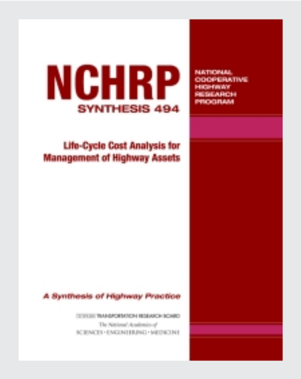

Life-Cycle Cost Analysis for Management of Highway Assets

DETAILS

35 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-27219-3 | DOI 10.17226/23515

AUTHORS

Aimee Flannery, Jessica Manns, and Marie Venner; National Cooperative Highway Research Program Synthesis Program; Synthesis Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

NCHRP

SYNTHESIS 494

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Life-Cycle Cost Analysis for Management of Highway Assets

A Synthesis of Highway Practice

TRB TRANSPORTATION RESEARCH BOARD

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 494

Life-Cycle Cost Analysis for Management of Highway Assets

A Synthesis of Highway Practice

Consultants
Aimee Flannery
Jessica Manns
Applied Engineering Management Corporation
Herndon, Virginia
and
Marie Venner
Venner Consulting
Lakewood, Colorado

Subscriber Categories
Finance • Highways • Hydraulics and Hydrology

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2016
www.TRB.org

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communication and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP SYNTHESIS 494

Project 20-05 (Topic 46-15)
ISSN 0547-5570
ISBN 978-0-309-27219-3
Library of Congress Control No. 2016933438

COPYRIGHT INFORMATION

NOTICE

The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the National Academies of Sciences, Engineering, and Medicine.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board; the National Academies of Sciences, Engineering, and Medicine; or the program sponsors.

The Transportation Research Board; the National Academies of Sciences, Engineering, and Medicine; and the sponsors of the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:
http://www.national-academies.org/trb/bookstore

Printed in the United States of America

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, non-governmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Ralph J. Cicerone is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. C. D. Mote, Jr., is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.national-academies.org**.

The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to increase the benefits that transportation contributes to society by providing leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied committees, task forces, and panels annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

Learn more about the Transportation Research Board at **www.TRB.org**.

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

Tanya M. Zwahlen
Consultant
Transportation Research Board

NCHRP Synthesis 494 documents the state of the practice of state highway agencies related to their incorporation of life-cycle cost analysis (LCCA) and risk-based analysis into their asset management plans for pavements and bridges on the National Highway System. The objective of this project was to develop an inventory of quantitative asset-level, project-level, or corridor-level processes and models for predicting life-cycle costs associated with the preservation and replacement of highway assets. The report includes a literature review, a survey of highway agencies, and case studies that document specific highway agency experiences with LCCA.

Aimee Flannery and Jessica Manns, Applied Engineering Management Corporation, Herndon, Virginia, and Marie Venner, Venner Consulting, Lakewood, Colorado, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

LIFE-CYCLE COST ANALYSIS FOR MANAGEMENT OF HIGHWAY ASSETS

SUMMARY

MAP-21 (the Moving Ahead for Progress in the 21st Century Act) requires agencies to incorporate life-cycle cost analysis (LCCA) and risk-based analyses into their asset management plans for, at a minimum, pavements and bridges on the National Highway System (NHS) and encourages similar proactive management of other transportation assets. To assist highway agencies in this task, this study was developed to provide insight as to the state of the practice of LCCA and the activities of state highway agencies. The objective of this project was to develop an inventory of quantitative asset-level, project-level, or corridor-level processes or models for predicting life-cycle costs associated with the preservation and replacement of highway assets, through a literature review, nationwide survey of highway agencies, and case studies that documented specific highway agency experiences with LCCA.

The literature review provided an overview of the typical costs included in LCCA. Challenges associated with including these costs in LCCA are also documented. The most noted hindrance to LCCA application or use appears to be the lack of information and data needed to support the analysis for assets other than pavements and bridges (e.g., ancillary assets). In addition, it is noted that although many, if not most, highway agencies are using LCCA to manage their pavement programs, many report challenges with including user costs. One potential approach to improving LCCA application to ancillary assets may be the use of a tiered approach to LCCA. In such an approach, higher capital cost assets that typically require routine maintenance and rehabilitation to extend their life may require more rigor and data to support an LCCA as compared with assets such as traffic signal systems that may require substantially less maintenance and are not anticipated to benefit from rehabilitation. This type of approach was demonstrated through the work documented on the LCCA of advanced traffic management systems and ramp metering systems in chapter two.

A thorough literature search allowed for the documentation of available LCCA tools by application level (asset, project, and program or network level) as defined in this report's glossary of terms. As anticipated, pavements and bridges appear to be the most widely analyzed using LCCA; however, models for other ancillary assets, including roadway barriers and culverts, were also identified and documented. Most state customization focused on the development of deterioration curves that better reflect individual state agency experience. Although FHWA has noted that the applications contained in their tool RealCost can be applied to a range of assets, few studies were identified that documented the use of the tool to analyze assets other than bridges and pavements. One study of note utilized LCCA to fully analyze the cost–benefit ratios associated with typical installations of adaptive traffic control systems and ramp metering systems. The authors captured costs associated with these systems in terms of infrastructure costs, incremental costs, and operations and maintenance costs and expanded the study to include documentation of the benefits of these systems. The approach used in this study provides a solid foundation on which agencies could begin to analyze the LCCA of Intelligent Transportation System technologies.

International studies revealed a similar focus on pavements and bridges for LCCA applications, and an emphasis on the resulting environmental impacts of design alternatives was noted. Some countries are in the early stages of framework development to support LCCA and are beginning to document the approach to the process as well as implications to public infrastructure investment.

Building on the findings of the literature review, a national survey of state highway agencies was conducted. The primary purpose of the survey was to identify LCCA applications within state highway agencies and to determine challenges and data needs as provided by the survey respondents. In addition, the survey was viewed as a screening tool to identify those state highway agencies that are applying LCCA and that were interested in participating in the case development stage of the study. The survey was sent to members of the AASHTO Standing Committee on Asset Management and extensive efforts were made to increase survey participation. In the end, 41 state highway agencies participated in the survey—a response rate of 82%.

According to the survey results, LCCA is currently being used by most state highway agencies for pavement and bridge management at all application levels. LCCA is most often being used as part of the decision-making process for analyzing asset-level design alternatives. Currently, 16 state agencies are using specialized software to assist with these LCCA applications. Most notably, the survey results showed that capital costs, maintenance costs, inspection/support costs, and user costs are the most common factors considered in LCCA analysis by state highway agencies. On the other hand, very little consideration is currently being given to the incorporation of resilience goals and uncertainty/risk factors into LCCA applications.

Since the purpose of this survey was to identify challenges in applying LCCA, it is important to focus on what factors and data state agencies reported to be lacking in order to properly perform LCCA or improve existing LCCA. Deterioration curves/models, uncertainty/risk, and resilience goals were reported as lacking available data to perform LCCA. Knowledge gaps also exist regarding salvage value and remaining service. According to the state agencies surveyed, there is a significant lack of data available at this time to properly perform LCCA applications for assets beyond pavements and bridges.

Five case examples were developed as part of this study, which documents the LCCA experiences of several states and one concessionaire. LCCA use in Utah for pavement management was documented, including its use of LCCA to highlight the need for additional resources to meet the demands of deteriorating pavement assets. Next, the efforts put forth by Florida Department of Transportation to calibrate bridge maintenance recommendations were documented in a case example that included the benefits of the calibration process to allow for better allocation of maintenance dollars given the ability to delay some maintenance and rehabilitation efforts. The data gathered through in-field inspections over a period of several years allowed researchers to recalibrate their deterioration curves to better align with field conditions, allowing for the delay of some maintenance expenditures. Washington State DOT's (WSDOT's) Maintenance Division is highlighted in the next case example. WSDOT has been crafting an evidence-based approach to maintenance priority-setting, budgeting, and legislative requests for many years, in addition to an ongoing government quest for efficiency. Short of having a comprehensive cradle-to-grave LCCA system in place at WSDOT, the Maintenance Division is doing what it can within its purview. Maintenance is working partially in coordination with other programs such as Design, Construction, and Preservation to create and implement the building blocks of LCCA-based management. Similarly, Minnesota DOT's (MnDOT's) HydInfra is documented through a case example. HydInfra stands for "Hydraulic Infrastructure" and is the culvert and storm drainage system inventory and inspection program MnDOT has developed for pipes with spans shorter than 10 ft. To support risk analysis and life-cycle cost assessment for culverts, MnDOT recently completed an extensive culvert repair cost data collection effort. Finally, the experiences of a private-sector company involved in many public–private highway ventures were documented. The differences between LCCA within state highway agencies and within the private sector are captured in the case example, including the most notable difference: the way the private sector views assets from a holistic systematic view instead of as independent asset classes when conducting LCCA.

Research needs that were identified through this effort include the need for more tools and guidance for agencies to apply LCCA to assets other than pavements and bridges. Although research appears to exist for specific components of LCCA, a central location that agencies can access for all of the information and example applications from their peer states is lacking. In particular, lessons learned about calibration of deterioration curves point to the need to provide better guidance to states about the importance of maintenance and performance records, to better align actual asset performance over time to all important deterioration curves, which drive much of the outcome of LCCA. Also, the benefits of LCCA for ancillary assets need to be better researched and documented. Suggestions were also made about the use of a tiered LCCA approach to remove some of the burden from capturing the costs associated with some assets that have shorter life spans and lower maintenance and rehabilitation costs, to facilitate expanded LCCA use.

CHAPTER ONE

INTRODUCTION

BACKGROUND

MAP-21 (the Moving Ahead for Progress in the 21st Century Act) requires agencies to incorporate life-cycle cost analysis (LCCA) and risk-based analyses into their asset management plans for, at a minimum, pavements and bridges on the National Highway System (NHS) and encourages similar proactive management of other transportation assets. LCCA takes into account "the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment" (*1*). LCCA allows agencies/owners to better understand the true cost of assets that take into account not only initial capital investment but also costs incurred by the traveling public as well as the costs associated with the ongoing maintenance requirements of various asset designs. Figure 1 provides a visual interpretation of the typical costs associated with LCCA.

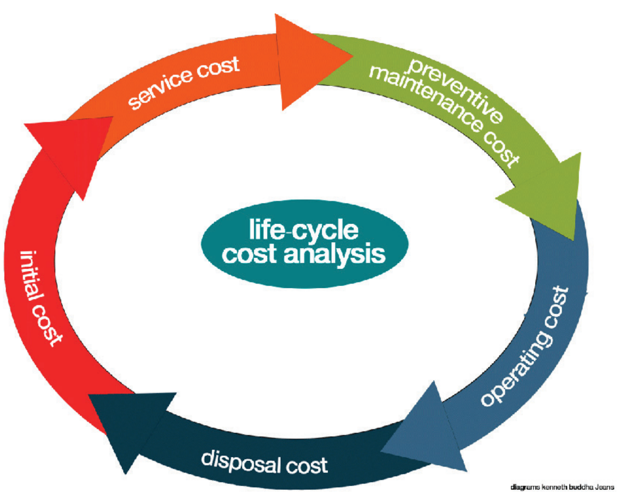

FIGURE 1 Typical costs associated with life-cycle cost analysis (*Source*: Kenneth Buddha).

LCCA, whereas most often utilized at the project planning and preliminary engineering stages, has several noted applications including the following:

- Helping to select the most effective alternative to meet a project objective, such as replacing a bridge;
- Evaluating a design requirement within a specified project, such as pavement types;
- Comparing overall costs between different types of projects to help prioritize limited funding in an agencywide program; and
- Calculating the most cost-effective approaches to project implementation (*2*).

The objective of this synthesis project was to document LCCA use by state highway agencies and the challenges faced by agencies when applying LCCA. In addition, an inventory of quantitative asset-level, project-level, or corridor-level processes or models for predicting life-cycle costs associated with the preservation and replacement of highway assets was captured through a literature review, nationwide survey, and development of five case examples.

STUDY APPROACH AND REPORT ORGANIZATION

This study utilized multiple methods to gather information related to LCCA use for highway assets including the following:

- A literature review of state, local, and international practices related to LCCA
- A survey of highway agency asset management staff
- Interviews with highway agency asset management staff.

Information gathered through the data collection methods has been incorporated into the following structure within this report:

Chapter two – State of the Practice of Life-Cycle Cost Analysis Tools and Models

Chapter three – Agency Perspectives on Life-Cycle Cost Analysis

Chapter four – Case Examples on the Use of Life-Cycle Cost Analysis

Chapter five – Findings, Conclusions, and Future Research Needs

In the next chapter, the state of the practice of LCCA tools is reviewed to help provide a solid foundation for the further discussion contained in later chapters.

CHAPTER TWO

STATE OF THE PRACTICE OF LIFE-CYCLE COST ANALYSIS TOOLS AND MODELS

This chapter summarizes the findings of the literature review tools and models used in LCCA for highway asset management. Efforts were made to capture the state of the practice in terms of tools and models for LCCA domestically and internationally. In addition, information is provided on the primary costs and factors utilized in LCCA and the variability of these throughout the practice.

COMMON ELEMENTS OF LIFE-CYCLE COST ANALYSIS

In this section, the typical elements of LCCA are reviewed along with some of the commonly noted challenges of each.

