State Specifications & Estimation Office 2013).

State DOTs calculate their HCCIs back for previous years: The base year and the year the state DOT started to calculate HCCIs are not necessarily the same. For instance, Caltrans started using the Fisher index in 2010 with a base year of 2007, and has calculated the HCCIs back to 1972.

Charts and Tables Online: Many state DOTs such as Iowa DOT, Florida DOT, and Colorado DOT 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 HCCI 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 neighboring state DOT market conditions.

Moving averages: Iowa and Florida DOTs calculate quarterly HCCIs and also compute three-quarterly moving averages to visualize smoother trend of their HCCI (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–the FHWA is using a proprietary system, Ohio DOT is using SAS based program, while most of the 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 includes ENR CCI, BLS PPI, and REMI.

2.4.5 Unique Approaches used by Ohio DOT

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

Outlier detection. Ohio DOT 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. Ohio DOT introduced a concept of the “missingness factor (δ)” to identify the frequently used items to develop item basket. The missingness factor of an item is defined mathematically as (Collins and Pritchard 2013)

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

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, Ohio DOT 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. Ohio DOT has used lump sum items under "maintenance of traffic control" item with a unique approach. It calculates total cost percentage of the maintenance of traffic control percentage (total cost of traffic control items divided by the total contract amount) and use it as the quantity of the item.

The Ohio DOT also publishes construction cost outlook and forecast (Bid Analysis & Review Team 2013). 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 Approaches used by Louisiana DOTD

Louisiana LDOT is developing 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 equation 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 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 presented.

Mills (2013) developed a HCCI forecasting model for Colorado DOT (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 input 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 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 there are multiple complex macroeconomic factors that affect highway construction costs and HCCIs and thus it is 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, n.d.). Ohio DOT 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 is the best rough surface interpolation and the Inverse Distance Weighted (IDW) is 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 provide 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 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. Others indexes such as 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 of 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 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 (Bureau of Labor Statistics (BLS) 2015a; Bureau of Labor Statistics (BLS) 2015b; Bureau of Labor Statistics (BLS) 2015c). Thus, its value may be limited to comapring 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 (Bureau of Labor Statistics (BLS) 2016c; Bureau of Labor Statistics (BLS) 2016b; Bureau of Labor Statistics (BLS) 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 4. The PPI data can be obtained from the BLS website (http://data.bls.gov/pdq/querytool.jsp?survey=wp).

Table 4 Bureau of Labor Statistics Producer Price Indexs relevant to the construction industry

Item code	Item name
058102	Asphalt
133301	Ready-mix concrete
1322	Cement, hydraulic
133	Concrete products

Item code	Item name
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 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" (Bureau of Labor Statistics (BLS) 2016d). The CPI is the most widely used measure of the inflation (BLS 2008). It is used as an economic indicator, as a deflator of other economic series, and as a measure of adjusting dollar values.

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 (Bureau of Labor Statistics (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 (Bureau of Labor Statistics (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 Insights

Global insights 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

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.

3 COMPASION OF HCCIS BETWEEN MDT AND NEIGHBORING STATES, AND EFFECTIVE PRACTICES

In this section, the HCCI values from neighboring state DOTs and the FHWA are compared and evaluated to identify correlations. After that, the effective practices of calculating and utilizing HCCIs are presented based on the findings from the literature review and the nationwide questionnaire survey.

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

In this section, MDT's HCCI values are compared with HCCIs from neighboring state DOTs and the 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 4. Both HCCIs are used for the comparisons. The HCCI data used for the analyses performed in this section are presented in Appendix F. 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. After that, 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 E.

3.1.1 HCCIs of Neighboring State DOTs

South Dakota DOT (SDDOT) and MDT have 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).

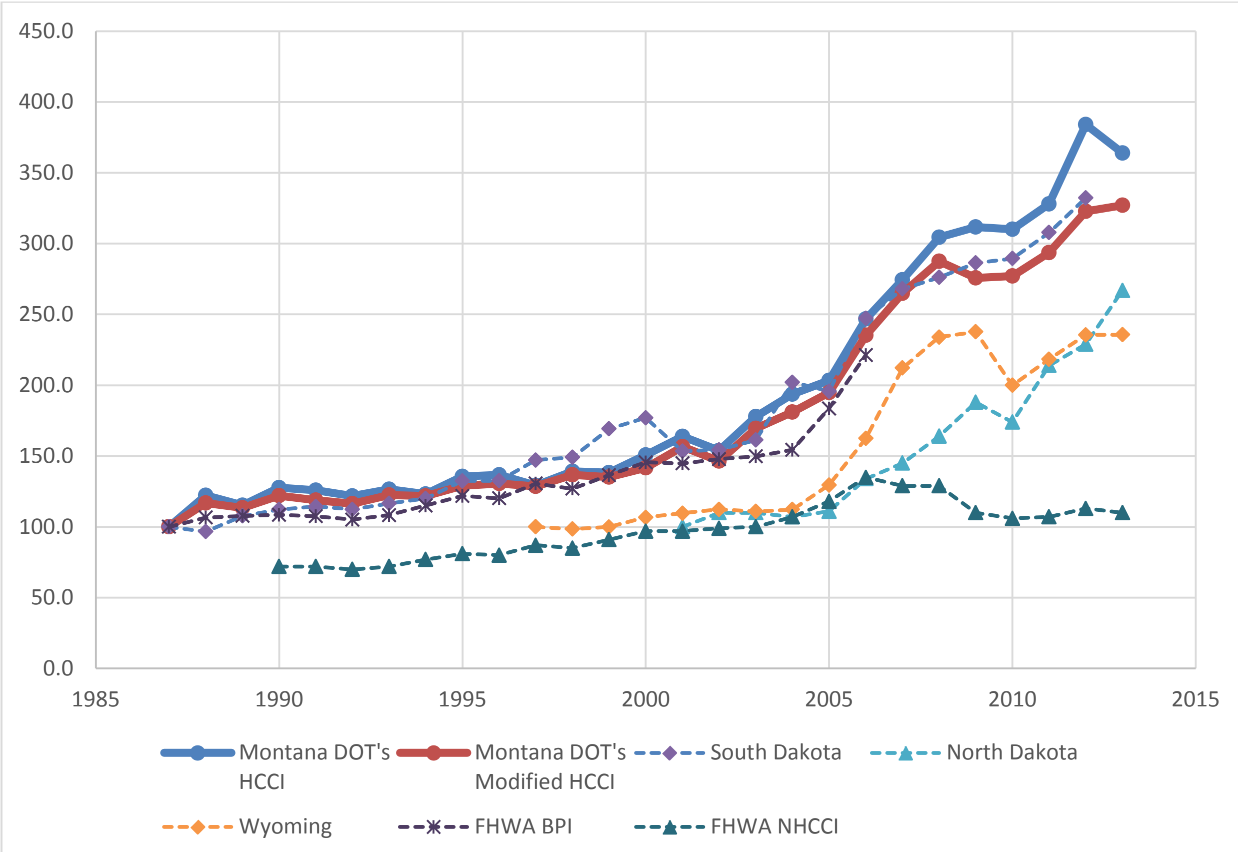

Figure 3 Comparison of HCCIs

3.1.2 Correlation Analysis

The results of the correlation analyses are presented in Table 5. Correlation coefficients measures the statistical relationship between two variables. Correlation coefficient can have values ranging from 0 to 1–higher values indicate 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 conditions changes in the next year in Montana. This analysis assumes that historical trends will continue in the future. However, 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 coefficient 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) and "MDT 1 year ahead" (correlation coefficients 0.98 and 0.98 for the original and modified MDT HCCIs). Thus, MDT HCCI can be predicted using SDDOT's previous years 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 the MDT's original HCCI trend is followed by North Dakota DOT HCCI with one and two year lags. Thus, MDT's original HCCIs can be used to predict the North Dakota HCCIs with one or two years' lag. The MDT HCCIs also follows the FHWA BPI trends with one and two year lags as indicated by the correlation coefficients of 0.97s and 0.95s for one and two year lags.

Statistically, this analysis result indicates that HCCI values and hence the effect of the regional construction market conditions are 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 cautions.

Table 5 Correlation coefficients of MDT HCCIs with other state DOT 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 BPI	0.96	0.97	0.97	0.97	0.95	0.95	0.94	0.95	0.94	0.95
FHWA NHCCI	0.75	0.79	0.81	0.84	0.83	0.86	0.68	0.72	0.64	0.66

3.2 Effective Practices of Calculating and Utilizing HCCIs

Several effective practices of calculating and utilizing HCCIs are observed from the literature review and the national survey. Those practices are summarized in this section.

