



COLORADO DEPARTMENT OF TRANSPORTATION'S CURRENT PROCEDURE FOR LIFE CYCLE COST ANALYSIS AND DISCOUNT RATE CALCULATIONS

Scott Harris, CDOT Pavement Design Program

January 2009

**COLORADO DEPARTMENT OF TRANSPORTATION
DTD APPLIED RESEARCH AND INNOVATION BRANCH**

The contents of this report reflect the views of the author(s), who is(are) responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Technical Report Documentation Page

1. Report No. CDOT-2009-2	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle COLORADO DEPARTMENT OF TRANSPORTATION'S CURRENT PROCEDURE FOR LIFE CYCLE COST ANALYSIS AND DISCOUNT RATE CALCULATIONS		5. Report Date January 2009	
		6. Performing Organization Code	
7. Author(s) Scott Harris		8. Performing Organization Report No. CDOT-2009-2	
9. Performing Organization Name and Address Materials and Geotechnical Branch 4670 Holly St. Unit A Denver, Colorado 80216		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Colorado Department of Transportation - Research 4201 E. Arkansas Ave. Denver, CO 80222		13. Type of Report and Period Covered Final	
		14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the US Department of Transportation, Federal Highway Administration			
16. Abstract This report provides information on life cycle cost analysis (LCCA) as applied to CDOT roadways. It describes the current method CDOT uses to select a discount rate. It also summarizes data collected from several states listing their HMA overlay cycles and discount rates. Implementation: The discount rate will be calculated annually by the HQ Materials Pavement Design Unit and distributed to the Pavement Design Engineers in each Region for use in their LCCA.			
17. Keywords LCCA, discount rate, probabilistic LCCA, deterministic LCCA, triangular distribution, normal distribution, lognormal distribution, inflation, rehabilitation cycles		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 13	22. Price

COLORADO DEPARTMENT OF
TRANSPORTATION'S CURRENT PROCEDURE FOR
LIFE CYCLE COST ANALYSIS AND DISCOUNT
RATE CALCULATIONS

by

Scott Harris

Report No. CDOT-2009-2

Prepared by

Colorado Department of Transportation

Materials and Geotechnical Branch

Sponsored by the

Colorado Department of Transportation

In Cooperation with the

U.S. Department of Transportation

Federal Highway Administration

January 2009

Colorado Department of Transportation
DTD Applied Research and Innovation Branch
4291 E Arkansas Ave.
Denver, CO 80222
(303) 757-9506

ACKNOWLEDGEMENTS

The author wishes to give special thanks to Jay Goldbaum and Bob Locander of the CDOT Materials and Geotechnical Branch for their efforts developing the LCCA procedures and time spent reviewing this document. Without them this report would not have been possible.

Introduction

The Colorado Department of Transportation (CDOT) has previously published life cycle cost analysis (LCCA) procedural reports in 2002 and 2006. This is an update to the earlier reports defining the currently approved LCCA practices for CDOT pavement designs statewide.

CDOT has a written LCCA process for pavements dating back to 1972. The original process remains fundamentally unchanged, although the CDOT LCCA procedure has been updated 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.

Life Cycle Cost Analysis

The Federal Highway Administration (FHWA) defines LCCA as an analysis technique that builds on the well-founded principles of economic analysis to evaluate the over-all-long-term economic efficiency between competing alternative investment options. It does not address equity issues. It incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments. It attempts to identify the best value (the lowest long-term cost that satisfies the performance objective being sought) for investment expenditures⁽¹⁾.

Before a LCCA can be carried out a benefit-cost analysis (BCA) is performed to determine if a project's desired benefit can be obtain through a reasonable cost. Once a BCA deems a project necessary, the LCCA approach is used to objectively compare alternatives over a predetermined amount of time. The primary use of LCCA by CDOT is to compare alternatives for asphalt and concrete pavements. Once the pavement designs for both alternatives have been completed, the initial construction, annual maintenance, required rehabilitations, and user costs are calculated for both. Then these costs are run through a 40-year life cycle cost analysis to identify the alternative with the lowest overall cost and best value for the traveling public. In 2002, CDOT increased the analysis period to 40 years. The 40-year analysis period was chosen by CDOT, because

FHWA's LCCA Policy Statement recommends an analysis period of at least 35 years for all pavement projects ⁽²⁾. CDOT planned to follow FHWA's recommendation, as well as account for pavement rehabilitation cycles to prevent having to use a salvage value. Unmodified HMA has a 10-year rehab life, which easily led to a 40-year analysis period.

