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Final Report

LIFE CYCLE COST ANALYSIS AND DISCOUNT RATE ON PAVEMENTS FOR THE COLORADO DEPARTMENT OF TRANSPORTATION

DEPARTMENT OF TRANSPORTATION

October 2006

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The report provides details regarding the recommended practice for the Colorado Department of Transportation when performing a life cycle cost analysis. However, it does not constitute a standard, specification, or regulation.

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16. Abstract

This report provides information on life cycle cost analysis (LCCA) as applied to CDOT's roadways. It describes the methodology CDOT uses to select discount rates to be used in LCCA calculations. It also summarizes pavement selection terminology for deterministic and probabilistic LCCA procedures.

Implementation:

The discount rate is a major input for calculating an LCCA, which is used in selecting pavement types or rehabilitation strategies.

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by

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INTRODUCTION

Agencies have historically used some form of life cycle cost analysis (LCCA) to assist in the evaluation of alternative pavement design strategies. For example, in the 1986 American Association of State Highway Transportation Officials (AASHTO) Guide for the Design of Pavement Structures, the use of LCCA was encouraged and a process laid out to evaluate the cost-effectiveness of alternative designs. The Colorado Department of Transportation (CDOT) requires that a life cycle cost analysis supporting the pavement type selection be prepared for all appropriate projects with more than $1,000,000 initial cost of the pavement[(1)]. LCCA is a process used by the CDOT to compare concrete to asphalt pavements, and/or compare alternative rehabilitation techniques. CDOT's life cycle cost analysis (LCCA) procedures were adopted in 1981, updated in 1994, 2000, and again in 2002.

Alternative designs for the same section of roadway, whether new construction, reconstruction, or rehabilitation, should have the same levels of reliability and serviceability loss. These factors are independent of pavement type and are dependent on the traffic load and use of a road.

BENEFIT COST ANALYSIS

Life cycle cost analysis (LCCA) is a tool used to compare the total user and agency costs of competing project implementation alternatives, specifically HMA and PCCP pavements[(2)]. LCCA is a subset of Benefit-Cost Analysis (BCA), an economic analysis tool that compares benefits as well as costs in selecting optimal projects or implementation alternatives[(3)]. Because the distinction between LCCA and BCA can be confusing in day-to-day practice, the differences between LCCA and BCA, and their appropriate applications, are discussed below. The agency that uses LCCA has already decided to undertake a project or improvement and is seeking to determine the most cost-effective means to accomplish the project's objectives. LCCA is appropriately applied only to compare project implementation alternatives that would yield the same level of service and benefits to the project user at any specific volume of traffic. LCCA, for instance, is an appropriate tool to use when comparing two alternatives to replace a bridge that has reached the end of its service life, where each design alternative will result in the same level of service to the user. Costs measured in LCCA typically include expenses to the state or local agency, such as construction, operation, and maintenance costs. As a matter of best practice, LCCA should also include costs accruing to the users of the project facility; especially costs associated with increased congestion and reduced safety experienced during project construction and maintenance. Unlike LCCA, BCA considers the benefits of an improvement as well as its costs and therefore can be used to compare design alternatives that do not yield identical benefits (e.g., bridge replacement alternatives that vary in the level of traffic they can accommodate), as well as to compare projects that accomplish different objectives (a road realignment versus a widening project). Moreover, BCA can be used to determine whether or not a project should be undertaken at all (i.e., whether the project's life cycle benefits will exceed its life cycle costs). Benefits measured in BCA are typically those associated with the desired results of the project (i.e., the reasons for undertaking the project), and may include shorter travel distance or time, reduced vehicle operating costs, improved safety, and other benefits to facility users. Other effects of a project that may be considered involve emissions and noise, which affect project nonusers as well as users, and are often referred to as "externalities." In summary, LCCA is a cost-centric approach used to select the most cost-effective alternative that accomplishes a preselected project at a specific level of benefits that is assumed to be equal among project alternatives being considered[4]. BCA is the appropriate tool to use when design alternatives will not yield equal benefits, such as when unlike projects are being compared or when a decision-maker is considering whether or not to undertake a project.