User Costs

One of the great advances in public-sector infrastructure management and decision making has been the more widespread assessment and inclusion of user costs when comparing options and making design, construction, and maintenance decisions. User costs associated with work zones are of particular interest. The costs associated with work zones include delays, vehicle operating costs, and costs associated with vehicle crashes. When performing maintenance activities, a lane closure is often necessary. This lane closure directly affects user costs. In sum, the user costs amassed from work zones associated with each design alternative may differ substantially and, as such, it is important that the inclusion of user costs be considered in LCCA analysis to truly reflect the overall costs of each design alternative over the life of the alternative. A study conducted for South Carolina Department of Transportation in 2008 found that of the 33 state highway agencies that responded to an industry survey, approximately 60% of the respondents did not include user cost in LCCA, although three states noted their plans to include user costs in the future (*3*). This sentiment was echoed in the survey of state highway agencies described in chapter three.

Agency Costs

Agency costs fall into four categories: initial construction costs (capital costs), maintenance costs, preservation costs, and rehabilitation costs. Initial construction costs are the initial expenditures made by an agency to construct a project. Based on a review of relevant literature, capital costs are among the most commonly incorporated costs in LCCA; however, uncertainties with data quality and incomplete data still exist (*4*). Maintenance costs are a critical factor in completing an accurate LCCA. These costs include future maintenance needed to prolong the service life of an asset and meet performance requirements set forth by highway agencies. As with capital costs, the uncertainties associated with maintenance costs include uncertainties with unit costs, confidence in engineering judgment, and quality of data (*5*). In chapter five of this document, efforts under way by Washington State DOT to improve maintenance information and costs are reviewed. This review may provide additional insight into one approach to improve the confidence of maintenance costs as applied in LCCA.

Preservation activities are increasingly being implemented throughout an asset's service life to ensure the greatest service life extension possible. These activities differ from maintenance and rehabilitation activities in that preservation activities are performed to prevent any deficiencies before they begin to surface. As a relatively optimal activity, many agencies may have an ideal preservation implementation schedule but mainly implement preservation projects as funds are available. Uncertainty with preservation costs, as with most costs, often comes from a lack of reliable or consistently collected data. Rehabilitation costs address maintenance needs that are more extensive than routine maintenance activities. As with maintenance activities, rehabilitation activities are an important and often a costly part of a project life cycle. The duration and timing of rehabilitation activities will greatly affect a project's overall life-cycle costs and must be obligated and proactively planned for to optimally and cost-effectively maintain an asset over its service life. Figure 2 provides an overview of the life-cycle costs associated with highway assets.

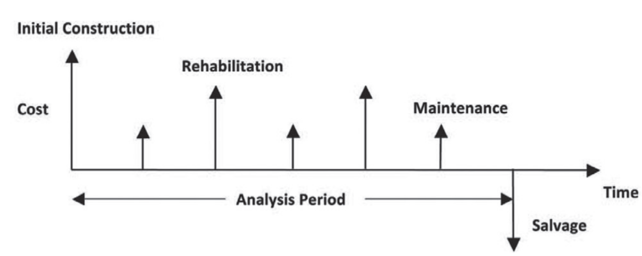

FIGURE 2 Life-cycle costs associated with highway assets.

At the end of a project's service life, after it's been determined it is no longer cost-effective to extend the life or improve the performance, the raw materials may be recycled to net a monetary gain or produce a beneficial value to a state DOT. This monetary gain is known as salvage value and can be included in an LCCA. It is very difficult to quantify the value returned to a state DOT in the recycling of materials at the end of a project's service life; however, this information can be gleaned from disposal costs or from an estimate of the value of the steel, asphalt, or concrete as an input to another construction project. Highway agencies are increasingly trying to calculate the remaining service life in their existing assets and the life extensions that accrue with the previously described maintenance treatments. Costs applied for maintenance treatments and preservation activities are included in the remaining service value. Furthermore, when the service life of a design alternative under consideration extends beyond the period of analysis, it is important to capture this remaining period using some value. With the lack of confidence in a project's service life, the inclusion of remaining service life value proves difficult and few agencies have tailored estimates of remaining service life based on their own experiences.

Tools and models have been developed and utilized within the highway industry to estimate life-cycle costs and provide a mechanism to compare design alternatives, to take into account all costs associated with each design. An overview of the tools and models most often used in the highway industry are reviewed in the next section.

LIFE-CYCLE COST ANALYSIS TOOLS AND MODELS

In 2011, a survey of agency LCCA tools for highway projects was completed by researchers for California Department of Transportation (Caltrans) (*6*). Seventeen states participated in the study and provided information on the types of tools and models utilized for LCCA. Of the respondents, five states reported using FHWA's RealCost, three states developed custom LCCA software, three states use custom spreadsheets, one state uses both AASHTO's DARWin program (recently renamed AASHTOWare Pavement ME DesignTM) and custom software, and five states did not specify a tool for LCCA estimation (*6*).

Pavement LCCA Tools

RealCost is a software designed to assist agencies with pavement design but is often touted as being applicable to other asset classes for LCCA. RealCost is available as a free download from FHWA's website and consists of a Microsoft Excel 2000 worksheet with additional Visual Basic for Applications (VBA) code. The VBA code provides the ability to perform Monte Carlo simulation in the analysis to incorporate probability distributions for a number of factors incorporated in LCCA. RealCost can perform LCCA in a deterministic or probabilistic manner. The deterministic approach requires the user to input the required data as discrete values, whereas the probabilistic approach allows the user to apply one of seven distributions to multiple input factors including the following:

- Discount rate
- Annual growth rate of traffic
- Free flow capacity
- Value of time for passenger cars
- Value of time for single unit trucks
- Value of time for combination trucks
- Agency construction cost
- User work zone costs
- Maintenance frequency
- Activity service life
- Agency maintenance cost
- Work zone capacity
- Work zone duration.

Users electing to utilize a probabilistic approach to LCCA estimates may choose between seven distributions:

- Uniform
- Normal
- Log normal
- Triangular
- Beta
- Geometric
- Truncated normal
- Truncated log normal.

The deterministic approach assigns each LCCA input variable a fixed, discrete value (*5*). The analyst using this approach assigns values based on historical costs or professional judgement to determine the value most likely to occur for each LCCA input parameter (*5*). Traditionally, this approach has been the one most used to perform LCCA. The deterministic approach makes LCCA straightforward, making the process easy to accomplish with a calculator or a spreadsheet (*5*). The input values used in this approach provide a single life-cycle cost estimate that is not reflective of the variability of input factors and does not demonstrate the uncertainty often associated with LCCA.

Unlike the deterministic approach, the probabilistic approach relies on a frequency, or probability, to determine the value of the individual analysis inputs (*5*). This type of analysis can compute results that describe their likelihood of occurrence while simultaneously factoring in different variable assumptions. For example, Colorado Department of Transportation uses RealCost's Monte Carlo simulation to randomly sample from probability distributions for each input.

NCHRP Report 703: Guide for Pavement-Type Selection (*7*) provides some insight into LCCA for pavements. The guidance document includes a chapter specifically related to

LCCA and provides additional information on deterministic and probabilistic approaches to estimating life-cycle costs. The guide also provides information on determining specific inputs for pavements including salvage value (i.e., remaining service life and residual value), indirect/user costs, and direct/agency costs. Suggestions for data sources to support an LCCA of pavements are also provided.

Some state highway agencies have made investments to customize RealCost. Caltrans has customized RealCost to reflect its design and operating conditions including updates to the traffic data module to reflect traffic patterns from its own historical databases; the addition of cost estimating modules based on historical bid databases and design procedures; and the addition of graphical user-friendly interfaces to integrate service life, maintenance frequency, and agency costs that reflect project constraints (*8*). Caltrans has continued to invest in the customization of RealCost and recently released RealCost2.5CA, which includes automated cost calculation modules to estimate future maintenance and rehabilitation costs based on construction scope and pavement type. The enhancements were made to improve the efficiency of LCCA use, which has led to the adoption of RealCost2.5CA as an official LCCA tool to comply with regulatory requirements for California state highway projects (*9*).

Indiana DOT also has made enhancements to RealCost, including improvements to the cost estimating module to be reflective of line items and unit rates based on historical data, inclusion of default or user-defined strategies for pavement preservation, and improved graphics for reporting analysis results. In particular, Indiana DOT also made changes to the tool to allow analysis to be completed for more than two pavement design and preservation alternatives at a time (*10*).

Researchers in Nebraska have published a study applying RealCost for bridge management (*11*). The objective of the study was to assess maintenance strategies using LCCA for deck overlay decisions, expansion joint replacement decisions, and deck widening versus deck replacement decisions. RealCost was used with updated deterioration and cost data based on Nebraska bridge performance using both deterministic and probabilistic modeling techniques. Several conclusions were drawn based on the analysis that supports LCCA use for bridge management.

AASHTO has invested in pavement design software since the release of the computerized version of the *1993 AASHTO Guide for Design of Pavement Structures* referred to as AASHTOWare® DARWin 3.1™ – Pavement Design and Analysis System. DARWin has been replaced by new software, and in 2014 TRB published *NCHRP Synthesis 457: Implementation of AASHTO Mechanistic-Empirical Pavement Design Guide and Software,* which documents the use of the 2011 software AASHTOWare Pavement ME Design™ (*12*). The software documented in the synthesis is based on the 2008 AASHTO *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice* (*MEPDG*) and is a significant departure from previous procedures and software, which were empirically based. A summary of the models and procedures included in the software are documented in detail in *NCHRP Synthesis 457* and are summarized here. The software is considered an analysis tool because the designer must note different properties of the various layers of the pavement design including the binder type and aggregate structure. The modules of the software include the following:

- General design inputs
- Performance criteria
- Traffic
- Climate
- Asphalt layer design properties
- Concrete layer design properties
- Pavement structure
- Calibration factors
- Sensitivity
- Optimization
- Reports.

The study also included a survey of 57 highway agencies to determine the use of MEPDG and accompanying software. The survey revealed that, at the time, three agencies had fully implemented MEPDG, whereas another 46 indicated they were in the process of implementing MEPDG and eight indicated they had no intention of implementing MEPDG. Agencies indicated using MEPDG for the design and analysis of new or reconstructed asphalt pavements and jointed plain concrete pavements as well as asphalt and concrete overlays.

In February 2015, the Louisiana Transportation Research Center published the results of a pooled-fund study, TFP 5(242), which developed a full-production software titled Prep-ME to assist agencies with data preparation required to run MEPDG. The product includes comprehensive database features capable of preprocessing, importing, checking the quality of raw Weigh-In-Motion traffic data, and generating three levels of traffic data inputs with clustering analysis methods for Pavement ME Design (*13*). The authors state that their product will help to improve the data preparation, management, and workflow of the Pavement ME Design input data module.

Bridge LCCA Tools

The same 2011 agency survey found that the most common tools for bridge LCCA used BridgeLCC (National Institute of Standards and Technology) and Bridge Life Cycle Cost Analysis (BLCCA) (*6*). BridgeLCC, developed in 2003 by Mark A. Ehlen, is based on the ASTM practice for measuring the life-cycle costs of buildings and building systems, ASTM E 917 (*14*). BridgeLCC primarily is used to compare project alternatives; however, BLCCA can be applied to networks (*14*, *15*).

BLCCA was developed under NCHRP Project 12-43 as an engineering-oriented analysis tool that includes cost models for agency, user, and vulnerability costs. The vulnerability cost models align nicely with risk-based asset management needs in that the potential costs of damage resulting from natural threats such as earthquakes, scour, and flooding can be determined, as well as direct threat costs such as collision, overload, or fatigue. These costs are calculated by multiplying the potential cost of a particular type of damage, such as seismic displacement or scour, by the likelihood of that damage occurring.

AASHTO's Pontis Bridge Management System was recently renamed AASHTOWare Bridge Management (BrM) and appears to be the most researched bridge management software. Florida and Virginia DOTs also published refinements of the software based on publicly available publication databases. Pontis is based on a relational database management system that provides a mechanism to analyze structures at the element level including girders, joins, decks, and railings. Pontis supports the entire bridge management life cycle, from inventory to inspection, performance assessment, strategy development, and project and program growth (*16*). Researchers in Virginia utilized information from bridges on the Interstate System in Virginia to develop new deterioration models. Further research revealed the need to improve data collection and recording practices for maintenance activities to better model bridge performance. Florida researchers have made significant investments to improve the deterioration models within Pontis to better reflect the field deterioration of bridge elements in the state (*17*). In addition, efforts have been made to address the threat of natural and man-made hazards in the state's bridge management system including hurricanes, tornadoes, floods and scour, and wildfires, as well as advanced deterioration, fatigue, collisions, and overloads. Efforts included the incorporation of risk models for each hazard, which helped the agency identify the types of bridges and specific bridge elements that are most at risk within the state.

Customized Tools

Several agencies have developed custom LCCA spreadsheets or applications, often to access external data repositories to support the analysis (*18*). Two of the states in the 2011 survey had made their custom LCCA spreadsheets publicly available. Chapter five contains additional information about the efforts undertaken by Florida DOT to customize LCCA tools to reflect its assets performance and costs. Next, an overview of experience with LCCA applied to ancillary assets is provided.

LCCA Tools—Ancillary Assets

Although information is widely published on state highway agencies implementing and calibrating pavement models to support LCCA and documented LCCA use in bridge management programs, very few published studies can be identified to document LCCA use for ancillary assets. Although some documentation exists on LCCA use for ancillary assets including Intelligent Transportation System (ITS) technologies, fleet vehicles, and road barriers, documentation that addresses state highway agencies implementing these methodologies within their organization is limited (*19*, *20*). A review of one study that documents LCCA for ITS investment is included here.

