

## Using Life Cycle Cost Analysis in Highway Project Development

*Requested by*

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November 29, 2011

*The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.*

### **Executive Summary**

#### **Background**

The National Highway System Designation Act of 1995 made life cycle cost analysis (LCCA) compulsory for National Highway System projects costing more than \$25 million. Enactment of the Transportation Equity Act for the 21st Century in 1998 removed this requirement. While no longer required, the Federal Highway Administration (FHWA) promotes LCCA as an engineering economic analysis tool that allows transportation officials to quantify the differential costs of alternative investment options for a given project.

A 2002 FHWA publication<sup>1</sup> describes the LCCA process:

In brief, the LCCA process begins with the development of alternatives to accomplish the structural and performance objectives for a project. The analyst then defines the schedule of initial and future activities involved in implementing each project design alternative. Next, the costs of these activities are estimated. Best-practice LCCA calls for including not only direct agency expenditures (for example, construction or maintenance activities), but also costs to facility users that result from these agency activities.

The predicted schedule of activities and their associated agency and user costs form the projected life-cycle cost (LCC) stream for each design alternative. Using an economic technique known as “discounting,” these costs are converted into present dollars and summed for each alternative. The analyst can then determine which alternative is the most cost-effective.

Caltrans is interested in learning about tools and practices related to the application of LCCA as part of the project development process for highway improvements. To aid in this effort, this Preliminary Investigation aims to synthesize national guidance, state practices, and completed and in-process national and state-related research that examines the use of LCCA for highway improvements, including the availability of tools and procedures and the calculations associated with LCCA. We also explore

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<sup>1</sup> Life-Cycle Cost Analysis Primer, Office of Asset Management, FHWA, Report No. FHWA-IF-02-047, August 2002.

innovative practices, attempts by agencies to incorporate worker safety considerations into LCCA practices, challenges associated with implementing LCCA and international LCCA practices.

### **Summary of Findings**

We gathered information in five topic areas related to the application of LCCA in highway project development:

- National Guidance.
- State Practices.
- International Practices.
- Related Research and Other Resources.
- Research in Progress.

Following is a summary of findings by topic area.

### **National Guidance**

We located tools and guidance for both pavement and bridges.

#### **Pavement**

- FHWA's RealCost software uses Microsoft Excel spreadsheets to perform LCCA for pavement selection in accordance with FHWA best practice methods. Supporting documentation includes a user manual, best practices for LCCA and an explanation of the software methodology.
- AASHTO's DARWin 3.1, a pavement design and analysis program for both initial design and rehabilitation, includes a life cycle cost module. AASHTO will sunset this version in December 2011, replacing it with DARWin-ME. It does not appear that DARWin-ME includes an LCCA-specific module.

#### **Bridges**

- Among the benefits expected to result from analysis of the data collected through FHWA's Long-Term Bridge Performance program is the effective use of LCCA.
- A 2003 NCHRP report establishes guidelines for conducting life cycle costing for bridges and includes a software program that considers agency and user costs.
- BridgeLCC, a user-friendly life cycle costing software program developed by the National Institute of Standards and Technology, allows bridge engineers to assess the cost-effectiveness of new, alternative construction materials.

### **State Practices**

We reviewed LCCA practices in 17 states:

- California.
- Colorado.
- Florida.
- Georgia.
- Illinois.
- Indiana.
- Michigan.
- Minnesota.
- New York.
- Ohio.
- Oregon.
- Pennsylvania.
- Texas.
- Utah.
- Virginia.
- Washington.
- Wisconsin.

We summarize our findings related to LCCA tools and parameters in the table below. Detailed information can be found in **State Practices**, which begins on page 9 of this Preliminary Investigation.

Some highlights from the table:

- Six states—California, Colorado, Florida, Indiana, Oregon and Washington—use FHWA’s RealCost software. The Michigan Department of Transportation (DOT) uses AASHTO’s DARWin program.
- Three states—Michigan, Texas and Wisconsin—have developed custom software packages to perform some or all of the LCCA.
- A custom spreadsheet is used by Georgia, Minnesota and Pennsylvania DOTs to conduct LCCA. See the **State Practices** section of this report for links to the spreadsheets used by Minnesota and Pennsylvania DOTs.
- An analysis period of 40 to 50 years is most common among the states we investigated.
- Almost half the states use a discount rate of 4 percent. Four states—Colorado, Michigan, Minnesota and Washington—use a rate based on recommendations by the federal Office of Management and Budget (OMB).
- While FHWA recommends their use, six states—Illinois, Minnesota, New York, Ohio, Virginia and Wisconsin—do not include user costs in LCCA.

<b>Selected States’ LCCA Tools and Parameters</b>				
<b>State</b>	<b>LCCA Tool</b>	<b>Analysis Period (Years)</b>	<b>Discount Rate (Percent)</b>	<b>User Costs Included</b>
<b>California</b>	RealCost	20, 35, 55	4	Yes
<b>Colorado</b>	RealCost	40	Determined annually (OMB)	Yes
<b>Florida</b>	RealCost	40	3.5	Optional
<b>Georgia</b>	Custom spreadsheet	30, 40	3	Yes (factor in weighted decision matrix)
<b>Illinois</b>	Not specified	45	3	No
<b>Indiana</b>	RealCost	At least 50 (new)	Generally 4, though consider a range of 0 to 10	Yes
<b>Michigan</b>	DARWin and custom software	10 to 20	Determined annually (OMB)	Yes
<b>Minnesota</b>	Custom spreadsheet	35 to 50	Determined annually (OMB)	No
<b>New York</b>	Not specified	Range	4	No

<b>Selected States' LCCA Tools and Parameters</b>				
<b>State</b>	<b>LCCA Tool</b>	<b>Analysis Period (Years)</b>	<b>Discount Rate (Percent)</b>	<b>User Costs Included</b>
<b>Ohio</b>	Not specified	35	Range of 0 to 6	No
<b>Oregon</b>	RealCost	40 (new) 50 (Interstate)	4	Optional
<b>Pennsylvania</b>	Custom spreadsheet	50	4	Yes
<b>Texas</b>	Custom software	30	Not specified	Yes
<b>Utah</b>	Not specified	25 to 40	4 (recommended)	Yes
<b>Virginia</b>	Not specified	50	4	No
<b>Washington</b>	RealCost	50	4 (based on OMB)	Yes
<b>Wisconsin</b>	Custom software	50	5	No

- Information about similar LCCA inputs for some of the states included in the table above as well as other states appears in publications cited in this investigation, including:
  - A tabular summary of results from a 2007 AASHTO survey that examined agencies' use of LCCA procedures for pavement type selection. See page 28 of this Preliminary Investigation for the report citation.
  - A 2008 report prepared for South Carolina DOT that displays survey results in a table of LCCA parameters. See page 26 of this Preliminary Investigation for the report citation.

For some states, it appears that LCCA inputs and practices have evolved over time.

- Pennsylvania and Washington State DOTs report reaching out to the paving industry when establishing and communicating LCCA guidelines.
- A 2006 Colorado DOT study aimed to develop guidelines for determining the long-term costs of adding additional capacity and other related transportation improvements to the state highway and bridge system. Researchers found gaps in the data needed to facilitate the development of long-term project costs.

### **International Practices**

- A 2009 conference paper prepared by Australian researchers reported on progress of research to develop and extend contemporary LCCA models in the evaluation of road infrastructure sustainability.
- A 2008 Australian study provided recommendations to develop a general LCCA model applicable across all sectors and industries.
- The 2011 International Infrastructure Management Manual published by the Institute of Public Works Engineering Australia addresses asset management practices, including LCCA, in

countries around the world. The 2006 volume updated by the 2011 edition included practices in New Zealand, Australia, South America, the United Kingdom and the United States.

- FHWA’s International Technology Scanning Program produced a 2007 report that provided insight into LCCA practices as they relate to concrete pavements in Canada and several European countries.

### **Related Research and Other Resources**

- In a 2009 journal article, researchers reported on a case study to assess impacts of risk and uncertainty considerations on estimating project benefits and on network-level project selection.
- The author of a 2009 *Better Roads* article noted that “while it’s not required by edict, states are adopting LCCA because it makes sense.” The article highlighted LCCA practices in Colorado and Texas, and reports on research conducted by South Carolina DOT to examine LCCA.
- South Carolina DOT sponsored a 2008 research project to evaluate LCCA practices among state highway agencies for pavement type selection. Of the 33 states surveyed, all but one—Maine—reported the use of LCCA as part of the decision-making process for selecting pavement type. The report concluded with proposed inputs for a probabilistic approach to LCCA for South Carolina DOT.
- AASHTO’s Research Advisory Committee sponsored a 2007 survey of state transportation agencies that examined LCCA for pavement type selection.
- In a 2004 conference paper, the authors presented the results of a three-year study that assessed the LCCA practice within state highway agencies. The paper also highlighted four basic disparities in the practice that contribute to the observed gap between the state-of-the-practice and state-of-the-art of LCCA.

