

Evaluation of Life-Cycle Cost Analysis Programs for Bridge Pile Repair Projects

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Life-Cycle Cost Analysis (LCCA), as a powerful economic assessment tool, has become a common practice in many fields of civil engineering during past decades in the United States. It enables engineers to choose the lowest life-cycle cost option among several alternatives and allocate limited funding of state or federal agencies in a more cost-effective way. Many LCCA computer programs have so far been developed to assist engineers to perform LCCA more systematically, while there is no comprehensive evaluation of those programs when applying them to bridge maintenance projects. This paper originated from a research project sponsored by Texas Department of Transportation (TxDOT), which seeks an effective repair system for deteriorated steel bridge piles without the need of dewatering. According to a set of criteria, the authors selected three existing federal-level LCCA programs that were developed recently, and then made a comparison of them comprehensively based on input requirements, types of economic analyses, and output data information. Particular emphasis is placed on the suitability and adaptability of them to bridge pile repair cases. Finally, RealCost is determined to be the most suitable one to perform a LCCA for bridge pile repair projects.

Key Words: Life-Cycle Cost Analysis (LCCA), Bridge Pile Repair, RealCost, BridgeLCC, BLCCA

Introduction

The Life-Cycle Cost Analysis (LCCA) is a cost-centered engineering economic analysis used to compare alternative courses of action over a specified time period (Kirk and Dell'Isola, 1995). The Life-Cycle Cost (LCC) are the summations of cost estimates from inception to disposal for projects as determined by an analytical study during the life-cycle term with consideration of the time value of money. The best balance among cost elements is achieved when the total life-cycle cost is minimized (Landers, 1996). Over past two decades, LCCA has attracted considerable attention to assist Departments of Transportation (DOTs) in their decision-making process as well as in managing assets, mainly because the federal government recognized the importance of the economic analysis of whole life investment for civil infrastructures, and thus now legally requires applying LCCA to specified projects. For example, Federal Executive Order 12893 (PFII, 1994), signed by President Clinton in January 1994, requires that all federal agencies use “systematic analysis of expected benefits and costs......appropriately discounted over the full life cycle of each project” in making major infrastructure investment decisions.

For federal and state transportation agencies, bridges compose a significant class of their assets and are usually regarded as a long-term investment. Therefore, the LCCA approach has been widely applied to bridge projects. For example, Purvis et al. (1994) performed a LCCA of the planning and design of highway bridge deck. Mohammadi et al. (1995) have Incorporated Life-Cycle Costs in highway-bridge planning and design. Hawk and Ehlen (2003) developed the bridge LCCA programs (BLCCA and BridgeLCC). The Federal Highway Administration (FHWA) introduced another LCCA program in 2004 (RealCost). Berg (2004) implemented life-cycle analysis to the novel design of concrete bridge deck with Fiber Reinforced Polymer (FRP).

This paper is based on a research project sponsored by TxDOT, which seeks a repair system for its deteriorated steel bridge piles that can be implemented without the need of dewatering. One main task of this project is to perform a LCCA for existing bridge pile repair alternatives and determine the most cost-effective method. Before accomplishing this mission, there is an urgent need to evaluate and compare currently available LCCA computer programs to investigate their feasibility and suitability since these software packages were not explicitly developed for the analysis of life-cycle costs of bridge pile repairs. Therefore, the authors selected three existing federal-level LCCA programs, i.e. BLCCA, BridgeLCC, and RealCost, in accordance with a set of criteria: (1) relevancy, (2) reliability, (3) accessibility, (4) economy, and (5) versatility. Then, the authors tried to make a comprehensive comparison of three programs, while addressing: (1) Describing how to use major LCCA computer programs on a personal computer environment, (2) Making a comparison between different programs with emphasis on integrated LCCA models that include direct and indirect cost models, and (3) Checking the suitability and adaptability of them to bridge pile repair projects. The LCCA computer programs evaluated here are developed by federal-level agencies and widely adopted by state agencies, including: BridgeLCC from the National Institute of Standards and Technology (NIST), BLCCA from the National Cooperative Highway Research Program (NCHRP), and RealCost from the Federal Highway Administration (FHWA). After a comprehensive comparison of these programs, RealCost is recommended as the most suitable one for bridge pile repair projects.