3.2.1 Identifying Useful Bid Data

Bid data is readily available in an electronic format to calculate HCCIs. Although, it is better to use all (or as many data points as possible) is expected to produce a better HCCI, some data points should be removed for a variety of reasons. Four types of data that are generally removed before calculating HCCIs are presented below.

Lump-sum items. Lump sum items do not have a measurable relationship between quantities and prices. Same lump sum item such as mobilization can have a large difference even if the quantities are same (1). Thus, those items do not aid in analyzing the market conditions or in calculating HCCIs. Those items should be removed before calculating HCCIs.

Non-Design Bid Build Projects. The data from non-design-bid build projects such as emergency contracts and design built should be removed as it does not necessarily represent the current market conditions. For instance, in emergency contracts, the bids are likely to be higher than for the regular contracts.

Smaller Projects. DOTs removes data points from smaller projects as outliers as it can potentially create some bias. Smaller projects can possibly have higher prices because of "economies of scales," i.e. prices tend to be higher for items with lower quantities. For instance, MnDOT removes data from projects that are $100,000 or less and the FHWA removes data form projects that are $50,000 or less.

Statistic Outliers. To further improve bid data, further analysis can be conducted to remove outliers. For example, CDOT removes bid data outside 5 and 95 percentiles; the FHWA removes data that are more than two standard deviations from the mean price; and ODOT uses MAD to remove outliers.

3.2.2 Identifying Item Basket

As many items as possible should be included to calculate HCCIs. However, many DOTs are using Excel based method to calculate HCCIs manually. As such, they limit the number of items used to calculate HCCIs. The most frequent and high cost items are generally chosen by DOTs to identify important items for calculating HCCIs.

3.2.3 *Selecting the Price Index Formula*

State DOTs are using chained and unchained Fisher, Laspeyres, Paasche, and Young index formulas to calculate their HCCIs. The chained Fisher index is the best index formula from the list based on two approaches of evaluating the index formulas. It has been and is being adopted by the FHWA and several state DOTs. As such, adopting the Fisher index formula has an added advantage that the comparison of the HCCIs from MDT and other DOTs would be fairer and conclusions from the comparison can be made with more certainty. Further, in chained index, a market basket can be dynamic, i.e. all the items common in two consecutive periods can be used to calculate a HCCI rather than using a static list of items. This ensures that the items and quantities of the items in the item basket are recent and relevant to indicate the up to date market conditions.

3.2.4 *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.

3.2.5 *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.

3.2.6 *Two Stage Aggregation and Sub-HCCIs*

State DOTs generally calculates HCCIs in two stages. First, they calculate category level sub-HCCIs such as earthwork HCCI and structural steel HCCI. Then, those HCCIs are combined into an overall HCCI. This enables them to monitor the category specific market conditions as well as the overall market conditions. Couple state DOTs also calculate HCCIs for various regions within the state to observe the regional fluctuations in the market conditions.

3.2.7 *Automating HCCI Calculation*

HCCIs calculations are generally done in Excel by many state DOTs. Ohio DOT 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.

3.2.8 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.

3.2.9 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.

3.2.10 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.

4 REVIEW OF CURRENT MDT HCCI PROCESS

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

4.1 Current MDT Practices of Calculating MDT HCCI

MDT has developed an Excel based tool "MDT Master.xlsm" to calculate its HCCI. The HCCIs are calculated from year 1987 to 2013. This first step in calculating the MDT HCCI is to extract 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 categorized into 9 categories.

Over the years, MDT have added, removed, and replaced a number of items from the item basket to calculate HCCI. The total number of items increased over the time: 54 items are used in 1995 and 56 items are used in 1997. In 2013, the number of items increased to 71 items–35 of which are also used in 1987. Some of those items have different item numbers in 1987 and 2013 but fundamentally represent the same items as indicated by the item descriptions. The complete list of items used in 1987 and 2013 are presented in Appendix G. After the original base year, MDT has updated the base years in 1995, 1997, 2000, 2003, and 2006. The base year change in generally accompanied by changes in the item basket. However, the base year value is 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 in several stages. First, item price relatives are calculated which are combined to calculate category level HCCIs. Finally, the category level HCCIs are combined to generate 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 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 follows (International Labor Office (ILO) et al. 2004):

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

Where s_i is the weight calculated as the shares of expenditure of the item in an arbitrary period. The period can be anywhere from period *0* to period *t*. In case of the MDT HCCI, the weights are obtained from the current period.

$$s_i = \frac{p_{i,t} q_{i,t}}{\sum_{i=1}^{n} p_{i,t} q_{i,t}} \qquad \textbf{\textit{(11)}}$$

If the weights are taken from the base period instead of the current period, the Young index becomes Laspeyres index.

To calculate an overall HCCI, the price relatives ($p_{t,t}/p_{i,0}$) in the 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 item basket in 1998 and 2013 are presented in Table 6. Note that the weights of categories from 1987 are not used–the HCCI value for the year was assigned as 1.00 and the first calculated HCCI is for 1988.

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

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

The Excel file also calculates 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. It appears to be used to make the index uniform from the beginning (base year) to the date.

Table 6 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 MDT Technical Committee on Cost Estimation realized the importance of tracking the current market conditions using in-house and third-party HCCIs (MDT 2009). MDT understands the challenge of developing budget for long term financial planning and considers HCCIs as the tools that can be used 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 the HCCI obtained from other indexes presented in the figure. In Chapter 3, we also observed that the MDT have higher HCCI values compared to neighboring state DOT HCCIs as well as the national HCCIs.