### **Research in Progress**

- A project that wrapped up this summer updated Alaska’s flexible pavement design software to include LCCA.

### **Gaps in Findings**

This report examines LCCA as it relates to pavements and bridges and does not investigate a more global application of LCCA to general asset management practices. We examine in some detail the LCCA practices of 17 states, including California. Current information about other states’ LCCA practices is likely also available, if not publicly.

We did not identify specific references to agencies’ consideration of worker safety in the development of LCCA practices.

### **Next Steps**

Caltrans might consider the following in its evaluation of the use of LCCA for highway improvement projects:

- Contacting states using FHWA’s RealCost software, including Colorado, Florida, Indiana, Oregon and Washington, to identify ways in which Caltrans’ use of the software might be enhanced.

- Contacting states that have developed custom LCCA software, including Michigan (CO<sup>3</sup>), Texas (Texas Pavement Type Selection and Rigid Pavement Life Cycle Cost Analysis) and Wisconsin (WisPave).
- Examining the custom spreadsheets used by Minnesota and Pennsylvania DOTs to glean variables and factors for possible application by Caltrans.
- Contacting states with a long history of using LCCA for pavement design such as Colorado, Michigan, Pennsylvania and Washington to learn the reasons for and effects of modifications to LCCA practices over time.
- Contacting Colorado DOT to learn about possible further work in connection with a 2006 project to develop guidelines for determining the long-term costs of adding additional capacity and other related transportation improvements to the state highway and bridge system.

## National Guidance

Pavement-related LCCA guidance at the national level comes in the form of FHWA's RealCost, a software program that uses Excel spreadsheets, and AASHTO's DARWin, a pavement design and analysis program that includes a life cycle cost module. We also highlight bridge-related LCCA guidance, including a 2003 NCHRP report that provides guidelines for conducting life cycle costing and a life cycle costing software program developed by the National Institute of Standards and Technology.

### Pavement-Related Tools and Guidance

**RealCost**, Version 2.5, FHWA.

Program available for download at <http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm>

This software provides a tool to perform LCCA for pavement selection in accordance with FHWA best practice methods. Best practices are outlined in the FHWA publication Life-Cycle Cost Analysis Primer, and the software methodology is documented in FHWA's Life-Cycle Cost Analysis Technical Bulletin; both documents are cited below. This web site provides access to compressed files that contain the setup programs for RealCost, which uses Microsoft Excel spreadsheets.

Related Resources:

**RealCost Life-Cycle Cost Analysis User Manual**, Office of Asset Management, FHWA, Version 2.1, May 2004.

<http://www.fhwa.dot.gov/infrastructure/asstmgmt/rc210704.pdf>

This manual provides direction on how to enter the data required to perform LCCA and how to incorporate the software's outputs into project-level decision making. LCCA steps include:

1. Establish design alternatives.
2. Determine activity timing.
3. Estimate costs (agency and user).
4. Compute life cycle costs.
5. Analyze the results.

The software can perform both deterministic and probabilistic modeling of pavement LCCA.

**Deterministic LCCA.** The analyst assigns each LCCA input variable a fixed, discrete value. The analyst determines the value most likely to occur for each parameter, usually basing the determination on historical evidence or professional judgment. Collectively, the input values are used to compute a single life cycle cost estimate for the alternative under consideration. Sensitivity analyses may be conducted to test input assumptions by varying one input, holding other inputs constant and determining the effect of the variation on the outputs. Pitfalls of the deterministic approach include its failure to address simultaneous variation in multiple inputs and convey the degree of uncertainty associated with the life cycle cost estimates.

**Probabilistic LCCA.** Inputs are described by probability functions that convey both the range of likely inputs and the likelihood of their occurrence. Probabilistic LCCA allows for the simultaneous computation of differing assumptions for many different variables. Outputs, like inputs, express the likelihood that a particular life cycle cost will actually occur.

Outputs are provided in tabular and graphic format. RealCost also supports deterministic sensitivity analyses and probabilistic risk analyses.

**Life-Cycle Cost Analysis Primer**, Office of Asset Management, FHWA, Report No. FHWA-IF-02-047, August 2002.

<http://isddc.dot.gov/OLPFiles/FHWA/010621.pdf>

This publication provides background for transportation officials interested in investigating the use of LCCA to evaluate alternative infrastructure investment options.

**Life-Cycle Cost Analysis in Pavement Design: In Search of Better Investment Decisions**, FHWA, Pavement Division Interim Technical Bulletin, Publication No. FHWA-SA-98-079, September 1998.

<http://isddc.dot.gov/OLPFiles/FHWA/013017.pdf>

This Interim Technical Bulletin presents technical guidance and recommendations on best practices in conducting LCCA in pavement design. Among the topics addressed:

- Input parameters, with simple examples of traditional LCCA in pavement design.
- The variability and inherent uncertainty associated with input parameters.
- Recommendations on acceptable ranges for the value of time as well as discount rates.
- The use of sensitivity analysis in traditional LCCA approaches.
- User costs—a combination of delay, vehicle operating costs and crash costs—and procedures to determine their value.

**Life-Cycle Cost Analysis**, FHWA, updated November 22, 2011.

<http://www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.cfm>

This web site offers a wealth of resources related to LCCA, including a user's group and an opportunity to "Ask the Expert."

**DARWin**, Version 3.1, AASHTO.

<http://darwin.aashtoware.org/>

AASHTO's DARWin is a complete pavement design and analysis program for both initial design and rehabilitation. Included in the 3.1 version of DARWin is a life cycle cost module, which the web site describes in this way:

The Life Cycle Cost Module is a comprehensive analytical tool that can be used to compare alternative designs. All costs are considered in the analysis, including initial construction costs, maintenance costs, rehabilitation costs, and salvage costs. The results can be output using different evaluation methods (net present value or equivalent uniform annual cost) and different cost parameters (total cost or cost per unit length in one or two directions). Cash flow diagrams are generated automatically for each project.

AASHTO will sunset this older version of its pavement analysis software by December 31, 2011. The new software, DARWin-ME, became available for licensing January 1, 2011.

Related Resource:

**DARWin-ME Pavement Design Software**, Trenton M. Clark, Asphalt Program Manager, Virginia Department of Transportation, *Pavement Evaluation 2010*, October 2010.

<http://www.cpe.vt.edu/pavementevaluation/presentations/Clark.pdf>

Slide 4 of this conference presentation describes DARWin-ME inputs and outputs. Unlike DARWin 3.1, LCCA does not appear to be addressed in a separate module of this new version of the software.



## **Bridge-Related Tools and Guidance**

**Long-Term Bridge Performance (LTBP) Program**, FHWA, updated June 28, 2011.

<http://www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/structures/ltpb/index.cfm>

Among the LTBP Program's goals is the compilation of a comprehensive database of quantitative information from a representative sample of bridges nationwide. The study will provide a detailed and timely picture of bridge health and better bridge management tools. Among the benefits expected to result from analysis of the data collected through the LTBP Program is the effective use of LCCA.

**Bridge Life-Cycle Cost Analysis**, *NCHRP Report 483*, 2003.

[http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_483a.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_483a.pdf)

This report establishes guidelines and standardizes procedures for conducting life cycle costing. The Guidance Manual outlines the concept of life cycle costing, identifies sources for data and explains the methodology by which life cycle costing can be conducted. An accompanying CD-ROM contains appendices to the report, the User's Manual and Guidance Manual, and the bridge life cycle cost analysis software. The software considers agency and user costs and enables the user to consider both vulnerability and uncertainty in the analysis.

**BridgeLCC**, Version 2.0, National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce, September 2003.

<http://www.nist.gov/el/economics/bridgelcc.cfm>

BridgeLCC is a user-friendly life cycle costing software developed to help bridge engineers assess the cost-effectiveness of new, alternative construction materials. The software uses a life cycle costing methodology based on both ASTM standard E 917 and a cost classification developed at the National Institute of Standards and Technology. BridgeLCC compares new and conventional bridge materials—for example, high-performance concrete versus conventional concrete—and analyzes alternative conventional materials. The program can also be used to analyze pavements, piers and other civil infrastructure.

Related Resource:

**BridgeLCC 2.0 Users Manual: Life-Cycle Costing Software for the Preliminary Design of Bridges**, National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce, Report No. NIST GCR 03-853, September 2003.

[http://www.nist.gov/customcf/get\\_pdf.cfm?pub\\_id=907943](http://www.nist.gov/customcf/get_pdf.cfm?pub_id=907943)

This user manual for BridgeLCC includes step-by-step instructions and example analyses.

