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Conceptual level life-cycle cost analysis algorithm for low volume bridges

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Conceptual level life-cycle cost analysis algorithm for low volume bridges

by

Rinita Anand

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in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Civil Engineering (Construction Engineering and Management)

Program of Study Committee:
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Hyung Seok "David" Jeong
Jing Dong

Iowa State University

Ames, Iowa

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

LCCA	Life Cycle Cost Analysis
LCC	Life-Cycle Cost
CLCCA	Conceptual Life Cycle Cost Analysis
TAM	Transportation Asset Management
IADOT	Iowa Department of Transportation
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
ADT	Average Daily Traffic
ASCE	American Society of Civil Engineers
SROI	Social Return on Investment
MAP-21	Moving Ahead for Progress in the 21st Century Act
BMS	Bridge Management System
TRB	Transportation Research Board
AASHTO	American Association of State Highway and Transportation Officials
Caltrans	California Department of Transportation
PennDOT	Pennsylvania Department of Transportation

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ABSTRACT

The Moving Ahead for Progress in the 21st Century (MAP-21) Act (P.L. 112-141) instituted in 2012 by the Federal Government emphasizes investing public funding to spur growth and development of the nation’s transportation infrastructure and as one its goals requires each state to develop a Transportation Asset Management (TAM) plan. The purpose of a TAM plan is to prioritize expenditures of transportation funding in a manner that promotes construction, replacement, and maintenance projects that provides the highest overall network condition. Current prioritization algorithms favor high volume roads and bridges over those with low volumes. Iowa is an agricultural state and as a result has a lot of Farm-to-Market (FM), major and minor collector roads. Much of the rural road network is managed at the county level. Iowa counties have limited ability to fund the needed maintenance and replacement of low volume bridges, making it essential for County Engineers to have a decision tool to properly allocate available funds and execute effective asset management.

This research focuses on the development of a simplified Conceptual Life-Cycle Cost Analysis (CLCCA) model that can be used as a decision making tool by county engineers. It focuses on rural low-volume bridges in three counties in Iowa – Boone, Story and Marion – which have an Average Daily Traffic (ADT) of less than 50 vehicles. The research found that the data necessary to populate the classic bridge LCCA model was not available in many cases because the counties simply do not use an accounting system that allows specific minor maintenance and repair costs to be directly associated with specific bridges. The lack of maintenance and repair cost data acts as a barrier to implementing a LCCA-based TAM plan at county-level. Therefore, the proposed model is designed to make maximum use of the available information to the typical Iowa County Engineer and provides a conceptual life-cycle cost. The conceptual life cycle cost thus obtained can be used for making important transportation investment decisions such as in the allocation of funds and to establish an efficient TAM plan at the county level.

The research validated the model using a stochastic sensitivity analysis. The results of the sensitivity analysis are presented and show that the most sensitive factor contributing to the final conceptual life cycle cost is the discount rate used in the calculation. The results of the CLCCA vary from a comprehensive LCCA by less than 1 % and are reasonably close to the actual costs. Hence, the thesis recommends that the CLCCA be used in lieu of classic LCCA to make TAM prioritization decisions for low volume bridges in Iowa.

CHAPTER 1. INTRODUCTION

BACKGROUND

With increasing public sophistication and scrutiny, it has become crucial for transportation agencies to be able to justify and explain the decisions related to taxpayers' money (FHWA, 2002). There has been an increasing focus on the existing transportation assets in the nation and the management and preservation of these assets has becoming an important priority for transportation agencies at all levels – federal, state and local (FHWA 2007). With this research focusing on the implementation of LCCA and Asset Management, it is essential to first understand the important definitions for the terms and concepts that are discussed in subsequent sections of the thesis.

Definitions and Concepts:

The following terms are defined as shown below:

- *Engineering Economic Analyses (EEAs)*: It is the application of economic concepts and methods to engineering problems to support decisions regarding transportation projects and selecting the best solution. Engineering economic concepts include LCCA, benefit-cost analysis (BCA), and present worth analysis among many others. These analyses may be used during various stages of a project beginning from the planning and design, resource allocation, construction, operation and maintenance, preservation techniques, etc. (Markow, 2012)
- *Asset Management*: FHWA and AASHTO define asset management as "a systematic process of maintaining, upgrading, and operating physical assets cost effectively by

combining engineering principles with sound business practices and economic theory” (FHWA, 1999).

- *Benefit-Cost Analysis (BCA)*: An analysis comparing the benefits generated by a project or service to the costs incurred for the project or service over the period analyzed known as the life cycle of the project. The results from such an analysis are generally expressed as the ratio of benefits to costs. (AASHTO, 2009; FHWA, Dec. 2007).
- *Life-Cycle Cost Analysis (LCCA)*: An economic analysis of project alternatives considering all significant agency costs and user costs over the service life of the project or service and expressed in terms of equivalent dollars. (AASHTO, 2009)
- *Agency Costs*: Agency costs are those typically incurred by the transportation agency for the implementation of the project or service. These costs consist of maintenance, rehabilitation, and replacement costs and include the costs related to materials, personnel, and equipment costs (Hawk, 2003).
- *User Costs*: User costs are those incurred by the users of the roadway or bridge and are typically the costs arising due to loss of time due to detours, increase in vehicle costs, accidents and functional deficiencies such a load posting of a bridge, closure, and clearance restriction. (Hawk, 2003)
- *Discount Rate*: The discount rate is a percentage rate that accounts for the time value of money when performing an economic analysis. (AASHTO, 2009)For EEA such as LCCA the real discount rate (reflects the opportunity value of time) is used. (FHWA, 2002).

- *Inflation*: A trend of an increase in the prices of goods and service over time, as measured in dollars, is called inflation. Inflation for a broad group of such goods and services is expressed as general inflation and that for a particular good/service which is not included in the general inflation rate is known as a differential inflation rate.
- *Present Value (PV)*: Any combination of flows (finite or infinite) and lump sums can be summed into a single value at a single point in time. (FHWA, 2002).
- *Equivalent Uniform Annual Costs (EUAC)*: This is an analysis method in which produces the yearly costs of a project if they occurred uniformly throughout the analysis period. (FHWA, 2002)
- *Annual Average Daily Traffic (AADT)*: It can be defined as the total volume during a given time period, in whole days, greater than one day and less than one year, divided by the number of days in the time period (AASHTO, 2009).

Life-Cycle Cost Analysis (LCCA)

The Section 303 of the National Highway System Designation Act of 1995 defines LCCA as:

> *"a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment"*.

LCCA is an economic analysis tool for officials in transportation agencies to identify the lowest life cycle cost option among a given set of alternatives for any project. It is also used as a tool in asset management and resource allocation. It is widely used as a decision making tool for pavements and bridges. The use of LCCA in transportation goes back as early as 1991 when the Intermodal Surface Transportation Equity Act suggested the use of LCCA in the design and engineering of pavements, tunnels and bridges. The National Highway Act in fact mandates that all projects above $25 million should have conducted a LCCA (FHWA, 2002).

LCCA as a tool has several important application as follows:

- In selecting the best alternative for a project both economically and benefit wise.
- Evaluating the design requirements for any transportation project
- Comparison of the costs between different types of projects within the agency for better prioritization of limited funding.
- Identifying cost-effective approaches for project implementation

A recent survey was conducted by the American Society of Civil Engineers (ASCE), in association with the Governing Institute on city and county governments in transportation decision making showed that even though there is a general agreement in the need for including LCCA as an imperative part of the decision-making process, only 59% percent of the respondents actually reported employing the tool in their agencies (ASCE and Eno, 2014). Even among the states that do apply LCCA for their projects, there seems to be a broad range of parameters utilized in the process, pointing to the lack of uniformity in the methodology followed for the analysis.

Most of the states that practice LCCA use it for decisions regarding pavement design process. The implementation of this tool beyond pavements is limited and varies widely (Rangaraju, et al., 2008) because of the lack of consistent data. For example, the Indiana

Department of Transportation cited lack of in-house contractual maintenance data as the primary problem for maintenance costs (Sinha, et al., 2005).

However, a number of studies on implementing LCCA for bridges and Bridge Management Systems (BMS) have successfully demonstrated its value as an asset management metric (Zayed et al. 2002; Kendall et al. 2008; Safi 2012). The FHWA initiated the Bridge Life-Cycle Cost Analysis (BLCCA) Software and Guidance Manual that focusses on the use of LCCA specifically for bridges (Hawk, 2003). Though the development of this bridge LCCA tool is quite promising, its actual application for the management of low volume bridge assets at the county level is virtually nil.

MOTIVATION

In Iowa, 22% of the bridges are reported as structurally deficient and 5 percent of the bridges are functionally obsolete, which is the third highest rate in the nation (TRIP, 2013). The low volume bridges serving Iowa's most productive agricultural counties were found to have among the highest percentage of structurally deficient bridges in the nation, creating detours that add to the transportation cost of Iowa produce as well as increase the carbon footprint of agricultural products (Miller and Gransberg, 2013). At the local level of transportation administration, the biggest challenge engineers is the limited availability of bridge maintenance and repair funds intensifying the need for efficient management of bridge assets through cost effective resource allocation. Given the funding constraints, budgeting at the county level is focused mainly on general maintenance, significant alterations, and replacement of assets like signage and drainage structures rather than the construction of new structures. County engineers generally prioritize their assets based on their professional experience and personal knowledge of the area under their jurisdiction, allocate funds accordingly and convey the decision to the County Board of Directors (Kieffer 2014). There is however no analytical tool that can be combined with their professional judgment and personal knowledge of the area that supports their decision making. Adding LCCA as a decision support tool for both decision making and rationally justifying the resulting decisions to the stakeholders and the county governors would benefit all the stakeholders in the process by furnishing an objective metric to compare the long term impact of bridge asset class decisions.