Researchers from Syracuse University developed a comprehensive cost–benefit framework to evaluate ITS investments ranging from life-cycle cost analysis to the benefits derived from the systems from users and agencies. Researchers studied the LCCA and benefits anticipated from both adaptive traffic control systems and ramp metering systems. Costs included in the LCCA included infrastructure costs, incremental costs, and operating and maintenance (O&M) costs. Life span was assumed to be 20 years and a fixed discount rate of 7% was utilized in the study. Salvage value was ignored, given the limited information on the value of ITS equipment at the end of service life. Infrastructure costs included infrastructure equipment, software installations, and labor cost for installing and operating the system. Incremental costs included changing and updating signal controllers, communication lines, loop detectors, and so forth, based on a fixed schedule. O&M costs were reported to vary by system complexity. The authors also developed additional models to capture the benefits provided by adaptive traffic control systems and ramp metering systems. The study provides information to agencies seeking to expand their LCCA to ancillary assets, including adaptive traffic control systems and ramp metering systems, and provides average cost and benefit information that may be useful for planning purposes (*21*). Next, international experiences with LCCA are reviewed.

LIFE-CYCLE COST ANALYSIS INTERNATIONAL STUDIES

A study in Switzerland performed an environmental life-cycle assessment and life-cycle analysis of processes needed to construct and maintain various pavement types applicable for the Swiss roadway network, including concrete, asphalt, and composite road pavements. The study analyzed the new construction and maintenance processes over a life span of 75 years, considered to be 1.5 times the average lifetime of a subbase layer. Costs included in the analysis for new construction were generated from the Cost Analysis 2011 available through the Swiss Builders Association. Because concrete and composite pavements have not been built in Switzerland over the past two decades, the costs were determined by comparison with cost values from Germany and Austria and a ratio of 1:1.53 between costs for asphalt and concrete pavements was used. The cost calculation utilized a discount rate of 2% and a life span of 75 years. The authors concluded that all three pavement types have very similar new construction costs; however, the concrete pavement resulted in overall lower costs over the analysis period. Although the new construction costs for all three types of pavement were comparable, concrete pavements were determined to have high initial environmental impacts and a longer service life. It was also noted that concrete pavement has specific environmental and economic benefits as compared with composite and asphalt pavements (*22*).

An LCCA study of project-level pavement management was also conducted in Portugal utilizing the AASHTO serviceability concept for flexible pavements. The Portuguese *Manual of Pavement Structure* considers a design period of 20 years for flexible pavements while also recommending that LCCA be developed for a period of 40 years. Researchers developed an optimization model called OPTIPAV that generates an optimal pavement structure, based on the predicted annual pavement quality, construction costs, maintenance and rehabilitation (M&R) plan and costs, user costs, and pavement residual value at the end of the project analysis period. The model allows for 20- or 40-year design periods and compares different pavement solutions in global costs for the selected pavement structure for highways or roads (*23*).

Highway structures in Myanmar were the focus of an LCCA study conducted at Nanyang Technology University in Singapore. The various components and statistical factors needed to conduct an analysis were discussed and a stepwise procedure was implemented to determine the cost components required. The authors performed a sensitivity analysis to illustrate the effect of uncertainties associated with various factors on the total life-cycle cost of highway structures. The analysis focused on incorporating agency costs (e.g., construction and maintenance costs) and user costs (e.g., delay costs, cost of additional fuel consumption, and cost of additional vehicle maintenance). Accident and external cost components were excluded owing to a lack of sufficient statistical data. The study emphasized the importance of integrating an LCCA tool into the policies and practices for the design of highway structures and recommended the development of a life-cycle costing framework for transportation projects in Myanmar, to highlight the need for continued maintenance of assets and capital costs for initial investments (*24*).

A study conducted in Iran, an oil-exporting country (bituminous materials are less costly than in other countries), compared the LCC of conventional and perpetual pavements on highways. The net present value method was used and all the costs were reduced to a single time cost. Three main categories were taken into account: construction costs, M&R costs, and user costs (environmental, accident, and work zone costs were not included). Two software models were used to compute LCC over a period of 40 years. The results of the study show that user costs are dominant, and construction and M&R costs constitute less than 0.5% of the LCC at a discount rate of 4.88%. In addition, perpetual pavements have a 4%–20% reduction in LCC compared with conventional pavements. This was explained by the reduced M&R costs (elimination of reconstruction) and reduced delays for roadwork and related user costs. It was also observed that even with varying discount rates, the perpetual pavements were found to have the lowest overall life-cycle costs (*25*).

SUMMARY

This chapter provided an overview of the typical costs included in an LCCA and highlighted some of the uncertainties associated with these costs including unclear definitions and lack of reliable or consistently collected data. In addition, tools and models to support the application of LCCA to highway assets were reviewed. It was noted that some states have taken steps to customize available tools to their assets and performance over time when such data are available.

A summary of typical costs included in an LCCA is included in the chapter along with a diagram of when these costs typically occur over the life of an asset. Challenges associated with including these costs in an LCCA are also documented. The most noted hindrance to LCCA application or use appears to be the lack of information and data needed to support the analysis for assets other than pavements and bridges. In addition, it is noted that while many, if not most, highway agencies are using LCCA to manage their pavement programs, many report challenges with including user costs. One potential approach to improving LCCA application to ancillary assets may be the use of a tiered approach to LCCA. In such an approach, higher capital cost assets that typically require routine maintenance and rehabilitation to extend the life of an asset may require more rigor and data to support an LCCA as compared with assets that may require substantially less maintenance and are not anticipated to benefit from rehabilitation, such as traffic signal systems. This type of approach was demonstrated through the work documented on the LCCA of advanced traffic management systems and ramp metering systems.

The most readily available tools for conducting LCCA appear to be aimed toward the analysis of pavements and bridges, with tools available for pavement analysis being the most readily studied and documented by highway agencies. Most state customization focuses on developing deterioration curves that better reflect individual state agency experience. Although FHWA has noted that the applications contained in its tool RealCost can be applied to a range of assets, few studies were identified that documented the use of the tool to analyze assets other than bridges and pavements.

The literature review revealed the limited documented LCCA use for the analysis of ancillary assets; however, some work has been completed related to the LCCA of barriers, fleet vehicles, and ITS technologies. One study of note utilized LCCA to fully analyze the cost–benefit ratios associated with typical installations of adaptive traffic control systems and ramp metering systems. The authors captured costs associated with these systems in terms of infrastructure costs, incremental costs, and O&M costs, and expanded the study to include the documentation of the benefits of these systems. The approach used in this study provides a solid foundation on which agencies could begin to analyze the LCCA of ITS technologies.

International studies revealed a similar focus on pavements and bridges for LCCA applications, and an emphasis on the resulting environmental impacts of design alternatives was noted. Some countries are in the early stages of framework development to support LCCA and are beginning to document the approach to the process as well as implications to public infrastructure investment.

The next chapter probes further to learn more about LCCA use at various levels (asset, project, network/program) and across other highway agency asset classes based on findings of a state highway agency survey.

CHAPTER THREE

AGENCY PERSPECTIVES ON LIFE-CYCLE COST ANALYSIS

AGENCY SURVEY

LCCA data requirements and available models were discussed in chapter two of this report. To learn more about LCCA use within state highway agencies, a survey was performed in spring 2015 using an online survey tool. The survey was developed to better understand the challenges of applying LCCA with a series of questions related to the software, data, and model needs of state agencies to support LCCA. The survey was designed to achieve an 80% rate (or 40 states) and to collect basic information on LCCA use, as well as to provide a mechanism to identify potential state highway agencies to showcase in the case examples presented in the follow on chapters of this report. The survey also offered insight as to which states are utilizing LCCA in their decision making and management of highway assets and to which assets they have applied the analysis technique. Additional questions were developed to learn at what level state highway agencies are applying LCCA. For example, the questionnaire asked agencies to specify their LCCA use at the asset level, network/program level, and project level as defined in the survey materials:

- Asset level—individual items. For example, individual bridges, individual culverts, and 1/10th mi pavement sections as defined by the state transportation agency.
- Project level—A proposed project with logical beginning and end termini, often related to a milepost or intersection that consists of multiple assets.
- Network/program level—A holistic view of the statewide asset class that addresses current conditions, performance goals, condition prediction, and available treatments within a defined budget. Example asset classes include pavements, bridges, signs, signals, and culverts.

Survey questions were developed and refined with input from the panel in fall 2014. The survey focused on three primary areas:

- LCCA use by asset and application area
- Identification of software and tools used
- Data and model needs.

The first set of questions focused on identifying if survey respondents are using LCCA for decision making for comparing design alternatives for capital investments and/or for maintenance treatment selection. Respondents were asked to provide specific information by asset as well as by application level. The information gathered through this set of questions was intended to identify highway agency LCCA use as well as identify unique LCCA applications that may be documented in a follow-on case study.

Next, respondents were asked to identify by asset type and application level the specific tools and software used to conduct LCCA. Space was provided within the survey to allow respondents to add specific information about the tools and software packages used. Again, this information helped to identify interesting aspects of LCCA that may be documented in a case study.

Finally, detailed information was requested about factors and data used in respondents' LCCA applications by asset type and application level. Questions were asked about the confidence that agencies had in specific data and areas that they believed needed additional information to confidently apply specific LCCA factors and data.

A draft survey was sent to panel members in November 2014. Comments were received and incorporated into the final survey in December 2014 and programmed into the online survey tool SurveyGizmo. The survey was then shared with the project panel for a second review in January 2015. By February, the survey was finalized and sent by e-mail to members of the AASHTO Subcommittee on Asset Management as provided by TRB staff. The survey instrument sent to subcommittee members is included in Appendix A of this report.

SURVEY PARTICIPATION

The survey was first sent to subcommittee members on February 4, 2015, and within the first week, four surveys had been completed. Following the initial distribution of the survey, reminder e-mails prompting the recipients to complete the survey were sent weekly throughout the month of February. The reminder e-mail list was updated each week as completed surveys were submitted to remove from the list agencies that completed the survey. In March, efforts were made to identify additional respondents in states where the project team had been unable to contact subcommittee members directly through phone or e-mail. In early April, AASHTO's program director for planning and policy was contacted to ask for assistance in encouraging state highway agency representatives to complete the survey. With AASHTO's assistance, participation increased and an additional 14 surveys were completed. In addition, phone calls and e-mails were sent throughout April to encourage survey completion. In total, as of May 20, 38 state highway agencies had responded to the survey. With assistance from the project panel, three additional states completed the survey in June and as of July 2015 three more surveys were added to achieve an 82% response rate. Reflected in the tables throughout this chapter, one state agency survey response is equal to about 2.5% of all responses. Figure 3 provides a graphical representation of the surveys completed and analyzed.

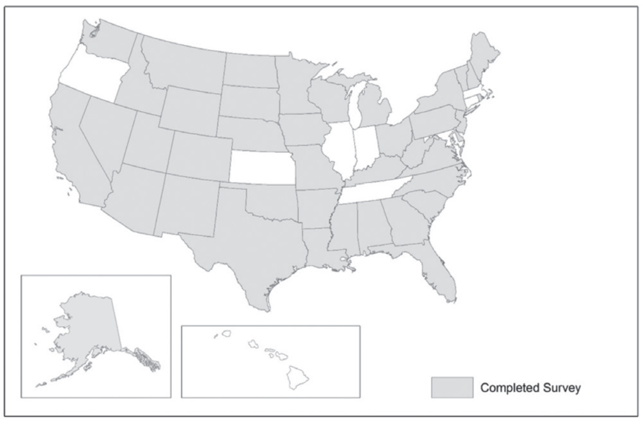

FIGURE 3 LCCA use survey responses.

SURVEY RESULTS

This section of the chapter describes the survey findings and identifies any trends that were found in the data. The initial set of survey questions focused on identifying agencies that are applying LCCA as part of their decision-making process, identifying to which asset classes LCCA is being applied, and identifying at what level the process is being applied (asset, project, and network/program level). As shown in Figure 4, 30 of the 41 survey participants indicated that their agencies are using LCCA at the asset level to assist with the decision-making process for analyzing design alternatives. Of those respondents who are using LCCA at the asset level, the majority of applications are to pavements and bridges. Some highway agencies indicated applying LCCA to assets other than pavements and bridges. For example, Virginia DOT currently uses LCCA at the asset level for culverts, tunnels, ITS, and traffic signals and signs. The Vermont Agency of Transportation uses LCCA at the asset level for signs, rock fall hazards, and maintenance equipment (dump trucks). Both the North Dakota and Wyoming DOTs indicated applying LCCA to decision making for traffic signs. Of those respondents who indicated "Other," LCCA was reported to be used in fleet, rock fall hazards, high mast lighting, and equipment decision making.

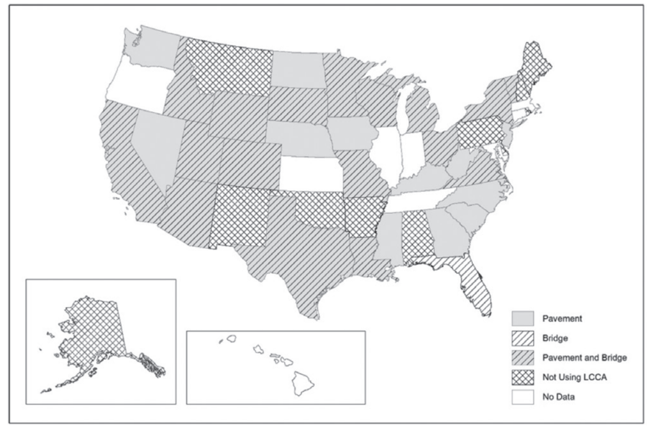

FIGURE 4 LCCA use (asset level).

