8-2017

Multidimensional Highway Construction Cost Indexes Using Dynamic Item Basket

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Abstract

A highway construction cost index (HCCI) is an indicator of the purchasing power of a highway agency. Thus, it must reflect the actual construction market conditions. However, current methods used by most state departments of transportation are not robust enough to meet this primary goal due to (1) a significantly insufficient sample size of bid items used in HCCI calculation; and (2) inability to address the need to track highway construction market conditions in specific submarket segments such as, but not limited to, various project types, sizes, and locations. This study proposes an advanced methodology to overcome these apparent limitations using two new concepts: (1) dynamic item basket; and (2) multidimensional HCCIs. The dynamic item basket process identifies and utilizes an optimum amount of bid-item data to calculate HCCIs in order to minimize the potential error due to a small sample size, which leads to a better reflection of the current market conditions. Multidimensional HCCIs dissect the state highway construction market into distinctively smaller sectors of interest and thus, allow state Departments of Transportation to understand the market conditions with much higher granularity. A framework is developed to integrate these two concepts and a standalone prototype system, named the Dyna-Mu-HCCI System, is developed to automate the data-processing part of the framework. The historical bid data of the Montana Department of Transportation are used to evaluate the performance of the Dyna-Mu-HCCI System and measure the effects of the dynamic item basket (DIB) and multidimensional HCCIs. The results show an eightfold increase in terms of the number of bid items used in calculating HCCIs and at least a 20% increase in terms of the total cost of bid items used. In addition, the multidimensional HCCIs reveal different cost-change patterns from different highway sectors. For example, the bridge construction market historically shows a very different trend compared with the overall highway construction market. The new methodology is expected to aid state Departments of Transportation in making more-reliable decisions in preparing business plans and budgets with more accurate and detailed information about the construction market conditions. Further, the prototype Dyna-Mu-HCCI System is expected to significantly facilitate the HCCI calculation process and rapidly implement this new system.

Keywords

Highway Construction Cost Index (HCCI), Inflation, Dynamic Construction Item Basket, Multidimensional HCCI, Construction Market Basket, Construction Market Conditions, Planning and Budgeting

Disciplines

Civil Engineering | Construction Engineering and Management | Transportation Engineering

Comments

This is a manuscript of an article published as Shrestha, K. Joseph, H. David Jeong, and Douglas D. Gransberg. "Multidimensional Highway Construction Cost Indexes Using Dynamic Item Basket." *Journal of Construction Engineering and Management* 143, no. 8 (2017): 04017036. DOI: 10.1061/(ASCE)CO.1943-7862.0001307. Posted with permission.

Final Manuscipt:
Shrestha, K.J., Jeong, H.D., and Gransberg, D.D., "Multidimensional Highway Construction Cost Indexes Using Dynamic Item Basket," *Journal of Construction Engineering and Management,* ASCE, Vol. 143 (8), August 2017.

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ABSTRACT

A Highway Construction Cost Index (HCCI) is an indicator of the purchasing power of a highway agency. Thus, it must reflect the actual construction market conditions. However, current methods used by most state departments of transportation are not robust enough to meet this primary goal due to a) a significantly insufficient sample size of bid items used in HCCI calculation and b) inability to address the need to track highway construction market conditions in specific sub-market segments in terms of project type, size and location. This study proposes an advanced methodology to overcome these apparent limitations using two new concepts: a) dynamic item basket and b) multidimensional HCCIs. The dynamic item basket process identifies and utilizes an optimum number of bid item data to calculate HCCIs in order to minimize the potential error due to a small sample size, which leads to a better reflection of the current market conditions. Multidimensional HCCIs dissect the state highway construction market into distinctively smaller sectors of interest and thus, allow state departments of transportation to understand the market conditions with much higher granularity. A framework is developed to integrate these two concepts and a standalone prototype system, namely, Dyna-Mu-

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HCCI System is developed to automate the data processing part of the framework.

The historical bid data of the Montana Department of Transportation is used to evaluate the performance of the Dyna-Mu-HCCI System and measure the effects of the DIB and multidimensional HCCIs. The results show an eight-fold increase in terms of the number of bid items used in calculating HCCIs and at least 20% increase in terms of the total cost of bid items used. In addition, the multidimensional HCCIs reveal different cost change patterns from different highway sectors. For example, the bridge construction market historically shows a very different trend compared with the overall highway construction market.

The new methodology is expected to aid state departments of transportation in making more reliable decisions on preparing business plans and budgets with more accurate and detailed information about the construction market conditions. Further, the prototype, Dyna-Mu-HCCI System is expected to significantly facilitate the HCCI calculation process and rapidly implement this new system.

Keywords: Highway Construction Cost Index (HCCI), Inflation, Dynamic Construction Item Basket, Multidimensional HCCI, Construction Market Basket, Construction Market Conditions, Planning and Budgeting.

INTRODUCTION AND BACKGROUND

A Highway Construction Cost Index (HCCI) is an indicator of the purchasing power of a highway agency (Guerrero 2003; Strickland and Beasley 2007; White and Erickson 2011). It is calculated to shows highway construction cost changes over time as a function of unit costs and quantities of various bid items used in highway construction.

State departments of transportation (DOTs) use it to track changes in highway construction costs over time and reasonably estimate future highway funding needs (Erickson and White 2011; Guerrero 2003). An HCCI is also used by some DOTs as an inflation factor for preliminary and detailed cost estimates and life cycle cost analysis (LCCA) of their highway projects (Gransberg and Diekmann 2004; Iowa Department of Transportation (IADOT) 2012; Mack 2012; Slone 2009; Wilmot 1999). HCCIs are also recommended as a factor to determine the gas tax rate to generate revenue necessary to properly maintain the existing highway infrastructure system (Arkansas Highway and Transportation Department (AHTD) 2013; Dodier 2014; Institute on Taxation and Economic Policy 2013). Thus, it is very important that HCCIs accurately reflect the actual construction market conditions.