MAJOR STEPS IN THE BENEFIT COST ANALYSIS PROCESS

The following major steps are essential in performing a benefit cost analysis:

1. Establish objectives
2. Identify constraints and specify assumptions
3. Define base case and identify alternatives
4. Set analysis period
5. Define level of effort for screening alternatives
6. Analyze traffic effects
7. Estimate benefits and costs relative to base case

8. Evaluate risk
9. Compare net benefits and rank alternatives
10. Make recommendations

Having identified objectives and assumptions, the analyst (or analytical team) then develops a full set of reasonable improvement alternatives to meet the objectives. This process begins with the development of a "do minimal" option, known as the base case. The base case represents the continued operation of the current facility under good management practices but without major investments. Under these "do minimal" conditions, the condition and performance of the base case would be expected to decline over time. Reasonable improvement alternatives to the base case can include a range of options, from major rehabilitation of the existing facility to full-depth reconstruction to replacement by a higher volume facility. Such alternatives will often involve construction, but alternatives that improve highway operations (such as the use of intelligent transportation systems) or manage travel demand (such as incentives for off-peak travel) are suitable for consideration. The project is considered acceptable if the ratio equals or exceeds 1.0, that is, if $B/C \geq 1.0$[(5)]. Benefit-cost analysis is the most comprehensive method to evaluate the reasonableness of highway projects in economic terms. This method is often used in municipal project evaluations where benefits and costs accrue to different segments of the community.

WHAT IS LIFE CYCLE COST ANALYSIS?

LCCA is an engineering economic analysis tool useful in comparing the relative merit of competing project alternatives[(6)]. By considering all of the agency and user costs incurred during the service life of an asset, CDOT is able to analyze and select the lowest cost option. Additionally, LCCA introduces a structured methodology that accounts for the effects of agency activities and roadways users and provides a means to balance them with the effects of construction, rehabilitation, and preservation. The process of conducting an LCCA is reasonably straightforward to understand and perform. It incorporates CDOT's institutional knowledge and the application of sound economic analysis techniques. 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 for an LCCA calls for including not only direct agency expenditures (for example, construction or maintenance activities), but also roadway users costs that result from CDOT 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. It is important to note that the lowest LCC option may not necessarily be implemented when other considerations such as risk, available budgets, and political and environmental concerns are taken into account. LCCA provides critical information to the overall decision-making process, but not the final answer.

LCCA is defined in the Transportation Equity Act for the 21st Century (TEA-21) as "a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user costs, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment." TEA-21 focuses on the engineering (project) costs and does not directly identify the social costs - air quality, accidents, and noise - which form the external costs of infrastructure construction and management[7].

INFLATION AND DISCOUNTING

An inherent problem in any kind of evaluation or decision analysis is the difficulty of making value comparisons among projects that are not measured in equal units. Even when values are stated in monetary units such as dollars, the values still may not be comparable, for at least two reasons:

1.) Inflation: Expenditures typically occur at various points in the past or future and are therefore measured in different value units because of changes in price (e.g., a 1980 dollar would, in general, have purchased more real goods and services in 1980 than a 2006 dollar would in 2006). A general trend toward higher prices over time, as measured in dollars, is called inflation[3]. A general trend toward lower prices is called deflation[3]. Dollars that include the effects of inflation or deflation over time are known as nominal, current, or data year dollars. Dollars that do not include an inflation or deflation component (i.e., their purchasing power remains unchanged) are called constant or base year dollars[3].