After the preliminary designs are completed for each pavement type's typical section, pavement quantities, costs, and construction time can be estimated. The estimated initial pavement costs, along with annual maintenance, rehabilitation, and user costs are the foundation for a reliable LCCA decision. The LCCA calculations for CDOT are done using FHWA's RealCost software. The RealCost software performs both deterministic and probabilistic calculations. Deterministic LCCA provides a discrete output based on specific inputs. Probabilistic LCCA takes into account the uncertainty of the input and carries that uncertainty through the calculation to create a distribution curve with costs associated to varying probabilities.

CDOT uses three types of distribution curves in the probabilistic LCCA process; triangular, normal, and lognormal. A triangular distribution, see Figure 1, is a subjective description of a population for which there is only limited sample data. It is based on the knowledge of the minimum and maximum and requires an educated guess as to what the most likely value might be. The triangular distribution is used when evaluating initial construction costs for probabilistic LCCA, because historical data combined with quantity of scale provide a reasonable minimum, maximum, and average.

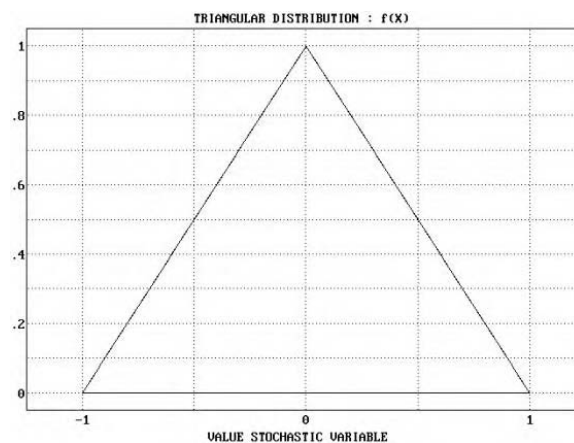


Figure 1. Triangular Distribution Curve

Unlike the triangular distribution, which may or may not be symmetrical, a normal distribution, see Figure 2, is a symmetrical bell-shaped density curve with two specific values one being the mean and the other being the standard deviation. The normal distribution is used for incorporating the discount rate into the probabilistic analysis, because a mean and standard deviation for the discount rate can be easily calculated from the 10-year moving average of real interest rates.

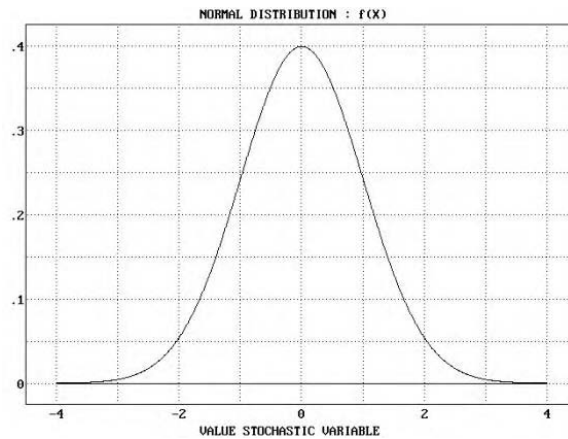


Figure 2. Normal Distribution Curve

Lognormal distributions, see Figure 3, are defined with reference to a normal distribution and the fact they must always be positive. A random variable is lognormally distributed if the logarithm of that random variable is normally distributed. The lognormal distribution was chosen to be used for the activity service life of initial construction and rehabilitation projects, because although there is some variability, the number of years required for service life must be positive.

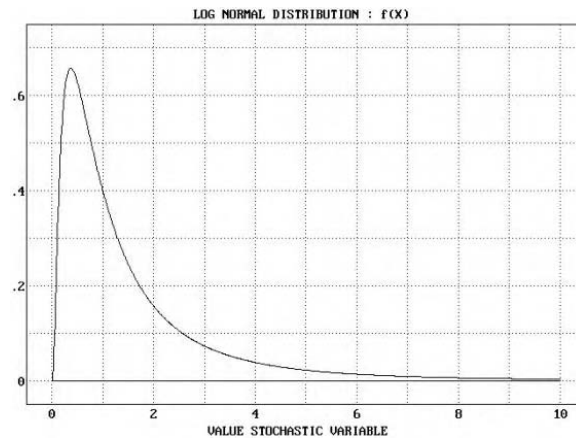


Figure 3. Lognormal Distribution Curve

Once all values are entered into the RealCost software and calculations are complete, a comparison of the alternatives is based on the probabilistic LCCA output for 75% confidence level. In 2008, CDOT recommended that the probabilistic approach to LCCA be used in conjunction with deterministic to allow designers some time to adjust. In January of 2009 CDOT required the probabilistic approach be the primary means of LCCA.