However, implementing LCCA at this level is not an easy task. There are various reasons that contribute to this, the foremost being the lack of sufficient financial and human resources. LCCA is data-intensive and the accuracy of the resulting life cycle cost depends on the quality of the input data (FHWA, 2002; ASCE and Eno, 2014). The biggest challenge for low volume bridges is the fact that the data is not as readily available as for those bridges on the primary road network or on highways. To perform a comprehensive LCCA using popular software such as BridgeLCC or RealCost, vital information such as long-term maintenance costs, etc., are not available at the county level. With the limited workforce and funding, it does not seem viable to spend resources on the meticulous collection and recording of information for these bridges.

User costs have also been a challenge in this research. The major impediment that most agencies face in LCCA is the difficulty in arriving at a rational number for the user costs (FHWA, 2002). A study conducted by the California Department of Transportation (Caltrans) on 17 states using LCCA also showed that six states (Illinois, Minnesota, New York, Ohio, Virginia and Wisconsin) that include LCCA in their decision-making processes do not include user costs in their evaluation methodology (CTC & Associates LLC, 2011).

For the three counties in this research, the user costs have not been included. This was based on the responses from three county engineers during informal interviews. Since the bridges are small and have low volume of traffic through them, including user costs adds an unnecessary level of complexity and potentially may obscure the primary objective of the research to simplify the LCCA process by restricting the amount of input data to that which is readily available to most county engineers.

Another major limitation in the use of LCCA is that it relies on assumptions for quantifying future costs, and this particular aspect involves a substantial amount of uncertainty associated with the assumptions required to compute future costs, which can influence the results of the analysis (Gransberg and Scheepbouwer 2010). While the uncertainty can be accounted for using a risk analysis, it is important that practitioners are aware that that LCCA is not a fool-proof prediction of the future costs, and county engineers cannot base their decisions solely on the results of the analysis (ASCE and Eno, 2014). Given that the inputs available for low volume bridges are limited, there is an amount of uncertainty in the input parameters like the initial cost of a new bridge, the discount rates used, and the projected maintenance costs during the bridge’s service life. The impact of these areas of uncertainty can be understood by the use of a sensitivity analysis on the LCCA (FHWA, 2002; Hawk, 2003).

OBJECTIVE

The main objective of the research for this thesis is:

> *"To develop a simplified conceptual-level LCCA (CLCCA) model to minimize the amount of specific input data and produce a valid conceptual life cycle cost that can be used as an effective decision support tool for resource allocation and asset management at the county level"*

Considering the lack of reliable data, the model produces a conceptual life cycle cost that provides a reasonable approximation of the life cycle cost computed if all the necessary data was available. Since the tool is used in the planning and programming phase of the project development process before the actual design of the bridge in question's replacement, the initial cost of the project is by definition a conceptual estimate (Markow 2012; Ozbay et al. 2004) itself. So not attempting a LCCA because certain minor maintenance or repair costs are not available is not logically justified (FHWA 2002). Thus, CLCCA using conceptual costs has the potential help the user make a more informed decision regarding the allocation of funds and management of transportation funds. This study will demonstrate how a top- down conceptual estimating approach to derive input variables from available county bridge cost data can be used to provide a quantitative metric to assist county engineers make informed recommendations as to the most effective allocation of scarce maintenance and repair project funding. Additionally, a sensitivity analysis is presented to show the effect of assumptions for initial costs and discount rates on the final conceptual life cycle cost and measure the confidence with which those recommendations can be made.

CONTENT ORGANIZATION

This thesis contains three research papers that comprise chapters 3, 4, and 5. The second chapter describes the overall approach to the research methodology and the research instruments. The third chapter presents the proposed CLCCA algorithm used in the pilot study on low volume bridges in Boone County, Iowa and reports the results of the stochastic analysis and sensitivity analysis. Chapter 4 presents the results of applying the CLCCA model used in the pilot study on low volume bridges in Marion County and demonstrates the use of life cycle costs as a factor for prioritization of bridge funding. Chapter 5 finally compares the results of the CLCCA and those produced using BridgeLCC software, a classic LCCA algorithm. Chapter 6 presents the conclusions reached in the research, the limitations encountered in the process, the contribution made to the body of knowledge and lastly the recommendations for future research on the topic.

CHAPTER 2. OVERALL APPROACH TO RESEARCH METHODOLOGY

The main research instruments used in this research are:

- Literature review, and
- Content analysis

A literature review was performed to understand and evaluate the economic analysis concepts used for transportation decision making in particular LCCA. LCCA being a very important tool has vast applications and has been the topic of research in many fields. The extensive literature review provides a background on the concept of LCCA, its applications in building infrastructure, pavements and other transportation infrastructure. It also provides an insight into the different ways LCCA has been applied for transportation assets, its advantages and the limitations faced in its implementation.

The research was conducted mainly on information from the content analysis of existing documents, and previous research in the field. Content analysis is a type of research method and can be defined as a "systematic assignment of communication content to categories according to rules and the analysis of relationships involving those categories" (Riffe, et al., 2005).

Figure 2.1 shows the methodology followed for this research. As shown, a comprehensive literature analysis was the point of departure for this study. Once the parameters for the model were established, data collection was performed using the research instruments shown in Figure 2.1. The content analysis was supplemented with informal interviews with County Engineers, which led to the discovery that the types of data originally anticipated at the outset, i.e. the typical input variables for the classic LCCA, were by and large available only for a few bridges. Due to limited availability of data, the study was forced to rely heavily on information from previous research.

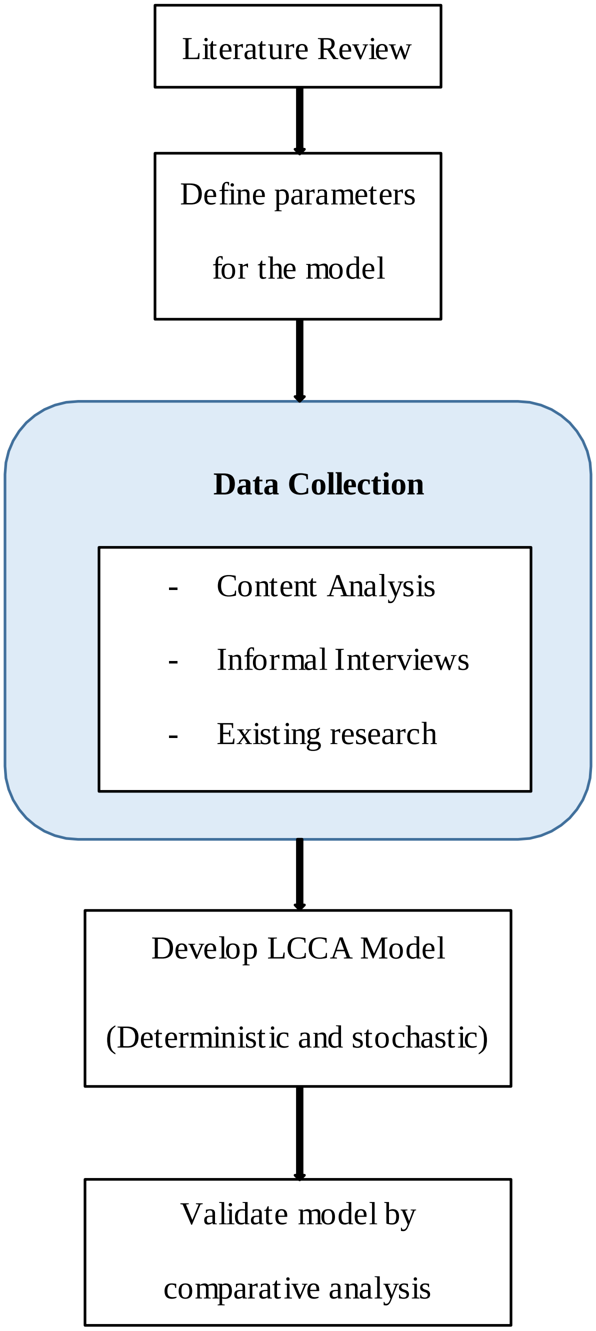

Figure 2.1. Research Methodology Flowchart

CHAPTER 3. A CONCEPTUAL LEVEL LIFE-CYCLE COST ANALYSIS MODEL FOR LOW VOLUME BRIDGES

Anand, R., D.D. Gransberg, “A Conceptual Level Life-Cycle Cost Analysis Model for Low Volume Bridges”, (To be submitted to the *Journal of Construction Engineering and Management*, ASCE)

ABSTRACT

Life-Cycle Cost Analysis (LCCA) is an important economic analysis technique and used as a decision making tool for transportation asset management. This paper presents a Conceptual-level LCCA (CLCCA) model that can be applied specifically for low volume bridges. Bridges having an ADT of 50 or less vehicles per day are considered as low volume in this study. A total of 10 low volume bridges were randomly selected from Boone County in Iowa. A CLCCA of these bridges is performed taking into consideration the initial construction costs, the maintenance costs and future replacement cost and is expressed in terms of the Equivalent Uniform Annual Costs (EUAC). A sensitivity analysis is also performed to analyze the effect of the discount rates used. The results of the analysis validated information found in the literature that the discount rate has a major impact on the final conceptual life cycle cost. The analysis also demonstrates the use of the CLCCA model in the management of resources and prioritization of funding at county level specifically for low volume bridges.