Background of Three Programs

This part describes the background of three programs, including a development background, LCCA methodology integrated within them, main LCCA functions, life-cycle cost types to be evaluated, and general analysis steps for each program. Table 1 summarizes the general information of three programs.

Table 1: General Information of Three Programs

Program	BLCCA	BridgeLCC	RealCost
Sponsor	National Cooperative Highway Research Program (NCHRP)	National Institute of Standard and Technology (NIST)	Federal Highway Administration (FHWA)
Date of Release	2003	2003	2004
Software Platform	Windows 95/98/NT4.x/XP	Windows 95/98/NT/2007/7	Windows95/98/NT/2000/XP/7
Source Code Available	No	No	Available upon request

Overview of Three Programs

The Bridge Life-cycle Cost Analysis (BLCCA) software was written as part of NCHRP Project 12-43 in 2003, a study to develop a comprehensive methodology for life-cycle cost analysis of bridges and implement it as a software package for a personal computer. The objective of that study is to conduct the research for current life-cycle analysis practices, availability and quality of data to support bridge life-cycle cost estimation, and computer-based facilities management tools usable within government transportation agencies. The results of that research are presented in a final report (NCHRP 483) and the BLCCA program. BLCCA can be used to compute the present value of life cycle cost for alternative sets of bridge management alternatives, including consideration of agency cost for construction and maintenance, user cost related to construction delays, accidents, and detours, and vulnerability cost (risks of damage due to earthquakes, floods, collisions, overloads, and scour). It is designed to support the analysis of individual bridges, as opposed to bridge networks (Hawk, 2003).

The BridgeLCC program is specifically designed to help engineers, material specialists, and budget analysts determine the life-cycle cost effectiveness of their bridge designs and processes. It was developed by the National Institute of Standards and Technology (NIST) in 2003. With BridgeLCC, the user can define a project, and then compiles the cost of building, maintaining, and then disposing of each of these alternatives. Cost components evaluated by BridgeLCC include: project cost incurred by the agency responsible for the structure (agency cost), cost incurred by drivers on the highway that are inconvenienced by bridge construction and other bridge activity (user cost), and cost incurred by third parties who are not direct users of the facility but are impacted by construction and repair activity (third-party cost). Once cost components are compiled, the user can compare the life-cycle cost of the alternative bridges or processes. The alternative with the lowest life-cycle cost, while all other factors being equal, is the cost effective bridge.

The RealCost program was originally developed to support the application of LCCA in the decision-making process for pavement projects by FHWA in 2004. But, with the integration of general LCCA economic principles and the FHWA's powerful capability of user cost calculation, RealCost has also been applied to various transportation fields by state agencies, including bridge projects. RealCost can calculate life-cycle values for both agency and user cost associated with initial construction and future repair or rehabilitation and present results in tabular and graphic format. It can also support deterministic sensitivity analyses and probabilistic risk analyses. Additionally, RealCost automates the method of FHWA's work zone user cost calculation. This method for calculating user cost compares traffic demand to roadway capacity on an hour-by-hour basis, revealing the resulting traffic conditions. This method is also computation intensive and ideally suited to a spreadsheet application.

Methodology

Although three programs are developed based on the same general economic fundamentals of LCCA, each program integrates its unique LCCA methodology and features. For example, BLCCA is integrated with the LCCA principles and methodology outlined by the report of NCHRP Project 12-43, which is a study to develop a comprehensive methodology for life-cycle cost analysis of bridges implemented as a software package for PC-style users. BridgeLCC uses a life-cycle costing methodology based on the ASTM practice for measuring the life-cycle cost of buildings and building systems (ASTM E917) and a NIST cost classification scheme for comparing life-cycle cost of alternatives. The ASTM practice ensures that the cost calculations follow accepted practice. The scheme helps the user account for all project cost, properly categorize them, and then compare breakdowns of the alternatives' life-cycle cost. RealCost, meanwhile, automates the FHWA's LCCA methodology and work zone user cost calculation method.