2.) Discounting: Costs or benefits (in constant dollars) occurring at different points in time past, present, and future cannot be compared without allowing for the opportunity value of time. The opportunity value of time as it applies to current versus future funds can be understood in terms of the economic return that could be earned on funds in their next best alternative use (e.g., the funds could be earning interest) or the compensation that must be paid to induce people to defer an additional amount of current year consumption until a later year. Adjusting for the opportunity value of time is known as discounting. Analytically, adjusting for inflation and discounting are entirely separate concerns, and they should not be confused by attempting to calculate both at once. Instead, future costs and benefits of a project should be expressed in constant dollars and then discounted to the present at a discount rate that reflects only the opportunity value of time (known as a real discount rate). This is because public sector project benefits should be dependent only upon real gains (cost savings or expanded output), rather than purely price effects[(2)].

This report addresses CDOT's practice to modify the discount rate. Discount rates used in LCCA typically range from 3 to 5 percent, representing the prevailing rate of interest on borrowed funds, less inflation. The CDOT currently uses 4% for its discount rate[(1)]. Because there is always an opportunity value of time, discount rates will historically always exceed zero. Through the use of a real discount rate, the following transformations can be performed to facilitate comparison of the constant dollar costs of alternative CDOT projects:

1.) Relocation in Time. A single figure can be "moved" (transformed into an equivalent value) backward or forward in time, without altering its real value, i.e., its present worth (PW) equation 1.

Present Worth (PW) = Future Value * $[1 / (1 + i_{dis})]^n$ **Eq. 1**

Where: $i_{dis} = i_{int} - i_{inf}$ (decimal) or real discount rate

i_{int} = Current Interest Rate

i_{inf} = Interest Rate of Inflation

n = number of years in the future when the cost will be incurred.

2.) Uniform Annual Cost. A lump sum can be transformed into an equivalent multiyear flow (e.g., uniform series or sinking fund) equation 2. A *sinking fund* is a fund or account into which annual deposits of A are made in order to accumulate F at *t(time) = n(number of compounding periods)* in the future. Because the annual deposit is calculated as A = F(A/F, *i%, n*), the (A/F) factor is known as the *sinking fund factor*.

$$\left(A/F, I\%, N\right) = F \times \left[\frac{i_{dis}}{\left(1+i_{dis}\right)^n - 1}\right]$$ **Eq. 2**

Where: $i_{dis} = i_{int} - i_{inf}$ (decimal) or real discount rate

A/F = Find F (Future sum of money) given A (Annual, equivalent end of period values)

I, *i* = Effective interest rate per interest period

N, *n* = number of compounding periods (e.g., years)

PW is the summation of all future costs over the project life in today's dollars; it combines the discounted future maintenance costs, rehabilitation costs, and a salvage value. The future costs are discounted to account for the time value of money using the discount (real interest) rate. Present worth analysis is limited to comparing alternates with equal analysis periods(8,9).

PRESENT VALUE

The present value calculation uses the discount rate and the time a cost was or will be incurred to establish the present value of the cost in the base year of the study period. Since most initial expenses occur at about the same time, initial expenses are considered to occur during the base year of the study period. Thus, there is no need to calculate the present value of these initial expenses because their present value is equal to their actual cost. The determination of the present value of future costs is time dependent. The time period is the difference between the time of initial costs and the time of future costs. Initial costs are incurred at the beginning of the study period at year zero, the base year. The present value calculation is the equalizer that allows the summation of initial and future costs. Along with time, the discount rate also dictates the present value of future costs. Because the current discount rate is a positive value, future expenses will have a present value less than their cost at the time they are incurred. If future costs of a project are provided in nominal dollars, conversion of these nominal dollars to constant dollars can be accomplished through the use of applicable indexes as follows:

$$\text{Net Present Value (NPV)} = \text{Initial Cost} + \sum \text{Future Value} * 1/(1+r)^n \qquad \textbf{Eq. 3}$$

Where: r = Real discount rate which is adjusted to eliminate the effects of expected inflation and used to discount constant year dollars or real benefits or costs.

n= number of years in the future when the cost will be incurred

The term $1/(1+r)^n$ is known as the discount factor and is always less than or equal to one. Using the above formula, a $1,000 cost incurred in year 30, discounted to the present (year zero) at a 4 percent real discount rate, would have a present value of $308. It should be noted that the term Net Present Value (NPV) is mostly used when referring to the present value of life cycle costs for roadway analysis. However, NPV is more appropriately used in benefit-cost analysis to convey the net difference between the present values of benefits and costs of an alternative or project. In roadway analysis the terms “net present value” and “present value” are identical[(2)].