INTRODUCTION

More than 25 percent of locally and state-maintained bridges in Iowa of 20 feet or more in length show significant deterioration or do not meet current design standards (TRIP,

2013) . Another 22 percent of Iowa bridges are structurally deficient giving the state the dubious distinction of having the third highest rate in the nation superseded only by Pennsylvania and Oklahoma. Finally, another 5 percent of Iowa bridges are functionally obsolete, no longer meeting current highway design standards (TRIP, 2013). Now that the federal transportation funding, which is the major source of funding for rural roads and bridges, has expired this September, it has become crucial for both state and federal transportation agencies to display efficiency in the management of the available funds for investment in transportation assets including bridges. The MAP-21 Act, which was approved by Congress in July 2012 to increase funding flexibility for states, expired on September 20, 2014 and the federal funding for transportation projects is also expected to be delayed, which would result in postponing several projects. Thus the need for efficient management of resources becomes all the more important at the county level where the availability of resources for management of the transportation assets under their jurisdiction is extremely limited.

The Section 303 of the National Highway System Designation Act of 1995 defines LCCA as

"a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment."

LCCA is an economic analysis tool that is most commonly used to identify the preferred option among the population of possible alternatives to satisfy the asset management decision criterion of minimize overall cost. LCCA has been successfully used by many state and federal agencies for decision making regarding the repair, maintenance, rehabilitation and replacement of pavements (Al-Wazeer, et al., 2005; Hawk, 2003). It has come to play a vital role in the transportation asset management of many states (FHWA, 2007).

Most LCCA research is focused largely on pavements. While its use in Bridge Management Systems is not widely practiced, LCCA is generally not widely used in transportation decision making, possibly due to the complexities involved with gathering meaningful input data and the challenges of applying concepts of engineering economics (Pittenger, et al., 2012). These issues contribute to the fact that implementation of LCCA is limited (Pittenger, et al., 2012). Most of the states that do practice LCCA, generally apply it only to their pavement management systems. However, recent studies on implementing LCCA for bridge systems have shown promising results claiming it adds value to the bridge asset management decision-making process (Kendall, et al., 2008; Rodriguez, et al., 2006; Sundquist and Karoumi, 2006). FHWA sponsored a study to develop a LCCA framework for bridges in 2002, and it resulted in the development of the Bridge Life-Cycle Cost Analysis software and Guidance Manual (Hawk, 2003). There are also other commercial software such as RealCost that transportation agencies use for evaluating transportation asset life cycle costs.

Despite such successful developments, the use of LCCA at the county level of transportation administration has been very limited (Gannon and Lebo, 1999; Klaiber and Wipf, 2004; Miller and Gransberg, 2013; Phares, et al., 1999; Practico, et al., 2011). This is mainly due to insufficient available cost data for low volume bridges for use in a comprehensive LCCA model. The model provides a solution to this drawback by taking selective input parameters from the information that is available for most small bridges to determine the life cycle costs and expresses it in terms of the EUAC rather than the Net Present Value (NPV). The use of EUAC avoids the issues faced with NPV such as the use of a common analysis period. EUAC has been the suggested for transportation decision making especially when the service lives of the alternatives differ (Pittenger, et al., 2012; Sinha and Labi, 2007). The use of EUAC further is justified because public maintenance funds are authorized on fiscal year basis and hence the period of analysis exactly matches the period of fund availability, synchronizing the two to facilitate fund allocation decision making.

DETERMINISTIC VERSUS STOCHASTIC LCCA

The classic LCCA taught in undergraduate engineering economics courses is deterministic involving the use of discrete input values and resulting in a single output value. Thus, most transportation agency LCCA results in a deterministic value (Pittenger, et al., 2012; Ozbay, et al., 2004). The use of discrete values in LCCA does not account for a high degree of certainty in the input values due to the limited ability of the analyst to predict future costs. The literature has shown that the most uncertain and as a result most sensitive input parameters are the discount rate, service life of the asset and commodity price volatility for construction materials (Reigle and Zaniewski, 2002; Gransberg and Scheepbouwer, 2010). A stochastic LCCA takes into consideration uncertain parameters by modelling them probabilistically. Unlike a deterministic LCCA where there is a single certain input value and its corresponding output, a stochastic LCCA models all probable values of the input variables as probability distributions and displays all the corresponding output values in the same manner. Stochastic LCCA helps transportation agencies to become more fluent with the impact of input on output and permits decisions to be made based on the model’s sensitivity to input values. The subsequent analysis shows the results of a sensitivity analysis done using commercial software to determine the impact of the input parameters in the model on the EUAC output.

CONCEPTUAL LCCA MODEL

Data Collection:

This analysis is focused on low volume bridges in Boone County, Iowa. In 2013, Boone County had a total of 133 bridges of which 45 are structurally deficient and 3 are functionally obsolete as of 2013 according to the FHWA reports (NBIS, 2014). From the population of 133 bridges, a total of 10 bridges having an ADT less than 50 were randomly selected. Specific information regarding these bridges such as the initial construction costs, physical characteristics and other necessary information were obtained from the records at the Boone County Engineer's Office and used as input for the development of the model.

The following steps have been applied in the development of the CLCCA model for the particular use on low-volume bridges.

Determine the service life of the system

The time between a bridge's construction and its replacement or removal from service is known as its *service life* and the *life cycle* of a bridge comprises of the activities such as construction, usage, aging, damage, repair and renewal that lead to the end of its service life (Hawk, 2003). Though the current practical service life of bridges in America is between 30-50 years, AASHTO specifies that the service life of new bridges should be 75 years (Hawk, 2003; Miller and Gransberg, 2014). This value varies according to different states. For this model, the service life of the bridges under consideration is taken to be 75 years.

Determine Cost Elements

The initial construction costs, annual maintenance costs and future replacement costs are the three main cost elements considered in this model. The original construction costs for the 10 bridges were obtained from the records available at the County Engineer’s office.

The prediction of the possible maintenance costs that can occur during the life cycle of a bridge is a challenging task. Generally, bridge deterioration models are employed to identify how the condition of a bridge deteriorates over the service life and what maintenance work would need to be done periodically. The use of fuzzy logic approach has also shown to be successful in determining the timing of maintenance, rehabilitation and reconstruction treatments for pavements (Chen and Flintsch, 2006), and this can also be adapted for the case of bridges. This model however, obtains the maintenance costs as an input parameter from the user. For the low volume bridges of Boone County, it has been observed that a periodic inspection is performed every two years as recommended by the FHWA. During these inspections, the condition rating of the bridge is assessed and any repair work that needs to be done is performed. However, there appears to be no certain trend of such repairs that could be used as a standard.

Since replacement costs for the bridges were not found, the research team turned to the literature on replacement cost models and found a model developed in 2002 for Indiana’s Bridge Management System (Rodriguez, et al., 2007) . This model presented the average replacement costs in $/sq. ft. of deck area for 5 common types of bridges namely concrete bridges (slab, T-beam, I-beam, box-beam) and steel bridges (Rodriguez, et al., 2006). This data has been used to obtain a conceptual replacement cost in the model by indexing it to the costs in Iowa and using current inflation rates.

Table 3.1. Unit Replacement Costs (Rodriguez, et al., 2007)

Bridge Type	Indexing for Location and Escalation		
	Indiana 2002 ($/SF)	**Iowa 2002 ($/SF)**	**Iowa 2014 ($/SF)**
Concrete Slab Bridge	193.48	191.40	362.65
Concrete T-beam Bridge	189.38	187.34	354.97
Concrete I-beam Bridge	183.82	181.84	344.55
Concrete box-beam Bridge	181.5	179.55	340.20
Steel Bridges	175.25	173.37	328.48

The last column in Table 1 shows the unit replacement costs for a sample bridge having a deck area of 3750 sq. ft. The costs are shown in $/sq. ft for both concrete and steel bridges.

Adjust costs to Present Value

The primary input into the CLCCA model is the discount rate, which accounts for the time value of money and converts any future costs into the current value. In this analysis, the real discount rate is considered. Currently, most states use a discount rate within the range of 3% to 5% with 4% being the most commonly used (Mack, 2012). However, the FHWA recommends using the 30-year real discount rate according to the Circular A-94 from the Office of Management and Budget (OMB). The OMB Circular is updated annually and provides specific guidance on the use of real and nominal discount rates.