CDOT requires the LCCA process for all new or reconstruction projects with a pavement material cost of more than \$2,000,000⁽³⁾. Pavement cost includes anything associated with the pavement structure i.e. asphalt, base coarse and subbase. The 2 million dollar amount is also the requirement for surface treatment projects when both concrete and asphalt are considered feasible alternatives. If one of the alternatives is determined to not be practical the decision should be documented in the Pavement Justification Report (PJR).

Examples of projects where LCCA may not be necessary are⁽³⁾:

- A concrete pavement, which is structurally sound and requires only resealing and/or minor rehabilitation work
- A concrete or asphalt pavement, which is structurally sound but may need skid properties restored or ride improved
- Minor safety improvements such as channelization, shoulder work
- Bridge replacement projects with minimal pavement work
- Locations where curb and gutter or barrier prohibits the use of alternative thicker treatments

Discount Rate

The discounting process allows people to compare projects with different funding requirements to identify the most beneficial by taking future costs and giving them an equivalent present dollar value.

A discount rate is the factor used to identify a present value of goods or services when dealing with a future cost expressed in constant dollars. Typically a discount rate is the difference between the interest rate and the inflation rate, which gives a value to money if saved rather than spent. Public agencies cannot invest or save the taxpayers' money, so they are responsible for finding the best use for these funds through public projects that provide a cost savings or expanded output. Even though the government cannot chose to save money versus spend it, the discount rate is still required, because by taxing the public the taxpayer is not given the chance to invest their money, which is known as the opportunity cost of capital.

CDOT has used a couple different methods to determine its discount rate, but after several meetings with FHWA, CDOT's Materials Advisory Committee (MAC) recommended in July of 2007 to use the Office of Management and Budget's (OMB) real interest rate data to calculate the discount rate for CDOT. The following link to the OMB website has a list of the real interest rates from 1979 to 2008.

<http://www.whitehouse.gov/omb/circulars/a094/dischist.pdf>

Due to the pavements initial design period and the 40-year analysis period for LCCA, the MAC determined that the longest maturity and most conservative investment strategy for interest rates should be used. The longest maturity for interest rates from the OMB is 30 years, which on the attached link to the OMB website is the far right column on the second page. The discount rate will then be calculated using the 10-year moving average to better account for the year-to-year movement in the real rates. The standard deviation calculation is then based on the previous 10-year moving averages.

Every year, the OMB publishes a new 30-year Real Treasury interest rate and CDOT will be using this annual value in order to update the discount rate. Table 1, shows how the data can be arranged to calculate the average and standard deviation. For example, for the 2008 data the 10-year moving average (1999 to 2008) provides a new discount rate of 3.3% and the previous 10 years of the moving average (1998 to 2007) are used to determine a standard deviation of 0.22%.

Table 1
Real Treasury Interest Rates and 10 Year Moving Average

Year	7-Year Note	10-Year Moving	10-Year Note	10-Year Moving	30-Year Note	10-Year Moving
1979	4.1		4.6		5.4	
1980	2.9		3.3		3.7	
1981	4.3		4.4		4.8	
1982	7.5		7.8		7.9	
1983	5		5.3		5.6	
1984	5.7		6.1		6.4	
1985	6.8		7.1		7.4	
1986	5.6		5.9		6.7	
1987	3.5		3.8		4.4	
1988	4.7	5	5.1	5.3	5.6	5.8
1989	5.3	5.1	5.8	5.5	6.1	5.9
1990	3.9	5.2	4.2	5.6	4.6	6
1991	3.7	5.2	3.9	5.5	4.2	5.9
1992	3.3	4.8	3.6	5.1	3.8	5.5
1993	3.9	4.6	4.3	5	4.5	5.4
1994	2.5	4.3	2.7	4.6	2.8	5
1995	4.6	4.1	4.8	4.4	4.9	4.8
1996	2.8	3.8	2.8	4.1	3	4.4
1997	3.4	3.8	3.5	4.1	3.6	4.3
1998	3.5	3.7	3.6	3.9	3.8	4.1
1999	2.7	3.4	2.7	3.6	2.9	3.8
2000	4	3.4	4	3.6	4.2	3.8
2001	3.2	3.4	3.2	3.5	3.2	3.7
2002	3	3.4	3.1	3.5	3.9	3.7
2003	2.2	3.2	2.5	3.3	3.2	3.6
2004	2.4	3.2	2.8	3.3	3.5	3.6
2005	2.3	3	2.5	3.1	3.1	3.4
2006	2.7	2.9	2.8	3.1	3	3.4
2007	2.7	2.9	2.8	3	3	3.4
2008	2.4	2.8	2.6	2.9	2.8	3.3