LCCA PROCESS

The first component in an LCC equation is cost. There are two major cost categories by which projects are to be evaluated in an LCCA: initial expenses and future expenses. Initial expenses are all costs incurred prior to occupation of the facility. Future expenses are all costs incurred after occupation of the facility. Defining the exact costs of each expense category can be somewhat difficult at the time of the LCC study. However, through the use of reasonable, consistent, and well-documented assumptions, a credible LCCA can be prepared.

One should also note that not all of the cost categories are relevant to all projects. The engineer is responsible for the inclusion of the pertinent cost categories that will produce a realistic LCC comparison of project alternatives. If costs in a particular cost category are equal in all project alternatives, they can be documented as such and removed from consideration in the LCC comparison. In other words, they can cancel each other out. An LCCA should be conducted as early in the project development cycle as possible.

The primary purpose of an LCCA is to quantify the long-term economic implications of initial pavement decisions. The initial pavement decision with related various rehabilitation and maintenance strategies can be employed over the analysis period see (Figure 1) below[1].

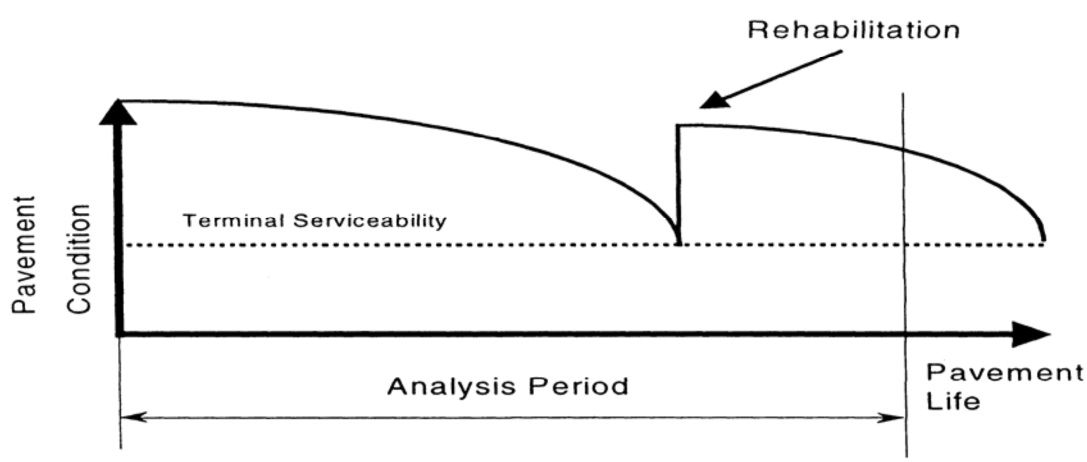

Figure 1
Lifetime of One Design Alternative

As outlined in the FHWA Interim Technical Bulletin, the LCCA process consists of the following eight steps:

1. Establish alternative pavement design strategies, (concrete vs. asphalt) for the analysis period.

2. Determine pavement performance periods and establish M&R activity timings.

3. Estimate agency costs.

4. Estimate user costs.

5. Develop expenditure stream diagrams.

6. Compute life cycle cost.

7. Analyze results.

8. Reevaluate strategies.

Steps two through six are performed for each alternative strategy. At the conclusion of the eighth and final step, the engineer will have either identified the most economical design or identified appropriate adjustments to be made to the design alternatives(2).