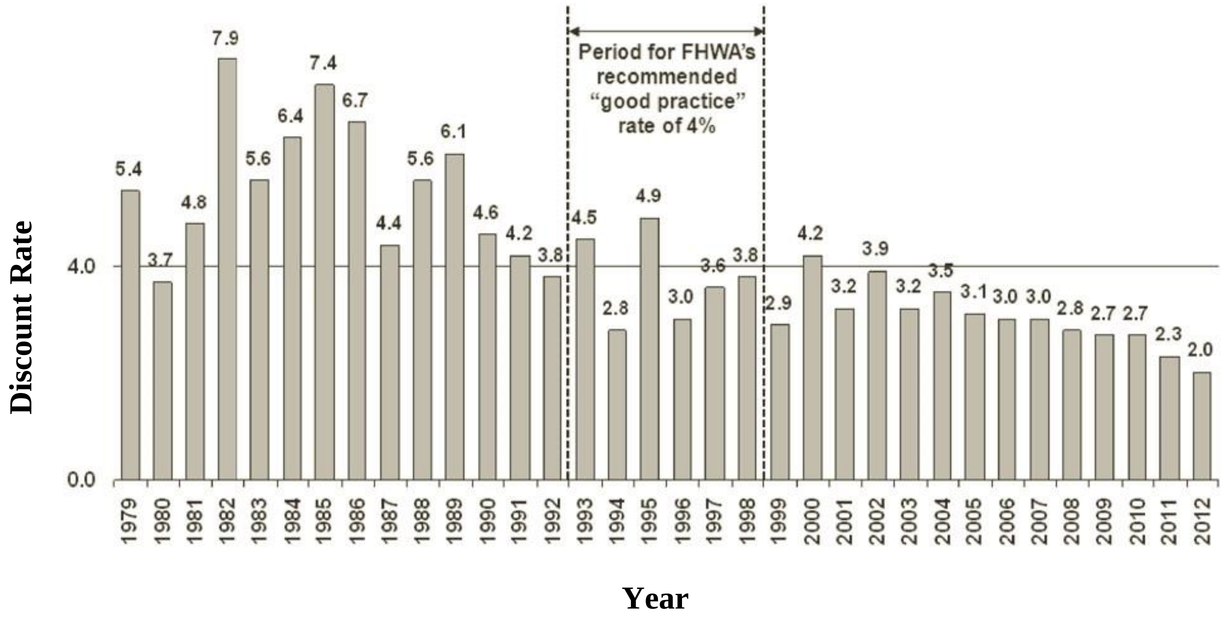

Figure 3.1. Real Discount rates recommended by OMB Circular A-94. (Mack, 2012)

The current real discount rate for 2014 according to the OMB Circular is 1.9%. Nevertheless, Boone County follows the commonly used rate of 4% and hence the same has been used in the model. The users however, can vary the discount rate according to their requirements and the life cycle cost would also vary accordingly.

The maintenance costs that are obtained as an input parameter from the user are converted into the present worth by using the following adjustment factor shown in Equations 1 and 2:

$$\mathrm{PWF} = \frac{1}{(1+i)^n} \tag{3.1}$$

Where:
PWF = Present Worth Factor
i = Discount Rate
n = total service life of the bridge in years

$$PV\text{-}M = PWF * MC \tag{3.2}$$

Where:
PV-M = Present Value of Maintenance Cost
PWF = Present Worth Factor
MC = Maintenance Costs

The present value of maintenance is the product of the present worth factor and the maintenance cost for the corresponding year. Since the replacement costs have already been calculated in present worth it is not required to use the adjustment factor.

Calculate EUAC and conceptual life cycle cost

The last step in the analysis followed in the model is the calculation of the EUAC and final life cycle costs. The total life cycle cost in terms of EUAC can be calculated using the standard formula given in Equation 3 below:

$$EUAC = PV * (A/P, i\%, n) \tag{3.3}$$

$$= PV * \left[\frac{(1+i)^n}{(1+i)^n - 1}\right]$$

Where:
A/P is the annualized cash flow payment
EUAC = Equivalent Uniform Annual Costs
i = Discount Rate
n = total service life of the bridge in years

The total life cycle cost of the bridge is calculated using Equation 4:

$$LCC = IC + PV\text{-}M + PV\text{-}R \tag{3.4}$$

Where:
LCC = Life-Cycle Cost

PV-M = Present Value of Maintenance Costs
PV-R = Present Value of Replacement Costs
The Figure 3.2 shows the methodology followed for the development of this model:

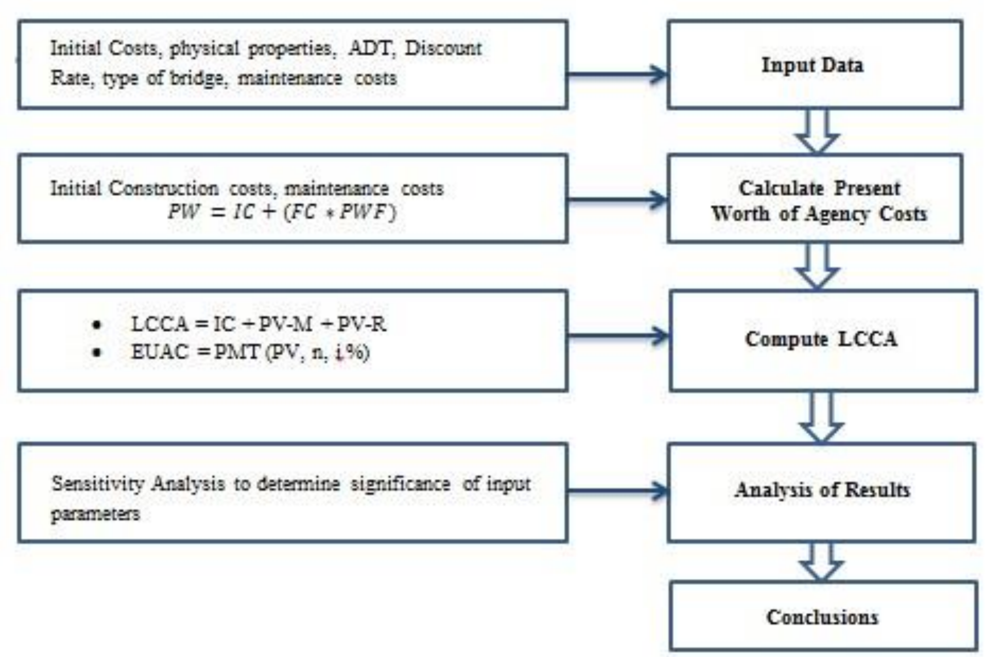

Figure 3.2. Methodology of Conceptual LCCA Model

RESULTS

Sensitivity Analysis

The historical values of the discount rates from 1979 to the current year (2014) were obtained from the OMB (Office of Management and Budget, 2013) and a probability distribution function was determined using the Monte Carlo Simulation. In a similar fashion, the probability density function for other input parameters such as the initial construction costs, maintenance costs and replacement costs were also determined.

Figure 3.3 shows the result of the stochastic model developed. From the figure it can be observed that there is a 95% confidence that the EUAC for the particular bridge under consideration lies within the ranges shown by the red bar.

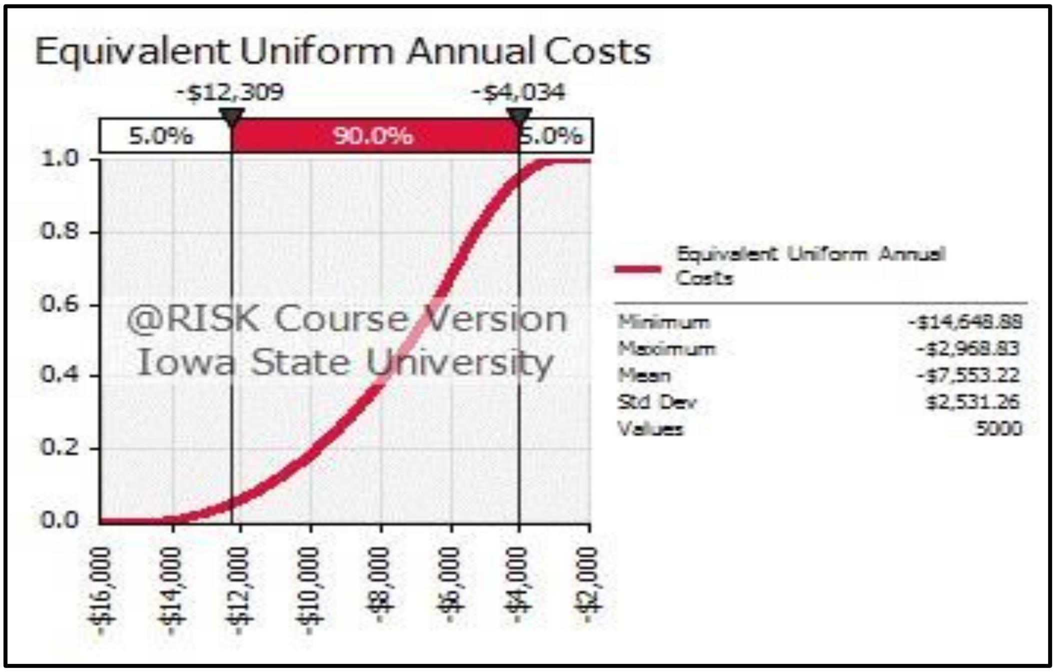

Figure 3.3. Cumulative probability density function of EUAC

A sensitivity analysis was also performed for the inputs in the model and Figure 3.4 shows the tornado diagram obtained as a result of the analysis. Figure 3.4 shows that the discount rate is the most sensitive input parameter in the model or in other words, the life cycle cost expressed in terms of the EUAC is very sensitive to the discount rate assumed by the analyst.