The survey results also revealed that 27 of the 41 agencies that completed the survey currently use LCCA for selecting preservation or maintenance treatments for assets. Figure 5 includes a breakdown of which states are using LCCA for maintenance treatment activities by asset type. Eleven states reported using LCCA for selecting preservation or maintenance treatments for pavements and bridge management. Twenty-five of the 41 states that responded to the survey reported using LCCA for selecting maintenance treatment for pavements only and 12 states are applying LCCA to select maintenance treatments for bridges. Nearly half of the survey respondents who use LCCA for selecting preservation maintenance treatments use this process for bridges. Of the 41 states that responded to the survey, 14 reported not using LCCA for maintenance treatment. Virginia DOT was the only state to report using LCCA for selecting preservation or maintenance treatments for both culverts and tunnels as well as bridge and tunnel treatments.

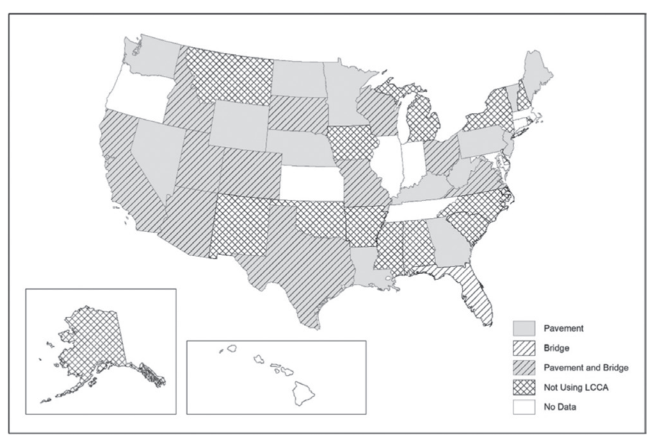

FIGURE 5 LCCA use (maintenance level).

Next, survey participants were asked questions to determine at what level they are applying LCCA. Of the survey responses, 26 of 41 state agencies surveyed are currently using LCCA at the project level. For example, the agency uses LCCA to select between project alternatives that result in the same benefits with the lowest expected life-cycle costs. Figure 6 details which states are currently using LCCA at the project level. Twenty of 41 survey respondents reported using LCCA at the network or program level to identify treatment efficiencies. Figure 7 details which states are currently using LCCA at the network or program level.

FIGURE 6 LCCA use (project level).

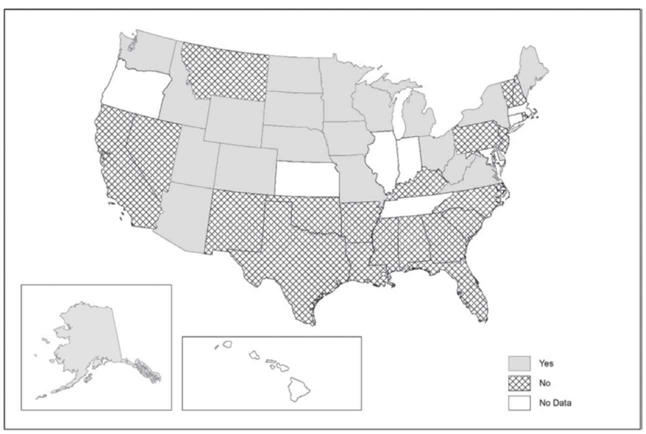

FIGURE 7 LCCA use (network level).

Next, survey participants were asked if they are using specialized software or tools to perform LCCA. Of the 41 survey respondents, 16 reported using specialized software for LCCA. Survey participants reported utilizing specialized LCCA software tools most often for pavements, with 11 states applying these tools at the network/program level, nine states at the project level, and nine states at the asset level. Nine states reported currently using specialized software for bridge LCCA, with seven of those states applying these tools at the network/program level. Currently, none of the state agencies surveyed reported using specialized software at any level for the LCCA of tunnels, traffic signals, end treatments, or striping.

The survey participants reported using several different types of specialized software; a brief overview of the software and tools are described here. Deighton's Total Infrastructure Management System (dTIMS) allows users to incorporate all of their agency's infrastructure assets and corresponding data into one platform. Five states reported using dTIMS for pavement and bridge LCCA across asset, project, and network/program levels. Minnesota Department of Transportation's own HydInfra, hydraulic infrastructure information application, is used to manage inventory, inspection, and maintenance activities for storm drainage features (culverts) at the asset level. This tool is highlighted in a case example in the following chapters of this report. The FHWA's RealCost uses Microsoft Excel spreadsheets to perform LCCA for pavement selection in accordance with FHWA best practice methods. RealCost was reported to be used by Washington State DOT, California DOT, and South Carolina DOT for the LCCA of pavements and bridges. Florida DOT uses in-house software PLAT (Project-Level Analysis Tool), which draws information from the Bridge Management Database, and generates cost–benefit ratios for various design and treatment options. Colorado DOT uses specialized software at the asset and network/program levels for ITS for LCCA. Texas DOT developed its own spreadsheets for LCCA of traffic barriers, bridges, pavements, and culverts. Finally, Wyoming DOT reported using an in-house software system for sign LCCA at the asset and network/program levels.

Next, agencies were asked if they have specific analysis periods for various asset classes. An analysis period refers to the time over which costs are evaluated. Of the 41 survey respondents, 23 reported that their analysis periods do vary by asset class. Once again, most of the states reported having specific analysis periods when applying LCCA to bridges and pavements. However, specific analysis periods were also reported to be used for ITS and culvert LCCA. For example, Colorado DOT reported that pavement, bridges, and ITS analyzed at the asset level have an analysis period of 10 years, although that number varies by asset type at the network/program level. Minnesota DOT analysis periods were longer, with pavement analysis periods at 70 years, bridge analysis at 200 years, and other assets at 100 years all at the network/program level. Currently, none of the states that responded to the survey reported specific analysis periods for tunnels, traffic signals and signs, end treatments, lighting, or striping. Figure 8 includes an overview of the information gathered from the survey for analysis periods by asset class and application level.

The next portion of the survey focused on specific data and factors used by agencies in their LCCA. Survey respondents were asked to provide information by application level and asset class on asset-specific discount rates used in their LCCA. Of the respondents, 19 of the 41 noted that they do vary their discount rate by application level or asset class. Most notably, LCCA performed for pavements at the project level was most frequently reported to have a specific discount rate. Of the 41 respondents, 11 have asset-specific discounting rates for pavement at the project level, seven at the network/program level, and four at the asset level. Currently, five states have discount rates for LCCA for bridges at the project and network/program levels. Most of the survey respondents reported using a discount rate between 2% and 5% for all assets at all levels. Two states reported using the federally published Office of Management and Budget circular to calculate their agency's discount rates. At this time, no specific discount rates were reported for applying LCCA to decision making for tunnels, signs, traffic barriers, end treatments, striping, or lighting. Figure 9 shows a breakdown of this information.

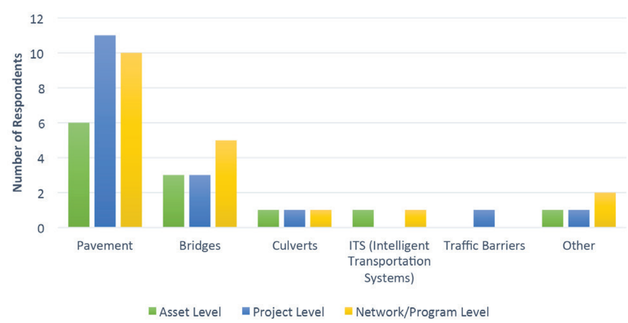

FIGURE 8 Asset-specific analysis periods.

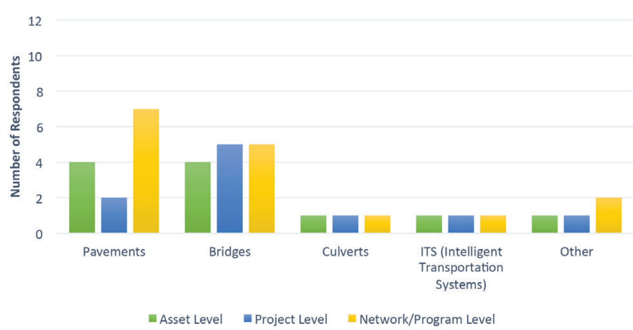

FIGURE 9 Asset-specific discount rates.

Next, survey participants were asked to provide information on factors used in their LCCA by application level. The goal of this set of questions was to learn more about which factors agencies were using and which they were not, to shed light on areas that agencies could benefit from additional information and guidance. State agencies were most likely to use capital and maintenance cost factors and data in LCCA at the project level. Resilience goals are the least likely factor to be taken into consideration by state agencies in their LCCA analysis. In addition, some costs still appear to be a challenge for state agencies, but this information may be lacking in availability; for example, inspection and operations costs. Deterioration curves were also noted to be a challenge at the asset level as compared with their use at the network/program level. Areas that appear to fall behind in their inclusion in LCCA include safety and resilience goals as well as uncertainty or risk in anticipated costs. Table 1 contains the findings of this question related to which factors and data agencies are incorporating LCCA by application level.

TABLE 1
DATA/FACTORS INCLUDED IN LCCA BY STATE HIGHWAY AGENCIES

Data/Factors Included in LCCA	Asset Level	Project Level	Network/ Program Level
Capital Costs	14 (34%)	25 (61%)	21 (51%)
Maintenance Costs	13 (32%)	20 (49%)	15 (37%)
Operations Costs	5 (12%)	9 (22%)	4 (10%)
Inspection/Support Costs	6 (15%)	4 (10%)	5 (12%)
User Costs	5 (12%)	13 (32%)	4 (10%)
Discount Rates	7 (17%)	19 (46%)	13 (32%)
Deterioration Curves/Models	11 (27%)	13 (32%)	19 (46%)
Uncertainty/Risk	3 (7%)	6 (15%)	5 (13%)
Resilience Goals	1 (2%)	0 (0%)	0 (0%)
Current Safety Performance	6 (15%)	6 (15%)	4 (10%)
Expected Safety Performance	3 (7%)	4 (10%)	2 (5%)
Desired Performance Levels	10 (24%)	11 (27%)	17 (42%)
Geospatial Location of Assets	6 (15%)	8 (20%)	9 (22%)
Salvage Value	4 (10%)	10 (24%)	4 (10%)
Remaining Service Value	6 (15%)	11 (27%)	8 (20%)

The second part of this question focused on asking participants to specifically name factors and data that they felt their agency lacked solid information needed to perform LCCA at the three application levels. According to the survey results, data to perform LCCA for capital, maintenance, and inspection/support costs is most readily available; however, data and information is needed to better incorporate deterioration curves/models, uncertainty/risk, and resilience goals in LCCA, as was also noted in the previous question. Many of the respondents surveyed reported a lack of data for salvage value and remaining service value; however, very few states reported a lack of data for desired performance levels or geospatial location of assets. Table 2 includes the findings from this survey question.

Of note is the concentration of responses focused on the need for data related to deterioration curves, uncertainty/risk, resilience goals, expected safety performance, and remaining service life. Most notably, nearly half of states feel a need for more data about uncertainty/risk at the project level for LCCA. Another common need among state DOTs is the lack of data and information needed to establish resilience goals and how to incorporate these into LCCA. This finding supports the lack of information needed by states to connect LCCA to overall risk management initiatives, which support the delivery of resilience highway systems. These findings are echoed in the case examples contained in chapter five.

TABLE 2
DATA/FACTORS NEEDED FOR LCCA BY STATE HIGHWAY AGENCIES

Data/Factors Needed for LCCA	Asset Level	Project Level	Network/ Program Level
Capital Costs	1 (2%)	1 (2%)	4 (10%)
Maintenance Costs	5 (12%)	6 (15%)	9 (22%)
Operations Costs	7 (17%)	9 (22%)	11 (27%)
Inspection/Support Costs	3 (7%)	7 (17%)	7 (17%)
User Costs	10 (24%)	11 (27%)	12 (29%)
Discount Rates	4 (10%)	4 (10%)	6 (15%)
Deterioration Curves/Models	12 (29%)	12 (29%)	7 (17%)
Uncertainty/Risk	12 (29%)	16 (39%)	13 (32%)
Resilience Goals	10 (24%)	14 (34%)	14 (34%)
Current Safety Performance	7 (17%)	8 (20%)	5 (12%)
Expected Safety Performance	9 (22%)	11 (27%)	7 (17%)
Desired Performance Levels	4 (10%)	6 (15%)	3 (7%)
Geospatial Location of Assets	4 (10%)	3 (7%)	3 (7%)
Salvage Value	8 (20%)	8 (20%)	10 (24%)
Remaining Service Value	11 (27%)	10 (24%)	12 (29%)

SUMMARY AND FINDINGS

The purpose of the survey was to better understand the challenges of applying LCCA with a series of questions related to LCCA application, software and tools used, and data and models needed to support LCCA. The survey results provided basic knowledge on how states are currently using LCCA in their decision making and management of highway assets. The survey results also specified which state agencies are applying LCCA at the asset level, project level, and network/program level. The findings also identify which state agencies are using LCCA for decision making for analyzing design alternatives for capital investments and for maintenance treatment selection. The results detailed the tools and software respondents are currently using to conduct LCCA for various assets. Finally, the survey respondents also specified the factors and data used in LCCA applications by asset type and application level, and which factors and data they feel they lack information to fully utilize.