The Federal Highway Administration (FHWA) pioneered the concept of HCCI in the U.S. highway construction industry in 1933 by introducing Bid Price Index (BPI) (White and Erickson 2011). Subsequently, some DOTs have adopted FHWA's methodology to develop their state level HCCIs (Luo 2009; Wilmot 1999). In 2011, FHWA introduced an updated National HCCI (NHCCI) as the replacement of the BPI (Erickson and White 2011). HCCI experts consider this change the most significant update in the national HCCI methodology. Among many notable changes such as a wider coverage of projects and electronic bid data collection processes, the switch to an enhanced indexing formula (Fisher index) is considered the major change. Currently, at least 21 DOTs compute their state level HCCIs, but most of them have not yet updated their methodologies to reflect the changes in the NHCCI methodology primarily due to lack of appropriate guidance (Shrestha et al. 2016; Walters and Yeh 2012).

In addition, current HCCI calculation methods adopted by most DOTs are not sophisticated enough to assure that an HCCI can be used as a reliable indicator of the changing market conditions. One of the reasons is the use of a significantly insufficient sample size of bid items in HCCI calculation. Since an HCCI is calculated using the cost information of bid items, ideally, the entire bid dataset should be used to truly reflect actual market conditions (International Monetary Fund (IMF) 2010). Currently, the coverage of bid items ranges from as little as 14% to not more than 50% of the total construction costs (Nebraska Department of Roads (NDOR) 2015; West Virginia Division of Highways (WVDOH) 2015; Wilmot 1999).

Another area for improvement in DOT's HCCI calculation methodology is in the current method's inability to address the need to track highway construction market conditions with higher granularity. Current methodologies typically produce only one overall HCCI as a representative index to indicate the entire state's highway construction market condition. However, highway construction costs are heavily affected by availability of local materials, equipment, and even specialty contractors. In addition, the project size and quantity of work significantly affect construction methods and their productivities which are directly associated with project costs. Moreover, many DOTs are forced to shift their highway project portfolio from new construction to maintenance and rehabilitation projects due to aging roadway systems. These unique characteristics of highway construction and changing business environments require DOTs to have customized HCCIs designed to better understand specific market conditions and trends based on local regions, project sizes and project types. The current system fails to address this issue.

The goal of this study aims at addressing the two specific issues described above by developing an advanced HCCI methodology with new concepts of dynamic item basket and multi-dimensional HCCIs. Specifically, this study will: a) develop a methodology to generate a *Dynamic Item Basket* (DIB) with a higher coverage of bid items, b) develop multidimensional HCCIs that can show construction market conditions with a higher granularity, c) automate the process to reduce efforts required to compute multi-dimensional HCCIs, and d) evaluate the performance of the new HCCI methodology.

THEORY OF COST INDEX

The calculation of any type of cost index starts with the identification of product items that are relevant to and representative of the specific industry sector of interest. The collection of those items is called 'market basket' or '*item basket* (IB).' An IB with 'n' items has two important properties: a cost vector (p) = [p_1, p_2, p_3, ..., p_n] and a quantity vector (q) = [q_1, q_2, q_3, …, q_n] that represent the cost and quantity of each item in the IB. The subscript in each element of cost and quantity vectors represents a specific item. Theoretically, a cost index measures the movement of the cost vector from one period to another. Oftentimes, the quantity vector is used to indicate the importance of items in the IB. Generally, the cost movement in the *current period* (t) is measured relative to the *base period* (t=0). The cost index for the base period is typically set to 1.00 or 100. Thus, cost and quantity vectors from the current period (p^t, q^t) and base period (p^0, q^0) must be available to compute a cost index at a minimum.

In the highway construction industry, Laspeyres, Paasche and Fisher indexing methods are three most popular formulas among DOTs to compute HCCIs (Shrestha et al. 2016). Their formulas are presented in equations *(1)*, *(2)*, and *(3)* respectively as functions of cost and quantity vectors from the base period to the current period.

$$\text{Laspeyres index}, L_{t,0}\ (p^0, p^t, q^0, q^t) = \frac{\sum_{i=1}^{n} p_i^t q_i^0}{\sum_{i=1}^{n} p_i^0 q_i^0} \quad (1)$$

$$\text{Paasche index}, P_{t,0}\ (p^0, p^t, q^0, q^t) = \frac{\sum_{i=1}^{n} p_i^t q_i^t}{\sum_{i=1}^{n} p_i^0 q_i^t} \quad (2)$$

$$\text{Fisher index}, F_{t,0}\ (p^0, p^t, q^0, q^t) = \sqrt{L_{t,0} X P_{t,0}} = \sqrt{\frac{\sum_{i=1}^{n} p_i^t q_i^0}{\sum_{i=1}^{n} p_i^0 q_i^0} X \frac{\sum_{i=1}^{n} p_i^t q_i^t}{\sum_{i=1}^{n} p_i^0 q_i^t}} \quad (3)$$

Laspeyres index is the ratio of the total expenditure in the current period to the total expenditure in the base period assuming that the same quantities of items are purchased in the current period as in the base period. Paasche, on the other hand, utilizes the quantity vector for the current period and assumes it to be the same for the base period. Because those two formulas consider the quantity vector from only one period, Laspeyres overestimates the impact of cost increases while Paasche underestimates it. Fisher index is calculated as a geometric average of the Laspeyres and Paasche indexes which can theoretically cancel out those two biases, (International Labour Organization (ILO) et al. 2004)

Over time, not only the quantities, but also the IB itself might be outdated because of changes in the market resulting in the addition, removal, and substitution of items. This results in a *sampling error*. Thus, the base year and IB are recommended to be updated periodically (i.e, every five or ten years). However, it is very possible that the IB and the quantity vectors might get outdated before the base year is changed. Thus, a chained cost index is recommended to overcome this error by calculating a cost index between two consecutive periods. In a chained cost indexing process, the *net cost index* between two periods [say current period (t) and some arbitrary base period (t=0)) is calculated by multiplying all consecutive cost indexes ($I_{k,k-1}$) between the two periods (equation *(4)*).

$$\text{Chained index, } CI_{t,0} = \prod_{k=1}^{t} I_{k,k-1} \tag{4}$$

Thus, the chained Fisher index formula is considered the most ideal method for calculating a cost index. This formula is used by FHWA for its NHCCI computation and is recommended for DOTs' HCCI calculation (Erickson and White 2011).