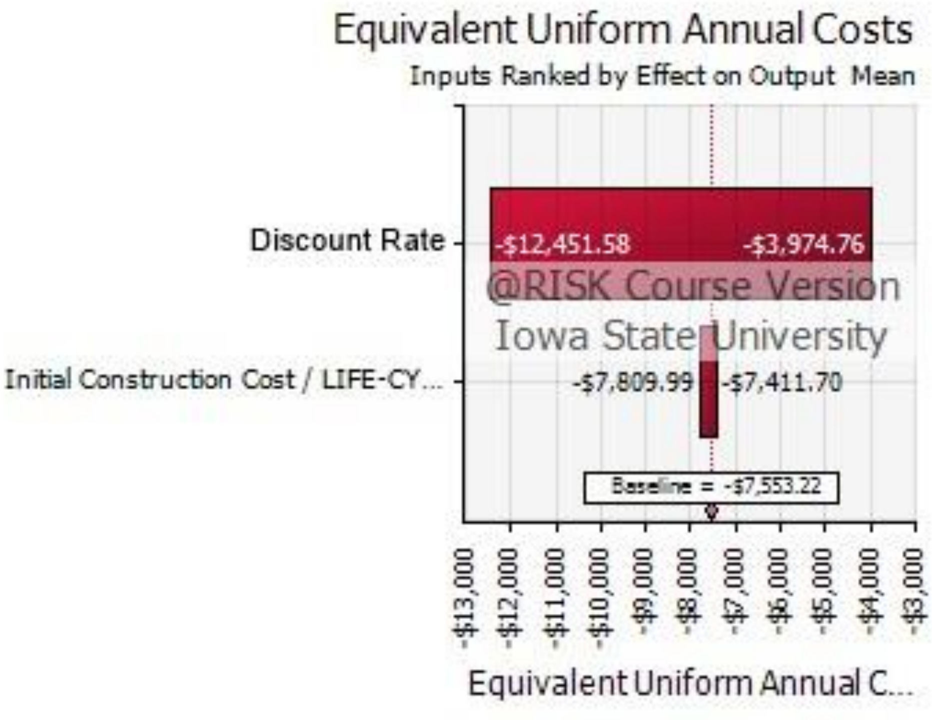

Figure 3.4. Results of sensitivity analysis

CONCLUSIONS

This paper describes the application of a stochastic CLCCA model with minimal input parameters for easy use for bridges with low ADT. The model demonstrated how the life cycle of a low volume bridge can be expressed in EUAC and the result can be used as a tool in supporting the decisions regarding low volume bridges. The sensitivity analysis results have shown that the life cycle cost of a bridge is sensitive to the discount rates that are used in the analysis and it can be concluded that selecting a suitable discount rate forms an essential part in analyzing the CLCCA. The model results in a is conceptual value and although it does not produce the most precise value of the life cycle cost that can be obtained from a comprehensive analysis with detailed input data, the results from the CLCCA model are closely accurate to the actual value and will be discussed further in Chapter 5. . The results from this model are intended to help the user to make a more informed decision regarding the allocation of funds and management of transportation assets.

CHAPTER 4. CONCEPTUAL LIFE-CYCLE COST ANALYSIS FOR DECISION MAKING FOR LOW VOLUME ROADS: CASE STUDY ON SELECTED BRIDGES IN MARION COUNTY, IOWA

Anand, R., “Conceptual Life-Cycle Cost Analysis for Decision Making for Low volume Roads: Case Study of Selected Bridges in Marion County, Iowa”, (To be submitted to the *Journal of Infrastructure Systems*, ASCE)

ABSTRACT

This paper presents the results of using a simplified conceptual Life-Cycle Cost Analysis (CLCCA) model for low volume bridges having Average Daily Traffic (ADT) of lesser than 50 vehicles. A total of 10 bridges were selected randomly Marion County of Iowa. The model uses the characteristics of the bridges, initial construction cost, maintenance costs and includes a generalized future replacement cost as input variables in the analysis. The final life cycle cost is presented in terms of the Equivalent Uniform Annual Cost (EUAC) and is used to compare the 10 bridges based on their sufficiency rating. The main objective of this study was to test the CLCCA model developed for Boone County as a tool for resource allocation and prioritization of funds by applying it to selected bridges in Marion County.

INTRODUCTION

The national movement to develop a more efficient asset management system of the transportation assets in the nation has been building since the passage of MAP 21 in 2012. However, little focus is being given to low volume roads and bridges because these assets are generally managed below state-level by local agencies. As previously stated, Iowa counties often lack sufficient resources and funding to properly maintain and preserve these assets. In

Iowa, the bridge problem is critical given that out of the approximately 26,000 bridges in the state, around 85% of them lie on the secondary road system, which are under the responsibility of the local agencies in the counties (Klaiber and Wipf, 2004). This paper presents the results of using a simplified Conceptual-level Life-Cycle Cost Analysis (CLCCA) model for low volume bridges having Average Daily Traffic (ADT) of less than 50 vehicles per year. A total of 10 bridges were selected randomly in Marion County, Iowa. The model developed in Chapter 3 is used and its input is the same four variables as the case in Boone County. They are the general characteristics of the bridges, initial construction costs, maintenance costs and future replacement cost to compute a conceptual life cycle cost expressed as the Equivalent Uniform Annual Cost (EUAC).

BACKGROUND

While a lot of attention is given to bridge structures with high traffic volumes, not much consideration is given to the management of low volume bridges with lower ADTs of 100 vehicles per day or less. With the introduction of MAP-21, there has been much focus on the management of transportation assets in the nation especially ones on the secondary road network. According to a report released by Transportation for America coalition, Iowa is among the 5 states in the country that have more than 20 percent of structurally deficient bridges. The report shows that out of the 100 worst counties nationwide in terms of percentage of deficient bridges, Iowa has 17 counties on the list, which is more than any other state so far (Transportation for America, 2011; Bleeding Heartland, 2011). The cost of regular periodic repair activities would be less than the actual cost that agencies would incur by allowing the bridges to fall in to disrepair and having to replace them. At the same time, research has shown that periodic maintenance and preservation efforts can extend the service life of structures for a longer period thus preventing the need for any major replacement or reconstruction (ASCE and Eno, 2014). At the county level, the major concern is the allocation of limited funding for the management of existing and new structures. Despite the Federal Highway Bridge Program created by the Congress, there is insufficient funding to manage the steadily deteriorating transportation structures. According to the FHWA, transportation agencies would need $70.9 billion to overcome the existing backlog of structurally deficient bridges in the country and this is no easy task (Bleeding Heartland, 2011).

In this current situation, it is of critical importance for an efficient asset management system at all levels of transportation agencies. At the county level, the biggest drawback is the lack of sufficient workforce and funding to implement new ideas.

Life-Cycle Cost Analysis (LCCA) in Transportation decision-making

LCCA has been the focus of many research studies over the years. It is a field that has continuously evolved to suit and benefit the agencies using it. There have been numerous studies that use LCCA for pavements, bridge structures and other infrastructure (CTC & Associates LLC, November 2011; Eno Center for Transportation, 2014; Hawk, 2003). Despite the increasing use of LCCA in asset management, it is still predominantly used only in pavement projects (Eno Center for Transportation, 2014). LCCA as a tool has generally been used for the evaluation of alternatives for both pavements and bridge systems and there is extensive literature supporting this. LCCA has been used generally in conjunction with bridge management systems for efficient asset management decisions regarding new constructions (Safi, 2012; Hawk, 2003; Rodriguez, et al., 2007). LCCA in transportation is mainly used for assessing the best alternative for new construction projects (Al-Wazeer, et al., 2005) and evaluation of the effect of different construction material (Kendall, et al., 2008; Zayed, et al., 2002; Klaiber and Wipf, 2004; Rodriguez, et al., 2007).

This paper presents the results of using a simplified CLCCA model that was developed to address the various difficulties faced at the county level for managing small low volume bridges. It takes limited input parameters and produces a conceptual life cycle cost which can be used as a decision support tool in resource allocation.

LCCA ISSUES

Despite the wealth of literature on the topic, its implementation is not easy. There are various reasons that serve as impediments to the implementation of LCCA in practice and the major ones are discussed below.

Data Requirements

LCCA is a very data-intensive analysis tool and as with any quantitative tool where, the accuracy of the result is dependent on the quality of data used as input (ASCE and Eno, 2014). It requires data such as historical maintenance information which are most often not readily available from the agency and need to be obtained from other external sources generally literature (Office of Asset Managment, 2002). The most common way that agencies validate their data is to rely on the experience of their staff. At the county level, the available information is inconsistent or incomplete, serving as a barrier to applying LCCA for bridges on low-volume roads. Introduction of a standard framework for data collection at all levels of transportation agencies is the first step to remedy this situation. This was also the biggest impediment faced during the collection of data for this study. Some agencies have automated data management systems. However, most do not have such systems.

The lack of consistent historical maintenance data was a major obstacle that had to be surmounted to develop the proposed model. This leads to a difficulty in the prediction of probable future maintenance activities. Due to this drawback, this model depends on the experience of the user to provide relatively accurate inputs for the model.