According to the survey results, most state highway agencies are currently using LCCA for pavement and bridge management at all application levels. Most often LCCA is being used as part of the decision-making process for analyzing asset-level design alternatives. Currently, 16 state agencies are using specialized software to assist with these LCCA applications. Most notably, the survey results showed that capital costs, maintenance costs, inspection/support costs, and user costs are the most common factors considered in LCCA analysis by state highway agencies. On the other hand, very little consideration is being given to incorporating resilience goals and uncertainty/risk factors into LCCA applications.

Since the purpose of this survey was to identify challenges in applying LCCA, it is important to focus on what factors and data state agencies reported to be lacking to properly perform LCCA or improve existing LCCA. As reflected earlier, deterioration curves/models, uncertainty/risk, and resilience goals lack available data to perform LCCA applications. Knowledge gaps also exist regarding salvage value and remaining service. According to the state agencies surveyed, there is a significant lack of data available to properly perform LCCA applications for assets beyond pavements and bridges. Also, the lack of understanding of the benefits of applying LCCA to assets other than pavements and bridges appears to be significant. In the next chapter, several state highway agencies' application of LCCA are highlighted to bring attention to unique and innovative approaches to LCCA. In particular, two states' approaches to pavement and bridge LCCA and two states' approaches to data gathering to support LCCA are presented.

CHAPTER FOUR

CASE EXAMPLES ON THE USE OF LIFE-CYCLE COST ANALYSIS

This chapter documents five case examples related to the collection of necessary data and models to fully implement LCCA by state highway agencies. The case examples were developed based on information gathered through the surveys, as well as through in-depth interviews with staff and for the following agencies and application areas:

- Utah Department of Transportation—Pavement
- Florida Department of Transportation—Bridges
- Washington State Department of Transportation—Ancillary Asset Management
- Minnesota Department of Transportation—Culvert Cost and Life-Cycle Management
- Initiative
- Public–Private Partnerships—A Concessionaire's Take on LCCA.

LIFE-CYCLE COST ANALYSIS FOR PAVEMENTS—UTAH DEPARTMENT OF TRANSPORTATION

Utah Department of Transportation (UDOT) maintains approximately 16,000 lane miles and has established a vision statement for the pavement management program: Good Roads Cost Less. In 1977, a study titled *Good Roads Cost Less* was conducted on behalf of UDOT (*26*). This study sought to demonstrate that with timely, cost-effective treatments, the cost of roadways can be minimized while maintaining a desired level of performance (*27*). This philosophy of good roads cost less is still present within UDOT and has shaped its vision of asset management. Since 1993, UDOT has used dTIMS CT, a management system developed by Deighton Associates Limited, to manage its pavement investments (*26*).

The agency estimates that $250 million dollars annually is needed to preserve the estimated $25 billion dollar pavement asset it maintains; however, for the past six years, only $200 million has been available to maintain pavements. To address the gap in funding, UDOT developed a tiered approach to pavement management that seeks to optimize investments. The tiers include Interstates; Level 1 facilities, which service more than 1,000 AADT (average annual daily traffic) and truck volume greater than 200; and Level 2 facilities, which service less than 1,000 AADT. Level 2 facilities are actively maintained by regional maintenance staff; UDOT staff acknowledged that the lack of funding for these facilities will result in degradation of performance measures for these facilities. Utilizing information generated by the agency's annual pavement condition data-gathering exercise and projections of performance provided by its pavement management program, the agency was able to provide information to the state's legislature to support the decision to increase the gas tax in January 2016. The five cent sales tax increase per gallon of gasoline is expected to generate an additional $17.14 million in revenue in FY 2016 and $55 million in FY 2017. The agency intends to target Level 2 facilities during these fiscal years to slow and reverse the anticipated degradation of these facilities.

UDOT representatives noted that their LCCA for pavement includes maintenance, preservation, repair, rehabilitation, and replacement actions that achieve and sustain a desired state of good repair over the life cycle of the asset at a minimum practicable cost. Having generated substantial performance and condition information for 1,446 identified sections of pavement across the state, UDOT pavement management staff reported being very confident with the deterioration curves produced by its pavement management system. These deterioration curves feed the LCCA process for its statewide pavements program.

Information was gathered as to specific data used within the agency's LCCA. The agency included in its analyses capital costs, maintenance costs, inspection/support costs (at the asset level), deterioration curves and models, current safety performance, desired performance levels, and geospatial location of assets. The agency noted it lacked sufficient information and models for the establishment of discount rates, deterioration curves/models (for bridges), and remaining service value (for bridges).

UDOT has begun to investigate remaining service life for its pavement program. Substantial efforts have been made over the past several decades to establish detailed information on the performance of specific sections of pavement throughout the state. Often referred to as "A Plan for Every Section of Road," UDOT has identified and tracked the condition of 1,446 sections of roadway allowing for optimization of surface treatments. The identified sections of pavement typically are between 5 and 10 mi in length and in many cases were defined at the time of construction. In

2014, UDOT conducted a pavement distress and detection survey using LiDAR (light detecting and ranging) to further enhance its understanding of pavement conditions across the state. The agency reported that it has contracted to collect two additional data sets over the next 5 years using the same type of technology, to further develop deterioration curves and remaining service life.

Additional efforts by the agency include incorporating its maintenance management system to the dTIMS model and developing a data warehouse to create a mechanism to incorporate and exchange of information between the two systems.

LIFE-CYCLE COST ANALYSIS FOR BRIDGES—FLORIDA DEPARTMENT OF TRANSPORTATION

This case example focuses on Florida Department of Transportation's (FDOT's) Bridge Asset Management practices and LCCA use. FDOT maintains more than 12,000 lane miles and 6,500 bridges across eight semiautonomous districts. Since 1997, FDOT has implemented AASHTO's Pontis Bridge Management System to support decision making. The agency has conducted a series of research studies to fine-tune Pontis to better suit the agency's needs including the following:

1. Development of a localized user cost model
2. Establishment of unit costs for maintenance, repair, and rehabilitation actions
3. Development of deterioration curves based on expert elicitation and field inspection reports
4. Development of truck and weight histograms to estimate user costs from detours and closures
5. Development of a project-level decision support tool.

Recent research efforts entailed the development of a project-level decision support tool to interpret Pontis results in a form more applicable to bridge-level decision making (*28*). In addition, a network-level tool was developed to provide estimates of expected performance and required funding at a systemwide level. In 2011, further research was conducted on the two custom tools to improve recommendations (*17*). As part of this recent research, recommendations were made to update deterioration models that were found to be overestimating bridge deterioration and underestimating repair costs. Utilizing two years of bridge inspection data, researchers were able to develop an improved standalone computer program to create a single condition rating for each bridge component, similar to FHWA's National Bridge Inventory Translator. Using case studies and field inspection reports, researchers were able to calibrate the single condition ratings for Florida conditions.

Additional research has been conducted on improving deterioration curves and action effectiveness models, to update previous models that were primarily based on expert-elicitation data. Data drawn from Florida's maintenance management system and AASHTO's Trns•Port Estimator database to support LCCA use for bridges were used to refine previously developed models that were found to underestimate the effectiveness of repair and rehabilitation actions. Researchers believe the improvements to these models and curves will greatly improve the condition predictions in Pontis and PLAT/NAT (Project-Level Analysis Tool and Network Analysis Tool), which they believe will improve funding decisions.

Research was also conducted to validate existing cost models within Florida's Pontis and PLAT/NAT utilizing information from a statewide construction bids database (AASHTO's Trns•Port Estimator), FDOT District Bridge Construction Bids Records, and the FDOT Work Library-Maintenance Management System Cost data for bridge-related maintenance work. Further research was conducted to estimate user costs at bridge sites where no detour is considered or possible. Researchers sought to include accident-related user costs within the overall user cost model that reflects travel time costs and vehicle operating costs. Utilizing Florida crash data at bridge locations between 2003 and 2006, researchers developed a negative binomial model that was found to be more accurate than the previously utilized linear regression model when compared with observed crashes in 2007.

The department noted that having rich element-level bridge inspection data allowed for in-depth analysis of bridge deterioration and the ability to better forecast life-cycle costs for the planning of maintenance, repair, rehabilitation, and replacement work. The investment made to gather the necessary data facilitated improvements in the applicability of recommendations and estimates of bridge conditions from Florida's Pontis Bridge Management System and PLAT/NAT. Confidence gained in the decision support tools is believed to have had a significant impact on capital and maintenance programs, potentially better utilizing constrained maintenance and replacement dollars.

Utilizing the improved decision support tools, FDOT has implemented LCCA for major bridge projects in the planning stage; however, LCCA is not yet used in routine bridge projects. LCCA is used to decide if it is more cost-effective to repair an existing bridge or to replace it by calculating both anticipated life-cycle costs as well as cost–benefit ratios for various design options.

One of the lessons learned by FDOT through the development and refinement of its bridge management tools is the need to standardize definitions and measurements used by various offices within the agency. For example, bridge management reporting systems were found to differ from maintenance and construction reporting systems, which made it challenging to compile information to support the calibration of the bridge management analysis tools. But, in the end, the products created appear to be generating results and recommendations that are much more reasonable and acceptable to FDOT staff.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION ANCILLARY ASSET MANAGEMENT

Washington State Department of Transportation

One of the LCCA application challenges noted by survey participants and through the literature review is the lack of maintenance cost information. Washington State DOT's (WSDOT's) Maintenance Division has been crafting an evidence-based approach to maintenance priority-setting, budgeting, and legislative requests for many years, in addition to maintaining an ongoing government quest for efficiency. Short of having a comprehensive cradle-to-grave LCCA system in place at WSDOT, the Maintenance Division is doing what it can within its purview. Maintenance is working partially in coordination with other programs such as Design, Construction, and Preservation, to create and implement the building blocks of LCCA-based management. WSDOT is anticipating that these and other building blocks will someday come together into a comprehensive, LCCA-based highway asset management plan.

WSDOT communicates to designers the cost and safety savings (because of quicker and easier maintenance) of design considerations such as the following:

- Adequate width of shoulders (so maintenance does not have to close a lane of traffic)
- Access to stormwater ponds and culverts (an area that continues to be overlooked to a surprising degree, according to staff)
- Good-quality roadside soils with low-maintenance vegetation.

WSDOT Maintenance has captured these design considerations in a laundry list of good practices that it has communicated with its design staff to help minimize the maintenance costs associated with asset management.

Within the Maintenance Division, WSDOT is using the owner's manual/maintenance schedule concept as a basis for the maintenance portion of LCCA. The easy-to-communicate and easy-to-understand analogy of this concept is the car owner's manual/maintenance schedule. The vast majority of people will not understand complex predictive computer models or mathematical equations, but they would agree that the owner's manual is a summary of what the owner needs to know. Although many of the maintenance tasks that are completed today will not make an immediate observable difference, they will make a difference in asset performance over time. At these longer intervals, proactive maintenance will extend the cycles of rehabilitation and preservation over what can be a long and even indefinite life span of many of WSDOT's highway assets.

Ongoing Implementation

As part of its ongoing push to implement sound asset management and maintenance LCCA, starting July 1, 2015, WSDOT is equipping maintenance staff with 800 tablets. The Highway Activity Tracking System (HATS) is WSDOT's in-house maintenance management system with which it manages its highway asset inventory and records the details of completed maintenance work. The asset-specific information that will be collected henceforth (versus hours of a certain maintenance activity and units accomplished) will provide the agency with a rich data set for LCCA. With the rollout of the tablets and the continued detail going into the creation of a record of maintenance, issues, conditions, and actions for each asset, WSDOT will have asset-specific maintenance histories available at the touch of a finger.

Pavement maintenance information collected in HATS has already been incorporated into the agency's Pavement Management System. Highway asset inventory, condition ratings, and completed maintenance work data for many other highway assets will be accumulated in HATS. When asset management systems, similar to those currently in place for pavements and bridges, are developed for the design, construction, rehabilitation, and preservation details of these assets, Maintenance will be ready to plug its portion of LCCA into the broader management system by means of HATS.

In the past few years, WSDOT has set a new direction in evaluating maintenance and overall cost accrual by measuring preventive maintenance and work accomplishments. Its approach has yielded noteworthy results, with lower analytical requirements than conventional LCCA approaches. By using an approach that is easier to communicate and understand, WSDOT found that the agency stood a much better chance of bringing partners on board with LCCA.

WSDOT was helped along in its new direction by a state legislative audit that found that "WSDOT's maintenance management system does not measure the backlog of essential maintenance, limiting the ability to determine effectiveness of effort" (*29*). At the conclusion of their 2007 audit, the auditors made the following recommendations to WSDOT:

- Determine needs from the agency's respective maintenance management systems (MMS) and the current backlogs of essential maintenance and repair;
- Prepare a comprehensive listing of the backlogs of essential maintenance and repair, assess the risk that

the backlogs may pose, if any, and include those in M&O budget justifications;

- Prioritize the development of a centralized MMS;
- Annually calculate an estimate of the current replacement cost of the infrastructure;
- Establish minimum maintenance and operations level of service (LOS) priorities and targets;
- Include each measurement of maintenance performance in WSDOT's performance measures program and Statewide Accountability Service Level Reports; and
- Increase the detail of the Maintenance Accountability Program (MAP) organizational review-level achievements to provide additional indication of accomplishments (e.g., not just condition assessments). MAP measures and communicates the outcomes of the maintenance activities, providing tools to link strategic planning, the budget, and maintenance service delivery. Once a year, field inspections are made of randomly selected sections of highway. The results of WSDOT's work are measured, recorded, and compared with the MAP criteria to determine the LOS delivered.