REAL VS. NOMINAL DOLLARS

When evaluating future costs and benefits as part of an LCCA, a decision must be made whether to use real dollars or nominal dollars in the calculation process. Real (or constant) dollars reflect dollars with the same or constant purchasing power over time, whereas nominal (or inflated) dollars reflect dollars that fluctuate in purchasing power as a function of time. For example, in the case of real dollars, if the current estimated unit cost of a full-depth PCC patch is $100/yd^2, then the same $100/yd^2 cost should be used for future-year patching cost estimates. Although the projected quantities of patching may vary from year to year, the same unit cost is used over time. When using nominal dollars, on the other hand, the estimated cost of patching would change as a function of the year in which it is accomplished. Thus, if inflation were estimated at 4 percent, the unit cost of the full-depth PCC patching at year zero would be \$100/ yd^2, whereas 1 year later the unit cost would increase to \$104/ yd^2 (i.e., \$100/ yd^2 * 1.04). The engineer must be sure not to mix the two types of dollars in any given LCCA. All costs must either be in real dollars or nominal dollars. CDOT currently uses real dollars, to keep things simple.

ANALYSIS PERIOD

The analysis period is defined as the time period over which the initial and future costs are evaluated for different design alternatives. As a rule of thumb, the analysis period should be long enough to incorporate the cost of at least one rehabilitation activity for all design alternatives, but no longer than the period for making reasonable forecasts. FHWA recommends a minimum of 35 years. For CDOT, a 40 year analysis period will be used[(1)]. There are two exceptions to the general guideline noted above. The first exception is for paving projects that are considered short-term or temporary fixes to roadways. For example, widening or rehabilitating a roadway that will be rebuilt in a high development or changing social economical area, or the structural-geometrical improvement of roadways to provide temporary access/capacity while adjacent roadways are being rebuilt or rehabilitated. For these cases, the analysis period should equal the expected life of the temporary pavement.

The second exception is for the long-life pavement design. Long-life pavements are those that are designed to an endurance limit (i.e., no structural damage from wheel loads) and only require surface repairs as a result of surface deterioration from environmental and wheel loads.

AGENCY COSTS

Agency costs include all costs incurred directly by construction being the major input over the life of the project. These costs typically include expenditures for cost of materials, labor, traffic management, preliminary engineering, contract administration, construction traffic control, construction, construction supervision, and all future maintenance (routine and preventive), resurfacing and rehabilitation.

USER COSTS

User costs are a key ingredient in any LCCA of competing pavement design alternatives. Although borne by the highway user, these costs must be given serious consideration by the highway agency, since the agency acts as the proxy for public benefit. User costs are the costs incurred by the highway user over the life of the project. The user costs of concern in an LCCA are the differential or extra costs incurred by the traveling public as a result of one design being used instead of another. For instance, a design that requires more frequent and/or longer lane closures in the future (to satisfy upkeep needs) will inevitably lead to added user costs due to increased delay, greater fuel consumption, and so on. Also, a design that provides a lower overall level of serviceability during normal operating conditions will yield increased Vehicle Operating Costs (VOCs) as a result of exposure to more pavement roughness.

User cost components recommended for consideration in the 2002 Design Guide 1-37A include time delay costs and VOCs. These components can be estimated reasonably well and comprise a large portion of the total user costs. The following components are extremely difficult to calculate, thus they are not used in calculating an LCCA:

1.) Accident costs can be a significant portion of total user cost; however, they are difficult to estimate because the value of a human life and the cost of a debilitating injury are very controversial. Due to the lack of crash cost data for certain types of work zone activities, CDOT will not consider the costs due to crashes.
2.) Discomfort costs are probably the most difficult to estimate and generally provide a relatively low contribution to total user costs.
3.) Environmental costs is a user cost component which requires much more research before practical application can occur. These costs include traffic noise, as well as the pollution created and energy expended in the construction and upkeep of a pavement facility.