User Costs

User costs are another challenge to LCCA implementation that most agencies face. The difficulty lies in quantifying the user costs associated with any transportation project. While this is relatively easy in the case of large bridges on the primary road network, it becomes an acute problem on bridges with lower ADT such as the ones in this study. Even within the practitioners of LCCA there is a widespread difference in opinion for the inclusion of user costs in the analysis with no consensus as to their value. Recent research undertaken by Caltrans on 17 states using LCCA showed that the states of Illinois, Minnesota, New York, Ohio, Virginia and Wisconsin do not include user costs in their decision making process which they attribute to the difficulty in quantifying it (CTC and , 2011). In this study however, in adhering to the idea of a simplified CLCCA process, the user costs have not been included. This is also validated by the respective County Engineer through informal interviews.

Uncertainty and risk

A thorough literature study showed that the uncertainty involved in LCCA is another major barrier to the implementation of LCCA. LCCA involves the prediction of future costs and this in itself presents a lot of uncertainty and risk in the estimation of future costs. This is generally accounted for by performing a risk analysis with the LCCA. Most agencies that use LCCA in their decision making process perform a probabilistic analysis rather than a deterministic one so as to take into consideration the probable risks involved. Though the use of a risk analysis can identify factors that are most sensitive and can affect the final life cycle cost of the project, it is highly important that the users keep in mind that the results are not fool proof and can be used as a decision support tool only.

MODEL AND METHODOLOGY

The model prepared under this study has the following simple objectives:

- A CLCCA model that takes limited input parameters to keep the process simplified and user friendly
- Uses a methodology that keeps in mind the limited data for low volume bridges
- Delivers a life cycle cost that is conceptual and can be used for decision making and prioritization

The model follows the common LCCA steps and methodology generally used by practitioners, the biggest advantage being the limited input factors.

The major input parameters considered in this model are the physical characteristics of the bridge such as the total length of the structure, width of deck, spans, ADT through the structure, initial construction costs and, the maintenance costs. Most of this information such as the physical characteristics and the initial construction costs are easily available for even low volume bridges and do not present any difficulty in obtaining.

While the initial construction costs can be obtained from the records at the county engineers’ office or from The National Bridge Inventory Database (NBI), the maintenance costs data present a major hurdle when considering low volume bridges. Unlike high traffic bridges on the primary road network, these bridges on gravel roads sometime have a maximum ADT of 50 vehicles most of which are trucks carrying produce. With limited resources and manpower at county levels, it is becomes a daunting and more often a time consuming task to maintain detailed records of periodic and routine maintenance work performed on small bridges. Most counties only keep track of any major maintenance activities such as the replacement of the bridge deck. The model has thus been created in such a way to rely on the knowledge and experience of the user to input typical maintenance costs. Generally county engineers have an extremely good knowledge of the bridges under their administration and with experience can easily judge the maintenance costs of a bridge given the current condition and estimated remaining service life. Hence, the maintenance costs thus obtained are adjusted to present worth when they are said to occur in the future.

The model also includes options for including future replacements. The future replacement costs have been adapted from a study done for Indiana Bridge Management System in 2005. This study estimates the pavement and bridge preservation costs using deterioration models and engineering analysis. The costs thus obtained from this model have been adapted in this paper after using appropriate factors for location and escalation. The user has options of selecting replacement of deck with concrete or steel bridges based on the deck area. For the case studies however, this cost has not been included.

RESULTS

This paper presents the results of the CLCCA on the 10 bridges from Marion County. The bridges were selected on the basis of having low traffic volume, preferably an ADT of lesser that 50 vehicles. The physical characteristics, ADT, initial costs were obtained from the records at the County Engineer’s office. This information are input into the model and final life cycle costs are calculated for the 10 sample bridges. The life cycle costs have been calculated using the general equation (3.4).

All the cost included in the model are brought to the base year of calculation (2014) and any future costs are also discounted using appropriated discounting factors. The final life cycle cost is represented in terms of Equivalent Uniform Annual Costs (EUAC). The reason why the life cycle cost is expressed in terms of EUAC, it that it provides an easier understanding and also for the purpose of decision making and resource allocation it is much easier to analyze the costs spent annually.

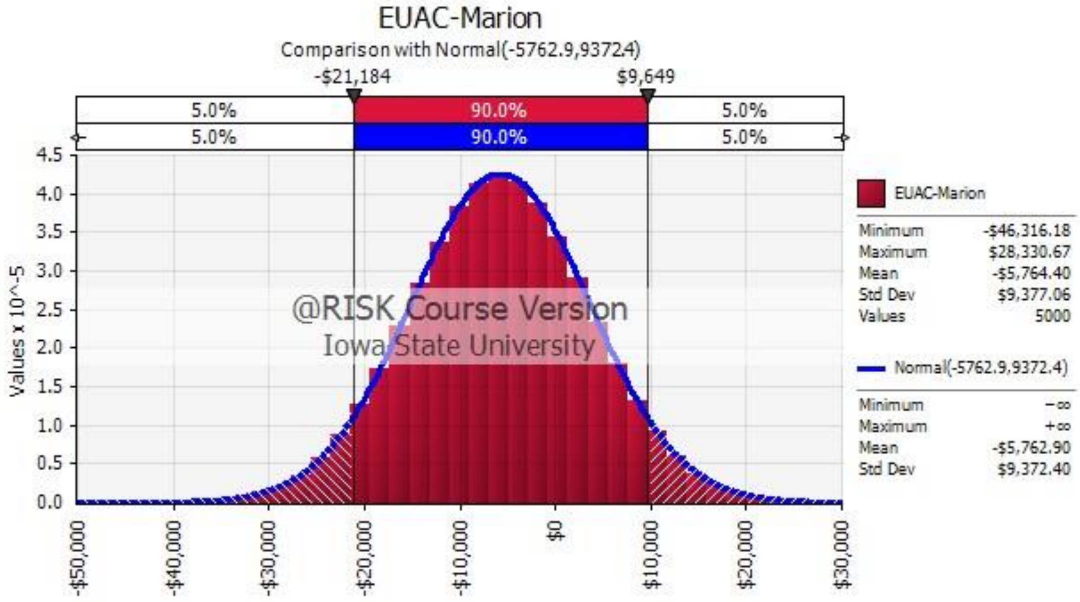

Figure 4.1. Stochastic Distribution of EUAC of bridges in Marion County

The probability density function of the EUAC for the bridges are represented in the figure below. The bridges selected for this study vary largely in the initial costs and the corresponding EUAC also varies accordingly. The above figure shows the range of EUAC for these 10 bridges at a 95 % confidence level.

Table 4.1. Input Parameters for Sample Bridge

Bridge No.	Sufficiency Rating	ADT	Initial Costs	EUAC	Ranking based on Sufficiency Rating
1	50.7%	20	$27,056.73	$1,168.14	**2**
2	96.0%	25	$486,722.72	$19,546.57	**9**
3	57.9%	15	$21,594.65	$949.76	**3**
4	65.8%	35	$5,922.94	$323.17	**5**
5	30.9%	50	$16,784.00	$757.42	**1**
6	67.0%	35	$22,547.27	$987.84	**6**
7	60.8%	40	$21,319.10	$938.74	**4**
8	70.6%	20	$39,788.48	$1,677.18	**7**
9	94.0%	40	$112,889.70	$4,599.93	**8**
10	98.3%	25	$665,144.61	$26,680.26	**10**

The table 4.1 shows the ten bridges from Marion County ranked according to their sufficiency rating from the inspection records. The CLCCA model was applied on these ten bridges and the resulting life cycle costs are also shown. It can be observed that in this case the bridge with the lowest sufficiency rating also has the highest ADT among the 10 sample bridges and the associated EUAC is marginally higher than the lowest of all the 10 bridges. In this particular scenario it would be economically justifiable to spend resources in the maintenance or rehabilitation of this particular bridge based on the "worst first" case.

However, this is not typical in practice. There are instances when spending resources for a particular bridge that has very low sufficiency rating or even one which has been closed despite a substantial ADT through them would not be economically feasible due to the high costs involved. One such instance has been described in Boone County (Appendix A). There are scenarios where spending funds and time on the repair or replacement of a bridge based only on the sufficiency rating may not always be the most prudent decision. In practice there are many other aspects such as political influence that play important roles in decision making.

CONCLUSIONS

The results of this study show that a CLCCA model can be used as a tool for decision making regarding resource and fund allocation for low volume bridges in addition to the existing factors that are generally considered for prioritization, the conceptual life cycle costs. While there are several software and guidebooks available for the use of LCCA, most of them do not consider the unavailability of sufficient data and resources for low volume bridges. The model in this paper has focused on this gap in the existing literature to provide users with a simplified model to calculate life cycle cost for decision making purposes.

CHAPTER 5. A COMPARATIVE STUDY BETWEEN COMPREHENSIVE AND CONCEPTUAL LIFE-CYCLE COST ANALYSIS

Anand, R. and D.D. Gransberg "A Comparative Study Between Comprehensive and Conceptual Life-Cycle Cost Analysis", (To be submitted to the *Cost Engineer Journal of AACEI*)

ABSTRACT

The use of LCCA as an economic analysis tool for transportation decision making is commonly practiced widely in the nation not just for pavement systems but for bridge systems too. Despite the growing popularity of LCCA by transportation agencies at the national and state level, not much focus has been given on its use for resource allocation and asset prioritization at the county level for low volume bridges primarily because LCCA is a tool that typically requires extensive data which is not generally available for such bridges. This paper presents the results of a comparative study between a comprehensive and a CLCCA, the latter which can be especially applied for low volume bridges with limited availability of data and can serve as a decision support tool. The main objective of this study is to establish the validity of using a simplified CLCCA model that takes on a top-down approach with limited input data to produce a conceptual life cycle cost.