## **State Practices**

Below we examine LCCA practices in 17 states:

- California.
- Colorado.
- Florida.
- Georgia.
- Illinois.
- Indiana.
- Michigan.
- Minnesota.
- New York.
- Ohio.
- Oregon.
- Pennsylvania.
- Texas.
- Utah.
- Virginia.
- Washington.
- Wisconsin.

For each state, we highlight key LCCA inputs, including analysis period, discount rate and user costs, and provide information about other elements of some of the LCCA programs.

## **California**

**Life-Cycle Cost Analysis Procedures Manual**, Pavement Standards Team & Division of Design, Caltrans, August 2010.

[http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement\\_Engineering/PDF/LCCA\\_Manual\\_09\\_01\\_2010\\_Final.pdf](http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/LCCA_Manual_09_01_2010_Final.pdf)

This manual describes LCCA procedures to be used on pavement projects for the state highway system, with limited exceptions. Included are step-by-step instructions for using the California edition of FHWA's software, RealCost.

Key LCCA inputs:

- **Analysis period.** 20, 35 and 55 years.
- **Discount rate.** 4 percent.
- **User costs.** User costs include the additional travel time and related vehicle operating costs incurred by the traveling public due to potential congestion associated with planned construction throughout the analysis period.
- **Other requirements.** Caltrans currently considers agency and user costs to be equivalent, but when analyzing LCCA results advises comparing the individual agency and user costs for each alternative in addition to total costs.

Related Resource:

**Life-Cycle Cost Analysis**, Office of Pavement Engineering, Caltrans.

[http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement\\_Engineering/LCCA\\_index.html](http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html)

This web site provides links to a variety of LCCA resources, including internal memos, training and related resources referenced in the Caltrans Life-Cycle Cost Analysis Procedures Manual.

## **Colorado**

**Chapter 10, Pavement Type Selection and Life Cycle Cost Analysis**, 2012 Pavement Design Manual, Colorado Department of Transportation.

[http://www.coloradodot.info/business/designsupport/bulletins\\_manuals/Complete%202012%20Pavement%20Design%20Manual%20Tables%20\\_6-25-2009\\_.pdf](http://www.coloradodot.info/business/designsupport/bulletins_manuals/Complete%202012%20Pavement%20Design%20Manual%20Tables%20_6-25-2009_.pdf)

The chapter related to LCCA begins on page 345 of the PDF. Among the cost factors considered in the manual: initial construction, maintenance, design, pavement construction engineering, traffic control, salvage value and user costs. Colorado DOT uses RealCost software for probabilistic LCCA. A real-world example using the RealCost software begins on page 370 of the PDF.

LCCA is used to:

- Compare concrete to asphalt pavements for all new or reconstruction projects with more than \$2 million initial pavement material cost.
- Compare asphalt and concrete for all surface treatment projects with more than \$2 million initial pavement cost where both pavement types are considered feasible alternatives as determined by the regional materials engineer.

Key LCCA inputs:

- **Analysis period.** 40 years.

- **Discount rate.** Colorado DOT calculates the discount rate and standard deviation annually. See the January 2009 publication cited below for further discussion of discount rate calculations.
- **User costs.** See Related Resources below for Colorado DOT's WorkZone program.
- **Other requirements.** See Table 10.1 in the 2012 Pavement Design Manual (page 348 of the PDF) for the default input values for treatment periods to be used in an LCCA.

Related Resources:

**WorkZone**, Colorado Department of Transportation.

<http://www.coloradodot.info/business/engineeringapplications/download-area.html>; scroll down to "CDOT WorkZone—User Cost program"

Colorado DOT uses this software program to calculate user costs.

**Hitch-Hikers Guide to the User Cost Program**, Colorado Department of Transportation.

<http://www.coloradodot.info/business/engineeringapplications/assets/documentation/hitchersguide>

This user's guide to the WorkZone software addresses the use of traffic data, the type of work and options to customize the WorkZone program to a specific project.

**Colorado Department of Transportation's Current Procedure for Life Cycle Cost Analysis and Discount Rate Calculations**, Colorado Department of Transportation, Report No. CDOT-2009-2, Final Report, January 2009.

<http://www.coloradodot.info/programs/research/pdfs/2009/lcca2009.pdf>

This report describes the current method used to select a discount rate and summarizes data collected from several states listing their hot-mix asphalt (HMA) overlay cycles and discount rates.

Colorado DOT's LCCA process for pavements dates back to 1972. The original process remains fundamentally unchanged, although the agency updated its LCCA procedure in 1981, 1994, 2000, 2002 and 2008. The changes made in 2008 addressed the minimum dollar amount requiring LCCA for pavement construction and the method for determining the state's discount rate.

A survey investigating state discount rates found that more states use a set value of 4 percent; the average for the states that participated in the survey is 3.8 percent. The authors note that discount rate selection is a critical process in LCCA because it directly impacts which alternative will be chosen.

- A high discount rate favors projects with low initial construction costs and higher maintenance costs dispersed throughout the remaining life of the project. The higher maintenance costs are discounted at a greater value making it more beneficial to defer those costs.
- A low discount rate favors projects with high initial costs and low maintenance costs because any remaining cost are factored in closer to face value.

Every year, the federal OMB publishes a new 30-year real interest rate. Colorado DOT uses this annual value to update its discount rate. For 2008 data, the 10-year moving average (1999 to 2008) provides a new discount rate of 3.3 percent; the previous 10 years of the moving average (1998 to 2007) are used to determine a standard deviation of 0.22 percent.

**Life-Cycle Cost Analysis: The Colorado Experience**, Transportation Asset Management Case Studies, FHWA, Report No. FHWA-HIF-10-007, 2007.

<http://www.fhwa.dot.gov/asset/if10007/if01007.pdf>

This publication highlights Colorado DOT's leadership role in developing an LCCA process that incorporates results from statistical research and knowledge from actual pavement projects into policies and procedures to produce a carefully considered, long-term approach to managing assets. Lessons learned include:

- A vocal advocate within the leadership of the organization is useful to champion a clear vision and facilitate the process.
- Involving contractor representatives from relevant industries helps clarify issues and promotes buy-in.
- Including other transportation-related offices in LCCA training sessions deepens the use of this practice across the organization. For example, middle management is analyzing how pavement LCCA may be applied to selection of culvert types.
- Since Colorado DOT uses LCCA to determine pavement type, and that affects construction cost, LCCA gives the agency some control over escalating costs because it creates an examination of competing options. The unit cost of material seems to be higher in areas where historically only one type of pavement has been used.
- Pavement performance is better predicted by data from the pavement management system than from subjective surveys.

**Life Cycle Costing**, Colorado Department of Transportation, Report No. CDOT-DTD-R-2006-3, Final Report, February 2006.

<http://cospl.coalliance.org/fez/eserv/co:5267/tra210063internet.pdf>

This research aimed to develop guidelines for determining the long-term costs of adding additional capacity and other related transportation improvements to the state highway and bridge system. Future costs including ongoing maintenance, rehabilitation and replacement costs have not been traditionally considered when a project is advanced.

Researchers proposed a methodology that would capture the incremental increase in long-term project costs associated with adding additional capacity to the system. Incremental costs were defined as not only geometric increases, but also include such things as roadway and bridge maintenance, intelligent transportation system (ITS) deployment and maintenance, and roadway and bridge rehabilitation. However, researchers found that a central repository of data that would facilitate the development of long-term project costs is lacking. The most noticeable data gaps in developing comprehensive long-term project costs are related to ITS and bridges.

## **Florida**

**Pavement Type Selection Manual**, Florida Department of Transportation, Document No. 625-010-005-F, June 2011.

<http://www.dot.state.fl.us/pavementmanagement/pcs/PTS%20Manual.pdf>

Florida DOT uses RealCost to calculate the present value of each alternative pavement. When the LCCA indicates that project costs for the competing pavement types are within 10 percent of each other, the costs will be considered equivalent and alternate bids will be sought unless other engineering factors, such as the need to minimize disruption to traffic in congested locations, dictate the particular pavement type.

Key LCCA inputs:

- **Analysis period.** 40 years, unless a longer period is justified, based on engineering principles, by the district and accepted by the state pavement design engineer.
- **Discount rate.** 3.5 percent.
- **User costs.** User costs (such as motorist delay time, vehicle operating costs and accident costs) will be considered separately if there is reason to believe that there will be significant differences in these costs between pavement types.

**Enhancement of the FDOT's Project Level and Network Level Bridge Management Analysis Tools**, Florida Department of Transportation, February 2011.

[http://www.dot.state.fl.us/research-center/Completed\\_Proj/Summary\\_MNT/FDOT\\_BDK83\\_977-01\\_rpt..pdf](http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_MNT/FDOT_BDK83_977-01_rpt..pdf)

In this project, Florida DOT investigated several additional modeling issues that were not possible during initial implementation of AASHTO's Pontis Bridge Management System. Researchers improved deterioration, action effectiveness and cost models for Pontis and Florida DOT's Project Level Analysis Tool.