As described below, user costs can be incurred during the operation of a work zone or during normal (non-restricted) highway operating conditions.

Work zone costs deals with costs brought about by the establishment of a work zone. A work zone is defined as an area of a highway where maintenance, rehabilitation, or construction operations are taking place, which impinge on the number of lanes available to moving traffic or affect the operational characteristics of traffic flowing through the area. A work zone disrupts normal traffic flow, drastically reduces the capacity of the roadway, and leads to specific changes in roadway use patterns that affect the nature of user costs.

During normal operating conditions, user costs are associated with using a facility during periods free of construction, repair, rehabilitation, or any work zone activity that restricts the capacity of the facility or an inconvenience to the traveling public.

A software program called "WorkZone" was developed for CDOT which calculates normal traffic flow with and without roadway construction activity; WorkZone is capable of calculating costs for construction lane closure or relocating traffic to the opposite direction of the facility. These costs are considered to be indirect "soft" costs accumulated by the facility user in the work zone as they relate to roadway condition, maintenance activity, and rehabilitation work over the analysis period. For example, these costs include user travel time, and increased vehicle operating costs (VOC). Though these "soft" costs are not part of the actual spending for CDOT, they are costs borne by the road user and are included in the LCCA(1).

MAINTENANCE COSTS

A final step in the completion of the LCCA of a project alternative is to define all the future maintenance costs of the alternative. Maintenance costs are those costs associated with maintaining a pavement at or above some predetermined performance level. This normally includes maintenance of the pavement surface, shoulders, and related drainage, and all associated costs (e.g., administrative costs, operating or overhead costs, traffic control costs, and any testing and contract administration costs, if CDOT contracts the maintenance work). Typical maintenance costs that should not be included in LCCA for pavement design and strategy selection include those that are equal between all alternatives, such as guardrail repair, sign repair, vegetation mowing, and tree/shrub maintenance. Maintenance costs should be subdivided into costs for preventive maintenance (carefully planned activities intended to extend pavement life) and routine maintenance (day-to-day activities performed to address safety and operational concerns). These costs can be projected to occur at certain periods over the life of a pavement or on an annual basis that are based on real performance data. Though maintenance costs can be estimated based on previous experience and historical cost data, the estimates should be modified for any differences that may exist between the proposed alternative and the projects from which the experience was derived (e.g., traffic levels, materials, reflection crack control). Maintenance costs depend on pavement deterioration and operational factors that are all highly variable. The determination of accurate and real design costs can be estimated only if CDOT maintains adequate accounting records[(1)].

SALVAGE VALUE

Salvage value represents the value of an investment alternative at the end of the analysis period. One future expense that warrants further explanation is that of residual value. Salvage value is the net worth of a pavement at the end of the LCCA study period. Unlike other future expenses, an alternative's salvage value can be positive or negative, a cost or a value. Since an LCC is a summation of costs, a negative salvage value indicates that there is value associated with the pavement at the end of the study period. Whatever the reason for the remaining value, it is a tangible asset of the pavement ownership and should be included in the LCCA. A positive salvage value indicates that there are disposal costs associated with the pavement at the end of the study period. Whatever the cause, these are costs of pavement ownership and should be included in the LCCA. The salvage value is the salvage value of the pavement at the end of the life cycle analysis period; CDOT uses a deterministic value of zero. Finally, CDOT has concluded that the probabilistic salvage difference is the value between years used and rehabilitation life all divided by the rehabilitation life that total multiplied by the rehabilitation cost. See equation 4 below for calculating a probabilistic salvage value[1].