INTRODUCTION

Various research studies have indicated that the investment in transportation infrastructure is inadequate (ASCE and Eno, 2014). LCCA is a popular economic tool and there are numerous studies and researches on the topic. As a well-accepted concept, LCCA has a number of drawbacks to implementing it on small bridges. The existing literature on the topic showed that the biggest limitation for the successful implementation of LCCA by transportation agencies is the lack of sufficient and more importantly accurate data (Eno, 2014). Lack of data becomes an obstacle for local transportation agencies especially at the county level where the availability of consistent data for small bridges is virtually non-existent.

The remedies to this situation would be to bring into place an efficient data collection and management system which is not only simple and user friendly but also cost efficient. The other solution would be to develop a simplified CLCCA model which does not require accurate and consistent data as needed by commercial software. The main objective of this study is to demonstrate that LCCA can be performed even with limited information to obtain reasonable results. This research compares the results of applying such a simplified CLCCA designed to fit the needs of low volume bridges with that obtained from a comprehensive LCCA performed using a more complex software as a tool.

BACKGROUND

A detailed study of the literature brings up numerous research studies on the applications of LCCA and a vast majority of these studies are on pavements. Even in practice, most of the states that implement LCCA primarily apply only to asset management decisions for pavement assets. PennDOT has used LCCA in their pavement management systems since the 1980s, and a FHWA report (2002) cites PennDOT as a leader in the use of LCCA for pavements. According to the statistics, there has been an estimated saving of over $30 million since its implementation. However, it does not apply LCCA for the prioritization of project funding (ASCE and Eno, 2014). PennDOT like many other states uses LCCA for the evaluation of different alternatives for a project (FHWA 2002). LCCA is an economic tool that can be applied in diverse fields from roads, pavements and bridges in the transportation sector to building infrastructure, roofing, etc. (Hoff 2007). Literature studies show that LCCA is in fact more prevalent in the private sector than the public sector and there might me more for the transportation sector to learn from the former (ASCE and Eno, 2014).

LCCA for Bridges

Using LCCA in transportation decision making is largely limited to pavement systems (Eno Center for Transportation, 2014; Hawk, 2003) because of a lack of sufficient maintenance data that can be used for an analysis (Rangaraju, et al., 2008). However, there are several transportation agencies that use this tool for decision making regarding construction of new bridge structures where different alternatives are analyzed (Phares, 2000; Eno, 2014; Hawk, 2003, Kendal et al, 2008). There are several government LCCA guidebooks that can be of help to practitioners. The *Life Cycle Cost Analysis Primer* released by the FHWA in August 2002 is a useful handbook that details the basic concepts of LCCA in a simplified manner. The National Cooperative Highway Research Program (NCHRP) sponsored a study in 2003 on use of LCCA for bridges and it resulted in the development of Bridge LCCA software. The report for the same project contains the methodology for applying LCCA to bridges and incudes aspects such as vulnerability and uncertainty in the analyses. Apart from this there are several other resources of information regarding LCCA, such as the American Association of State Highway and Transportation Officials' *User and Non-User Benefit Analysis for Highways (2010),* California Department of Transportation's *Life Cycle Cost Analysis Procedures Manual (2010),* the FHWA's *RealCost (2004)*software (CTC & Associates LLC, November 2011; Federal Highway Administration, 2004).

MODEL AND METHODOLOGY

This study uses the BridgeLCC software for the comprehensive LCCA. BridgeLCC is a software that was developed by the National Institute of Standards and Technology (NIST) to help bridge engineers assess the cost effectiveness of new, alternative construction materials. BridgeLCC was specifically designed for comparing new and conventional bridge materials. It includes deterministic analyses and analyses including uncertainty and options to conduct sensitivity analyses to identify the effect of individual parameters on the final life cycle cost. An important feature of this software is the provision of supporting tools that can be used to estimate the user costs – vehicle operating costs, user delay costs and accident costs (NIST, 2011). The major purpose of this software is to compare different alternatives for a bridge project based mainly on the type of construction material.

The CLCCA model has been developed as a spreadsheet. The major input parameters being considered here are the initial construction costs of the bridge under consideration, the maintenance costs, and the future replacement costs. Assuming the current year of calculation as the base year, the initial costs are escalated to the present value using appropriate factors. Both the user costs and the third party costs have been ignored in this analysis. For both the analyses, the life of the bridge has been assumed to be 75 years.

The maintenance costs of the bridges present a major limitation especially because there is a lack of sufficient and consistent historical data on the maintenance of the bridges. Most county engineers make decisions regarding the maintenance of a transportation asset based on the inspection reports and have a rich experience in the maintenance framework of the bridges under their administration. The model takes advantage of this experience and obtains the maintenance costs as a user input and hence the accuracy or validity of the final life cycle cost is greatly dependent on how close to the actual value that this maintenance cost can be. In this analysis for the continuous concrete slab bridge across Beaver Creek, the maintenance costs are considered to be $2,000 occurring every 10 years (Kieffer, 2014). All future maintenance costs are brought to the present worth by adjusting using equations (3.1) and (3.2).

The discount rates that are used in the calculations have been obtained from the Circular A-94 released by the Office of Management and Budget. While some states follow the discount rates from the OMB, a majority of the agencies in the country follow a discount rate of around 4 percent and the same has been used as a deterministic value for the software analysis (CTC & Associates LLC, November 2011; Eno, 2014). The FHWA also suggests using a 4 percent rate for “good practice” (OMB, 2013). The life cycle costs are calculated using the general equation 3.4 and expressed in terms of the Net Present Value (NPV). Since the resulting life cycle cost from the BridgeLCC software is expressed as NPV, the values from the model are also represented in the same for easy comparison.

The model incorporates the above discussed equations and results in a final life cycle cost. A sensitivity analysis is then performed on this result using commercial Monte Carlo simulation software to analyze the effect of individual parameters on the final life cycle cost. The Table 5.1 shows the basic input parameters that have been considered for this analysis and the corresponding results obtained.

Table 5.1. Comparative LCCA for Continuous Concrete Bridge across Beaver Creek

Continuous Concrete Bridge across Beaver Creek		
	BridgeLCC Software	**CLCCA Model**
Design Life	75 years [1]	75 years [1]
Initial Costs	$193,399.25	$193,399.25
Maintenance Costs	- Assumed to be uniform at $2,000 annually [1] - Frequency of occurrence 10 years	- Assumed to be uniform at $2,000 annually [1] - Frequency of occurrence 10 years
Discount Rates	4.00% [1]	Probability Distribution using historical rates from OMB (0.2 – 7.9%)
Life Cycle Cost	$197,452	$197,558
[1] Kieffer, 2014		

RESULTS OF ANALYSIS

The analyses in Table 5.1 show that the results are almost the same. The CLCCA model computed a life cycle cost that with less than 1 % of different from the one calculated by the comprehensive BridgeLCC model. This can be attributed to the difference in the discount rates used. While the simplified model uses the mean of the historical rates obtained from the Circular A-94, the discount rates used in the BridgeLCC software are deterministic Figure 5.1 shows the results of the sensitivity analysis for the sample bridge that the life cycle cost is most sensitive to the discount rates that are used in the calculation. This result supports the conclusion obtained in Chapter 3. It also shows that using a deterministic discount rate increases the probability that the rate, not the costs incurred on the bridge, will have the largest influence on the bridge’s life cycle cost.

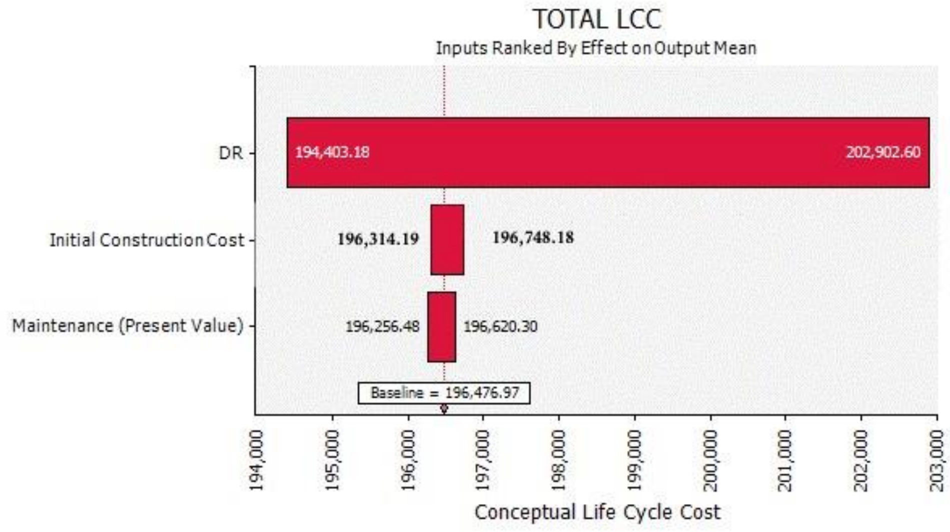

Figure 5.1. Sensitivity analysis results from Monte Carlo Simulation

CONCLUSIONS

The results of this paper support the initial hypothesis that extensive data does not necessarily add value to low volume bridge LCCA output. Including all the potential input values creates a barrier to implementation because the data is simply not available. The analysis does show that a conceptual-level LCCA model with simplified inputs generates and answer that is not much different than the one found by the comprehensive model used in BridgeLCC. Therefore, the model discussed in this paper has been validated and demonstrates that despite limited availability of detailed information, LCCA can still be performed to obtain a conceptual cost that can be helpful in decision making. For purposes of prioritization of funds and resource allocation, such a conceptual life cycle cost can serve as an excellent support tool by giving the user an approximate idea of how much funds are required for the repair, maintenance or replacement of the bridges. The difference between the results of a comprehensive LCCA and the CLCCA is less than 1 % percent and hence is a reasonable representation of the actual life cycle costs of a bridge.