CURRENT PRACTICES IN HCCI CALCULATION

Despite the clear advantages of the chained Fisher index, only Colorado, Ohio, and South Dakota DOTs currently use the Fisher index and Wisconsin and North Dakota DOTs are updating their methodologies to use the chained Fisher index (Shrestha et al.2016).

Also, state level HCCIs are calculated using IBs with its cost coverage as low as 14% and as low as 7% in terms of its bid item coverage (Table 1). The highest IB coverage in terms of total costs is 60% for FHWA's NHCCI. The coverage of 271 bid items in Utah DOT may appear to be large, but considering that DOTs typically use more than 2,000 bid items, it is quite small. There are several possible reasons for using IBs with such small coverages.

Table 1 Item Basket (IB) Coverage Comparison

DOT	Item Basket (IB) coverage	
	Number of bid items	% of total construction costs
West Virginia	7	14%
Wisconsin	91	-
Colorado	-	45%
Nebraska	101	46%
Ohio	-	48%
Mississippi	116	-
Nebraska	119	-
Iowa	190	-
Utah	271	--
FHWA	-	60%

First, lump sum items are typically removed from HCCI calculation, because these items are mostly unit-less and their costs do not have consistent relationships with their quantities, if there were quantities assigned. Removal of lump sum items such as mobilization is likely to reduce the IB coverage in terms of costs substantially due to the significant percentage of lump sum items in total project costs.

Second, DOTs generally remove data from smaller projects and item data with smaller quantities. For example, Minnesota, California, and Wisconsin DOTs remove data from projects smaller than $100,000 in value (Hanna et al. 2011; Lacho 2015; Minnesota Department of Transportation (MnDOT) 2009). Similarly, Iowa DOT removes concrete items with quantities less than 125 cubic yards and Colorado DOT removes excavation items less than 1,000 cubic yards (Colorado Department of Transportation (CDOT) 2015; Iowa Department of Transportation (IADOT) 2013). They also utilize various outlier detection techniques to remove items whose unit costs appear to be different than most of the unit costs. However, removal of such data may create a *sampling error*, i.e. the HCCI becomes more representative of a specific segment of the market rather than the entire market (Hanna et al. 2011; Lacho 2015; Minnesota Department of Transportation (MnDOT) 2009).

Third, DOTs choose a few important bid items from various work categories such as asphalt, concrete, and earthwork with a rationale that those selected items can represent all items in the category (Hanna et al. 2011). In this process, most DOTs consider items with high unit costs and/or high frequency as the important items with reasonable rationale that non-frequent items should be excluded mathematically in HCCI calculation and higher cost items may have higher impact on project costs (Shrestha et al. 2016). Such sampling process is common in the general inflation calculation such as consumer price index as it requires a significant amount of effort to use a larger IB, and it is practically impossible to use an IB of the entire product items in general inflation calculation (Bureau of Labor Statistics (BLS) n.d.; International Monetary Fund (IMF) 2010). However, for HCCI calculation, the entire bid dataset is readily available in an electronic format which provides an opportunity to potentially eliminate any sampling error. Next section presents the concept of Dynamic IB (DIB) to address this issue by improving the coverage of IB. Then, the concept of multidimensional HCCI is also presented.

CONCEPT OF DYNAMIC ITEM BASKET (DIB)

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

HCCI calculation.

In dynamic IB (DIB), the items in the IB, and corresponding cost and quantity vectors are updated automatically based on the current purchasing behavior of DOTs. The DIB generation process identifies the largest IB that can be generated from the bid data and hence increases the coverage of the IB to the maximum possible value. To explain the DIB generation process, consider a universal set U consisting of all standard bid items used by DOTs (Figure 1).

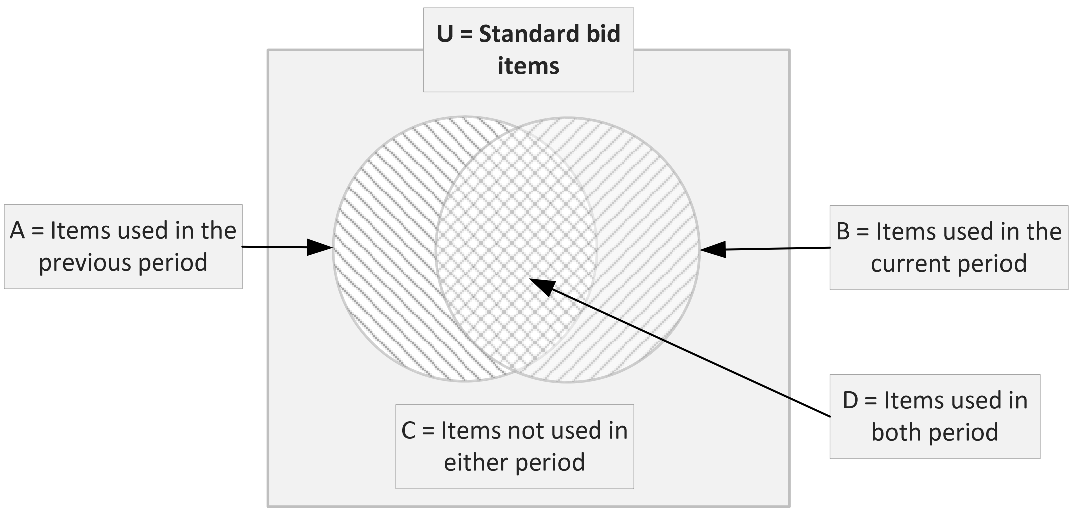

Figure 1 Dynamic Item Basket (DIB)

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

CONCEPT OF MULTIDIMENSIONAL HCCIS

The concept of multidimensional HCCIs is to develop cost indexes for highway construction market sectors defined by project size, project type, and location. Thus, in addition to an overall HCCI that is used to indicate the state level market conditions, three dimensional sub-HCCIs are developed: project size specific HCCIs (S-HCCI), project type specific HCCIs (T-HCCI), and location specific HCCIs (L-HCCI) which are visually depicted as HCCI cubes in Figure 2.