The audit called for Maintenance to increase its ability to determine actual maintenance needed and impact on workloads. The audit also called for the estimate of the extent of essential maintenance and repair backlog and cost thereof, as well as the budget impacts of compliance with new requirements. Overall, WSDOT needed to increase its ability to identify and communicate the cumulative effects of maintenance requirements. With the help of this type of documentation, WSDOT Maintenance won additional funding to help catch up on the maintenance backlog for eight activities, including signal maintenance. WSDOT also found considerable accountable benefits (reduced time spent on "call-outs" covered the time needed for more preventive maintenance) and important unaccounted ones (the congestion, safety impacts, and customer unhappiness associated with signal outages that were avoided since outages were minimized).

Although Maintenance is one of many contributors to asset condition, task completion is Maintenance's responsibility. Task completion provides a sense of ownership to Maintenance staff; it also communicates well—people understand the tie between task completion and the "car owner's manual" analogy. In the December 2010 *Gray Notebook*, WSDOT explains:

> Task completion will increasingly be the primary tool used to measure maintenance performance. Asset condition (MAP surveys) will serve as a quality assurance tool used to verify or support changes in the maintenance task completion measure. Task completion quantifies the number of tasks needed for a specific activity each year, and how many of those tasks were completed. Completion of higher percentages of needed maintenance work contributes to good asset condition. Using these two performance measures together, overall program delivery can be more accurately explained.

The owner's manual approach and work accomplished ultimately comes down to work-unit planning. Most Maintenance staff are used to being "more reactive, having more control over their daily lives, and acting independently." More preventive maintenance will allow greater control and lower stress in some ways, but work processes are more set and prescribed. When WSDOT develops an owner's manual/maintenance schedule for a type of highway asset, it uses whatever resources are available for the contents. Manufacturer recommendations are available for a limited number of assets, such as some automated traffic management systems and cable barriers. High-tension cable barrier manufacturers recommend that systems be visually inspected and tension checked annually. Legal requirements sometimes constitute the LCCA maintenance schedule. For example, WSDOT's National Pollutant Discharge Elimination System (NPDES) permit lays out a detailed and strict schedule of inspection frequencies and maintenance standards. It has made WSDOT's job of identifying the owner's manual/maintenance schedule very easy for this particular asset. This required maintenance and inspection schedule was easy to communicate to WSDOT partners and paved the way for full support and funding. As a result, WSDOT has the resources and is implementing a complete LCCA program (at least for maintenance LCCA) for catch basins and stormwater ponds.

As described in the December 2010 *Gray Notebook*, because WSDOT could quantify the backlog for eight maintenance activities, the legislature provided $16.8 million for the 2009–11 biennium to begin the process of catching up on the identified $85 million backlog of maintenance work. Task completion is to be captured as a percentage of identified tasks and reflected as an LOS performance measure. With the establishment of funding, WSDOT was able to stabilize falling LOS scores and begin to meet or exceed its plan in all eight areas. In the next (2011–13) biennium the legislature provided an additional $6.4 million toward the maintenance backlog, not tied to specific activities, but this was a relatively small portion of what Maintenance calculated was needed.

The Washington DOT Maintenance Division has utilized an owner's manual/maintenance schedule approach to begin to convey to its staff tasks that need to be accomplished to proactively manage assets. In addition, the information gathered in its efforts to better understand the demands required for asset maintenance has been shared with its design teams to help reflect maintenance costs within overall life-cycle costs of highway assets. Ultimately, WSDOT believes that understanding maintenance costs in a manner that is easily conveyed to all staff and stakeholders will support the agency's objectives of LCCA for highway assets.

MINNESOTA DEPARTMENT OF TRANSPORTATION CULVERT COST AND LIFE-CYCLE MANAGEMENT INITIATIVE

Minnesota DOT's (MnDOT's) HydInfra system was first profiled in detail on the national level as part of AASHTO's Compendium of Environmental Stewardship Practices, Policies, and Procedures in 2004. Since that time it has been documented in several publications, including the following:

- FHWA's Transportation Asset Management Case Studies: "Culvert Management Systems Alabama, Maryland, Minnesota, and Shelby County" in 2005;
- MnDOT MAP-21 Transportation Asset Management (TAMP) federal study with Minnesota, Louisiana, and New York in 2014; and
- Federal Lands Highways' Chapter 2-Culvert Assessment Tool of the FHWA Federal Lands Highways Culvert Assessment Guide, which borrowed elements from HydInfra condition rating criteria in 2014.

HydInfra stands for "Hydraulic Infrastructure" and is the culvert and storm drainage system inventory and inspection program MnDOT has developed for pipes with spans less than 10 ft.

In 2014, MnDOT's TAMP committee ranked culverts as the agency's number one priority and area of risk. To support risk analysis and life-cycle cost assessment for culverts, MnDOT recently completed an extensive culvert repair cost data collection effort. Three specific pieces of information were collected:

- Condition Rating Codes—5-point qualitative scale plus Not Able to Rate/Unknown.
- Inspection Flags—problems identified in the field including deformation, joint separation, and so forth (Table 3 contains an example of potential inspection flags by material type).
- Pipe Material—to help track expected deterioration over time.

As presented by MnDOT hydraulic staff at the 2014 national hydraulics meeting, the HydInfra system capabilities include a range of management and design products including life-cycle cost analysis:

- Performance Measures
- Prioritize Repairs
- Cost Estimation
- Maintenance Tasks
- Project Predesign
- Respond to Flood Damage
- MS4 Water Quality Record Keeping
- Utilities Locations
- Research
- Life-Cycle Cost.

TABLE 3
MATERIAL/FLAG COMBINATIONS SEEN AT MNDOT

Material	Defect or "Flag"	Defect or "Flag"	Defect or "Flag"
Concrete	Deformation	Cracks	Spalling
Concrete	Joint Separation	Road Void	
Concrete	Inslope Cavity	Joint Separation	
Concrete	Joint Separation	Infiltration	
Steel	Holes	Road Distress	
Steel	Holes	Deformation	
Steel	Holes	Piping	
Steel	Holes	Road Void	
HDPE	Cracks		
HDPE	Misalignment (floating)		
Linear HDPE	Deformation		

Source: MnDOT.
Note: HDPE = high-density polyethylene pipe.

Currently, HydInfra users can run a web-based report that uses an automated sorting process for pipe inspection data. It then produces a suggested repair method, to give a first-pass idea for the repair of individual pipes in poor condition. Figure 10 provides an overview of the type of information generated through the *Suggested Repair Report*. In 2010, MnDOT staff used their *Suggested Repair Report* for culverts to create a statewide cost estimate of prospective repairs of MnDOT culverts. This also positioned MnDOT to request more funding for what they had determined was a high-risk area.

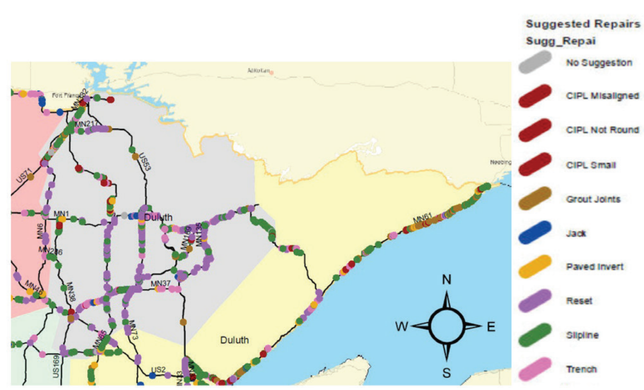

FIGURE 10 Suggested repair report. *Note*: CIPL = cured-in-place pipe liner.

To improve the understanding of maintenance costs associated with culverts, MnDOT Maintenance collected data on individual culvert repairs and cleanings by recording all the labor, equipment, and materials in the agency's new Culvert Cost app (built on ArcGIS Collector software) in 2014. The estimated cost of each repair was then calculated from data collected in the field. This project was recommended by the Drainage Asset Management group to support the prediction of life-cycle asset costs.

MnDOT Maintenance is continuing to collect culvert maintenance costs for repairs, replacements, and cleanings. It is anticipated that 2015 data will include all culverts, not just highway culverts, and has been broadened to accommodate drainage features other than culverts (though the others are not required to be recorded). MnDOT anticipates that the data collection method will evolve when HydInfra and Culvert Cost move into an asset management software package, as soon as 2018.

Culvert repair cost data have been developed for several repair methods—repairs that are routinely completed by Maintenance forces—to improve the accuracy of culvert repair and replacement cost estimates. Data from 2015 repairs will give the agency more information to support the *Suggested Repair Report*. In addition, MnDOT plans to apply these costs starting in 2016, to create statewide MnDOT culvert repair cost estimate.

Given the anticipated influx of data and information for culvert repair cost data and the current lack of data, at this time MnDOT is using the average cost for each repair category to support decision making. Figure 11 contains an example of such an average cost estimate for a variety of maintenance repairs broken out by materials, equipment, and staff costs. Next year, once additional data are collected, the data can be reanalyzed to quantify the influence of parameters such as pipe material or size on maintenance repair costs.

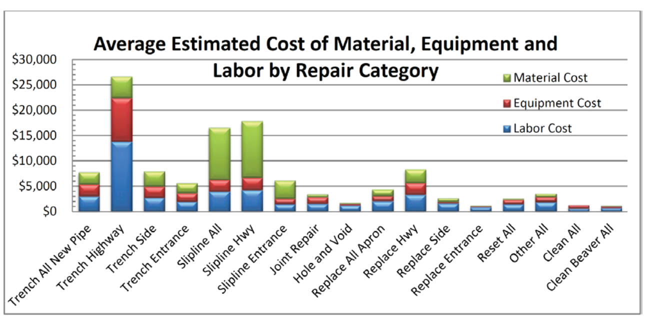

FIGURE 11 Average estimated cost of material, equipment, and labor by repair category (*Source*: MnDOT).

Regular validation and refinement of costs is planned to ensure the consistency and quality of the data collected. MnDOT's 2014 and 2015 data collection was significant and is improving understanding statewide on what repairs are being completed by Maintenance as well as where, how often, and at what cost. It is critical to have this type of information when moving toward asset management. MnDOT is planning to migrate HydInfra to the new departmental asset management system in the next 2 to 5 years. Ideally, the maintenance cost application and data will be integrated into the new HydInfra asset management system at that time.

PUBLIC–PRIVATE PARTNERSHIPS—A CONCESSIONAIRE'S TAKE ON LIFE-CYCLE COST ANALYSIS

The project panel that oversaw the development of this NCHRP synthesis report capitalized on its membership by requesting that one of its panel member's share her experience with LCCA from a concessionaire's view. Through this case example, efforts were made to differentiate between the identified methods employed by state highway agencies to model and reflect total asset costs through LCCA and those utilized by organizations engaged in public–private partnerships (P3s). Panel member Andrea Warfield arranged for an in-person interview with several members of her staff to provide some insight on the similarities and differences in LCCA between these two organizational structures.

System Versus Asset-Class Approach to LCCA

One of the most noted differences between the documented application of LCCA within state highway agencies and P3s is the view of assets by asset class versus viewing assets as a system. It was noted multiple times that a concessionaire is focused on reducing costs and, therefore, is driven by viewing the system as a whole as compared with asset-driven decision making. For example, concessionaires view the system from right-of-way line to right-of-way line and optimize performance across the entire spectrum of assets present. They also benefit from multiyear funding cycles, which allow them to align maintenance requirements for various asset classes to reduce lane closures and multiple deployments by maintenance crews. The "use it or lose it" philosophy of many highway agencies often leads to less-than-optimum decision making. P3s benefit from having a set period of performance that allows for easier coordination of required maintenance activities across multiple years to reduce overall costs. There is also an "owner" mentality to the system as a whole, and efforts are made in the planning, design, and construction stages of projects to include O&M staff, to ensure they can contribute to the process of reducing the overall life-cycle costs of the systems operated and maintained for multiple decades. Experience and knowledge gained from O&M staff who oversee the bulk of the systems' lives help to recognize costly design and construction choices upstream of project delivery to drive down overall LCC.

Holistic View of Costs

Another advantage to including O&M staff in the planning, design, and construction stages of projects is the realistic and documented cost information they can bring to the table regarding often overlooked expenses including painting, irrigation, mowing, lane availability for maintenance, and snow and ice removal. As a concessionaire, the driving force is to reduce project costs while meeting performance goals set forth by the public agency. Understanding the full cost of maintenance activities and being engaged in the project planning process allows the private investor to make better-informed decisions that will meet the project's performance goals, while reducing overall maintenance costs over the project's life. Also, there are no perceived barriers between maintenance and pavement management programs. For example, just-in-time maintenance to address potholes may help to reduce more major pavement repairs, again resulting in savings to the overall bottom line. As was noted, potholes never go away or get smaller.