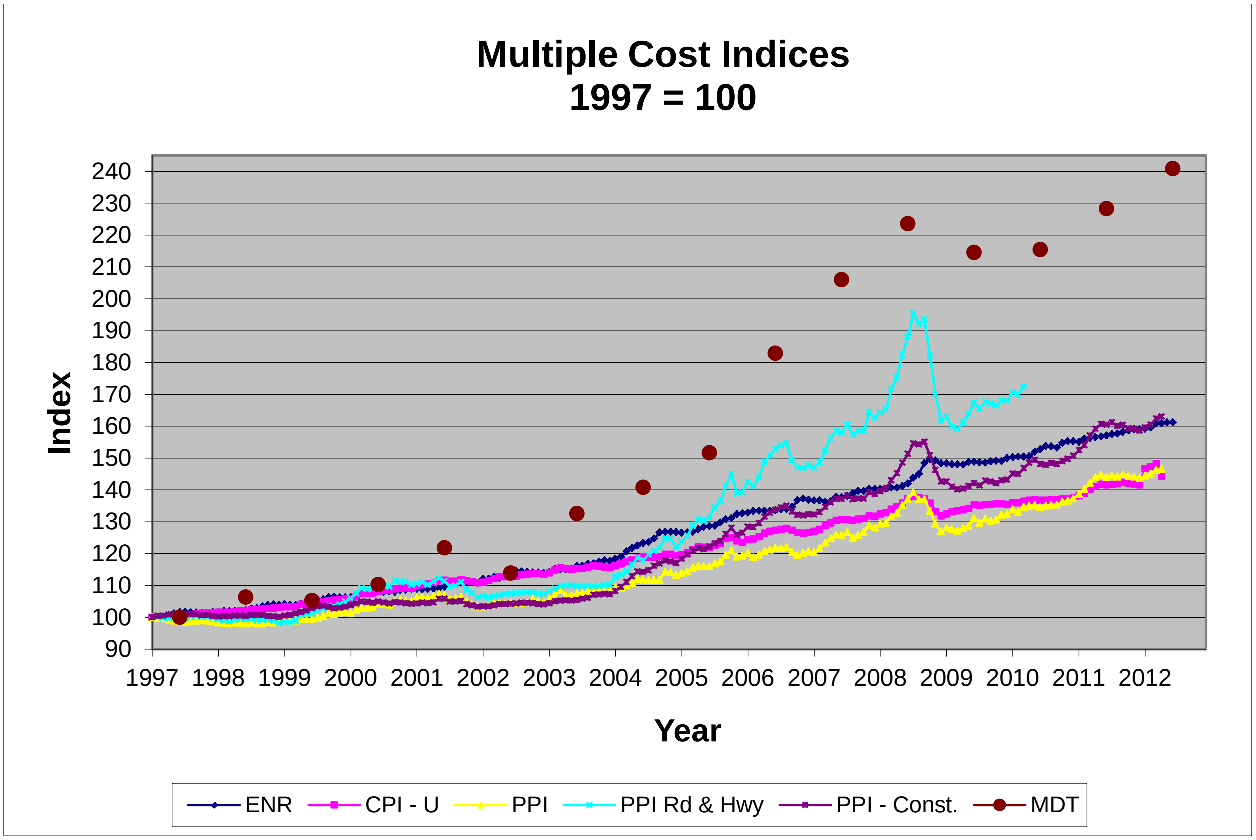

Figure 4 MDT HCCI vs other indexes

4.3 Available and Useful Data Attributes in MDT Systems

The researchers' vision is to develop multidimensional HCCIs with sub-HCCIs for project type, size, and location. The availability of data attributes in the MDT datasets that are necessary to develop an overall HCCI and sub-HCCIs are discussed in this Chapter. The research team reviewed 163 data attributes from MDT PPMS system and AASHTOWare SiteManager for their applicability in calculation of advanced HCCI. The important datasets containing those data attributes 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 H enlists an exhaustive list of data attributes available in MDT that are analyzed for this Chapter. The following sections present the results of the analyses, i.e. 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 the Figure 5. The dashed line shows indicate 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 projects can be included or excluded from the calculations as required.

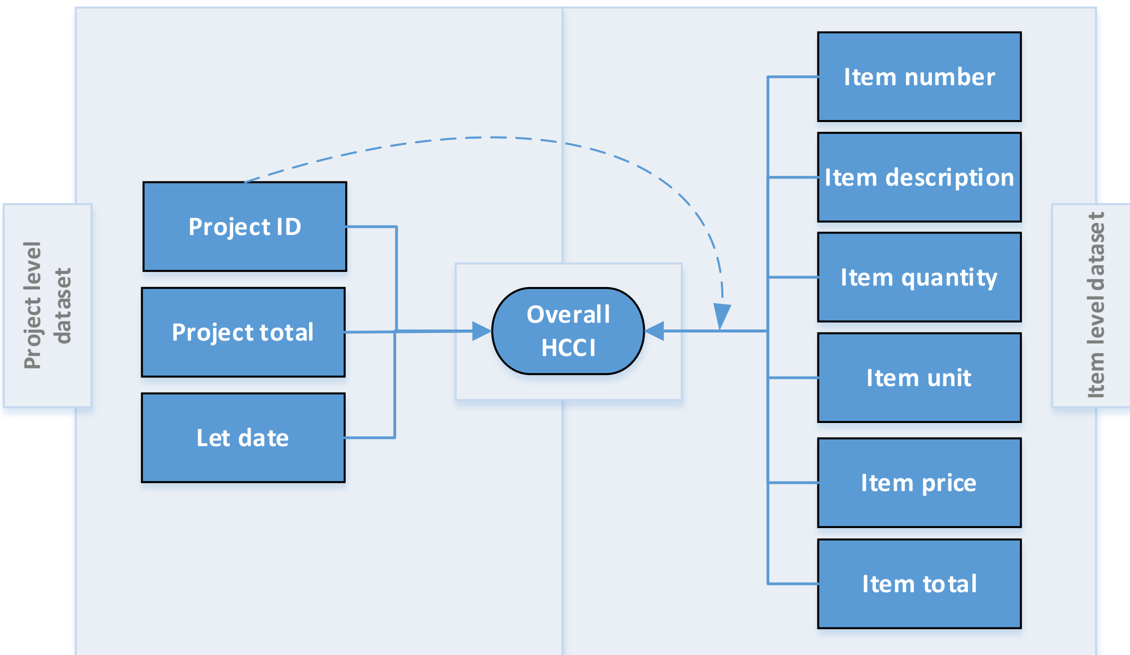

Figure 5 Project level and item level dataset required to calculate an overall HCCI

The project ID and project total are required if our methodology requires to exclude datasets from smaller projects 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 years can be isolated programmatically or manually to calculate the indexes. If desired, it can be used to further analyze the quarterly HCCIs.

4.3.2 Sub-HCCIs Calculations

The calculation of three-dimensional HCCIs required three additional data attributes as presented in Figure 6. The data attributes for location, project type classification, and size are available in the bid datasets provided by MDT.

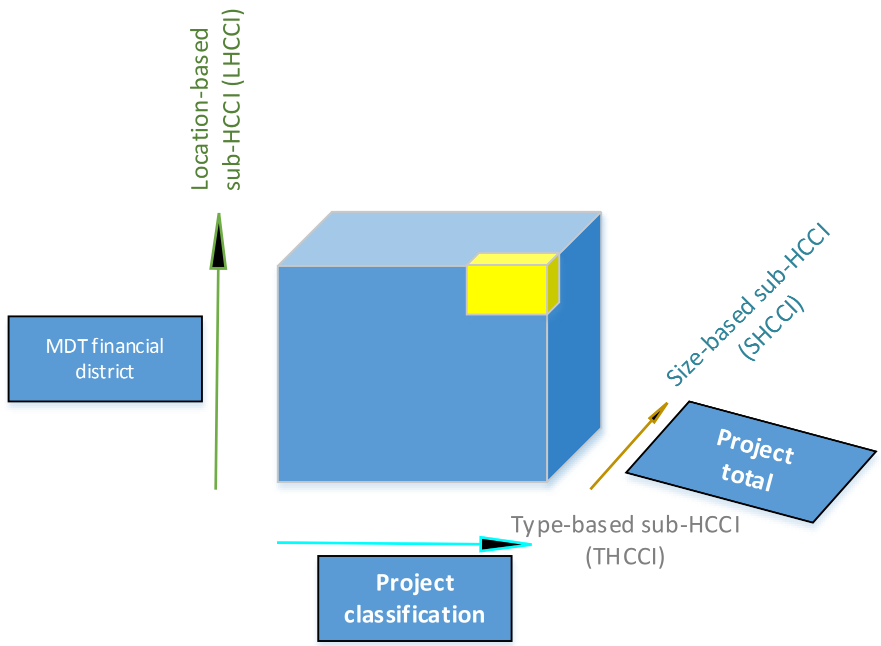

Figure 6 Data attributes required to calculate Sub-HCCIs

To calculate the size-based sub-HCCI (SHCCI), the project total construction cost data was 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. In Figure 7, the vertical axis represents the construction cost. The horizontal axis represents an arbitrary project serial number and does not have any significant. But, it eases the visualization of the unidimensional (cost) data points. Based on the analyses, the average projects have dollar values from $3,500,000 to $10,500,000. This constitutes of 15% of the projects. Smaller projects of $3,500,000 consists of 82% of the projects. Finally, larger projects that of or above $10,500,000 consist of 4% of the total projects.