The specific steps of analysis may be slightly different for each program, but the general steps of three programs can be summarized in a flow-chart (Figure 1). Usually, to perform a LCCA with these programs, the first step is to create a new project, which needs to meet design objectives and performance requirements from the DOTs. The second step is to input the project-level data, which are applied throughout the whole project, like project service life time, discount rate, traffic conditions, etc. In the third step, several alternatives can be created and each of them needs to fulfill project objectives and requirements. Each alternative has its own alternative-level data, e.g., different activities (or events), different timing of activities (or events), different work zone conditions and different agency and user cost, etc. After inputting all of the project-level and alternative-level data, the life-cycle cost analysis can be implemented, either deterministic or probabilistic (if there are probabilistic project-level or alternative-level inputs). The final step is to select the best LCC strategy from alternatives based on the LCCA results from those programs.

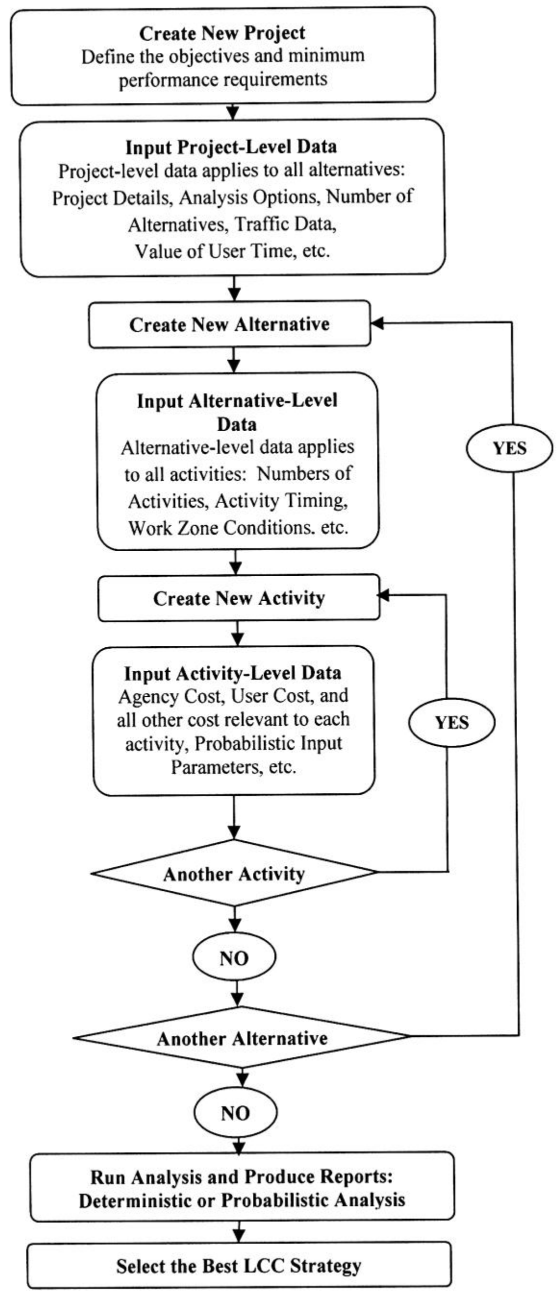

Figure 1: General Analysis Steps for Three Programs

Comparison of Three Programs

This part presents the comparison of three programs. The comparison made majorly based on: 1) Input requirements, 2) Types of cost and analysis, 3) Limitations and strengths.