## **Georgia**

**Life-Cycle Cost Analysis: The Georgia Experience**, Transportation Asset Management Case Studies, FHWA, Report No. FHWA-IF-07-009, 2007.

<http://www.fhwa.dot.gov/asset/if07009/if07009.pdf>

Georgia DOT adopted the agency's first LCCA guidelines in 1994. After experimenting with the RealCost software, the agency developed a customized spreadsheet that follows methodology outlined in the FHWA publication Life-Cycle Cost Analysis in Pavement Design. (See page 8 of this Preliminary Investigation for this citation.) At the time of publication, Georgia DOT planned to partner with FHWA on enhancements for RealCost to address concerns the agency has about attracting and retaining staff to run customized software. The agency is also considering its timing of the LCCA in the project development process. (At the time of publication, LCCA took place after preliminary plans were complete.)

Key LCCA inputs:

- **Analysis period.** 30 and 40 years.
- **Discount rate.** 3 percent.
- **User costs.** Since agency and user costs are different costing streams, Georgia DOT does not combine them. Instead, the agency incorporates the calculated user costs as a factor in the weighted decision matrix to understand their influence.

**Pavement Design Manual**, Georgia Department of Transportation, December 7, 2005.

<http://www.dot.state.ga.us/doingbusiness/PoliciesManuals/roads/Pavement/Pavement%20Design%20Manual.pdf>

See page 88 of the PDF for Section 10.10, Life Cycle Cost Analysis. At the time of publication, an LCCA will only be required at the direction of the project manager or in the event of a value engineering study.

## Illinois

**Chapter 54, Pavement Design**, Bureau of Design and Environment Manual, Illinois Department of Transportation, April 2011.

<http://www.dot.state.il.us/desenv/BDE%20Manual/BDE/pdf/Chapter%2054%20Pavement%20Design.pdf>

See page 112 of the PDF for Section 54-7.05, Selection Process, for equations used to determine annual costs of alternatives during the selection process.

Page 13 of the PDF describes the types of projects subject to LCCA:

- New construction/reconstruction projects that involve more than 4,750 square yards of pavement and/or pavement costs exceed \$500,000.
- If the economic analysis does not result in one design being more than 10 percent cheaper than the others, the pavement selection will be based upon an alternate pavement bidding process. See page 14 of the PDF for project criteria and requirements for use of the alternate pavement bidding process.

Key LCCA inputs:

- **Analysis period.** 45 years.
- **Discount rate.** 3 percent.
- **User costs.** Not used.

## Indiana

**52-12.0. Life-Cycle Costs**, Chapter 52, MEPDG Pavement and Underdrain Design Elements, Part 5, Road Design, The Indiana Design Manual, Indiana Department of Transportation, 2011.

<http://www.in.gov/dot/div/contracts/standards/dm/2011/Part5/Ch52/ch52.htm>

A discussion of life cycle costs begins on page 67 of the PDF. Indiana DOT uses FHWA's RealCost, Version 2 or higher, to perform LCCA. See page 71 of the PDF for Section 52-12.03, Analysis Steps, which lists the LCCA details that provide the inputs for RealCost.

An LCCA is completed:

- On a project that includes more than one feasible alternative as directed by the INDOT Pavement Selection Panel or Pavement Steering Committee.
- For a new pavement, pavement replacement or major rehabilitation project with mainline pavement of more than 10,000 square yards.
- For each treatment identified in Section 52-11.0 (see page 60 of the PDF) to compare preventive maintenance preservation treatments with differing design lives.

Two scenarios that are determined to have a total net present value within 10 percent (15 percent for a preservation project with an initial cost as calculated for the LCCA of less than \$750,000) are considered to be essentially the same. Other factors should be used to make the final selection such as initial costs, constructability, work zone traffic control and user delay costs.

Key LCCA inputs:

- **Analysis period.** At least 50 years when comparing new pavements. In comparing treatments with lesser design lives, the analysis period may be shorter.

- **Discount rate.** For general purposes, a 4 percent discount rate can be assumed. However, a range of rates from 0 percent to 10 percent should be used to determine if the alternate scenarios are discount-rate sensitive.
- **User costs.** May include user delay costs during construction and rehabilitation, user vehicle operating and accident expenses, engineering fees or other expenditures over the life of the pavement.
- **Other requirements.**
  - The design life of the pavement should be varied to test the LCCA for sensitivity based on the existing pavement condition, past performance or the condition of the drainage system.
  - The cost of work zone traffic control and the cost of user delays during construction may have a significant effect on the analysis. These costs should be quantified for the designs.

## **Michigan**

**“Evaluation of Life-Cycle Cost Analysis Practices Used by the Michigan Department of Transportation,”** Arthur Chan, Gregory Keoleian, Eric Gabler, *Journal of Transportation Engineering*, Vol. 134, No. 6, June 2008: 236-245.

[http://sci.umich.edu/docs/Chan\\_et\\_al\\_08\\_Evaluation\\_of\\_Life-Cycle\\_Cost+.pdf](http://sci.umich.edu/docs/Chan_et_al_08_Evaluation_of_Life-Cycle_Cost+.pdf)

Michigan DOT adopted LCCA as part of its pavement selection process in the mid-1980s. This journal article analyzes MDOT’s accuracy in projecting the actual costs over the pavement service life and choosing the lowest-cost pavement alternative with the use of 10 highway sections in Michigan grouped into four case studies.

While results indicate that MDOT’s LCCA procedure correctly predicts the pavement type with lower initial construction cost, actual costs are usually lower than estimated in the LCCA. This outcome may be partly because the cost estimation module in MDOT’s model is not site-specific enough. Refinements to its pavement construction and maintenance cost estimating procedures would assist MDOT in realizing the full potential of LCCA in identifying the lowest-cost pavement alternatives for the pavements studied.

**Pavement Design and Selection Manual**, Michigan Department of Transportation, March 2005.

[http://www.mi.gov/documents/mdot/MDOT\\_Pavement\\_Design\\_and\\_Selection\\_Manual\\_257723\\_7.pdf](http://www.mi.gov/documents/mdot/MDOT_Pavement_Design_and_Selection_Manual_257723_7.pdf)

MDOT’s pavement selection policy requires that an LCCA be performed on all projects with paving costs greater than \$1 million. The department uses the equivalent uniform annual cost (EUAC) method to calculate a life cycle cost on a per annum basis. Inputs to an LCCA include both initial costs and maintenance costs.

MDOT uses a range of tools to conduct an LCCA:

- DARWin Version 3.01 is used to prepare pavement designs.
- MDOT developed user cost analysis software—Construction Congestion Cost (CO<sup>3</sup>)—to aid traffic engineers in performing the user cost analysis portion of a pavement selection analysis. This software is based on the user cost analysis method recommended by FHWA in the Interim Technical Bulletin Life Cycle Cost Analysis in Pavement Design.
- Project costing software, also developed by MDOT, calculates initial agency costs that are included in the LCCA. This software uses stored unit price data for all applicable work items and user input data for each design alternative to calculate initial costs.



Key LCCA inputs:

- **Analysis period.** See page 7 of MDOT's Pavement Design and Selection Manual for a table that reflects the design life of a range of pavement fixes.
- **Discount rate.** The discount rate used in LCCA calculations is obtained from the federal OMB and is updated yearly, usually in February. See <http://www.whitehouse.gov/sites/default/files/omb/memoranda/2011/m11-12.pdf> for the February 2011 memo.
- **User costs.** Information about the CO<sup>3</sup> analysis software is available at <http://www.ricarr.com/Papers/CO3%20Materials/CO3%20Abstract.html> and [http://mich.gov/documents/mdot/MDOT\\_SOA\\_2010-02\\_Construction\\_Congestion\\_Cost\\_CO3\\_Software\\_325726\\_7.pdf](http://mich.gov/documents/mdot/MDOT_SOA_2010-02_Construction_Congestion_Cost_CO3_Software_325726_7.pdf).

## **Minnesota**

**Life Cycle Cost Analysis (LCCA) of Pavement Preservation Projects**, Policy, Safety and Strategic Initiatives Division, Minnesota Department of Transportation, Technical Memorandum No. 10-04-MAT-01, January 28, 2010.

<http://dotapp7.dot.state.mn.us/edms/download?docId=887550>

In 2008, the state Legislature passed legislation that requires an LCCA for all pavement projects in the reconditioning, resurfacing and road repair funding categories that are to be constructed after July 1, 2011. If the chosen option does not have the lowest life cycle cost, the justification must be documented.