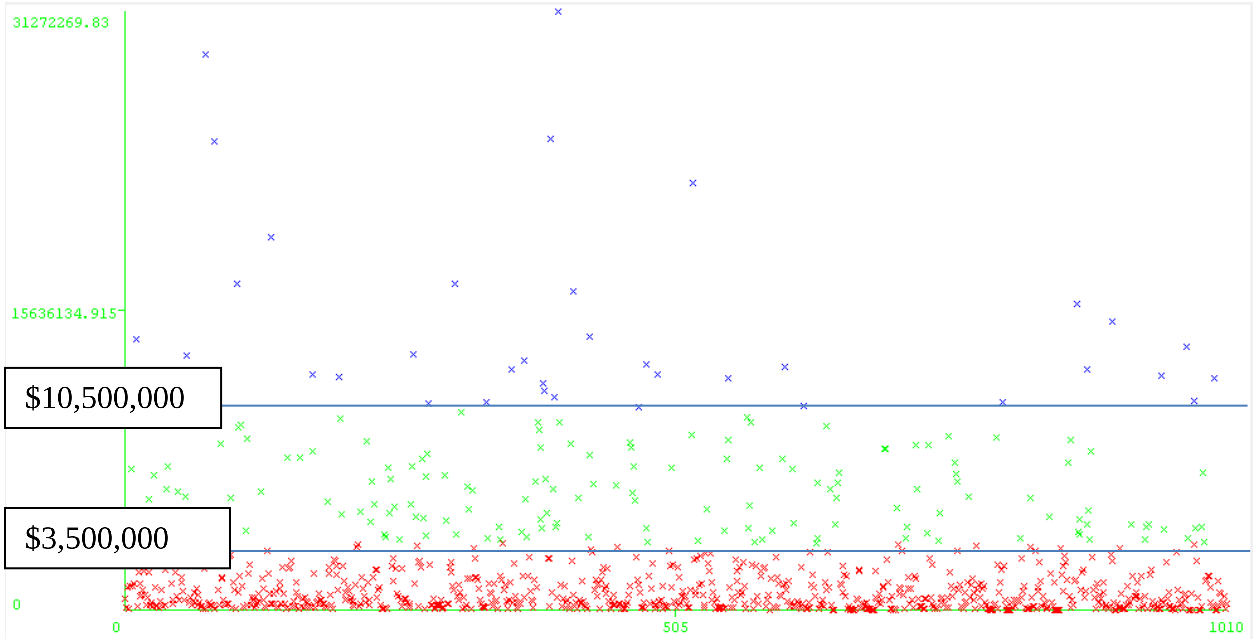

Figure 7 Clustering of projects based on construction cost data

To calculate the location-based sub-HCCI (LHCCI), several alternatives are available. MDT have divided the state into financial districts, maintenance districts, administrative & construction districts, and counties. The counties for each project is listed in the bid dataset. The county border and financial district borders overlaps. Thus, the financial districts can be generated for each project. However, after the meeting with MDT in Feb 2016, the administrative & construction district was considered to be better location divisions for LHCCI calculation. The administrative & construction district borders do not overlap perfectly with the county borders (Figure 8). In the figure, the bold lines represent administrative & construction district borders; the faint lines represent county borders. Based on the location, 5 LHCCIs will be developed. The dataset also includes a data attribute titled “admin_dists” that represents the administrative & construction districts.

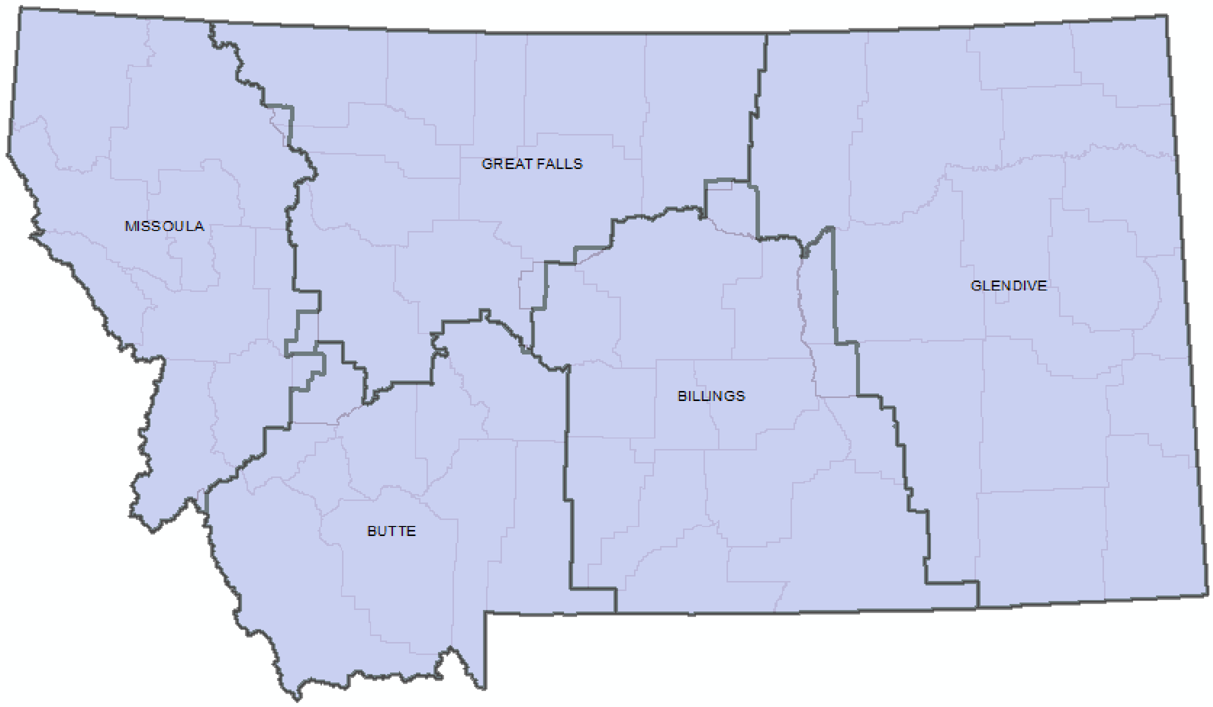

Figure 8 Administrative & construction district and county borders

For type-based classification, two options are available: one based on project work type and another based on the high level work type. The project work type contains 28 different types of bid items. As the list is very large and MDT is expected to have relatively smaller bid data size compared to other state DOTs, the research team recommends project classification based on work type. The 7 project classification under this system are construction, resurfacing, bridge, spot improvement, miscellaneous, and facilities. The details of those data attributes are presented in Appendix H.

A traditional category level HCCI can be generated by the state MDT. Some other state DOTs are already using it. The categories can be taken from the MDT's specification manual, the bid item type can possibly be adopted to 9 categories, or it can be calculated for 32 sub-HCCIs.

Finally, the research team also obtained several MDT GIS datasets including MDT district boundaries and routes. Those datasets can be used to visualize the highway construction market trend in Montana.

4.4 Summary

This chapter reviewed current MDT HCCI processes and available data. The datasets obtained by the research team contains all required data for the advanced HCCI calculation for the MDT.

The existing project type, location, and project size classifications will be used for the multidimensional HCCI calculation. A comprehensive database is developed by compiling all the useful data obtained from the MDT. A software system is being developed to automate the HCCI calculation process.

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APPENDIX A QUESTIONNAIRE USED FOR THE 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,

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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 conducted in summer 2015. The findings of the survey confirm the findings of the literature review. In order to reduce repetition in the main report, the results of the survey are presented in this appendix.

Thirty-four state DOT representatives and a FHWA (DC) representative responded to the questionnaire, i.e. 67% response rate (Figure 9). 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.

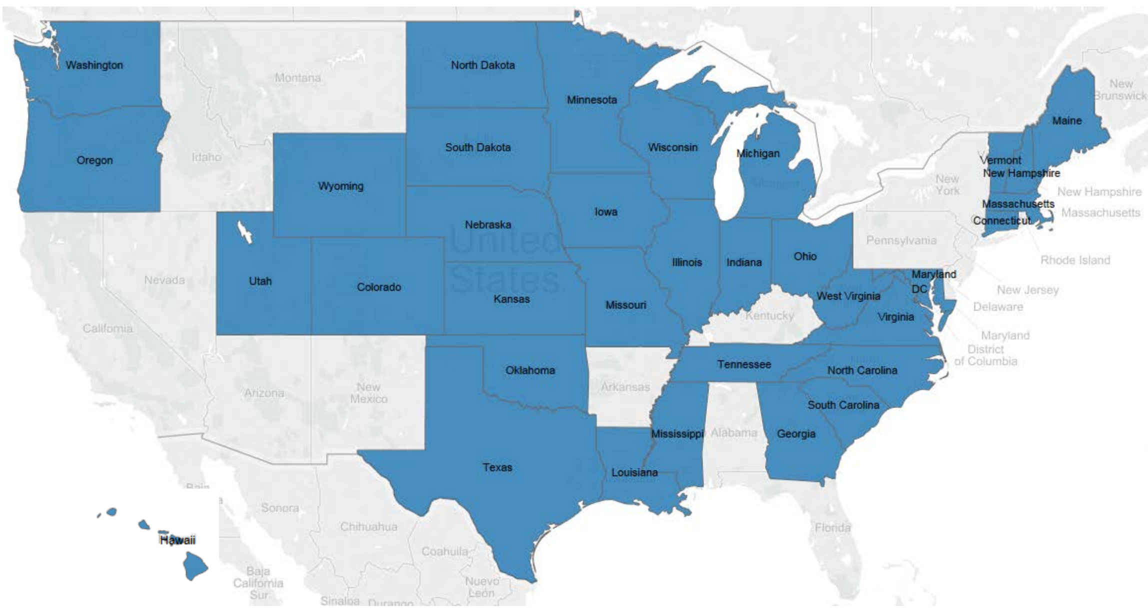

Figure 9 State DOTs that responded to questionnaire survey

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 10). 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.