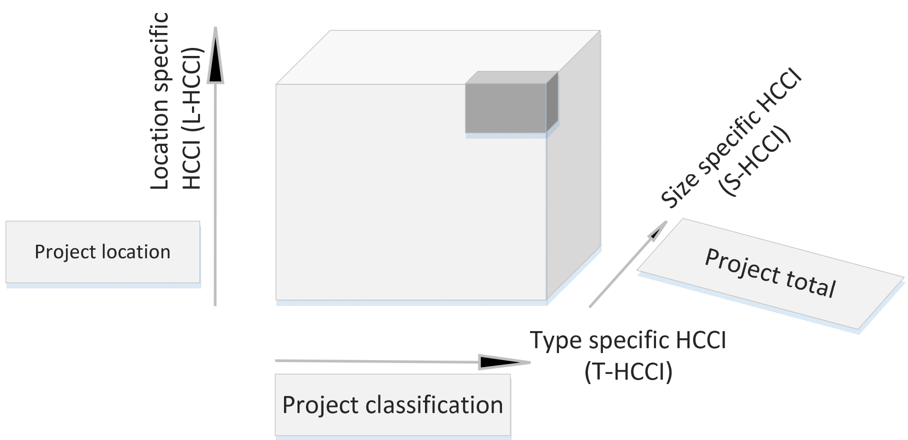

Figure 2 HCCI cubes

The size specific sub-HCCIs (S-HCCIs) are necessary because of the effect on costs by the economies of scale. The cost of an item is less when purchased in bulk. As such, larger projects that would contain larger quantities of items are likely to have a different market trend than that of smaller projects. Further, the level of competition for projects of different sizes also varies because contractors often need to be prequalified to perform larger projects. Similarly, contractors are often specialized to perform a certain type of projects. In addition, work items for different types of projects also vary. Those reasons necessitate a project type specific HCCI (T-HCCI) (Erickson and White 2011; Rueda and Gransberg 2015). One may argue that DOTs already calculate item category specific HCCIs (I-HCCIs) for different work categories such as structures, pavements, etc. However, a typical highway project consists of various work items from different item categories. Thus, T-HCCIs are different from I-HCCIs.

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

FRAMEWORK FOR MULTIDIMENSIONAL HCCI WITH DIB

The framework to integrate DIB into multidimensional HCCI calculation process is illustrated in Figure 3. The framework can be divided into four components: a) database development, b) project filtering, c) DIB generation, and d) multidimensional HCCI calculation. In the first component, data required for calculating multidimensional HCCIs with DIB are collected and systematically compiled in a structured database. *Project filtering* is a process to filter project data in three stages to obtain a list of projects relevant to a particular sub-HCCI. In *DIB generation*, two sets of cost and quantity vectors from previously selected projects are extracted. Finally, the Chained Fisher index formula is applied in the final component to generate sub-HCCIs. The project filtering component and the following components are repeated to generate various sub-HCCIs (such as small, medium, and large sized S-HCCIs).