Input Requirements

The LCCA process requires two levels of information: 1) Data pertaining to the proposed project and 2) Data defining the design alternatives that are being compared for accomplishing the project. Project-level data are applied to all alternatives being considered for the project (e.g., bridge information, project objectives, base year, the analysis period, discount rate, traffic profile, normal traffic flow data, value of user time, etc.). The best LCCA practice methodology by FHWA requires that the analysis period, discount rate, normal operations traffic data, and normal operations roadway geometry be the same for all alternatives (FHWA, 2004). Alternative-level data defines the differences between project alternatives (e.g., definition of activities or events, agency and user cost data associated with activities, and work zone specifics for each component activity, etc). Turning to the specific program, BLCCA needs the user to input two types of analysis assumptions: primary models and cost models. BridgeLCC requires the user to define the elements of bridge structures and dimensions, like deck, superstructure, substructure, etc. RealCost is found to require the most detailed inputs for user cost calculation, including traffic flow parameters, hourly traffic distribution, work zone conditions, the value of user time, and added stopping costs. Those detailed inputs produce correspondingly the most accurate and detailed breakdown user cost, compared with the other two programs.

Types of Cost and Analysis

From the comparison, each program can perform most types of the analysis and some program can produce one or two unique types of cost than other programs, as shown in Tables 2 and 3. BLCCA uses more systemic but also more complicated models in its life-cycle cost analysis, compared with other programs. There are two types of models in BLCCA: Primary Models and Cost Models. The primary models are used to forecast physical conditions of the bridge, which include the Average Daily Traffic, the Condition Index and the Load Capacity. While the cost models are used to predict the actual expenses expected during the life of the structure, which are comprised of two basic categories, during event cost and after event cost, including user cost, vulnerability cost and distributed agency cost. Although the results of life-cycle cost from BLCCA may be more accurate on the condition that the user has very strong background in the life-cycle cost analysis and make the good decision for every single cost model, it would be too hard for a regular bridge engineer in this decision-making process of choosing models and the results would have relatively large deviations based on the knowledge of individual bridge engineers. BridgeLCC allows bridge engineers to input a detailed cost breakdown of initial construction and future events based on their estimate of the quantities of materials needed for the bridge and unit cost from bid drawings and previous working experience. Bridge engineers can organize those cost into initial construction cost, operation, maintenance, and repair (OM&R) cost, and disposal cost. They are quite familiar with those types of cost, since they are using them frequently in their daily work. But BridgeLCC has a very poor function to calculate user cost and only present it in a preliminary total amount, not in detailed breakdown cost.

For bridge pile repair projects, the initial construction cost would not be considered as a significant factor by state agencies, while user cost incurred by repair activities would become a main concern to state DOTs and play an important role in the decision process to choose appropriate repair strategies. RealCost incorporates a component of detailed user cost analysis and has a powerful capacity to calculate user cost as one of its unique features, compared with BLCCA and BridgeLCC. RealCost provides a detailed breakdown of user cost for each alternative of the initial construction and each future rehabilitation or reconstruction during the life-cycle term. To perform this task, RealCost includes seven user cost components which can be divided into two categories: (1) Three components associated with a base case situation where traffic operates under free-flow conditions: Work Zone (WZ) Speed Change Vehicle Operation Cost (VOC), WZ Speed Change Delay, WZ Reduced Speed Delay; and(2) Four components are associated with a queue situation where traffic operates under forced-flow conditions: Queue Stopping Delay, Queue Stopping VOC, Queue Added Travel Time, and Queue Idle Time. FHWA provides an approach for actually quantifying and costing the individual work zone user cost components encountered (FHWA, 2004).

Based on that approach, RealCost can calculate these mentioned components of user cost for each activity and each alternative.

Table 2: Analysis Types for Three Programs

Comparison of Analysis Types			
Type of Analysis	**BLCCA**	**BridgeLCC**	**RealCost**
Life-cycle cost analysis	Applicable	Applicable	Applicable
Probabilistic analysis	Applicable	Applicable	Applicable
Sensitivity analysis	Applicable	Applicable	Applicable

Table 3: Cost Types for Three Programs (Note: N/A - Not Applicable)

Comparison of Cost Types			
Cost	**BLCCA**	**BridgeLCC**	**RealCost**
Agency Cost	Applicable	Applicable	Applicable
User Cost	Applicable	Applicable	Applicable
Life Cycle Cost	Applicable	Applicable	Applicable
Present Value Cost (PVC)	Applicable	Applicable	Applicable
Equivalent Uniform Annual Cost (EUAC)	N/A	N/A	Applicable