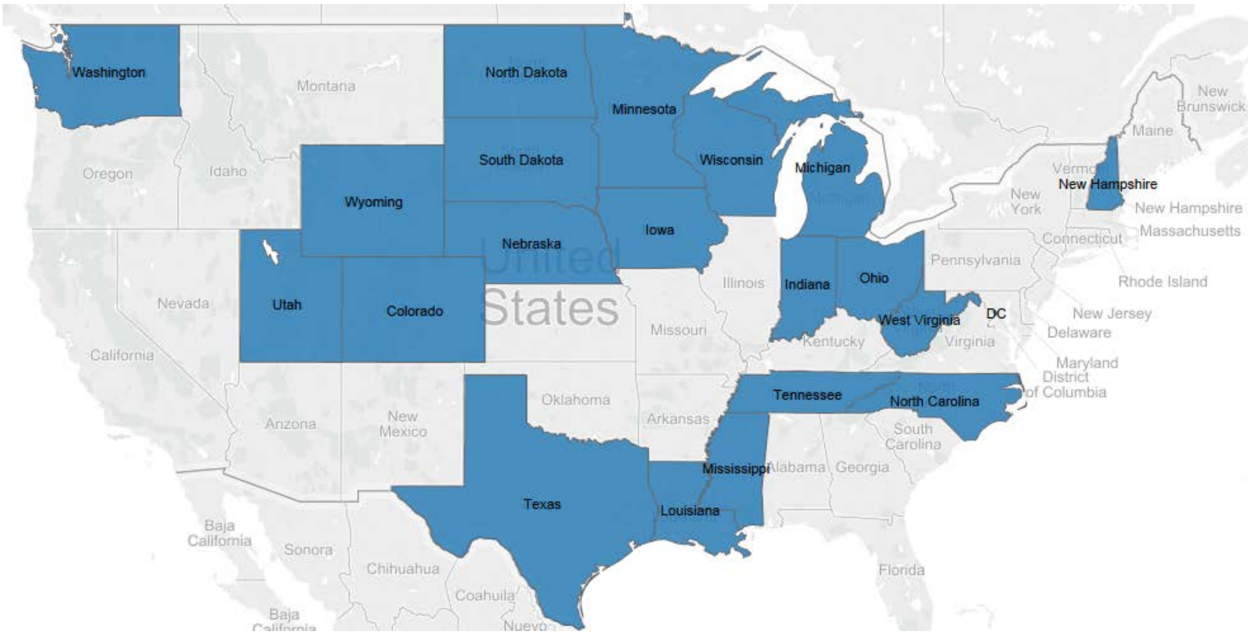

Figure 10 State DOTs that calculate HCCIs

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 11). 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.

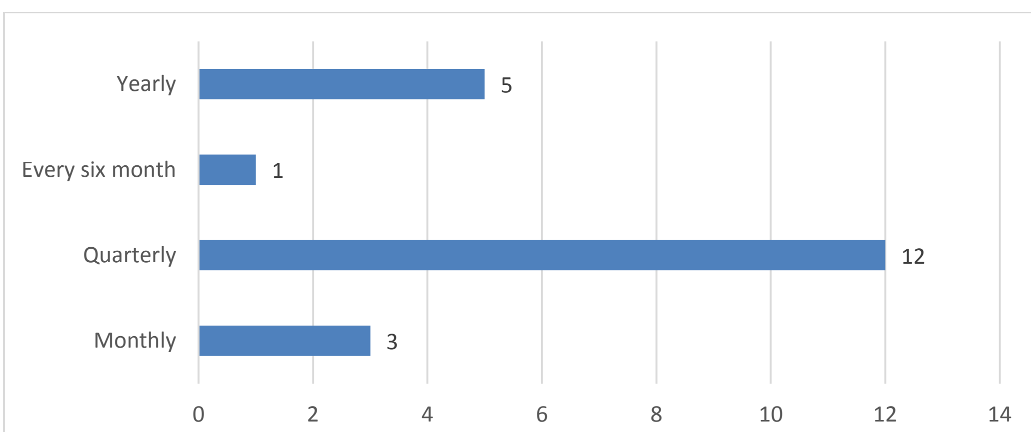

Figure 11 Frequency of calculating HCCIs

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 12). 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. Ohio DOT 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.

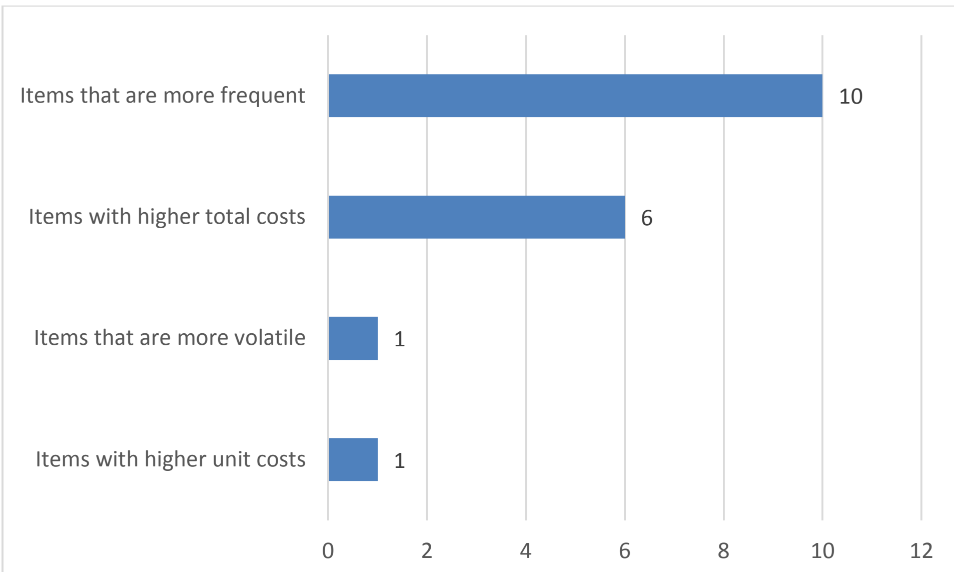

Figure 12 Item identification for HCCI

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; 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 13). 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.

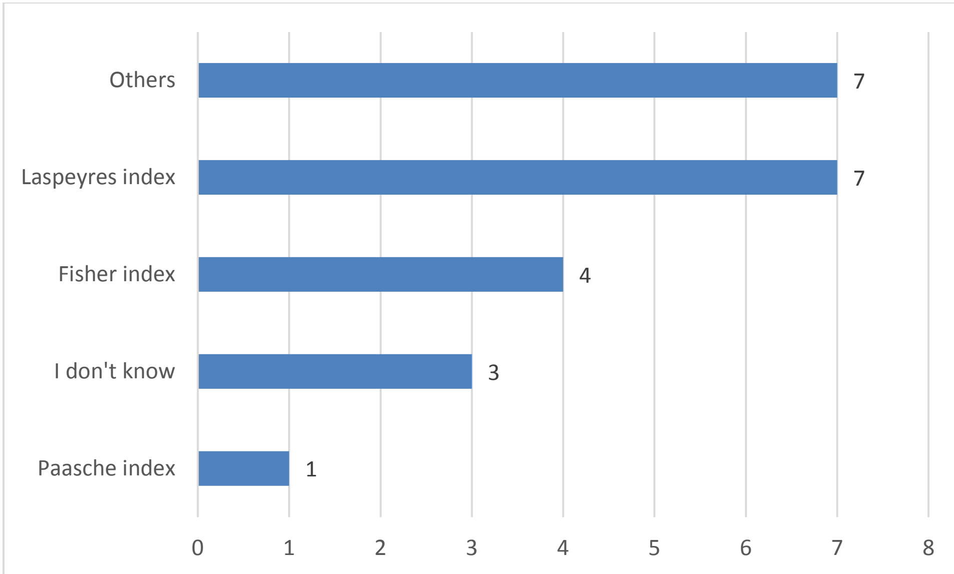

Figure 13 Indexing formulas used by state DOTs

Four states indicated that they use chained HCCIs and four others stated they are using a non-chained HCCIs (Figure 14). Ten state DOT representatives did not know whether they are using a chained index or non-chained HCCIs.