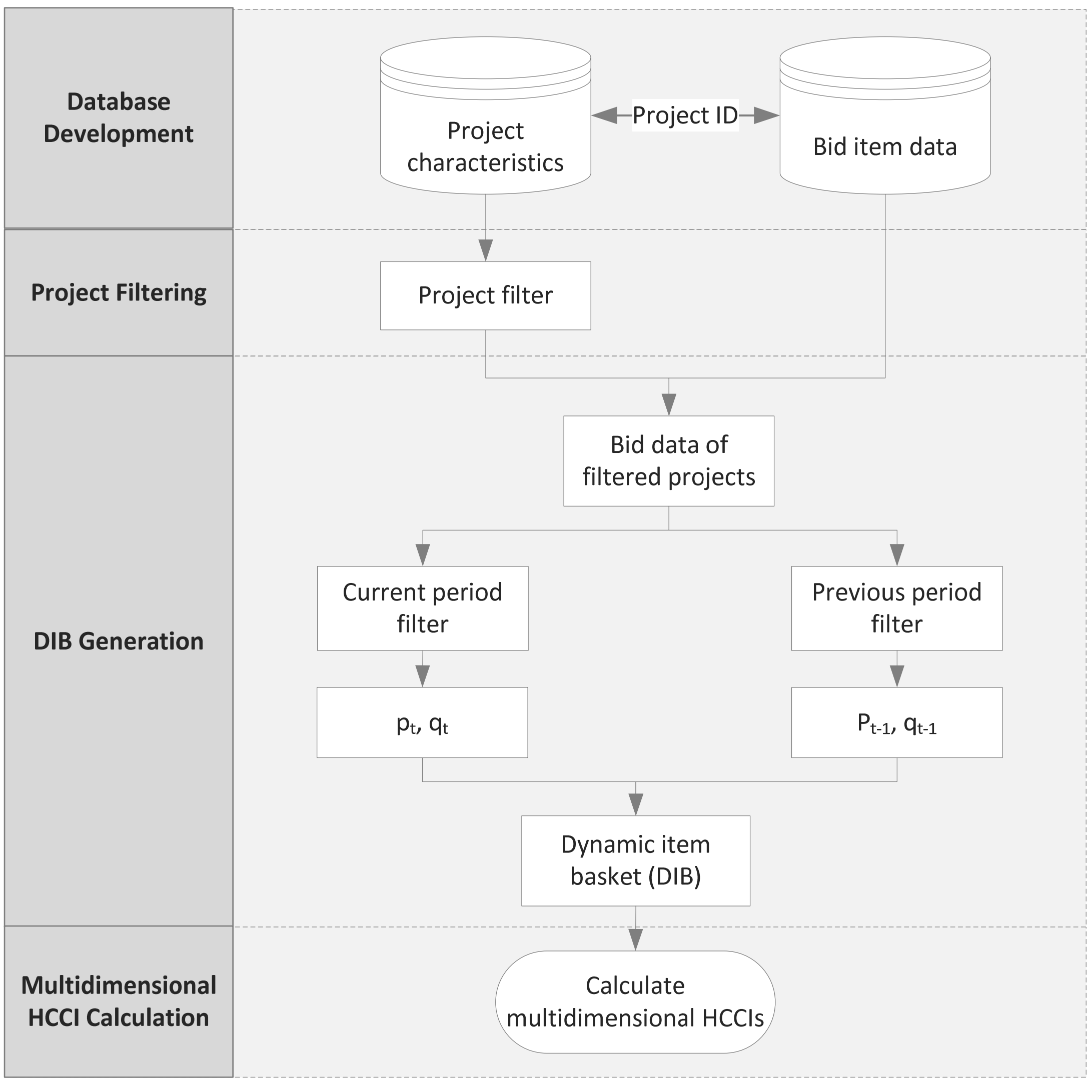

Figure 3 Framework for advanced multidimensional HCCI calculation using DIB

Database development

In this component, project characteristics and bid item data that are necessary for HCCI calculation are obtained from electronic bid letting systems and compiled into a new database for further processing. Currently, 41 DOTs use AASHTOWare Project Expedite System that stores data in a structured database such as Oracle and Microsoft SQL (Structured Query Language) Server (American Association of State Highway and Transportation Officials (AASHTO) 2015, 2016). SQL queries can be executed in the database used by such systems to generate relevant data. Alternately, those databases can be used directly as the database for this framework. At minimum, the database should contain *project characteristics* and *bid item data*. Project characteristics should include project size, type, and location. Bid item data should include information such as the item number, quantity, and cost for each bid item. These two datasets need to be tied together by a unique project ID as shown in Figure 3 so that relevant bid items from a list of projects of our interest can be obtained by automated filtering process.

Project Filtering

In this component, projects relevant to calculating sub-HCCIs are selected in three phases: a) removal of non-design-bid-build projects, b) selection of projects from the current and previous or base periods, and c) selection of projects of a particular category corresponding to the selected sub-HCCI. Figure 4 shows the detailed procedure for project filtering. The third phase (c) is required only to generate sub-HCCIs and is skipped for an overall HCCI calculation. For an overall HCCI calculation, data from all project sizes, types, and locations are used.

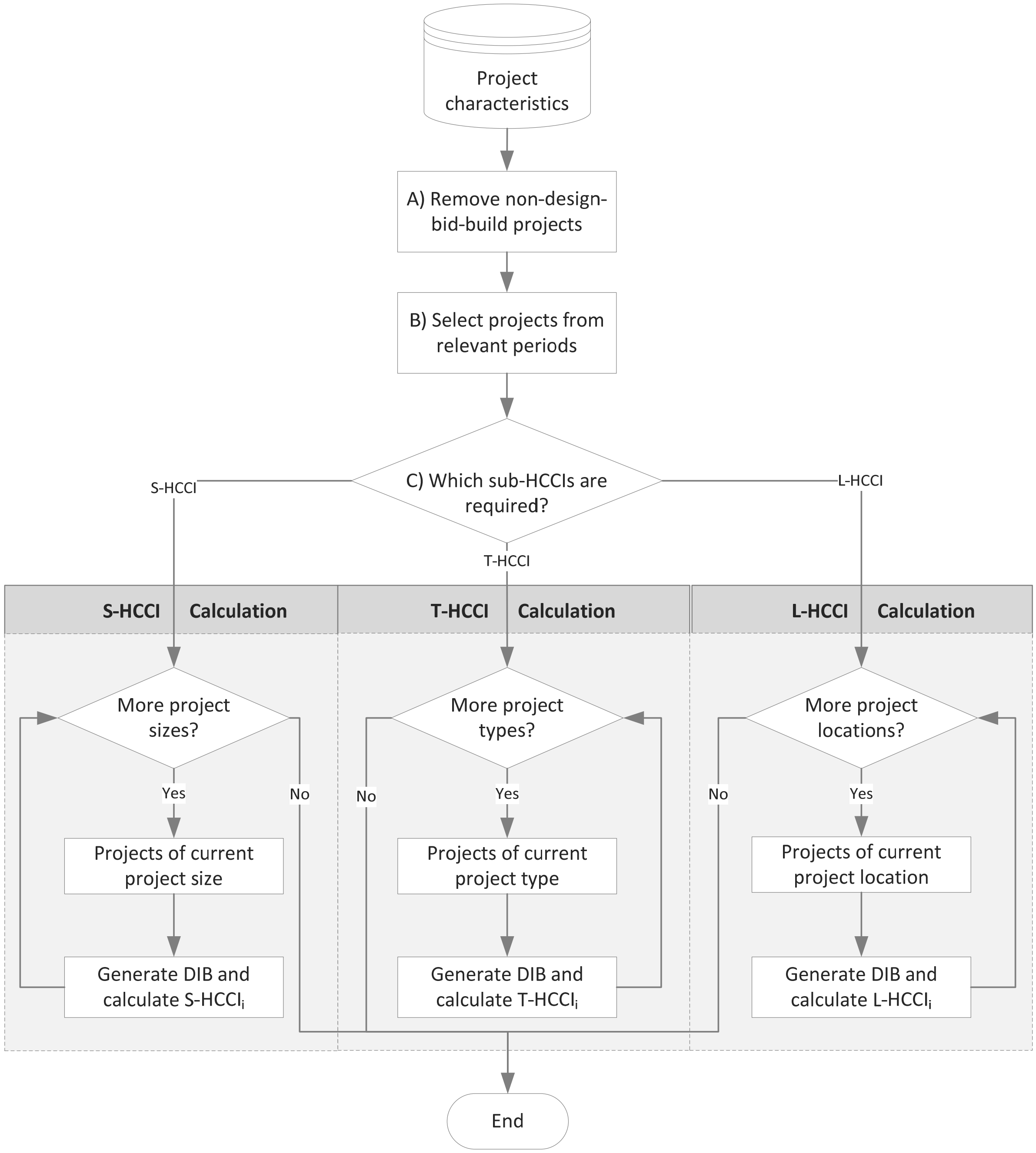

Figure 4 Project filtering component

In the first phase, projects that are procured through nonstandard design-bid-build procurement method are removed. For example, in ‘indefinite delivery infinite quantity’ contracts, a predetermined inflation rate is used (Rueda-Benavides and Gransberg 2014) and in 'design-build' contracts, non-standard bid items are used. Thus, those projects need to be eliminated. In the second phase, projects let in the current period or previous period are selected. Finally, projects relevant to the specific sub-HCCI are shortlisted using one of the three subcomponents (S-HCCI Calculation, T-HCCI Calculation, and L-HCCI Calculation) shown in Figure 4 for generating DIBs for the sub-HCCI in the next phase. Further, each sub-HCCI consists of multiple sub-HCCI values (i.e., S-HCCIs for small sized projects, medium sized projects, and large sized projects). The list of projects for each of the sub-HCCI value calculation is filtered separately and each list is sent to the DIB generation component one at a time.