SUMMARY

This chapter documented the experiences of four state highway agencies and a P3 concessionaire utilizing LCCA. Utah and Florida DOTs successfully implemented LCCA (1) to improve the public's understanding of the funding needed to maintain pavement performance and (2) to fully utilize maintenance records to better allocate limited preservation and maintenance dollars. Their efforts support the projects under way at Minnesota and Washington State DOTs to develop the building blocks needed for LCCA. The holistic view of a system of assets by P3 concessionaires may provide insight to state highway agencies on how to further improve LCCA methods and models to optimize investments. Multiyear maintenance budgets were also noted by P3 concessionaires to allow for better engineering decision making and preventative maintenance schedules. Also, engaging operations and maintenance staff in the project planning, design, and construction stages was viewed as a way to further reduce overall life-cycle costs. The next chapter outlines the overall study findings and recommendations for further research in the area of LCCA.

CHAPTER FIVE

FINDINGS, CONCLUSIONS, AND FUTURE RESEARCH NEEDS

The objective of this synthesis project was to develop an inventory of quantitative asset-level, project-level, or corridor-level processes or models for predicting life-cycle costs associated with the preservation and replacement of highway assets, through a literature review, nationwide survey of highway agencies, and case examples that documented specific highway agency experiences with life-cycle cost analysis (LCCA).

A thorough literature search allowed for the documentation of available LCCA tools by application level (asset, project, and program or network level) and it was noted that some states have taken steps to customize LCCA tools to better reflect their practices and asset performance over time. An overview of the steps taken by Florida Department of Transportation to customize and calibrate tools to its field experiences and measurements was documented in a case example.

Building on the literature review findings, a national survey of state highway agencies was conducted. The primary purpose of the survey was to identify LCCA applications within state highway agencies and to determine challenges and data needs as provided by the survey respondents. In addition, the survey was viewed as a screening tool to identify those state highway agencies that are applying LCCA and that were interested in participating in the case development stage of the study. The survey was sent to members of the AASHTO Standing Committee on Asset Management, and extensive efforts were made to increase survey participation. In the end, 41 state highway agencies participated in the survey. The survey revealed that 71% of respondents are applying LCCA to their assets, with 96% of those respondents applying LCCA to pavements and 63% to bridges. Other LCCA applications were noted, including culverts, tunnels, and traffic signs. The most noted challenges with data and models needed for LCCA were estimating user costs, developing or identifying deterioration models that reflect asset performance in the field, capturing uncertainty and risk within LCCA, incorporating resilience and safety goals within LCCA, and modeling the remaining service life of assets.

Five case examples were developed that document LCCA efforts and methods employed by four state highway agencies and a Public–Private Partnerships (P3) concessionaire. Information was documented on the efforts made by Florida DOT to calibrate deterioration curves to better align with field conditions and bridge performance in the state, resulting in the delay of maintenance activities owing to higher-than-anticipated performance ratings. Utah DOT's pavement management program was also documented, including "A Plan for Every Section of Road" and the efforts made to document the return on investment expected from increased pavement management budgets. Efforts made by Washington State DOT to develop an owner's manual/maintenance schedule concept to help improve maintenance completion rates and convey maintenance requirements to planning, design, and construction staff. The experience of Minnesota DOT (MnDOT) to develop a robust inventory and condition rating system for culverts was also documented. MnDOT recognizes the need for such a program to support LCCA. Finally, the experience of a P3 concessionaire and LCCA was documented, noting the holistic system view of assets from right-of-way to right-of-way as compared with asset-class LCCA.

FINDINGS

In general, the benefits of LCCA appear to be recognized by state highway agencies and have been applied extensively to support pavement management and, to a lesser extent, bridge management. When further probed as to the "completeness" of LCCA, many agencies reported struggling with several costs including user and maintenance costs. When reviewing the data requirements affiliated with calculating user costs, it is evident that the 20 pieces of information needed to generate user costs within the most commonly used software among highway agencies may be a hindrance. Some agencies have begun to realize the importance of good maintenance records that allow for estimation of costs associated with a range of maintenance approaches and have begun to invest in data collection and tracking systems that will ease the accumulation of such costs in the future.

Customizing and calibrating nationally distributed models for LCCA also appears to be an activity that some highway agencies have initiated. Similar to efforts required to generate costs, agencies have expended resources to calibrate deterioration curves to better align with their field inspection reports, which in the case of Florida DOT resulted in large cost savings resulting from the refinement of recommendations for major rehabilitation or replacement of assets that were not warranted.

Although the primary applications of LCCA are reported for pavements and bridges, it is important that efforts be made to work with state highway agencies to improve applications of LCCA to these assets. Survey results and interviews with highway agency representatives noted the lack of clarity or use of significant costs within LCCA, meaning that more education, data sources, and information may be needed to accurately apply LCCA to pavements and bridges before agencies can expand its application to ancillary assets.

FUTURE RESEARCH NEEDS

Two primary research needs were identified through this study effort. The first is the need for additional models—potentially simplified models—to model LCCA of assets other than pavements and bridges. In addition, guidance is needed to allow for the full inclusion of all costs—including user, agency, and maintenance costs in LCCA—as many noted the lack of user and maintenance costs within their LCCA models. Simplified models may also support the idea of a tiered approach to LCCA in that assets that are not expected to have intensive maintenance schedules and will have relatively short life spans may not require the level of detail in models such as RealCost.

Second, the need to house the range of information and models within a single guidance document will greatly help to improve LCCA implementation. This document could be similar to TRB's *Highway Capacity Manual*, which serves as a resource for transportation professionals on the topic of highway operations and level of service modeling. Professionals need a similar resource to bring together peer-reviewed research and modeling approaches for LCCA for multiple asset types, systems analysis techniques, and default or example data sets to bridge gaps in data that may hinder LCCA application. The additional benefit to a comprehensive guide for LCCA that reflects a holistic systematic view is the potential ease of incorporation by educational professionals into undergraduate curriculum to expand the knowledge and use of LCCA by all levels of engineers.

GLOSSARY

Analysis period: LCCA uses a common period of time to assess cost differences between design alternatives so that the results can be accurately compared.

Ancillary assets: Assets that are considered to be of secondary importance. For example, traffic signs and guardrails.

Asset-level LCCA: Analysis of individual transportation investments. For example, individual bridges, individual culverts, and 1/10th mi pavement sections as defined by the state transportation agency.

Current safety performance: Typical safety performance measures related to the number and rate of fatalities and/or crashes and incidents, emergency response times, public perceptions of safety, and so on, for the relevant transportation modes.

Deterioration curves/models: Models that describe performance and condition over the service life of an asset.

Discount rate: The investor's minimum acceptable rate of return.

Initial construction costs (capital costs): The initial expenditures made by an agency to construct a project. These initial costs vary across all design alternatives under consideration.

Inspection/support costs: Ongoing costs associated with acquiring data on the condition of assets through field inspection.

Maintenance costs: Ongoing costs that are required to keep the transportation facility functioning at its expected level of service throughout its lifetime. Adequate maintenance is necessary to prolong the service life of an asset and meet performance requirements set forth by state highway agencies.

Network/program-level: A holistic view of the statewide asset class that addresses current conditions, performance goals, condition prediction, and available treatments within a defined budget. Examples of program-level asset classes include pavements and bridges.

Operational costs: Ongoing costs associated with the administration of assets on a daily basis.

Preservation costs: The cost of activities performed to prevent any deficiencies before they begin to surface. Preservation activities delay the onset of deterioration and have been reported to increase asset service life, whereas maintenance and rehabilitation activities are typically performed in response to a deficiency.

Project-level: A proposed investment with logical beginning and end termini, often related to milepost or intersection that consists of multiple assets.

Rehabilitation costs: These costs address maintenance needs that are more extensive than routine maintenance activities. For example, rehabilitation activities for pavements are described as projects that restore the structural capacity of a pavement by eliminating age-related or environmental deficiencies. Rehabilitation activities are also defined as strengthening the existing pavement to support existing or future traffic loads.

Remaining service life value: When the service life of a design alternative under consideration extends beyond the period of analysis, the extended life is referred to as the remaining service life value. This value includes costs used for rehabilitation.

Salvage value: At the end of a project's service life, after it has been determined it is no longer cost-effective to extend the life or improve the performance, the raw materials may be recycled to net a monetary gain or produce a beneficial value to a state DOT, which is referred to as the salvage value.

User costs: Costs incurred by highway users over the asset service life. While performing maintenance, rehabilitation, and preservation activities, a lane closure is often required for safety, which affects user costs. Costs include delay, vehicle operation, and costs associated with vehicle crashes.

REFERENCES

1. "Improving Transportation Investment Decisions," Federal Highway Administration (FHWA), Washington, D.C., updated Aug. 2015 [Online]. Available: http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccafact.cfm.
2. American Society of Civil Engineering (ASCE) and Eno Center for Transportation, *Maximizing the Value of Investment Using Life Cycle Cost Analysis,* ASCE, Reston, Va., 2014.
3. Rangaraju, P. R., S. Amirkhanian, and Z. Guven, *Life Cycle Cost Analysis for Pavement Type Selection,* FHWA, South Carolina Department of Transportation, Clemson, Apr. 25, 2008.
4. Al-Wazeer, A., B. Harris, and C. Nutakor, "Applying LCCA to Bridges," *Public Roads*, Vol. 69, No. 3 Nov./Dec. 2005.
5. Office of Asset Management, *Life-Cycle Cost Analysis Primer,* FHWA, Washington, D.C., 2002.
6. CTC & Associates LLC, *Using Life Cycle Cost Analysis in Highway Project Development,* Caltrans Division of Research and Innovation, Sacramento, 2011.
7. Hallin, J., *NCHRP 703: Guide to Pavement-Type Selection,* Transportation Research Board of the National Academies, Washington, D.C., 2011.
8. Changmo, K., L. Eul-Bum, and J. Harvey, *Enhancement of Life-Cycle Cost Analysis Tool: RealCost California Customization,* Transportation Research Board 91st Annual Meeting Compendium of Papers, Washington, D.C., Jan. 2012.
9. Changmo, K., et al., "Automated Sequence Selection and Cost Calculation for Maintenance and Rehabilitation in Highway Life-Cycle Cost Analysis (LCCA)," *International Journal of Transportation Science and Technology,* Vol. 4, 2015.
10. Lamptey, G., et al., *Life Cycle Cost Analysis for INDOT Pavement Design Procedures,* FHWA//IN/JTRP-2004/28, Joint Transportation Research Program, Purdue University, Indianapolis, and Indiana Department of Transportation, West Lafayette, 2005.
11. Morcous, G., *Life-Cycle Assessment of Nebraska Bridges,* Nebraska Department of Roads, Lincoln, 2013.
12. Pierce, L. and G. McGovern, *NCHRP Highway Synthesis 457: Implementation of the AASHTO Mechanistic-Emperical Pavement Design Guide and Software,* Transportation Research Board of the National Academies, Washington, D.C., 2014.
13. Wang, K., J. Li, and C. Cheng, *Traffic and Data Preparation for AASHTO DARWin-ME Analysis and Design,* Louisiana Transportation Research Center, Baton Rouge, 2015.
14. Ehlen, M.A., *BridgeLCC 2.0 Users Manual: Life-Cycle Costing Software for the Preliminary Design of Bridges,* NIST-GCR-03-853, National Institute of Standards and Technology, Gaithersburg, Md., 2003.
15. Hawk, H., *NCHRP Report 483: Bridge Life-Cycle Cost Analysis,* Transportation Research Board of the National Academies, Washington, D.C., 2003.
16. Chase, S., *Virginia Bridge Inventory Systems Laboratory,* Virginia Center for Transportation Innovation and Research, Charlottesville, 2014.
17. Sabnajo, J. O. and P. D. Thompson, *Enhancement of the FDOT's Project Level and Network Level Bridge Management Analysis Tools,* State Maintenance Office, Florida Department of Transportation, Tallahassee, Feb. 2011.
18. Zilay, R. and J. Fisher, *Maintenance Life Cycle Cost Analysis Findings and Recommendations,* 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 2013.
19. Karim, H., R. Magnusson, and K. Natanaelsson, "Life-Cycle Cost Analyses for Road Barriers," *Journal of Transportation Engineering,* Vol. 138, No. 7, July 7, 2012, pp. 830–851.
20. Wyrick, D.A. and S. Erquicia, *Fleet Asset Life Cycle Costing with Intelligent Vehicles,* Intelligent Transportation Systems Institute, Center for Transportation Studies, University of Minnesota, Minneapolis, 2008.
21. Salem, O., J. Chen, and B. Salman, *Enhancing TSM&O Strategies Through Life Cycle Benefit/Cost Analysis,* U.S. Department of Transportation, Washington, D.C., 2015.
22. Gschösser, F. and H. Wallbaum, *Life Cycle Assessment of Representative Swiss Road Pavements for National Roads with an Accompanying Life Cycle Cost Analysis,* Vol. 47, No. 15, 2013, pp. 8453–8461.
23. Santos J. and A. Ferreria, "Life-Cycle Cost Analysis System for Pavement Management at Project Level," *International Journal of Pavement Engineering,* Vol. 14, Jan. 2013, pp. 71–84.
24. Singh, D. and R.L.K. Thiong, "Development of Life Cycle Cost Framework for Highway Bridges in Myanmar," *International Journal of Project Management,* Vol. 23, 2005, pp. 37–44.

25. Amini, A., M. Mashayekhi, H. Ziari, and S. Nobakht, "Life Cycle Cost Comparison of Highways with Perpetual and Conventional Pavements," *International Journal of Pavement Engineering,* Vol. 16, 2011, pp. 553–568.

26. Zavitski, J.L., et al., *Good Roads Cost Less: 2006 Study Update,* Utah Department of Transportation, Salt Lake City, 2006.