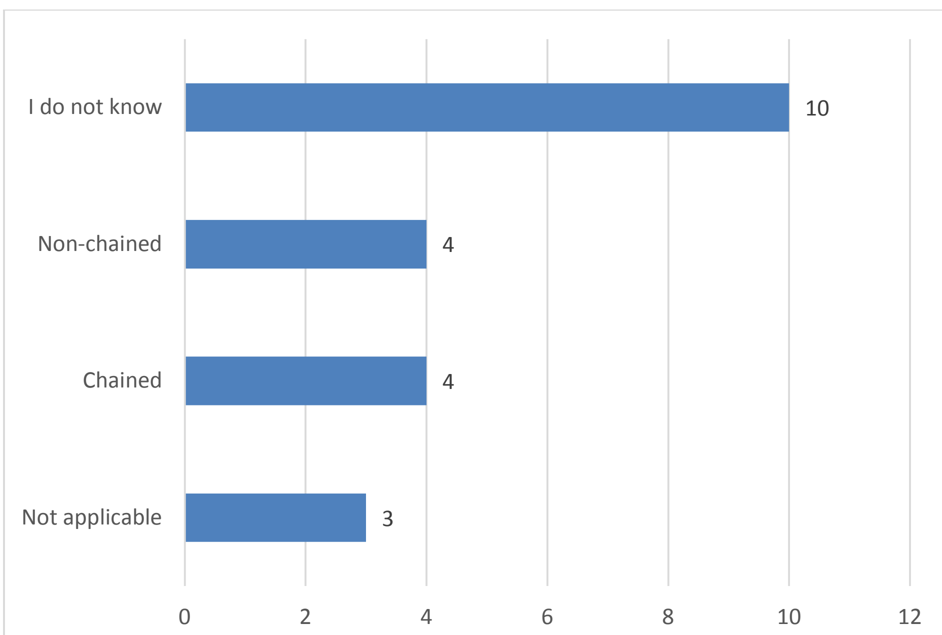

Figure 14 Chaining of indexes

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 extent. The National Highway Construction Cost Index (NHCCI) is the most popular third party HCCI (Figure 15). 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.

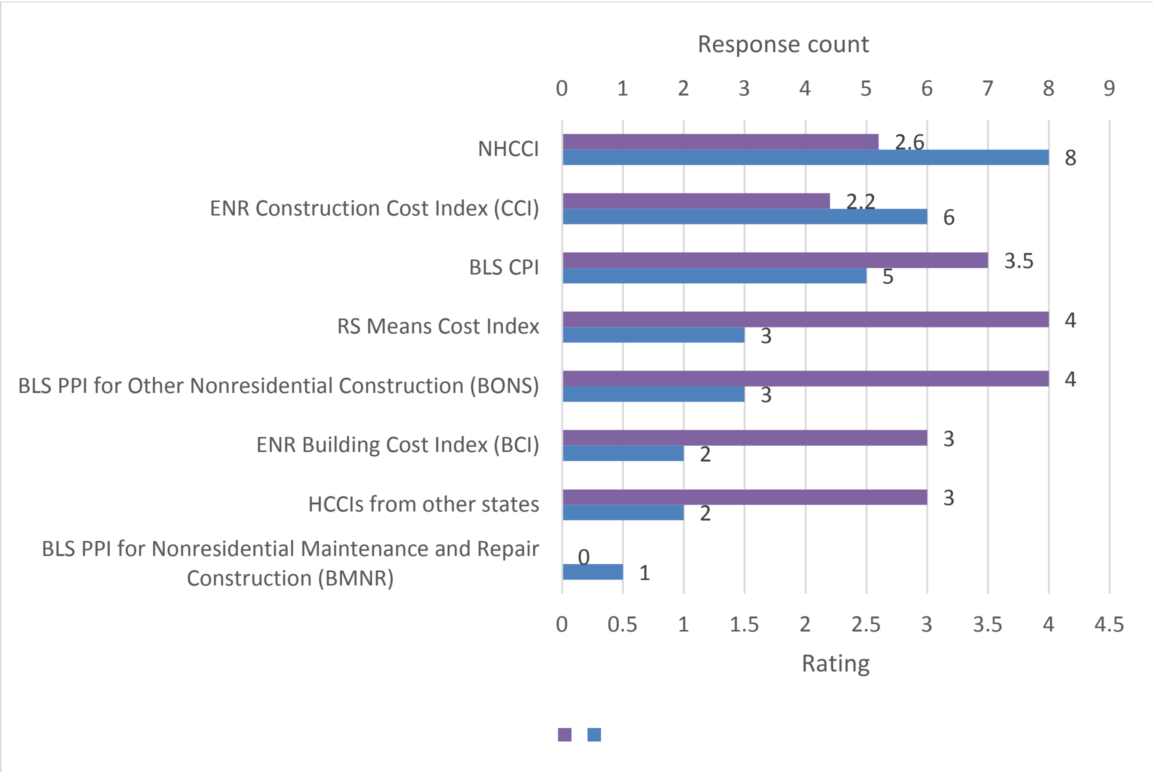

Figure 15 Various indexes being monitored and their relevance

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 16). 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.

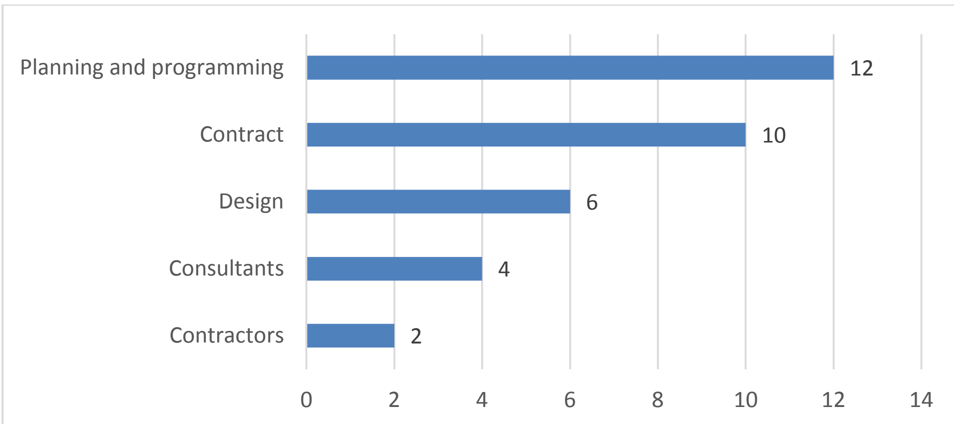

Figure 16 Current users of HCCIs

Use of HCCIs

State DOTs use their HCCIs for multiple purposes (Figure 17). 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 have 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.

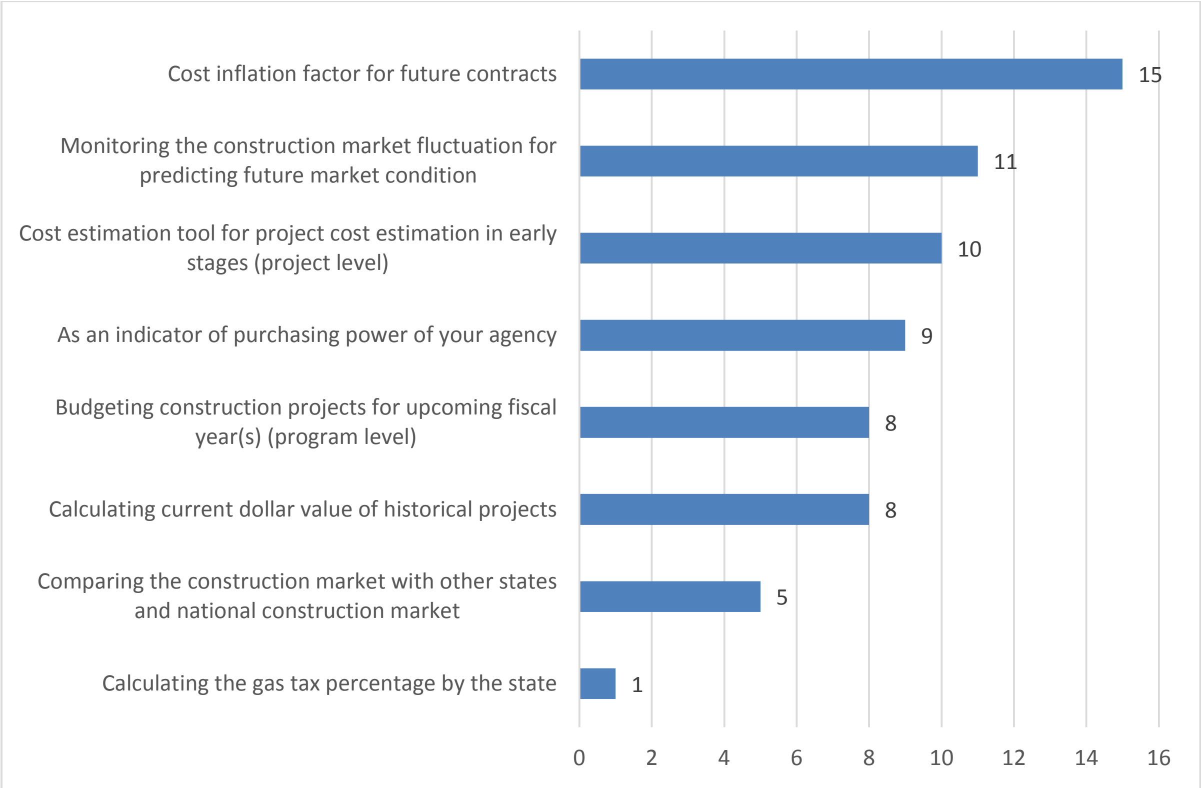

Figure 17 Current uses of HCCIs

State DOTs use third party HCCIs mostly as an indicator of an overall market condition (Figure 18). Five respondents reported that their agencies use third party HCCIs for side-by-side comparison with their in-house HCCI. Two respondents stated that their agency relies on third party HCCIs to determine an inflation rate for their construction projects.