DIB Generation

In this component, a DIB and corresponding cost and quantity vectors required to calculate sub-HCCIs are generated in three phases: a) extraction of relevant bid data, b) splitting the data into current and previous period data, c) generation of initial cost and quantity vectors, and d) removal of irrelevant items to generate the final cost and quantity vectors.

First, all bid data corresponding to the projects selected from the project filtering component is *extracted*. This can be achieved by SQL (Structured Query Language) command *Inner Join* (LeCorps 2001). The inner join can be considered as SQL equivalent of *intersection* in the set theory (Jech 1978). In this case, project ID is used for the intersection operation (equation *(5)*).

$$\begin{aligned}&\text{Bid data of filtered projects}\\&\quad= (\text{Bid data and } \mathit{Project\ IDs} \text{ of all projects}) \cap (\mathit{Projects\ IDs} \text{ of selected projects})\end{aligned} \qquad \textbf{\textit{(5)}}$$

The resulting dataset is *split* into two groups: one for the current period and another for the previous period. As items for all projects are based on a finite list of standard bid items used by DOTs, same bid items appear in various construction projects. However, for HCCI calculation, data from each unique item needs to be converted into a single line of data to *generate initial cost and quantity vectors*. For that, quantities are generated as a sum of quantities of the same items from all the projects (equation *(6)*) while costs are generated as weighted averages of the costs (equation *(7)*).

$$\text{Total quantity of an item } (q_i) = \sum Quantity\ of\ the\ item \tag{6}$$

$$\text{Weighted average cost of an item } (p_i) = \frac{\sum(\text{Cost of the item X Quantity of the item})}{\sum Quantity\ of\ the\ item} \tag{7}$$

So far, the item lists (ILs) and corresponding cost and quantity vectors are obtained for both periods. These ILs are further processed to develop DIB using equation *(8)*. The cost and quantity vectors corresponding to this DIB is the final vectors required for the next component. First, an item should coexist in both periods to use it for HCCI calculation. Thus, an *intersection* operation is performed between the two ILs.

$$DIB_t = IL_{t-1} \bigcap IL_t - IL_{irrelevant} \tag{8}$$

Then, this dataset obtained from the intersection operation is cleaned by *removing* all items that are not relevant to measuring the market conditions ($IL_{irrelevant}$). These items include lump sum items and items whose costs do not have a consistent relationship with their quantities. For example, costs for mobilization and utility relocation may vary widely despite its constant quantity (one unit). Some DOTs also remove seemingly outlier items based on cost fluctuation (Collins and Pritchard 2013; Federal Highway Administration (FHWA) 2014; Nassereddine et al. 2016). However, HCCIs are meant to measure the cost fluctuations and hence the removal of items with high cost fluctuations may not be the best approach. Thus, in this framework, those items are also included.

The items obtained using this process described above is the largest IB that can be generated from any given bid and project datasets. Further, the process updates IB dynamically based on the project characteristics and bid item data, current period selection, and sub-HCCI that is calculated. Thus, this IB can also be called an *optimum IB*. Unlike traditional methods where smaller and/or less frequent items are ignored and only larger and more frequent items are used, this method utilizes all items if they are purchased in both the current and previous period. This DIB and corresponding final cost and quantity vectors are transferred to the next component for multidimensional HCCI calculation.

Multidimensional HCCI Calculation

In the final component, single staged chained Fisher index (equation ***(3)***) based sub-HCCIs are calculated using the cost and quantity vectors generated from the previous component. In equation ***(3)***, instead of base period (t=0) cost and quantity vectors, previous period cost and quantity vectors (t-1) are used. Different chaining intervals can be used depending on the DOT's needs. In quarterly chained HCCIs, the chaining error can occur if both cost and quantity vectors of the IB oscillate over time (Nygaard 2010). In case of annual HCCIs, such oscillation is less likely to occur which reduces the chaining error. Finally, the sub-HCCI can be chained using equation *(4)*. A base year can be selected arbitrarily, for which the cost index is set to 1.00 or 100. Generally, the base year is selected when the market is in a normal economic condition (e.g. not affected by heavy recession, etc.).

PROTOTYPE DEVELOPMENT

A prototype, namely, Dynamic Multidimensional HCCI Calculation System (Dyna-Mu-HCCI-System) is developed with MS Access database (Figure 5) and Visual C#.NET frontend (Figure 6) to implement the framework. Seven data tables are created using Entity-Relation Model (ERM) to optimize the database (Stephens 2010). The ‘m_project_characteristics’ and ‘m_bidtabs_winning’ contain the required project characteristics and bid item data. The ‘m_bid_item_specs’ and ‘m_item_type’ contain additional information about the standard bid items.