An example case presented herein is originally included in the user manual of BridgeLCC and then adopted by the user guide of BLCCA to provide a comparison of results and procedures used by two programs for calculation of the same life-cycle cost. The results of this case by RealCost will be also provided here and compared with those from BLCCA and BridgeLCC. In this case, "…an engineer is making a preliminary design of a highway bridge and is considering two alternative types of concrete. The base case concrete is the conventional mix currently used by the engineer. The alternative concrete mix is high-performance concrete that the engineer has not used before. But, it should produce stronger and more durable bridge members. The engineer wants to determine which material is more life-cycle cost effective for this situation (NCHRP, 2003; Ehlen, 2003)." The engineer is considering two alternatives for this case, as shown in Table 4.

Table 4: Description of Two Alternatives (Adapted from user manuals of BLCCA and BridgeLCC) (NCHRP, 2003; Ehlen, 2003)

Case	**Description**
Base Case: Conventional Mix	7 Beams Deck Repairs at years 25&50 Year 75 Demolition
Alternative Case: High-Performance Concrete Mix	5 Beams Deck Repairs at year 49 Year 75 Demolition

The base alternative, Conventional Concrete, involves four activities and each activity lasts one year (or less), while only three activities happen in the second alternative (High-Performance Concrete). The activities and their corresponding cost are shown in Table 5. After inputting all of the LCCA parameters and creating the alternatives by following appropriate procedures of each program, the results from all three programs are shown in Table 6. Unlike the other two programs only providing the user cost in a total number, RealCost has the ability to present the user cost in a detailed breakdown components (see Table 7).

Table 5: Activities and Cost (Adapted from user manuals of BLCCA and BridgeLCC) (NCHRP, 2003; Ehlen, 2003)

Base Case: Conventional Concrete		
Activity	Description	Cost
Activity 1	Initial Construction	$678,478
Activity 2	Deck Repair 1@YR 25	$52,800
Activity 3	Deck Repair 2@YR 50	$52,800
Activity 4	Demolition @YR 75	$80,000
Alternative Case: High-Performance Concrete		

Activity 1	Initial Construction	$652,478
Activity 2	Deck Repair @ YR 40	$52,800
Activity 3	Demolition @YR 75	$80,000

Table 6: LCCA Results in Present Value from Three Programs

(Present Value:$)	**Base Case**	**Alternative Case**
	Agency Cost	**Agency Cost**
BLCCA	$689,390	$647,277
BridgeLCC	$715,496	$671,761
RealCost	$709,248	$666,188
	User Cost	**User Cost**
BLCCA	$8,547	$3,771
BridgeLCC	$8,874	$3,914
RealCost	$8,468	$3,598
	Total Cost	**Total Cost**
BLCCA	$697,937	$651,048
BridgeLCC	$724,370	$675,675
RealCost	$717,716	$669,786

Table 7: Detailed User Cost Component Results from RealCost (Base Case)

Cost Components	**Cost**	**Percent**
WZ Speed Change VOC	$19.05	0%
WZ Speed Change Delay	$6.36	0%
WZ Reduced Speed Delay	$330.25	4%
Queue Stopping Delay	$152.42	2%
Queue Stopping VOC	$1,016.16	12%
Queue Added Travel Time	$5,504.2	65%
Queue Idle Time	$1,439.56	17%
Total Cost	**$8,468**	**100%**

Assessment of Three Programs

The strengths and limitations of each program have been identified from the comprehensive study and presented in Table 8. RealCost has been determined as the most suitable and adaptable LCCA program for bridge repair projects, based on the following strengths:

(1) The most powerful capability of user cost: Traffic disruptions, accidents, local businesses disruptions, increased vehicle operating costs in terms of fuel consumption and vehicle repair costs, increased travel time, and pollution can lead to high user cost which can have a detrimental impact on the competitiveness of local and even national economies (Salem and Genaidy, 2008). Hence, it is very important to factor these user cost in when making decisions on bridge repair projects. RealCost is able to compute seven possible user cost components and present them in breakdown detailed cost.