Related Resources:

**LCCA Standard Spreadsheet**, Minnesota Department of Transportation, undated.

[http://www.dot.state.mn.us/materials/pvmtdesign/docs/LCCA\\_Standard\\_Spreadsheet.xls](http://www.dot.state.mn.us/materials/pvmtdesign/docs/LCCA_Standard_Spreadsheet.xls)

This spreadsheet is used to calculate an LCCA.

**LCCA Exception Form**, LCCA Exception for Pavement Preservation Project In reconditioning (RD), resurfacing (RS), or road repair (RX) funding categories, Minnesota Department of Transportation, undated.

[http://www.dot.state.mn.us/materials/pvmtdesign/docs/LCCA\\_Exception\\_Form.pdf](http://www.dot.state.mn.us/materials/pvmtdesign/docs/LCCA_Exception_Form.pdf)

This form is used to justify not selecting the lowest-cost alternative resulting from an LCCA.

Key LCCA inputs:

- **Analysis period.** Range of 35 years (HMA or portland cement concrete (PCC) overlay, HMA on base) to 50 years (PCC pavement).
- **Discount rate.** The present worth will be calculated using a discount rate equal to the real interest rate on 30-year Treasury bonds as published each year by the federal OMB.
- **User costs.** Not used.
- **Other requirements.** Include any remaining life value of the pavement alternative that remains at the end of the analysis period. Remaining life value is calculated as the prorated share of the cost of the last activity based on the service life that extends past the analysis period.



## **New York**

**Life Cycle Cost Analysis**, Regional Design Instruction, New York State Department of Transportation Region One, RDI 04-017, July 6, 2004.

<https://www.dot.ny.gov/regional-offices/region1/repository/RDI%2004-017%20Life%20Cycle%20Cost%20Analysis.pdf>

This document provides an example of the LCCA procedure implemented in New York State DOT Region One. The starting point for the LCCA calculation is the result of an investigation of treatment alternatives by the regional materials engineer (RME). A sample LCCA request containing the information supplied by the RME and the resulting calculation begins on page 2 of the PDF. Final treatment selection may be subject to factors other than the LCCA result.

**Chapter 5, Appendix 5A, Part 3: Life-Cycle Cost Analysis**, Comprehensive Pavement Design Manual, New York State Department of Transportation, May 1993.

<https://www.dot.ny.gov/divisions/engineering/design/dqab/cpdm/repository/chapter5app5a2.pdf>

For New York State DOT, an LCCA is only one step in the decision-making process. Other factors that may influence treatment selection include budgetary constraints, nonpavement construction needs and heavy traffic volumes. An LCCA example begins on page 16 of the PDF.

Key LCCA inputs:

- **Analysis period.** The minimum analysis period is the longest expected service life of the initial treatment and one rehabilitation treatment for each alternative strategy considered.
- **Discount rate.** 4 percent.
- **User costs.** Not used.
- **Other requirements.** A sensitivity analysis is performed to determine sensitivity of the LCCA to a particular variable.

## **Ohio**

**Pavement Design Manual, October 21, 2011, Update**, Appendix A, Pavement Policies, Pavement Type Selection Policy, Highway Operations, Policy Number 22-009(P), September 1, 2006.

[http://www.dot.state.oh.us/Divisions/Engineering/Pavement/Pavement%20Design%20%20Rehabilitation%20Manual/PDM\\_Update\\_2011-10-21.pdf](http://www.dot.state.oh.us/Divisions/Engineering/Pavement/Pavement%20Design%20%20Rehabilitation%20Manual/PDM_Update_2011-10-21.pdf)

Provisions of this policy related to LCCA include:

- When more than one feasible alternative exists, an LCCA is prepared.
- If the life cycle costs of one or more alternatives are within 10 percent of the lowest life cycle cost alternative, they are considered to be equal to the lowest life cycle cost alternative. Any of the equal alternatives may be selected.
- Alternatives not within 10 percent of the life cycle cost of the lowest-cost alternative are eliminated from consideration.
- If no alternatives are within 10 percent, the lowest-cost alternative is automatically selected.

**Section 700, Life-Cycle Cost Analysis**, Pavement Design Manual, Ohio Department of Transportation, January 1999.

<http://www.dot.state.oh.us/Divisions/Engineering/Pavement/Pavement%20Design%20%20Rehabilitation%20Manual/Sect700.pdf>

This section of Ohio DOT's Pavement Design Manual describes the LCCA process. LCCA examples begin on page 7 of the PDF.

Key LCCA inputs:

- **Analysis period.** 35 years.
- **Discount rate.** Rather than choose one discount rate, Ohio DOT uses a range of rates to see how the discount rate affects the outcome. Total life cycle cost is calculated for discount rates of 0 percent, 1 percent, 2 percent, 3 percent, 4 percent, 5 percent and 6 percent. Results are then displayed in tabular and graphical form to see how the discount rate affects the apparent least-cost alternative.
- **User costs.** Not used.

## **Oregon**

**ODOT Pavement Design Guide**, Pavement Services Unit, Oregon Department of Transportation, August 2011.

[http://www.oregon.gov/ODOT/HWY/CONSTRUCTION/docs/pavement/pavement\\_design\\_guide.pdf](http://www.oregon.gov/ODOT/HWY/CONSTRUCTION/docs/pavement/pavement_design_guide.pdf)

Chapter 9, Life Cycle Cost Analysis, begins on page 63 of the PDF. When an LCCA is applicable, it should be conducted as early in the project development cycle as possible. The level of detail should be consistent with the level of investment. Oregon DOT uses RealCost for the following:

- New pavement construction where more than one mile of new roadbed will be constructed.
- Rehabilitation of existing pavements where major rehabilitation such as total reconstruction or rubblization is necessary or where options of different life expectancies are being considered.
- When considering pavement design strategies with structural life less than the minimum standard of 15 years. A pavement design exception is also required for options with less than eight years of structural pavement life.

Projects not requiring an LCCA require a cost analysis to compare the construction costs for each alternative. For final selection of an alternative, when life cycle costs are within 10 percent, a consensus should be reached among key Oregon DOT staff.

Key LCCA inputs:

- **Analysis period.** 40 years for new construction or projects with extensive pavement rehabilitation; 50 years for projects on the Interstate highway system. For projects where pavement design alternatives are developed to provide pavement life until total reconstruction, a shorter analysis period is appropriate.
- **Discount rate.** 4 percent.
- **User costs.** For those projects in locations where one of the alternatives being considered will create a significant queue for an extended period of time either during initial construction or rehabilitation, a user cost analysis should be considered in addition to an agency cost LCCA. User cost analysis is treated separately from the agency cost analysis, and the two costs are not combined for a single LCCA value.

- **Other requirements.** Unit costs also consider maintenance and salvage value.

## **Pennsylvania**

**Pavement Policy Manual**, Bureau of Maintenance and Operations, Pennsylvania Department of Transportation, Commonwealth of Pennsylvania, Publication 242, April 2, 2010.

<ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%20242.pdf>

See Chapter 11.2, Life-Cycle Cost Analysis Guidelines, which begins on page 116 of the PDF. Highlights of the PennDOT LCCA program include:

- An LCCA is required for all structural improvement projects in excess of \$3 million of total project costs on the Interstate system and \$15 million on all other facilities.
- The total present worth (initial construction + maintenance activities + annual maintenance + user delay) cost of each design alternative is to be compared and all alternatives must have the same analysis period unless a residual life discount factor is applied. Residual life discount = year 45 treatment cost x (age of treatment @ year 50/life of treatment - 1).
- The residual life discount is used in the LCCA calculation to even out the analysis periods of the concrete and bituminous alternatives to make them equal to 50 years.
- The LCCA is performed without a separate inflation rate.
- The shelf life of an LCCA shall be no longer than three years from the time it is performed.
- A difference of 10 percent or more in life cycle costs will be sufficient to conclusively determine the pavement type. Engineering judgment, adjacent pavement types or other factors are considered in cases where the difference in life cycle cost is less than 10 percent.

Key LCCA inputs:

- **Analysis period.** 50 years.
- **Discount rate.** 4 percent.
- **User costs.** User delay is considered in the present worth calculation.

Related Resource:

**Life Cycle Cost Analysis Spreadsheet**, Version 4.4, Pavement Design and Analysis LCCA Roadway Management Division, Pennsylvania Department of Transportation, December 9, 2009.

[ftp://ftp.dot.state.pa.us/public/Bureaus/BOMO/RM/LCCA\\_Version\\_4.4.xlsx](ftp://ftp.dot.state.pa.us/public/Bureaus/BOMO/RM/LCCA_Version_4.4.xlsx)

This is a Microsoft Excel spreadsheet for the preparation of a paving project LCCA following the guidelines in Chapter 11 of the Pavement Policy Manual. (See the citation above.)

**PennDOT Pavement Life-Cycle Cost Analysis—Phase 1**, Pennsylvania Department of Transportation, FHWA, Report No. FHWA-PA-2006-032-030102-2, April 2005.