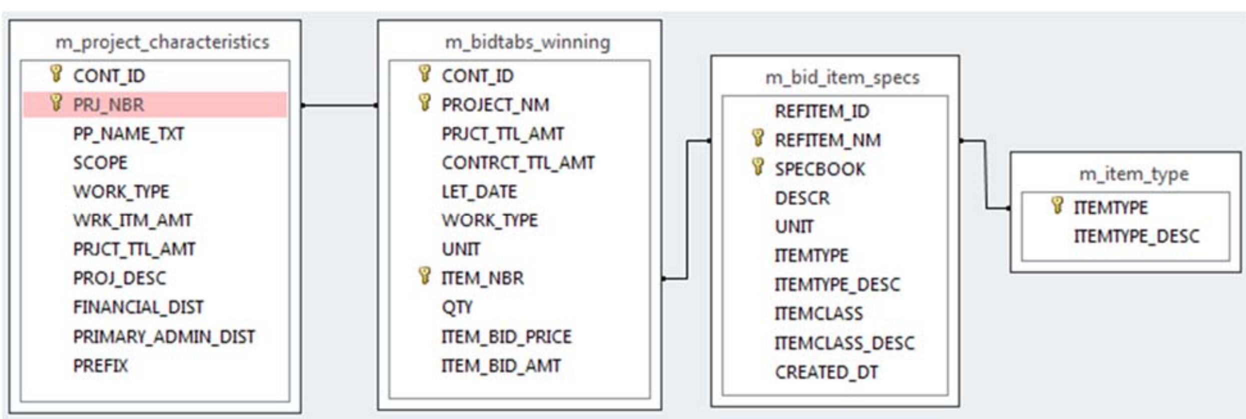

Figure 5 MS Access database

The Graphical User Interface (GUI) has the menu items on top to calculate various sub-HCCIs and perform some additional bid data analysis. The prototype is capable of generating sub-HCCIs using the raw bid data in a single click. Users can select a year as the current year to calculate sub-HCCIs for that particular year. Figure 6 shows the item basket generated for T-HCCI on the left and six T-HCCI values on the right. Next section discusses the analysis of the results regarding the performance of this new methodology generated using this prototype.

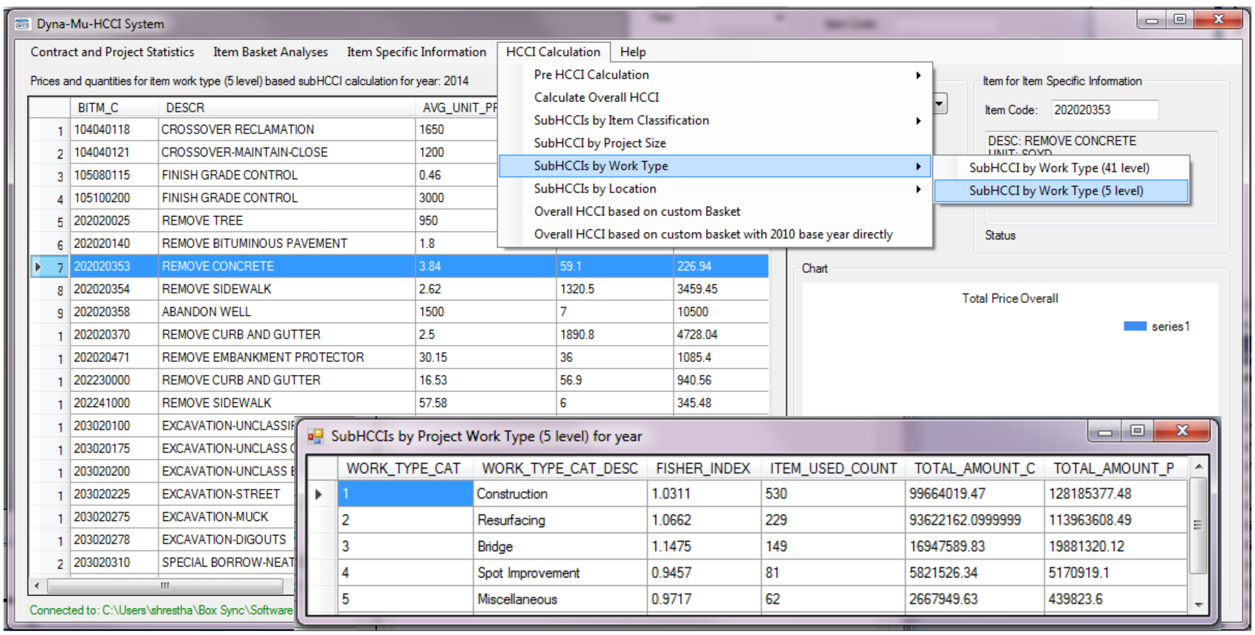

Figure 6 Visual C#.NET frontend

PERFORMANCE EVALUATION OF DYNA-MU-HCCI-SYSTEM

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

Data Collection

The researchers obtained the historical bid data from MDT in an excel format which was imported into the database. The database consists of bid data of 687 projects let from 2010 to 2014 that represent more than $1.8 billion of construction projects. The dataset consists of 33,975 lines of items based on 2,529 standard bid items from MDT's specification. MDT has developed a list of 5,645 unique bid items in its 2006 specification manual (Montana Department of Transportation (MDT) 2006). Each bid item represents a unique work item. For example, bid item "402020091" represents ASPHALT CEMENT PG 64-22. All bid items that begin with 402 represent bituminous materials and include the cost of "furnishing and applying bituminous materials, on bases and surfacing." The obtained bid data was imported into the Dyna-Mu-HCCI-System.

Improvements in IB using DIB

To evaluate the effect of the DIB, overall HCCIs are calculated using DIB ($HCCI_{DIB}$) and the current IB used by MDT ($HCCI_{current\ IB}$). MDT's current item basket includes 71 high cost items handpicked by MDT. In the DIB, items are selected automatically using the framework developed in this study. The number of items in the DIB ranges from 610 to 735 items in various years (2010 – 2014). This indicates that DIB consists of items more than eight times the number of items in the original IB. In terms of the cost coverage, the current MDT's item basket represents less than 50% of the total project costs. The DIB improves the cost coverage to over 70% of the total project costs indicating at least 20% increase in the coverage. The overall HCCI values calculated from year 2011 to 2014 are presented in Table 2. Year 2010 is assigned as the base year with the base cost index of 100. The difference in terms of percentage ranges from

2.34% up to 5.98%.