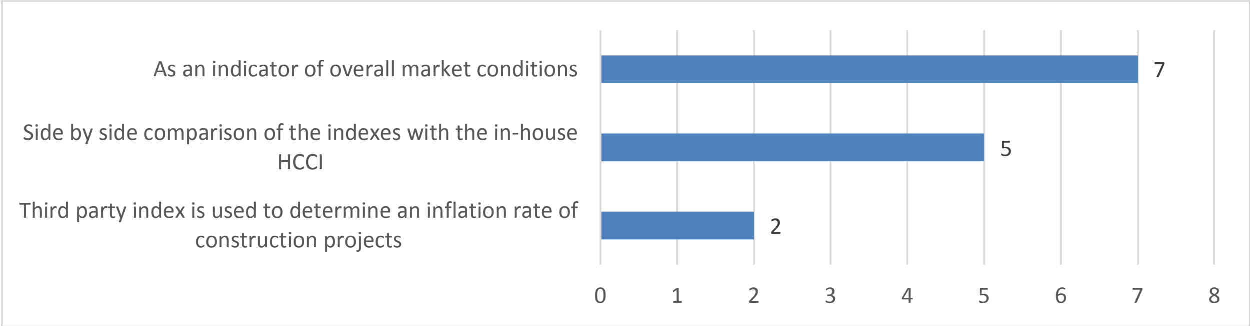

Figure 18 Current uses of third party HCCIs

Other Findings

A survey respondent noted that the costs of major items are 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 bidding 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 below. Equal weight is given to the relative quantities in both periods by using a geometric rather than an arithmetic mean.

$$\text{Walsh index}, W = \frac{\sum_{i=1}^{n} p_{i,t}\sqrt{q_{i,0}q_{i,t}}}{\sum_{i=1}^{n} p_{i,0}\sqrt{q_{i,0}q_{i,t}}} \quad \textbf{\textit{(12)}}$$

The superlative indexes such as Fisher index and 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; International Labor Office (ILO) et al. 2004).

Young index is calculated as the weighted arithmetic average of the individual price relatives (International Labor Office (ILO) et al. 2004).

$$\text{Young index}, Y = \sum_{i=1}^{n} s_i \left(\frac{p_{i,t}}{p_{i,0}}\right) \quad \textbf{\textit{(13)}}$$

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

$$s_i = \frac{p_i q_i}{\sum_{i=1}^{n} p_i q_i} \quad \textbf{\textit{(14)}}$$

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 below (International Labor Office (ILO) et al. 2004).

$$\text{Törnqvist index}, T = \prod_{i=1}^{n} \left(\frac{p_{i,t}}{p_{i,0}}\right)^{\sigma_i} \quad \textbf{\textit{(15)}}$$

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

$$\sigma_i = \frac{1}{2}\left[\frac{p_{i,0}\ q_{i,0}}{\sum_{j=1}^{n}(p_{j,0}\ q_{j,0})} + \frac{p_{i,t}\ q_{i,t}}{\sum_{j=1}^{n}(p_{j,t}\ q_{j,t})}\right] \quad \textbf{\textit{(16)}}$$

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

$$V(t) = \sum_{i=1}^{n} p_i(t)\ \ q_i(t) \tag{17}$$

The Divisia index can be obtained by differentiating the expenditure with respect to time:

$$V'(t) = \sum_{i=1}^{n} p_i{}'(t)\ \ q_i(t) + \sum_{i=1}^{n} p_i(t)\ \ q_i{}'(t) \tag{18}$$

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 owners' perspective. Thus, Divisia index can be considered a theoretical index which has less practical value.

APPENDIX D AXIOMATIC AND ECONOMIC THEORY APPROACHES TO EVALUATE PRICE INDEX FORMULAS

Price index formulas can be evaluated from two major perspectives: axiomatic or test approach and economic theory approach (Oulton 2006). In the *axiomatic approach*, the price index formulas are tested for having reasonable properties. Price and quantity are considered to be independent variables. IMF (2010) presents 20 axiomatic tests grouped under 5 categories (Table 7). Those tests are called the first axiomatic tests. The objectives of each category of tests are presented in Table 8.

In Table 7, P or $P(p_0, p_t, q_0, q_t)$ represents the price index formula as a function of prices and quantities of items in the base period (p_0 and q_0) and the current period (p_t and q_t). For some tests, prices or quantities in the two periods are assumed to remain constant; in those scenarios $p_0 = p_t = p$ or $q_0 = q_t = q$ are used. The term quantity index–used in price reversal test, mean value test for quantities, monotonicity in current quantities, and monotonicity in base quantities–indicates the price index obtained by interchanging the quantities and prices.

Table 7 Axiomatic approach to evaluating price index formulas

SN	Category	Test	Description
1	General tests	Positivity	P is always a positive number. i.e., $P > 0$
2		Continuity	P is a continuous function.
3		Identity or constant price	If the prices of all items remain same during the two periods, the value of the price index should be 1. i.e. $P(p, p, q_0, q_t) = 1$
4		Fixed basket or constant quantities test	If the quantities of all items are same during the two periods, the price index should equal to the expenditure in the current period divided by the expenditure in the base period. i.e. $P(p_0, p_t, q, q) = (\sum p_{i,t} * q_{i,t}) / (\sum p_{i,0} * q_{i,0})$
5	Homogeneity tests	Proportionality in current prices	If the prices of all items in the current period are multiplied by a positive number λ, the new price index should be λ times the original index. i.e. $P(p_0, \boldsymbol{\lambda} * p_t, q_0, q_t) = \boldsymbol{\lambda} * P(p_0, p_t, q_0, q_t)$ for $\lambda > 0$
6		Inverse Proportionality in base period prices	If the prices of all items in the base year are multiplied by a positive number λ, the new index should be 1/ λ times the original price index. i.e. $P(\boldsymbol{\lambda} * p_0, p_t, q_0, q_t) = \boldsymbol{\lambda}^{-1} * P(p_0, p_t, q_0, q_t)$ for $\lambda > 0$
7		Invariance to proportional changes in current quantities	If the quantities of all the items in the current period are multiplied by λ, the price index should remain unchanged. i.e. $P(p_0, p_t, q_0, \boldsymbol{\lambda} * q_t) = P(p_0, p_t, q_0, q_t)$ for $\lambda > 0$

SN	Category	Test	Description
8		Invariance to proportional changes in base quantities	If the quantities of all items in the base period are multiplied by λ, the price index should remain unchanged. i.e. $P(p_0, p_t, \lambda*q_0, q_t) = P(p_0, p_t, q_0, q_t)$ for $\lambda > 0$
9	Invariance and symmetry tests	Commodity reversal tests	If the order of the items are changed in both the base period and the current period in a same manner, the resulting price index should remain same. i.e. $P(p_0^*, p_t^*, q_0^*, q_t^*) = P(p_0, p_t, q_0, q_t)$ where $p_0^*, p_t^*, q_0^*\ q_t^*$ are the rearranged p_0, p_t, q_0, q_t in the same order.
10		Invariance to changes in the units of measurement (Commensurability test	If the units of measurements are changed, the price index should remain same.
11		Time reversal test	If the base period and the current period data are interchanged, the resulting price index should be the reciprocal of the original price index. i.e. $P(p_0, p_t, q_0, q_t) = 1/P(p_t, p_0, q_t, q_0)$
12		Quantity reversal test	If the quantities of two periods are interchanged, the resulting price index should remain same. i.e. $P(p_0, p_t, q_0, q_t) = P(p_0, p_t, q_t, q_0)$
13		Price reversal test	If the prices of two periods are interchanged, the resulting quantity index (prices and quantities are interchanged in the formula–it is not equal to the price index) should remain same. i.e. $[(\sum p_{i,t},q_{i,t})/ (\sum p_{i,0},q_{i,0})]/ P(p_0, p_t, q_0, q_t) = [(\sum p_{i,0}*q_{i,t})/ (\sum p_{i,t}*q_{i,0})]/ P(p_t, p_0, q_0, q_t)$
14	Mean value tests	Mean value test for prices	Price index should lie between the minimum and maximum price relatives (p_t/p_0) of individual items. Minimum of $[p_{t,1}/p_{0,1}, p_{t,2}/p_{0,2},\ldots\ldots\ldots\ldots, p_{t,n}/p_{0,n}]$ $\leq P(p_0, p_t, q_0, q_t)$