(2) The simplest user interface and operations among three programs: RealCost is developed from Microsoft Excel spreadsheet, which is widely used by DOT engineers in their daily working environment and they are very familiar with its interface.

(3) The most versatility among three programs to be customized for special needs from DOTs: RealCost is developed based on Microsoft Excel spreadsheet, which makes it the most versatile software among three programs. It can be relatively easily customized and enhanced for the local DOT's requirements. It was found that California, Indiana, Quebec, Maryland and Louisiana are using RealCost to perform their life-cycle cost analysis (Salem and Genaidy, 2008). RealCost is also much more easily tailored to local bridge repair projects when needed.

(4) The abundant references, maintenance, and updates from FHWA: RealCost is kept being updated since its first release and the most recent version is always available on the FHWA website. FHWA also provides on-line classes or on-site training during the year.

Conclusions

Life-Cycle Cost Analysis accounts for the effects on users by the agency's construction and maintenance activities, as well as the direct cost to the agency. Hence, LCCA provides a powerful economic tool for the agency in determining the lowest life-cycle cost way to accomplish the project from several alternatives.
In this paper, three federal-level LCCA computer programs (BLCCA, BridgeLCC and RealCost) have been evaluated and compared comprehensively, with the emphasis on their adaptability and suitability to bridge pile repair projects. Based on the preceding comparisons of their integrated LCCA methodology, life-cycle cost types to be evaluated, and strengths and limitations of each program, RealCost is determined as the most suitable one to perform a LCCA for bridge pile repair projects, based on the following main features: (1) the powerful user cost computing capability, (2) the simple user interface and operations, (3) the versatility to be tailored for local agencies' needs, and (4) the abundant supports, references and updates from FHWA. Currently, RealCost has been widely accepted in the transportation field throughout the U.S. and Canada. It was found that state agencies of California, Indiana, Quebec, Maryland and Louisiana are using RealCost as a main tool to perform their LCCA, even though they still apply the program to major infrastructure projects. For state agencies, implementing RealCost to perform a LCCA for their bridge pile repair projects is at a minimal cost and without any need of developing a new LCCA program.

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Table 8: Assessment of Three Programs

	BLCCA	BridgeLCC	RealCost
Strength	• Optional interface with standard NBI file. • Incorporates North Carolina user cost models for accidents and detour cost, and Bridgit models for load capacity changes. • Includes many graphic displays of results.	• BridgeLCC is specifically tailored for comparing conventional bridge materials with alternative materials (for example, conventional concrete versus high-performance concrete). • BridgeLCC has an easy-to-use interface that enables designers to view the life-cycle cost for project alternatives from different perspectives, such as that of cost holders (Agency cost or user cost), bridge components, application of new technologies, and cost timeline. • BridgeLCC may be extended to the analysis of pavements, piers, and other civil infrastructure, besides bridge structures.	• RealCost has been keeping updated since it was released in 2003. It has the best compatibility among three programs. • FHWA provides abundant resources to the users: manuals, presentations, best case practices, learning classes (online or on-site), etc. • RealCost incorporates a powerful tool to calculate user cost. • RealCost is developed from the Microsoft Excel program, which has been used daily and widely in the current office environment. • RealCost is also easily to be tailored to meet the individual state's needs, when taking into consideration regional factors.
Limitation	• Obsolete software platform and poor compatibility with current Windows 7 system. • Never being updated since the initial release in 2003. • Users must specify every event and its impacts in detail; no simulation capability for condition-based triggers of events. • Reliable results depend on agencies’ ability to research and develop appropriate model parameters and other inputs.	• BridgeLCC has only a poor capability to calculate work zone user cost: The user can not specify user cost based on his own calculation and the program only shows user cost in total. The parameters of work zone conditions are limited in the program. • The program has not been updated since September 2003. • The program cannot be customized to meet the requirements of local state agencies.	• One of the drawbacks of this software is the lack of support for the analyst in the design of work zones (Flintsch and Kuttesch, 2004). The analyst must have specific knowledge of work zone characteristics to perform an analysis using RealCost.