Table 2 Comparison of overall HCCI calculated using DIB and current IB

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

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

$$Correlation\ coefficient\ (r) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}}. \qquad \textbf{\textit{(9)}}$$

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

Further, an overall error between the two HCCI series is calculated using Mean Absolute Percentage Error (MAPE) (equation *(10)*). The higher MAPE indicates more variation between the two series. Generally, one may expect to have a higher MAPE value associated with a lower r-value and vice-versa.

$$MAPE = \sum_{i=2011}^{2014} \frac{\frac{|HCCI_{DIB,i} - HCCI_{current\ IB,i}|}{HCCI_{DIB,i}} * 100}{n} \qquad \textbf{(10)}$$

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

Fluctuations of multidimensional HCCIs

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

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

Table 3 Sub-HCCI calculation parameters and number of sub-HCCIs

<table>
<tr><th colspan="3">Sub-HCCI type</th><th>Number of sub-HCCIs</th><th>Sub-HCCIs</th><th>Number of continuous sub-HCCIs</th></tr>
<tr><td rowspan="5">Project characteristics based</td><td rowspan="2">Project Type</td><td>Project Type</td><td>6</td><td>Construction; Resurfacing; Bridge; Spot Improvement; Miscellaneous; Facilities</td><td>5</td></tr>
<tr><td>Extended Project Type</td><td>41</td><td>New Construction; Reconstruction – with added capacity; Reconstruction – without added capacity; Resurfacing – Crack Sealing; New Bridge; Bridge Replacement with added capacity; etc.</td><td>13</td></tr>
<tr><td rowspan="2">Project Location</td><td>Administrative and Construction District</td><td>5</td><td>Glendive; Billings; Great Falls; Missoula; Butte</td><td>5</td></tr>
<tr><td>Financial District</td><td>5</td><td>Glendive; Billings; Great Falls; Missoula; Butte</td><td>5</td></tr>
<tr><td colspan="2">Project Size</td><td>3</td><td>Small (0 - $3,500,000)
Medium ($3,500,000 - $10,500,000)
Large ($10,500,000 - $50,000,000)</td><td>3</td></tr>
</table>

Sub-HCCI type		Number of sub-HCCIs	Sub-HCCIs	Number of continuous sub-HCCIs
Item characteristics based	Item Division	6	General Provisions; Earthwork; Aggregate Surfacing and Base Courses; Bituminous Pavements; Rigid Pavement and Structures; Miscellaneous Construction	6
	Item Class	31	Liquid Asphalt; Base Course; Concrete Paving; Crushing; Drainage; Earthwork; Removals; Signing; Structures; Surface Treatment, etc.	24
	Item Type	10	Grading/ Drainage; Paving; Structures/ Buildings; Materials; Equipment; Traffic Control; Landscaping; Other, misc.; Trucking; Unknown	7

The values of overall HCCIs and all continuous sub-HCCIs are presented in Table 4. Correlation coefficients and MAPE values are calculated for the two series to quantify the similarities and differences between them. Most of the bituminous pavement and paving sub-HCCIs have a very high correlation (r = 0.94 and 0.96) with the overall HCCI. However, T-HCCI for bridges has r-value of -0.04 indicating slightly negative correlation. It might be because a large portion of bridge costs are associated with concrete and steel but the majority of construction projects are asphalt intensive roadway projects. Concrete and steel costs do not necessarily follow the cost movement of asphalt items. This weak relationship is also visible in structures/buildings HCCI (r = 0.10) and rigid pavement & structures HCCI (r=0.02). From L-HCCI perspective, Glendive district has the strongest correlation (r = 0.99 for both financial district and administrative & construction district) while others have lesser correlation but still strong correlation. In terms of project sizes, the overall HCCI was a better representative of small and large sized projects rather than medium sized projects.

MAPE confirms correlation analysis results and provides additional insights. For instance, in most cases such as T-HCCI for resurfacing projects and S-HCCI for large projects, MAPEs are less than 5%, which is in accordance with the strong correlations observed with higher r-values. The MAPE and r-value for the T-HCCI for spot improvement might seem contradictory at first sight. The T-HCCI has the highest MAPE value (68%) as well as a high r-value (0.94). This indicates that spot improvement projects do have a similar trend to an overall HCCI, but their rates of change (i.e. inflation rates) are very different. Specifically, while the overall HCCI increased from 100 in 2010 to only 115.46 in 2014, the spot improvement project T-HCCI increased to 207.12 during the same period.

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

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

Table 4 Overall HCCIs and sub-HCCIs and their correlation coefficients (r)

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

Sub-HCCI Type		sub-HCCI	2010	2011	2012	2013	2014	r	MAPE
		Traffic Control	100.00	117.94	122.83	121.00	119.56	0.92	7%
		Landscaping	100.00	93.25	91.93	106.51	124.36	0.45	12%
		Other, misc.	100.00	99.59	105.05	102.75	121.73	0.61	7%

CONCLUSIONS

This study identifies a gap in the knowledge on the current HCCI calculation methodology in DOTs and develops an advanced methodology to fill the gap. It develops a concept of Dynamic Item Basket (DIB) to improve the coverage of Item Basket (IB) used to calculate HCCIs. A concept of multidimensional HCCIs is also developed to enable more granular overview of the market conditions. A prototype system is developed to automate the framework. The automated system will facilitate the use of advanced concepts and reduce the time and effort required to compute HCCIs. The results of this study can serve as a guide to DOTs that desire to update their current methodology.

The study used bid data from Montana Department of Transportation (MDT) to validate the new methodology. The new DIB methodology improves the coverage of the bid items dramatically more than 8 times higher in terms of the number of bid items used and at least 20% higher in terms of the total project costs covered. Multidimensional HCCIs revealed high fluctuations in specific construction markets such as bridges compared to the overall market conditions. These granular and more accurate HCCIs are expected to aid DOTs to assess their market condition accurately and develop more customized business plans for different project types and sizes in different locations.

ACKNOWLEDGEMENT

The researchers would like to thank Montana Department of Transportation (MDT) for funding this study. The study would not have been possible without help from MDT staff who provided valuable datasets and guidance on the current MDT practices. We would also like to thank DOT representatives who provided insights about their current practices of calculating HCCIs.

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