SN	Category	Test	Description
			$\leq$ maximum of $[p_{t,1}/p_{0,1}, p_{t,2}/p_{0,2},\ldots\ldots\ldots, p_{t,n}/p_{0,n}]$
15		Mean value test for quantities	Quantity index (not price index) should lie between the minimum and maximum quantity relatives (q_t/q_0) of individual items. Minimum of $[q_{t,1}/q_{0,1}, q_{t,2}/q_{0,2},\ldots\ldots\ldots, q_{t,n}/q_{0,n}]$ $\leq [(\sum p_{i,t}*q_{i,t})/ (\sum p_{i,0}*q_{i,0})]/P(p_0, p_t, q_0, q_t)$ $\leq$ maximum of $[q_{t,1}/q_{0,1}, q_{t,2}/q_{0,2},\ldots\ldots\ldots, q_{t,n}/q_{0,n}]$
16		Paasche and Laspeyres bounding test	The price index P should lie between the Laspeyres and Paasche index.
17	Monotonicity tests	Monotonicity in current prices	If the price of items in the current period increases, the price index must increase. i.e. $P(p_0, p_{t1}, q_0, q_t) < P(p_0, p_{t2}, q_0, q_t)$ if $p_{t1} < p_{t2}$
18		Monotonicity in base prices	If the price of items in the base period increases, the price index must decrease. i.e. $P(p_{01}, p_t, q_0, q_t) > P(p_{02}, p_t, q_0, q_t)$ if $p_{01} < p_{02}$
19		Monotonicity in current quantities	If the current period quantity increases, the quantity index (not price index) must increase. i.e. $[(\sum p_{i,t}*q_{i,t})/ (\sum p_{i,0}*q_{i,0})]/P(p_0, p_t, q_0, q_{t1}) < [(\sum p_{i,t}*q_{i,t})/ (\sum p_{i,0}*q_{i,0})]/P(p_0, p_t, q_0, q_{t2})$ if $q_{t1} < q_{t2}$
20		Monotonicity in base quantities	If the base period quantity increases, the quantity index (not price index) must decrease. i.e. $[(\sum p_{i,t}*q_{i,t})/ (\sum p_{i,0}*q_{i,01})]/P(p_0, p_t, q_{01}, q_{t1}) < [(\sum p_{i,t}*q_{i,t})/ (\sum p_{i,0}*q_{i,02})]/P(p_0, p_t, q_{02}, q_t)$ if $q_{01} < q_{02}$

Table 8 Objectives of axiomatic approach test categories

Axiomatic approach test category	Objectives
General tests	General tests that do not fall under other categories
Homogeneity tests	Test the behavior of price index as the scale of variables (price or quantity) change
Invariance and symmetry tests	Test the behavior of the price indexes when variables are interchanged
Mean value tests	Test if the price index lies between certain bounds
Monotonicity tests	Test how the change in the price or quantity is reflected in the price index.

Table 9 lists the performances of all five price index formulas. The Fisher index is the best from the axiomatic perspectives as it satisfies all 20 tests. The Laspeyres and Paasche indexes fail three tests, Walsh index fails four tests, and Törnqvist fails nine tests. The failure to satisfy the time reversal test is considered to be a major drawback of both Laspeyres and Paasche indexes.

In addition to the first axiomatic tests presented in the Table 7, there are many other tests under the second axiomatic tests. The factor reversal test is one of the most important second axiomatic tests. It states that the product of the price index and quantity index should be identical to the ratio of the total expenditure between the current period and the base period. The Laspeyres and Paasche indexes fail to satisfy this test while the Fisher index satisfies this test. The Fisher index is also called an "ideal index" as it satisfies all the axiomatic tests presented above, uses a symmetric average (geometric mean) of the Laspeyres and Paasche indexes, and uses the quantities from both the current period and the base period."

Table 9 Performances of price index formulas in axiomatic approach tests

Indexing formula	Axiomatic approach test results
Fisher index	Satisfies all 20 tests
Laspeyres index	Fails 3 tests: • Time reversal test • Quantity reversal test • Price reversal test
Paasche index	Fails 3 tests: • Time reversal test • Quantity reversal test • Price reversal test

Walsh index	Fails 4 tests: • Price reversal test • Paasche and Laspeyres bounding test • Monotonicity in current quantities • Monotonicity in base quantities
Törnqvist index	Fails 9 tests: • Fixed basket or constant quantities test • Quantity reversal test • Price reversal test • Mean value test for quantities • Paasche and Laspeyres bounding test • Monotonicity in current prices • Monotonicity in base prices • Monotonicity in current quantities • Monotonicity in base quantities

In the *economic theory approach*, the quantities are assumed to be the functions of prices. When prices of certain items increase, utility-maximizing consumers would reduce the quantities of those items and substitute them with cheaper alternatives to have the same level of utility. In the Laspeyres index, the reductions in quantities of such items are not considered as it only considers the base period quantities. Thus, if the economic capacity of the consumer is increased as much as the value of the Laspeyres index, the consumer will be able to obtain a higher level of utility. Thus, the Laspeyres index overestimates the true price index while the Paasche index understates it by similar reasons. The index that captures the notion of this true price index is termed as a superlative index (Oulton 2006; Diewert 1976). Superlative indexes treat prices and quantities of both the current period and the base period symmetrically. The Fisher, Walsh, and Törnqvist indexes are the examples of a superlative index (IMF 2010). Those superlative indexes are among the best from the economic theory approach (IMF 2010).

Thus, the Fisher index is the best from axiomatic approach and is among the best from the economic theory approach. Overall, the Fisher index can be considered the best price index formula.

APPENDIX E 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

$$Correlation\ coefficient\ (r) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \qquad \textbf{\textit{(19)}}$$

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 10.

Table 10 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 F STATE DOT HCCI VALUES

Table 11 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 G BID ITEMS USED IN MDT HCCI CALCULATION

The items used under each category in 2013 and 1987 are presented in Table 12. 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 12 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 13 lists four items replaced in 2013 for calculating MDT HCCI. The item numbers as well as the item descriptions are changed in 2013.

Table 13 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 H AVAILABLE DATASETS AND DATA ATTRIBUTES

Table 14 lists the bid data attributes available in research_bidder_info_ii_v2_042715.xlsx file.

Table 14 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	

Bob 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 15 lists the 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 15 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 16 and Table 17. 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 few select categories will be used to calculate the sub-indexes. For HCCI calculation, the design build (DB) projects and corresponding items will be removed.

Table 16 Bid item classes

SN	Item class	Item class description

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 17 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 18.

Table 18 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 to 28 categories based on the work types, which can also be used in developing project type specific indexes. The list of MDT work types are presented in Table 19.

Table 19 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 & 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 & 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 to 40 categories based on the work types are presented in Table 20.

Table 20 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 & 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 & Rehab – PCCP 172 Restoration & 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 & 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 & Roadside Safety Improvements 311 Railroad/Highway Crossing Safety Improvements 312 Structure Safety **Miscellaneous** 313 Pedestrian & Bicycle Safety 410 Traffic Signals & Lighting 411 Signing, Pavement Markings, Chevrons, Etc.. 412 Miscellaneous Electronic Monitoring or Information Services 510 Environmental 520 Landscaping, Beautification 610 Maintenance Stockpiles 620 Bicycle & Pedestrian Facilities 660 Historic Preservation 710 Pedestrian and Bicycle Facilities CTEP **Facilities** 111 New Construction – Facilities