27. Utah Department of Tranportation (UDOT), *Pavement Asset Management,* UDOT, Salt Lake City [Online]. Available: https://www.udot.utah.gov/public/ucon/uconowner.gf?n=8132902110162772.

28. Sobanjo, P., D. Thompson, and O. John, *Project Level Analysis Tool,* State Maintenance Office, Florida Department of Transportation, Tallahassee, Mar. 2004.

29. Washington State Department of Transportation, Olympia [Online]. Available: http://www.wsdot.wa.gov/NR/rdonlyres/7D456546-705F-4591-AC5B-7E0D87D15543/78408/UnstableSlopeFinaFolioWEBSMALL.pdf.

BIBLIOGRAPHY

American Association of State Highway and Transportation Officials (AASHTO), *Fiscal Year 2015 Catalog,* AASHTO, Washington, D.C., 2014.

Ehlen, M.A., *BridgeLCC,* National Institute of Standards and Technology, Germantown, Md., Sept. 2003 [Online]. Available: http://www.nist.gov/el/economics/bridgelcc.cfm.

Eno Center for Transportation and ASCE, *Maximizing the Value of Investments Using Life Cycle Cost Analysis,* Washington, D.C., 2014.

Geiger, D.R., *ACTION Pavement Preservation Definitions,* Memorandum, FHWA, Washington, D.C.

New Zealand Land Transport, *A Review of the HDM/dTIMS Pavement Models Based on Calibration Site Data,* Land Transport New Zealand, Wellington, 2006.

Office of Asset Management, *Life-Cycle Cost Analysis Real-Cost User Manual,* FHWA, Washington, D.C., 2004.

Office of Management and Budget (OMB), *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs,* White House, Washington, D.C., 1992.

Rangaraju, P.R., S. Amirkhanian, and Z. Guven, *Life Cycle Cost Analysis for Pavement Type Selection,* Department of Civil Engineering, Clemson University, South Carolina Department of Transportation, Columbia, 2008.

Transportation Asset Management Plan, Minnesota Department of Transportation, Minneapolis, 2014.

Using DARWin 3.1 in Undergraduate Pavement Design Courses, M. Obadat, Ed., 120th ASEE Annual Conference & Exposition, Atlanta, American Society for Engineering Education, 2013.

Utah Department of Transportation (UDOT), *Pavement Preservation Manual Part 4: Pavement Condition Modeling with dTIMS,* UDOT, Salt Lake City, 2009.

Walls, J., III, and M.R. Smith, *Life-Cycle Cost Analysis in Pavement Design—Interim Technical Bulletin,* FHWA, Washington, D.C., 1998.

WSDOT's Unstable Slope Management Program, Washington State Department of Transportation, Olympia, Jan. 2010 [Online]. Available: http://www.wsdot.wa.gov/NR/rdonlyres/7D456546-705F-4591-AC5B-7E0D87D15543/78408/UnstableSlopeFinaFolioWEBSMALL.pdf.

APPENDIX A

Final Survey

Final Agency Survey

The following pages include the final survey including a description of the purpose and use of the information gathered through the agency survey and contact information if participants had concerns or questions.

Dear Member of the AASHTO Standing Committee on Asset Management:

The Transportation Research Board (TRB) is preparing a synthesis on Life-Cycle Cost Analysis (LCCA). This effort is being conducted for NCHRP, under the sponsorship of the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration.

Life-Cycle Cost Analysis (LCCA) for asset management has been promoted by the Federal Highway Administration (FHWA) since the passage of the Intermodal Surface Transportation Equity Act (ISTEA) of 1991. With the passage of the Moving Ahead for Progress in the 21st Century Act (MAP-21), state transportation agencies are to develop risk-based asset management plans for pavements and bridges on the national highway system, at a minimum, and are encouraged to include additional assets in their asset management plans. MAP-21 defines asset management as a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality and quantitative information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost.

This questionnaire is part of an effort in NCHRP Synthesis Topic 46-15 to develop an inventory of asset-level, project-level, and network/program-level processes or models for predicting life-cycle costs associated with preservation and replacement activities on a full range of highway assets and to better understand the data and knowledge gaps that exist for applying LCCA to a broad range of assets.

LCCA is an economic analysis process that allows an agency to fully understand the total cost of project implementation not only to the agency but also to the user. LCCA includes costs for the life of an asset (i.e., construction to replacement) and user costs associated with typical maintenance and construction activities as well as costs associated with normal operations versus work zones.

Please complete the questionnaire through SurveyGizmo by March 31, 2015. We estimate that it should take approximately 15 minutes to complete. If you have any questions, please contact our principal investigator Aimee Flannery. Any supporting materials can be sent directly to Aimee Flannery by e-mail (aimee.flannery@aemcorp.com). To encourage a high response rate to this survey, TRB has approved the following incentive structure; please provide your contact information below to receive the incentive:

$20 Starbucks gift card if survey completed within 3 weeks of receipt of survey (February 27, 2015).

$10 Starbucks gift card if survey completed within 6 weeks of receipt of survey (March 13, 2015).

For the purposes of this survey, the following definitions have been established for consistency:

- Asset-level – An individual item. For example, individual bridges, individual culverts, and 1/10th mile pavement sections as defined by the state transportation agency.
- Project-level – A proposed project with logical beginning and end termini, often related to a milepost or intersection that consists of multiple assets.
- Network/Program-level – A holistic view of the statewide asset class that addresses current conditions, performance goals, condition prediction, and available treatments, within a defined budget. Example asset classes include pavements, bridges, signs, signals, culverts, etc.

This questionnaire is being sent to you given your work in asset management. Your cooperation in completing the questionnaire will ensure the success of this effort. If you are not the appropriate person at your agency to complete this questionnaire, please forward it to the correct person.

QUESTIONNAIRE INSTRUCTIONS

1. To view and print the entire questionnaire, click on the following link and print using "control p"

2. To save your partial answers and complete the questionnaire later, click on the "Save and Continue Later" link in the upper right-hand corner of your screen. A link to the incomplete questionnaire will be e-mailed to you from SurveyGizmo. To return to the questionnaire later, open the e-mail from SurveyGizmo and click on the link. We suggest using the "Save and Continue Later" feature if there will be more than 15 minutes of inactivity while the survey is opened, as some firewalls may terminate due to inactivity.

3. To pass a partially completed questionnaire to a colleague, click on the on the "Save and Continue Later" link in the upper right-hand corner of your screen. A link to the incomplete questionnaire will be e-mailed to you from SurveyGizmo. Open the e-mail from SurveyGizmo and forward it to a colleague.

4. To view and print your answers before submitting the survey, click forward to the page following question 11. Print using "control p."

5. To submit the survey, click on "Submit" on the last page.

Thank you very much for your time and expertise.

Please enter the date (MM/DD/YYYY). ______________________

First Name ______________________

Last Name ______________________

Title ______________________

Agency/Organization______________________

Street Address ______________________

Suite ______________________

City______________________

State ______________________

Zip Code______________________

Country ______________________

E-mail Address ______________________

Phone Number ______________________

Does your agency use Life-Cycle Cost Analysis (LCCA) as part of the decision-making process for analyzing asset-level design alternatives?

☐ Yes

☐ No

If yes, which asset types are **currently** analyzed through a process that includes a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost? (Select all that apply. Selected options will appear in subsequent tables.)

☐ Pavement

- ☐ Bridges
- ☐ Culverts
- ☐ Tunnels
- ☐ Intelligent Transportation Systems (ITS)
- ☐ Traffic Signals
- ☐ Signs
- ☐ Traffic Barriers (Guardrails, Concrete Barriers, Cable Barriers)
- ☐ End Treatments (Anchorages, Terminals, Crash Cushions/Impact Attenuators)
- ☐ Striping
- ☐ Lighting
- ☐ Other (Please specify):

____

Does your agency use LCCA for selecting preservation or maintenance treatments for assets?

- ☐ Yes
- ☐ No

If yes, which asset types are **currently** analyzed using LCCA for selecting preservation or maintenance activities? (Select all that apply.)

- ☐ Pavement
- ☐ Bridges
- ☐ Culverts
- ☐ Tunnels
- ☐ Intelligent Transportation Systems (ITS)
- ☐ Traffic Signals
- ☐ Signs
- ☐ Traffic Barriers (Guardrails, Concrete Barriers, Cable Barriers)
- ☐ End Treatments (Anchorages, Terminals, Crash Cushions/Impact Attenuators)
- ☐ Striping
- ☐ Lighting
- ☐ Other (Please specify):

____

Does your agency have an LCCA application that it would like to have shared with other agencies through the development of a Case Study as part of this NCHRP Study?

- ☐ Yes
- ☐ No

Please indicate what you feel is most notable about the LCCA practice at your agency:

____

____

____

Does your agency utilize LCCA at the project level? For example, once logical beginning and end termini have been established, does your agency use LCCA to select between project alternatives that result in the same benefits with the least life-cycle cost?

☐ Yes

☐ No

Does your agency utilize LCCA at the network or program level to identify treatment efficiencies? For example, a holistic view of the statewide asset class that addresses current conditions, performance goals, condition prediction, available treatments, and within a defined budget. Example asset classes include pavements, bridges, signs, signals, culverts, etc.

☐ Yes

☐ No

Does your agency use any specialized software for LCCA?

☐ Yes

☐ No

If yes, please provide the name(s) of the tool/software you use or have developed for LCCA analysis in the table below. (Please provide any additional comments or information in the dialogue box below.)

[Answers from Question #1 will populate the assets listed in this table.]

	Software Used (Asset Level)	Software Used (Project Level)	Software Used (Network/ Program Level)
Pavement			
Bridges			
Culverts			
Tunnels			
Intelligent Transportation Systems (ITS)			
Traffic Signals			
Signs			
Traffic Barriers (Guardrails, Concrete Barriers, Cable Barriers)			
End Treatments (Anchorages, Terminals, Crash Cushions/Impact Attenuators)			
Striping			
Lighting			
Other			

Additional comments or information:

____

Does your agency have any asset-specific analysis period(s) for LCCA?

☐ Yes

☐ No

If yes, please provide the length of the selected analysis period(s) by asset type (Please provide any additional comments or information in the dialogue box below.):

[Answers from Question #1 will populate the assets listed in this table.]

	Analysis Period Used (Asset Level)	Analysis Period Used (Project Level)	Analysis Period Used (Network/ Program Level)
Pavement			
Bridges			
Culverts			
Tunnels			
Intelligent Transportation Systems (ITS)			
Traffic Signals			
Signs			
Traffic Barriers (Guardrails, Concrete Barriers, Cable Barriers)			
End Treatments (Anchorages, Terminals, Crash Cushions/Impact Attenuators)			
Striping			
Lighting			
Other			

Additional comments or information:

____

Does your agency have asset-specific discounting rates used for LCCA?

☐ Yes

☐ No

If yes, please provide the discounting rate used by asset type (Please provide any additional comments or information in the dialogue box below.):

[Answers from Question #1 will populate the assets listed in this table.]

	Discounting Rate Used (Asset Level)	Discounting Rate Used (Project Level)	Discounting Rate Used (Network/ Program Level)
Pavement			
Bridges			
Culverts			
Tunnels			
Intelligent Transportation Systems (ITS)			
Traffic Signals			
Signs			
Traffic Barriers (Guardrails, Concrete Barriers, Cable Barriers)			
End Treatments (Anchorages, Terminals, Crash Cushions/Impact Attenuators)			
Striping			
Lighting			
Other			

Additional comments or information:

____

What factors/data are used in your agency's LCCA? (Select all that apply.)

	Asset Level	Project Level	Network/ Program Level
Capital Costs	☐	☐	☐
Maintenance Costs	☐	☐	☐
Operations Costs	☐	☐	☐
Inspection/Support Costs	☐	☐	☐
User Costs	☐	☐	☐
Discount Rates	☐	☐	☐
Deterioration Curves/Models	☐	☐	☐
Uncertainty/Risk	☐	☐	☐
Resilience Goals	☐	☐	☐
Current Safety Performance	☐	☐	☐
Expected Safety Performance	☐	☐	☐
Desired Performance Levels	☐	☐	☐
Geospatial Location of Assets	☐	☐	☐
Salvage Value	☐	☐	☐
Remaining Service Value	☐	☐	☐

Other (Please provide details below.):

____

What factors/data does your agency lack to perform LCCA or improve existing LCCA? (Select all that apply.)

	Asset Level	Project Level	Network/ Program Level
Capital Costs	☐	☐	☐
Maintenance Costs	☐	☐	☐
Operations Costs	☐	☐	☐
Inspection/Support Costs	☐	☐	☐
User Costs	☐	☐	☐
Discount Rates	☐	☐	☐
Deterioration Curves/Models	☐	☐	☐
Uncertainty/Risk	☐	☐	☐
Resilience Goals	☐	☐	☐
Current Safety Performance	☐	☐	☐
Expected Safety Performance	☐	☐	☐
Desired Performance Levels	☐	☐	☐
Geospatial Location of Assets	☐	☐	☐
Salvage Value	☐	☐	☐
Remaining Service Value	☐	☐	☐

Other (Please provide details below.):

____

The survey is complete. Thank you for your participation!

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

TRANSPORTATION RESEARCH BOARD
500 Fifth Street, N.W.
Washington, D.C. 20001

ADDRESS SERVICE REQUESTED

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

The nation turns to the National Academies of Sciences, Engineering, and Medicine for independent, objective advice on issues that affect people's lives worldwide.
www.national-academies.org

ISBN: 978-0-309-27219-3
90000
9 780309 272193