CHAPTER 6 – CONSOLIDATED CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

CONCLUSIONS

This section provides an overview of the conclusions arrived in each of the three papers discussed in this thesis. The paper in Chapter 3 presented the methodology for the CLCCA developed in this research and the results obtained from applying the same to the bridges from Boone County. The results of this paper validated the findings from the literature analysis on the discount rate being an important factor in a LCCA and established the use of the model as a tool for decision making at the county level.

Chapter 4 presented a paper which calculates the conceptual life cycle costs of the 10 sample bridges from Marion County and compares their ranking based on their sufficiency rating. The analysis demonstrated the use of including life cycle costs as an important factor when considering prioritizing bridges for replacement or major rehabilitation.

Chapter 5 showed the conclusion that detailed information is not required to perform a LCCA. The comparative study between the life cycle costs from a comprehensive LCCA and the CLCCA model demonstrated resulted in almost alike values with the difference being less than 1 %. The major conclusion from this chapter is that limited input data can also be used to calculate considerably accurate life cycle costs that can be used in prioritization of funds for low volume bridges.

Given the current situation where there is not enough federal funds for construction and maintenance of transportation structures at the county level, it is the need of the hour to make more informed and efficient decisions while allocating funds and budgeting. Most county engineers make decisions based on own experiences in dealing with such acute situation but providing them with a support tool for such prioritization decisions is an added advantage and would enable them to make a more informed decision.

In addition, when communicating the decisions to the shareholders and members of the Board, the results of a CLCCA proves to be an efficient communication tool in conveying the decision based on dollar values. This model considers all the major drawbacks that are faced in implementing LCCA at the county level and accommodates these drawbacks to produce a simplified CLCCA.

LIMITATIONS

This study presents a number of limitations which are discussed below:

- The model has been developed with the main aim of simplifying the whole process of LCCA and considers only very limited input factors and does not take into consideration the user costs involved due to the unavailability of sufficient data.
- As discussed in the introduction, LCCA is a data intensive tool and requires consistent information as the input to have an accurate result. Since at the county level there is not enough information available, the results of the model may not represent those that would be obtained from a detailed analysis with accurate input information.

- While the uncertainty involved in the LCCA can be accounted for using a risk analysis, it is highly important that practitioners keep it in mind when making decisions that CLCCA is not necessarily a fool-proof prediction of the future costs and cannot base their decisions solely on the results of the analysis. It is essentially in all terms a tool that can be used to support the decisions and not the sole reason for basing decisions on.
- The lack of historical data on the maintenance costs involved for the bridges under the study is another limitation of this study. Due to the unavailability of a basic framework of future maintenance activities for low volume bridge, the model considers the maintenance costs as an input factor by the user. Hence the resulting value would be entirely dependent on how accurately the user is able to provide the input based on his or her experience in the field.

CONTRIBUTIONS

From the study of literature on previous research in the field of LCCA, it was observed that there is no simplified model or methodology of analysis that can be used in instances where there is acute unavailability of data. This can be a hindrance when a LCCA is required to be done as part of a research with a larger scope. This model was developed with the intention of being used for another research project which studies the application of Social Return on Investment (SROI) for bridge Transportation Asset Management (TAM) in Iowa. The SROI research also focusses on low volume bridges in Iowa and uses the life cycle cost generated from the model produced by this study in its calculations.

RECOMMENDATIONS FOR FUTURE RESEARCH

With increasing emphasis being given to asset management and preservation of existing transportation assets especially the ones on the secondary network, any contribution to the field of asset management has valuable benefits. A simplified maintenance costs prediction model which can be used in conjunction with this CLCCA model would be a great take off point for further research in developing the conceptual model.

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APPENDIX – INFORMAL INTERVIEW REPORTS

1. Boone County

The meeting with the Boone County Engineer Mr. Robert J. Kieffer was held on March 17, 2014 at the Boone County Office.

According to Mr. Kieffer, Boone County currently has 200 miles of paved roads and 800 miles of gravel roads which contain the majority of the bridges in the county. Out of the total 105 bridges in the county, currently 18 bridges are posted. These contain some bridges that are too narrow for trucks and larger vehicles. Boone County hires a bridge consultant to conduct inspections on the bridges in the county every 2 years and makes its decisions regarding the management of assets based on the reports submitted by the consultant. This report also contains the estimated remaining life of any bridge structure. Some major indicators that are considered while making decisions are the traffic pattern, traffic flow (count), prospective businesses that would be affected, classification of the gravel roads such as Farm to Market, detour length and user costs (for larger bridges). Emphasis is given to those with lesser useful life remaining.

Another important factor influencing the decision making process is the political aspect. The decisions are discussed with the Board and also communicated to the farmers every year at the meetings with the Farm Bureau. Farmers are also encouraged to communicate through emails or letters or walk in anytime and discuss their views with the County Engineer. Some of the maintenance works done on paved bridges are sealing of the bridge decks every 5 years, removal of debris of the piers, and erosion during times of flood. Boone County generally considers bridges on gravel roads with ADT of around 20 vehicles/day and cost of around $300,000 bridge money as low volume bridges. For a typical bridge on a gravel road, the construction costs would be around $400,000. The main problems faced in the construction or replacement of bridges in this county is the acquisition of the Right of Way (ROW) for the bridge.

An interesting example stated in the meeting was the Wagon Wheel Bridge in the west of the county across the Des Moines River. It has been closed for almost 4 years now. Though it had a high ADT through it and that people have to take a detour around the bridge now, it has not been possible to replace the bridge since to do that it would cost $4 million and it would not be practical to justify spending the limited funds on just one bridge.

Another interesting factor that was discussed in the meeting was that Boone County does not follow any specific methodology to forecast the ADT through its bridges.

2. Story County

The meeting with the Story County Engineer Mr. Darren Moon was held on May 22, 2014 at the Story County Office in Nevada.

Story County has 200 bridges > 20’ and another 76 bridges< 20’. These bridges range from 13’ to 410’ long. Out of these 276 bridges, 50 have a sufficiency rating below 50 and 80 bridges are posted with load or width restrictions. It includes 74 bridges listed as “structurally deficient” or “functionally obsolete”. According to the County Engineer, the Federal Bridge Funding received is $330,000 per year.

Major indicators such as bridge posting, sufficiency rating, total ADT, etc., are used to prioritize budget allocation for the bridges of Story County. Detour length, when considered is generally not greater than 4 miles. As observed in other counties, political issues influence the decision making process greatly.

The county keeps track of only major maintenance work done on the bridges through its life span. In general temporary replacement work is done on bridges with the intention of extending its service life by a few more years.

The decisions made by the county engineer regarding the roads and bridges in the county are based on expert knowledge of the area and the surroundings. No specific or systematic method is followed for this. The standard "worst first" procedure is followed for replacement and other major works.

The decisions are discussed with the Board and also to the farmers at the meetings with the Farm Bureau and so far there have been no major obstacles in communicating the decisions to the Board.

3. Marion County

The interview with Marion County Engineer, Mr. Tyler Christian was an informal phone interview.

Marion County has a total of 221 bridges out of which 36 are currently posted for load restrictions. A majority of these bridges are located in agricultural zones. Inspections are done on the bridges every 24 months through a consultant and any action needed to be taken is based on these inspection results.

When prioritizing budget allocation for bridges, Marion County uses the following indicators: Estimated total ADT, sufficiency rating of the bridge, detour length when applicable, bridges that have been posted. As with other counties, the political aspect plays an important role in decision making at the county level. Also as in the case of the other two counties, there are records only for major maintenance works such as replacement of the deck of a bridge. However, there is no detailed record keeping for routine or periodic maintenance activities and the associated costs. According to Mr. Christian, there have definitely been challenges in justifying the allocation of resources to a bridge with lower ADT against one with a higher ADT. This happens mostly in cases where the bridge under consideration lies on a dead end road surrounded by agricultural land or residential areas.

There is no standard framework (such as SROI to consider the social and economic impact) or methodology that is used when prioritizing bridges. Marion County does use Life Cycle Cost Analysis (LCCA) but only for evaluation alternatives generally for bridge replacements. However, it does not include user costs in its calculations.

The decisions made by the County Engineer are presented and discussed with the Board for approval. There are regular meetings with the public for the bridges under the 5-year program and this is the major form of feedback and communication with the public. Users are also welcome to walk in with their suggestions and feedback.