Citation at <http://trid.trb.org/view/2005/M/798170>

The main objective of this study was to evaluate PennDOT's current method of pavement LCCA and recommend steps to improve the process. Key findings and recommendations include:

- Standardized procedures for estimating initial costs using data contained in PennDOT's Engineering and Construction Management database should be developed.
- The schedules for pavement maintenance and rehabilitation in the Pavement Policy Manual need to be updated to reflect improvements made in the design and materials used in both rigid and flexible pavements over the last 10 years.

- There is no external review of the process by the affected industries in Pennsylvania. An annual joint PennDOT and pavement industry review program for the LCCA process should be instituted.
- The criteria for selecting a discount rate of 6 percent could not be determined and it was found that the rate used by PennDOT is higher than rates used by most other states surveyed. Researchers recommend adopting the federal OMB procedure.

**Life-Cycle Cost Analysis: The Pennsylvania Experience**, Transportation Asset Management Case Studies, FHWA, Report No. FHWA-IF-03-O38, 2003.

<http://www.fhwa.dot.gov/infrastructure/asstmgmt/dipa2.pdf>

Since the mid-1980s, PennDOT has conducted an LCCA for all Interstate pavement projects with an estimated initial cost of more than \$1 million and for all other pavement projects with an estimated cost of more than \$10 million. PennDOT bases its design selections primarily upon life cycle costs and includes the effects of user delay and increased vehicle operating costs due to the presence of a work zone.

Lessons learned include:

- **LCCA data inputs.** PennDOT has relied on both expert opinion and historical data to develop LCCA inputs.
- **Uncertainty.** When the total agency costs of different alternatives are similar, other factors are specifically included in the decision process. PennDOT believes that the “10 percent rule” accounts for uncertainty in LCCA inputs and allows engineering judgment to be incorporated into the pavement design selection decision.
- **Industry relationships.** PennDOT has reached out to the state’s paving industry groups to improve their understanding of PennDOT’s selection process. Making the pavement-type selection process transparent has enhanced the credibility of the process and has turned potential adversaries into allies.

## **Texas**

**Section 5, Pavement Type Selection**, Chapter 2, Pavement Design Process, Pavement Design Guide, Texas Department of Transportation, January 2011.

<http://onlinemanuals.txdot.gov/txdotmanuals/pdm/pdm.pdf>

Section 5 begins on page 43 of the PDF. The manual notes that LCCA is only one of many processes for selecting a pavement type. Projects that require an LCCA are those projects with greater than 30 percent trucks or 100,000 average daily traffic (ADT), or any combination of truck percentage and ADT that falls above the curve in a chart that appears on page 44 of the PDF.

Related Resources:

**Life Cycle Cost Analysis of Portland Cement Concrete Pavements**, Texas Department of Transportation, Report No. FHWA/TX-00/0-1739-1, September 1999.

[http://www.utexas.edu/research/ctr/pdf\\_reports/1739\\_1.pdf](http://www.utexas.edu/research/ctr/pdf_reports/1739_1.pdf)

This report describes the development of a new LCCA methodology for PCC pavements that considers all aspects of pavement design, construction, maintenance and user impacts throughout the analysis period. The modular nature of the methodology allows for easy updating.

**A Rational Pavement Type Selection Procedure**, Texas Department of Transportation, Report No. FHWA/TX-04/0-1734-S, December 1998.

[http://www.utexas.edu/research/ctr/pdf\\_reports/0\\_1734\\_S.pdf](http://www.utexas.edu/research/ctr/pdf_reports/0_1734_S.pdf)

This report describes the development of Texas Pavement Type Selection, or TxPTS, which evaluates and quantifies three factors associated with candidate strategies—agency costs, user delay costs and performance levels.

Key LCCA inputs:

- **Analysis period.** 30 years.
- **Discount rate.** Not specified.
- **User costs.** LCCA considers all agency expenditures and user costs throughout the life of the facility, not just the initial investment.

**Rigid Pavement Design and Analysis Web-Based Training Site**, Texas Department of Transportation, Product 5-1869-03-P8, 2004.

[http://www.utexas.edu/research/ctr/pdf\\_reports/5\\_1869\\_03\\_P8.pdf](http://www.utexas.edu/research/ctr/pdf_reports/5_1869_03_P8.pdf)

While the training site's URL does not appear to be operational, this training publication offers brief descriptions of two tools TxDOT uses to perform LCCA:

**Rigid Pavement Life Cycle Cost Analysis (RPLCCA).** This Windows-based program allows direct comparisons of all costs associated with several design and rehabilitation strategies over the life of the pavement. Performance prediction models assess the rate of distress development characteristic to each type of pavement. Because the program attempts to include all costs associated with a strategy, a large number of inputs are required, including material properties and such difficult-to-determine factors as traffic growth, vehicle operating costs, emissions and accidents. The program attempts to provide reasonable default values that can be overridden by the user when better data are available.

**Texas Pavement Type Selection (TxPTS).** This program allows a user to compare several paving strategies and ranks them according to their cost-effectiveness. Primarily using LCCA to rank the various strategies under consideration, TxPTS is similar to the RPLCCA program but takes fewer costs into account and thus requires fewer user inputs. The tool's performance models are less complicated than those included in RPLCCA and do not address specific distresses. However, TxPTS includes flexible pavements for new construction whereas RPLCCA only allows flexible overlays over rigid pavements.

## Utah

**Pavement Management and Pavement Design Manual**, Utah Department of Transportation, March 2008.

<http://www.udot.utah.gov/main/uconowner.gf?n=200311041134232>

Section 3E, Life Cycle Cost Analysis for Pavement Design and Rehabilitation, begins on page 64 of the PDF. Utah DOT does not consider salvage or energy costs in the LCCA. Factors included in the analysis are the availability of funds, project-specific and environmental conditions or constraints, and constructability. Results that show a 15 percent or less benefit in LCCA indicate the use of an alternate bid process. One rigid design and one flexible design are carried through the design process and into bidding.

**Life Cycle Cost Analysis**, Value Engineering, Engineering Services Division, Utah Department of Transportation, August 2007.

<http://www.udot.utah.gov/main//uconowner.gf?n=89198019100205627>

Page 20 of the PDF lists the steps used in an LCCA for new or rehabilitated pavements. At the time of publication, the manual indicates that LCCA is inappropriate for bridges because information on

differential costs did not exist. As reliable data becomes available, the department will consider using LCCA for bridges.

Key LCCA inputs:

- **Analysis period.** 25 to 40 years. The recommended analysis period for each project will be determined by the regional pavement management team.
- **Discount rate.** 4 percent is recommended; the discount rate will be established by the Utah DOT Value Engineering group.
- **User costs.** These costs include those associated with vehicle operating costs (such as fuel consumption, parts and tires) and user delay costs (such as denial-of-use, speed change delays and idling time). Application of user costs use will be determined by the regional pavement management engineer and the regional pavement management team. See page 14 of the PDF for a user cost calculation.

## Virginia

**Pavement Type Selection Procedures in Virginia**, Pavement Design and Evaluation Section—Materials Division, Virginia Department of Transportation, July 2011.

<http://www.virginiadot.org/business/resources/Materials/bu-mat-pavementsselection.pdf>

This document describes how LCCA is used and provides a Pavement Type Selection Decision Work Flow on page 11 of the PDF.

LCCA is performed after designing the possible alternate pavement sections. For most projects, Virginia DOT uses the present worth approach, though also uses the EUAC approach for major rehabilitation projects where the design life of the competing options is not the same. If the present worth or EUAC values in the LCCA differ more than 10 percent, the pavement type with the lowest present worth or EUAC for certain major rehabilitation projects is recommended for final selection. When the net present worth or EUAC is within 10 percent, other factors are examined or the project is selected for alternate bidding.

**Life Cycle Cost Analysis**, Materials Division, Virginia Department of Transportation, July 2011.

<http://www.virginiadot.org/business/resources/Materials/bu-mat-LLCA.pdf>

This document provides technical guidance to Virginia DOT engineers involved in selecting a pavement type for major construction and rehabilitation projects. Tables outline the assumed performance and rehabilitation year and treatment for different pavement types. LCCA is necessary for projects where multiple pavement types are feasible and considered. See the citation below for the situations where LCCA is required.

**Chapter VI, Pavement Evaluation and Design**, Materials Division, Manual of Instructions, Virginia Department of Transportation, July 2011.

<http://www.virginiadot.org/business/resources/Materials/bu-mat-moiVI.pdf>

Section 606 outlines the situations where LCCA is required to select the most cost-effective pavement design.

Key LCCA inputs:

- **Analysis period.** 50 years.
- **Discount rate.** 4 percent.
- **User costs.** Not used.