Standard Deviation = **0.22**

The newly calculated discount rate will be compared to the original, and if it changes by more than two standard deviations from the original, in this case 0.44%, a new LCCA should be performed on all projects not yet through Field Inspection Review (FIR) to verify the proper pavement was selected. Standard deviations will be calculated annually as well to ensure an appropriate year-to-year comparison can be made.

The Colorado Asphalt Paving Association (CAPA) performed a preliminary survey of several other states to find out their discount rates and the rehabilitation time periods used in their LCCA for asphalt. Table 2 shows all the states that participated in the survey. Most states use a set value of 4.0% for their discount rate. While Ohio appears to be the only state that references the OMB's real interest rate directly. The average for the states that participated is 3.8%. 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 the projects with high initial costs and low maintenance costs, because any remaining cost are factored in closer to face value. An example of this would be the traditional view of hot mix asphalt (HMA) versus portland cement concrete pavement (PCCP). Until the recent fluctuation in oil prices, HMA was believed to have a lower initial construction cost, higher annual maintenance cost and more expensive rehabilitation costs than PCCP. In a situation such as this, HMA would benefit from a high discount rate in the LCCA calculation because it is deferring a greater amount of its overall cost until the future. HMA on the other hand would suffer from low discount rates, because the deferred costs are added in closer to their actual value.

Table 2
State Discount Rate and Asphalt Overlay Timetable for LCCA

	State	Yr@1st OL	Yr@2nd OL	Yr@3rd OL	Yr@4th OL	Total Years	Discount Rate
1	Alabama	12.0	20.0			28.0	4.0
2	Alaska						
3	Arizona	15.0	20.0	30.0		35.0	4.0
4	Arkansas	12.0	20.0			30.0	3.8
5	California	20.0	25.0	30.0	35.0		4.0
6	Colorado	10.0	20.0	30.0		40.0	3.3
7	Connecticut						
8	Delaware	12.0	20.0			30.0	3.0
9	Florida	14.0	28.0			40.0	4.0
10	Georgia	10.0	20.0			40.0	3.0
11	Hawaii	17.0	35.0			40.0	4.0
12	Idaho						
13	Illinois	20.0	40.0			40.0	3.0

14	Indiana	20.0	35.0				4.0
15	Iowa	20.0	40.0			40.0	
16	Kansas	12.0	22.0	32.0		40.0	3.0
17	Kentucky	10.0	20.0	30.0		40.0	4.0
18	Louisiana	15.0	30.0			30.0	4.0
19	Maine	16.5	25.5				4.0
20	Maryland	14.8	26.6			40.0	4.0
21	Massachusetts						
22	Michigan						
23	Minn < 7M ESALS	20.0	35.0			50.0	3.5
	Minn > 7M ESALS	15.0	27.0	40.0		50.0	3.5
24	Mississippi	12.0	22.0	30.0		40.0	4.0
25	Missouri	20.0	33.0			45.0	2.3
26	Montana						
27	Nevada	20.0				35.0	4.0
28	New Hampshire	20.0	31.0				4.0
29	New Jersey						
30	New Mexico						
31	New York						
32	Nebraska						
33	North Carolina	10.0	20.0			30.0	4.0
34	North Dakota						
35	Ohio	12.0	22.0	34.0		35.0	2.8
36	Oklahoma						
37	Oregon	20.0	40.0				4.0
38	Pennsylvania	10.0	20.0			35.0	6.0
39	Rhode Island	20.0	31.0			20.0	4.0
40	South Carolina	12.0	22.0			30.0	
41	South Dakota						
42	Tennessee	10.0	20.0	30.0		40.0	4.0
43	Texas						
44	Utah						
45	Vermont	17.5	31.0				4.0
46	Virginia	12.0	22.0	32.0	44.0	50.0	4.0
47	Washington						
48	West Virginia						
49	Wisconsin	18.0	12.0	12.0	12.0	54.0	5.0
50	Wyoming						
	Average	15.1	26.1	30.0	30.3	38.0	3.8

For comparison, Table 3 includes PCCP rehabilitation schedules used in LCCA. This data was collected from a survey posted on www.transportation.org as well as information available on State DOT websites.