**Life Cycle Cost Analysis Pavement Options**, Materials Division/Virginia Transportation Research Council, May 2002.

<http://www.virginiadot.org/business/resources/bu-mat-pde-LCCADocMay02.pdf>

This document describes LCCA, its history in Virginia DOT and projects requiring LCCA.

## **Washington**

**WSDOT Pavement Policy**, Environmental and Engineering Programs Division, Washington State Department of Transportation, June 2011.

<http://www.wsdot.wa.gov/NR/rdonlyres/D7971B81-5443-45B9-8B9B-BFC0D721F5A1/0/WSDOTPavementPolicyFinal71211.pdf>

A discussion of LCCA begins on page 45 of the PDF. WSDOT uses RealCost to perform its LCCAs. Points of interest include:

- Appendix 3, Example Pavement Type Selection Report (page 58 of the PDF). This example applies WSDOT's Pavement Type Selection Protocol Analysis to a specific project.
- Appendix 4, WSDOT Probabilistic Inputs (page 85). These are the input values for WSDOT's probabilistic analysis; see Appendix 5 for a sample analysis.
- Appendix 5, Probabilistic Analysis Example (page 89).
- Appendix 6, Project Specific Details Items for Consideration (page 100). When the LCCA indicates that competing designs are approximately equivalent, regions should include the engineering reasons that suggest the selection of one pavement type over another. Appendix 6 provides a list of possible considerations.

Key LCCA inputs:

- **Analysis period.** 50 years.
- **Discount rate.** 4 percent, as based on OMB methodology.
- **User costs.** User costs associated with each of the rehabilitation alternatives are determined using only costs associated with user delay. This is based on the construction periods and the traffic volumes that are affected by each of the rehabilitation alternatives, considering both day and night construction scenarios.
- **Other requirements.** If the LCCA of the two alternatives is greater than 15 percent, select the least expensive alternative. If the LCCA of alternatives is within 15 percent, perform an engineering analysis.

**“PTSP: Pavement Type Selection Protocol,”** Thomas E. Baker, State Materials Engineer, Environmental and Engineering Programs, Washington State Department of Transportation, *2008 TRB Annual Meeting*, January 17, 2008.

<http://onlinepubs.trb.org/onlinepubs/archive/am/2008/baker.pdf>

This conference presentation described Washington State DOT's Pavement Type Selection Protocol (PTSP). The protocol includes three analyses: foundation, life cycle cost and engineering. The presentation also provides a historical perspective on the WSDOT program:

- WSDOT has had a pavement type selection protocol since the 1960s. The program was updated in 1986 to include probabilistic calculations of life cycle cost.
- In 2003, the agency was met with controversy and agitation.
  - Industries wanted more information and more participation.



- Industry proposals included excluding life cycle costs and bidding only on initial costs.
- Industry partners offered valuable input and while neither industry liked the final PTSP, both supported WSDOT's efforts and appreciated having a clear, published protocol.
- A revised protocol was published in 2005, including a new section on selecting dowel bar types for concrete pavements.
- WSDOT evaluated and chose not to move to competitive bidding to select pavement, citing the following reasons:
  - Life cycle cost moves disagreement from pavement selection to bid factor.
  - Different sets of plans are expensive and introduce the potential for confusion and claims.
  - Owner interests are not always easily captured in dollars and cents.

## **Wisconsin**

**FDM 14-15-1, Chapter 14: Pavements, Section 15: Pavement Type Selection**, Facilities Development Manual, Wisconsin Department of Transportation, November 17, 2010.

<http://roadwaystandards.dot.wi.gov/standards/fdm/14-15.pdf>

Pavement type selection is primarily based on the outcome of the LCCA. This procedure identifies the types of projects for which an LCCA is required and those that are exempt from the process. WisDOT uses its own software—WisPave—for pavement design and LCCA.

For state highways:

- The process is completed if the low-cost LCCA alternative is chosen. If the cost difference between the desired option and the LCCA low-cost option is less than or equal to 5 percent, then the selection is at the region's discretion and supporting documentation is required.
- If the difference between the desired pavement structure option and the low-cost LCCA option is more than 5 percent, the region pavement engineer requests a review committee meeting. This committee, which is established on a case-by-case basis, reaches a consensus that is documented in the Pavement Design Report.

For local road projects that require an LCCA, local agencies are responsible for costs that exceed the cost of the LCCA low-cost alternative.

Key LCCA inputs:

- **Analysis period.** 50 years.
- **Discount rate.** 5 percent.
- **User costs.** Not used.
- **Other requirements.** For alternatives that have rehabilitation cycles that extend beyond 50 years, a rehabilitation salvage value is calculated and credited back into the alternative's total facility cost. The rehabilitation salvage value calculation consists of discounting the linearly prorated rehabilitation cost.



## International Practices

Below we highlight publications that describe recommended advances in LCCA for Australia and New Zealand and LCCA practices used for concrete pavements in Canada and in Europe.

**“Extending Life-Cycle Costing (LCC) Analysis for Sustainability Considerations in Road Infrastructure Projects,”** Kai Chen Goh, Jay Yang, *Proceedings of 3rd CIB International Conference on Smart and Sustainable Built Environment*, June 2009.

<http://eprints.qut.edu.au/31344/1/c31344.pdf>

This conference paper presented by Australian researchers reported on the progress of research aimed at developing and extending contemporary LCCA models in the evaluation of road infrastructure sustainability. The suggested new model development is based on sustainability indicators identified through previous research and incorporates industry-verified cost elements of sustainability measures. See Figure 3, A New Model for Sustainability Life Cycle Cost Analysis of Road Infrastructure, on page 6 of the PDF.

**Life Cycle Cost Analysis (LCCA)**, Australian Asset Management Collaborative Group, 2008.

[http://www.aamcog.com/wp-content/uploads/2011/08/LifeCycle-Costing-Project-Report-April-2008-\(2\).pdf](http://www.aamcog.com/wp-content/uploads/2011/08/LifeCycle-Costing-Project-Report-April-2008-(2).pdf)

Through a literature review, this study aimed to capture any general LCCA methods with the intent of forming a general model applicable across all sectors and industries. Recommendations include:

- A more uniform and universal approach to selecting the discount rate used in the analysis is needed.
- The most important paradigm shift required in LCCA is the acknowledgment by practitioners of the variability in nearly all model inputs.
- One of the major areas where life cycle cost is currently underutilized is during the operational life of the asset.
- LCCA is simply one tool in a much larger portfolio of asset management techniques, and therefore should be one input among many in a larger evaluation or management process. Techniques such as benefit-cost analysis, statistical activity cost theory and real options theory can incorporate different factors into the overall management framework of the asset.

Related Resources:

**International Infrastructure Management Manual**, Institute of Public Works Engineering Australia, 2011.

Purchase information available at <http://www.ipwea.org.au/bookshop/iimm/>

This manual provides basic asset management principles and practical steps for implementing advanced asset management systems. While we were unable to view this edition, we could confirm that the 2006 edition addresses asset management practices in New Zealand, Australia, South America, the United Kingdom and the United States.

**Life Cycle Costing—An Application Guide**, Standards New Zealand, AS/NZS 4536, April 4, 1999.

Purchase information available at <http://www.standards.govt.nz/web-shop/?action=viewSearchProduct&mod=catalog&pid=4536%3A1999%28AS%7CNZS%29&searchId=1192058&searchOrderingIndex=1&searchSessionId=8C4E18088932CDAA387E4C695CC42D58>

This standard describes a process for life cycle costing of a product as a component of an economic evaluation. Appendices include hypothetical examples, a sample spreadsheet indicating typical costs that may occur over the life cycle phases, typical cost-generating activities and an elaboration of real cost, nominal cost and discounted cost.

**Long-Life Concrete Pavements in Europe and Canada**, International Technology Scanning Program, FHWA, Report No. FHWA-PL-07-027, August 2007.

<http://www.pavement.com/Downloads/LLCP.pdf>

Chapter 2, Pavement Selection Strategies, which begins on page 25 of the PDF, describes LCCA practices in Canada, Germany, Austria, Belgium, The Netherlands and the United Kingdom.

The publication's summary notes:

Although most countries visited state that they consider life-cycle costs, in practice, other factors such as functional class, truck traffic levels, initial cost and environmental issues drive pavement type selection.

## **Related Research and Other Resources**

The following publications use case studies and surveys to assess the state of the practice with regard to LCCA, with some authors offering recommendations for process improvements.

**“Highway Project Level Life-Cycle Benefit/Cost Analysis under Certainty, Risk, and Uncertainty: Methodology with Case Study,”** Zongzhi Li, Sunil Madanu, *Journal of Transportation Engineering*, Vol. 135, No. 8, August 2009: 516-526.