Table 3
State PCCP Rehabilitation Timetable for LCCA

<u>State</u>	<u>Year</u>	<u>Rehabilitation</u>
Alabama⁽⁵⁾	20	Performs Concrete Pavement Repair
Arkansas⁽⁵⁾	15	Major Patching, Diamond Grind and Joint Seal
	25	Patch, Joint Seal, and HMA Overlay
	30	Seal Reflective Cracks
Colorado⁽⁵⁾	22	0.5% Slab Replacement, Diamond Grind, and Joint Seal
Florida⁽⁵⁾	20-25	3% Slab Replacement of outside lane, Diamond Grind and Joint Seal
	30-35	5% Slab Replacement, or Crack Seal, or Rubbilize and Overlay
Illinois⁽⁵⁾	7	0.5 % Full-Depth PCC patch
	10	1% Full-Depth PCC patch, and Joint Seal
	15	1.5% Full-Depth PCC patch
	20	Underseal, 4% Full-Depth PCC patch, Diamond Grind, Joint Seal
	25	1.5% Full-Depth PCC patch
	30	2.5% Full-Depth PCC patch
	35	3.5% Full-Depth PCC patch
Indiana⁽⁵⁾	9	15% Crack Seal
	17	15% Crack Seal
	25	15% Crack Seal
	30	PCCP patch with 4" HMA Overlay
	33	5% Crack Seal
	36	5% Crack Seal
	39	5% Crack Seal
Kansas⁽⁵⁾	20	3% Patch with 3" Overlay
	30	5% Patch with 4" Overlay
Missouri⁽⁵⁾	25	1.5% Slab Replacement, and Diamond Grind
Montana⁽⁵⁾	20	2% Slab Replacement, Diamond Grind, Joint Seal
New Jersey⁽⁵⁾	10	Crack Seal
	20	Crack Seal
	30	5% Slab Replacement, Diamond Grind, and Crack Seal
	40	30% Slab Replacement, 4" HMA Overlay
New York⁽⁶⁾	8	Joint Seal
	15	Full-Depth Slab Replacement, Spall Repair, Joint Seal
	23	Joint Seal
	30	3" HMA Overlay
Ohio⁽⁵⁾	22	4% Full-Depth Repair of driving lanes, Diamond Grind
	32	2% Full-Depth Repair of driving lanes, and 3.25" HMA Overlay
South Carolina⁽⁵⁾	20	Full-Depth Patching, Diamond Grinding, Joint Seal
Virginia⁽⁷⁾	10	3% Full-Depth Repair, Joint Seal
	20	10% Patching, Diamond Grind, Joint Seal
	30	10% Patching, HMA Overlay
Washington⁽⁵⁾	20-30	Diamond Grind
Wyoming⁽⁵⁾	20	4% Slab Replacement, Diamond Grind travel lane, Joint Seal

References

1. Life Cycle Cost Analysis in Pavement Design, U.S. Department of Transportation Office of Asset Management, September 1998.
2. The 2009 Colorado Department of Transportation Pavement Design Manual, Chapter 10, Pavement Selection.
3. Life Cycle Cost Analysis Primer, U.S. Department of Transportation Office of Asset Management, August 2002.
4. Life Cycle Cost Analysis and Discount Rate on Pavements for the Colorado Department of Transportation, October 2006.
5. <<http://www.transportation.org/sites/research/docs/LCCA%20Replies.xls>> (14 January 2009).
6. New York Department of Transportation, “Comprehensive Pavement Design Manual Part 3: Life Cycle Cost Analysis”. June 2001. <<https://www.nysdot.gov/divisions/engineering/design/dqab/cpdm/repository/chapter5app5a2.pdf>>. (14 January 2009).
7. Virginia Department of Transportation, Materials Division. “Life Cycle Cost Analysis”. May 2002. <<http://www.virginiadot.org/business/resources/bu-mat-pde-LCCADocMay02.pdf>>. (14 January 2009).