Citation at [http://dx.doi.org/10.1061/\(ASCE\)TE.1943-5436.0000012](http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000012)

The authors introduce an uncertainty-based methodology for highway project-level life cycle benefit/cost analysis that handles certainty, risk and uncertainty associated with input factors used in the computation. Data on system preservation and expansion, usage and candidate projects for state highway programming are used to compute project benefits using deterministic, risk-based and uncertainty-based analysis approaches. Significant differences are identified with and without uncertainty considerations when the three sets of estimated project benefits are implemented in a model for project selection.

**“Apples, Oranges and Pavements: The Value of Life-Cycle Cost Analysis Lies in Its Ability to Effectively Compare a Variety of Different Entities,”** Tom Kuennen, *Better Roads*, Vol. 79, No. 6, June 2009: 16-18, 20-21.

<http://www.expresswayonline.com/pdf/BR%20RS%20JUNE%202009%20LIFE%20CYCLE%20COST%20ANALYSIS.pdf>

The author notes that “while it’s not required by edict, states are adopting LCCA because it makes sense.”

The article highlights LCCA practices in Colorado and Texas, and reports on research conducted by South Carolina DOT to examine LCCA. (See the citation below.) At the time of publication, South Carolina DOT made infrequent use of LCCA in its pavement selection process.

**Life Cycle Cost Analysis for Pavement Type Selection**, Final Report, South Carolina Department of Transportation, Report No. FHWA-SC-08-01, April 25, 2008.

<http://www.clemson.edu/t3s/scdot/pdf/projects/SPR656Final.pdf>

In this project, researchers evaluated LCCA practices among state highway agencies for pavement type selection process and proposed a probabilistic LCCA approach for use by South Carolina DOT. The project analyzed data obtained from surveys of transportation agencies in the United States and Canada. A total of 33 states and two Canadian provinces participated in a preliminary survey. Results include:

- All but one of the responding agencies—Maine—reported the use of LCCA as part of the decision process for selecting pavement type.
- Half of the respondents use RealCost, DARWin or other customized software to conduct LCCA. Among these states, six states use RealCost, six states use customized software and only one state

uses DARWin exclusively. The remaining states use a combination of available software programs and one state is in the process of adopting RealCost software.

- Most of the responding states (approximately 60 percent) do not consider user costs in LCCA calculations. However, three states that do not currently include user costs in the analysis reported that they are planning to include user costs in the future.
- Most of the state DOTs incorporating user costs into the analysis calculate only user delay costs during construction and major rehabilitation activities.

Tables of interest in the report include:

- Table 3.2, Analysis Period and Rehabilitation Timings (page 59).
- Table 4.1, Proposed Minimum, Most Likely and Maximum Service Lives Values for Initial and Rehabilitation Service Lives (page 67).
- Table B.1, Practice of LCCA and LCCA Parameters (page 73).

Given the wide use of RealCost and FHWA's role in providing support to customize the software to meet the needs of individual states, researchers proposed RealCost as the preferred software for South Carolina DOT's use in conducting LCCA for pavement type selection.

Proposed LCCA inputs for South Carolina DOT:

- **Analysis period.** 40 years.
- **Discount rate.** Discount rates published in the OMB circular, corresponding to a 30-year maturity, appear to be most reasonable and annually updated source of information for choosing a discount rate.
- **User costs.** User costs independent of agency costs, rather than combining the agency costs and user costs into a lump sum value for further analysis.
- **Other requirements.** Conducting sensitivity analysis on input parameters, especially on discount rate, analysis period and rehabilitation timings, is recommended to be able to understand which inputs make the largest impact on the results. Sensitivity analysis may also be conducted to determine break-even points that alter the ranking of the alternatives. Examples of such analyses are provided in Appendix E, which begins on page 130 of the PDF.

**Life Cycle Cost Analysis for Pavement Type Selection**, AASHTO Research Advisory Committee (RAC) Survey, May 2007.

<http://research.transportation.org/Documents/LCCARepplies.xls>

This survey, conducted by Mississippi DOT, asked agencies to respond to eight questions regarding LCCA procedures for pavement type selection. Responses were received from 21 agencies. In the table below we highlight a selection of responses from those agencies using LCCA for determining pavement type for more than only major projects.

**Excerpts from May 2007 AASHTO RAC Survey on LCCA for Pavement Type Selection**

State	Analysis Period (Years)	Discount Rate (Percent)	User Costs Included	Data Used to Determine Maintenance Treatments	Alternate Pavement Type Bidding Procedures
<b>Alabama</b>	28	4	No	Historical	Yes
<b>Colorado</b>	40	4 (deterministic model) 4.5 (probabilistic model)	Yes	Historical	No
<b>Florida</b>	40	4	Optional; developing guidelines	Historical and engineering judgment	Pilot projects in 2009
<b>Illinois</b>	40	3	Not currently, though research is ongoing	Historical and theoretical	No, but in development
<b>Indiana</b>	30 and 40	4	Sometimes; may use 10% of user costs	Theoretical and semiempirical	No
<b>Kansas</b>	40	3	Only adverse travel if an alternate requires traffic detour	Theoretical	No
<b>Missouri</b>	45	Current OMB real discount rate	No	Historical and theoretical	Yes, for projects with more than two lane miles
<b>Montana</b>	40	3	No	Historical	No
<b>New Jersey</b>	10, 20, 30 and 40	3, 4 and 5; typically 4	No	Primarily historical	No
<b>New York</b>	50	4	No; working on implementing user and user delay costs using RealCost guidelines	Historical	No

<b>Excerpts from May 2007 AASHTO RAC Survey on LCCA for Pavement Type Selection</b>					
<b>State</b>	<b>Analysis Period (Years)</b>	<b>Discount Rate (Percent)</b>	<b>User Costs Included</b>	<b>Data Used to Determine Maintenance Treatments</b>	<b>Alternate Pavement Type Bidding Procedures</b>
<b>Ohio</b>	35	Current OMB real discount rate	No	Historical data adjusted for improvements in specifications and materials	Generally no
<b>South Carolina</b>	30	3.5	No	Theoretical	No
<b>Washington</b>	50 (Interstate and primary); 20 (all others)	4	Yes	No response	No
<b>Wyoming</b>	30	4	No	Historical	No

**“Life Cycle Cost Analysis: State-of-the-Practice vs State-of-the-Art,”** Kaan Ozbay, Dima Jawad, Neville A. Parker, Sajjad Hussain, *TRB 2004 Annual Meeting CD-ROM*.

<http://rits.rutgers.edu/files/lifecyclecost.pdf>

This conference paper presented the results of a three-year study that assessed the LCCA practice within state highway agencies. In addition to presenting the study results, this paper offered an analysis of the observed gap between the state-of-the-practice and state-of-the-art of LCCA. Researchers concluded that this gap is the result of four basic disparities in the practice:

- *The statistical nature of the uncertain input parameters.* In the state-of-the-practice, virtually all analysts assume discrete values for the uncertain input parameters. In the state-of-the-art, uncertain parameters are represented by probability distributions that best describe the possible variability in the value of the parameter.
- *The determination of the timing of future rehabilitation activities.* In general, state DOTs rely on expert opinion and past practices to establish the life cycle strategies for the alternatives, which specify the timing of rehabilitation, upgrading and reconstruction. Conversely, academic research applies facility performance prediction models to predict the time when rehabilitation activities must take place in accordance with a preset minimum threshold for the facility serviceability (i.e., each type of distress or a composite index of distresses).
- *The inclusion/exclusion of user and social costs.* The general tendency of state DOTs is to exclude some components of the costs encountered by users on the assumption that such costs are common to all alternatives. However, research indicates that costs associated with comfort, risk and reliability, noise and health effects are significant and should be included.
- *The treatment of uncertainty.* State DOTs often overlook the uncertainty factor when applying LCCA. To address this, risk analysis using the probabilistic approach is gaining acceptance, including the use of probabilistic techniques based on Monte Carlo simulation to treat uncertainty in LCCA.

Related Resource:

**Guidelines for Life Cycle Cost Analysis**, New Jersey Department of Transportation, Report No. FHWA-NJ-2003-012, July 2003.

<http://cait.rutgers.edu/files/FHWA-NJ-2003-012.pdf>

This is the full report of the research described in the article cited above. Cycle-Cost-Analysis Survey Results begin on page 92 of the PDF.

### **Research in Progress**

The project presented below is updating Alaska's flexible pavement design software to include LCCA.

**“Inclusion of Life Cycle Cost Analysis in Alaska Flexible Pavement Design Software,”** Alaska Department of Transportation and Public Facilities, expected completion date: July 31, 2011.

<http://trid.trb.org/view/2009/P/976535>

The objective of this study is to update the current Alaska Flexible Pavement Design (AKFPD) software with LCCA to create a single software package capable of executing the economic cost analysis and structural analysis functions. Upon completion, the project will provide updated AKFPD software, a modified AKFPD manual and case studies with complete analysis processes to help the user navigate through the software.