Salvage value = [(Rehab. Life – Years Used)/Rehab. Life] * Rehab. Cost **Eq. 4**

THE DISCOUNT RATE (THE FEDERAL RESERVE BOARD)

The discount rate is the interest rate charged to commercial banks and other depository institutions on loans they receive from their regional Federal Reserve Bank's lending facility--the discount window. The Federal Reserve Banks offer three discount window programs to depository institutions: primary credit, secondary credit, and seasonal credit, each with its own interest rate. All discount window loans are fully secured.

Under the primary credit program, loans are extended for a very short term (usually overnight) to depository institutions in generally sound financial condition. Depository institutions that are not eligible for primary credit may apply for secondary credit to meet short-term liquidity needs or to resolve severe financial difficulties. Seasonal credit is extended to relatively small depository institutions that have recurring intra-year fluctuations in funding needs, such as banks in agricultural or seasonal resort communities.

The discount rate charged for primary credit (the primary credit rate) is set above the usual level of short-term market interest rates. (Because primary credit is the Federal Reserve's main discount window program, the Federal Reserve at times uses the term "discount rate" to mean the primary credit rate.) The discount rate on secondary credit is above the rate on primary credit. The discount rate for seasonal credit is an average of selected market rates. Discount rates are established by each Reserve Bank's board of directors, subject to the review and determination of the Board of Governors of the Federal Reserve System. The discount rates for the three lending programs are the same across all Reserve Banks[10].

CDOT'S DISCOUNT RATE

The discount rate used in roadway LCCA is a function of both the interest rate and the inflation rate. In general, the interest rate (often referred to as the market interest rate) is associated with the cost of borrowing money and represents the earning power of money. Low interest rates favor those alternatives that combine large capital investments with low maintenance or user costs, whereas high interest rates favor reverse combinations. The inflation rate is the rate of increase in the prices of goods and services (construction and upkeep of highways) and represents changes in the purchasing power of money. The discount rate used in roadway LCCA is approximately the difference of the interest rate minus inflation rates. Discount rate represents the real value of money over time.

The exact mathematical relationship between the discount rate, the interest rate, and the inflation rate is as follows:

$$i_{dis} = [(1 + i_{int}) / (1 + i_{inf})] - 1 \qquad \textbf{Eq. 5}$$

Where: i_{dis} = discount rate, decimal

i_{inf} = inflation rate, decimal

i_{int} = interest rate, decimal

Selection of an appropriate discount rate is highly debatable. The FHWA Office of Engineering, Pavement Division, conducted a pavement design review and found that the discount rates currently used by State Highway Agency to have a distribution of values clustering in the 3 to 5 percent range. A range of discount rates is recommended for use in the Guide for Mechanistic-Empirical Design 1-37A procedure to determine the effect or sensitivity of the discount rate on the life cycle costs of a project.

The discount rate has two advantages associated with it use.

1.) It is not the absolute values of the interest and inflation rates that matter, but rather their difference that is important.
2.) The discount rate takes into account the competing forces of interest and inflation. This allows the engineer performing the analysis to use constant, or today's, dollars in an analysis.

For example, the present value of $1,000 of benefits received 30 years in the future is $412 when discounted at 3 percent per year, $231 when discounted at 5 percent, but only $57 when discounted at 10 percent. Thus, present values of costs and benefits 30 years in the future can be changed by more than a factor of 5 depending on the discount rate used[1].

CDOT DISCOUNT RATE SELECTION METHODOLOGY

Figure 2 is a graphical representation of a 10 Year T-Bill vs. 10 Year Discount Rate. http://inflationdata.com/Inflation/Inflation_Rate/HistoricalInflation.aspx is a link for calculating inflation. http://www.forecasts.org/data/data/GS10.htm is used for calculating 10-Year Treasury Constant Maturity Rate. Figure 3 is a histogram of discount rates from 1981-2005. CDOT historically used a discount rate of 4% for deterministic LCCA. Figure 4 was used to calculate both deterministic and probabilistic LCCA, after further analysis we've calculated the deterministic value to be 2.8 and the probabilistic value to be log normal 4.1 with a standard deviation of 1.84.

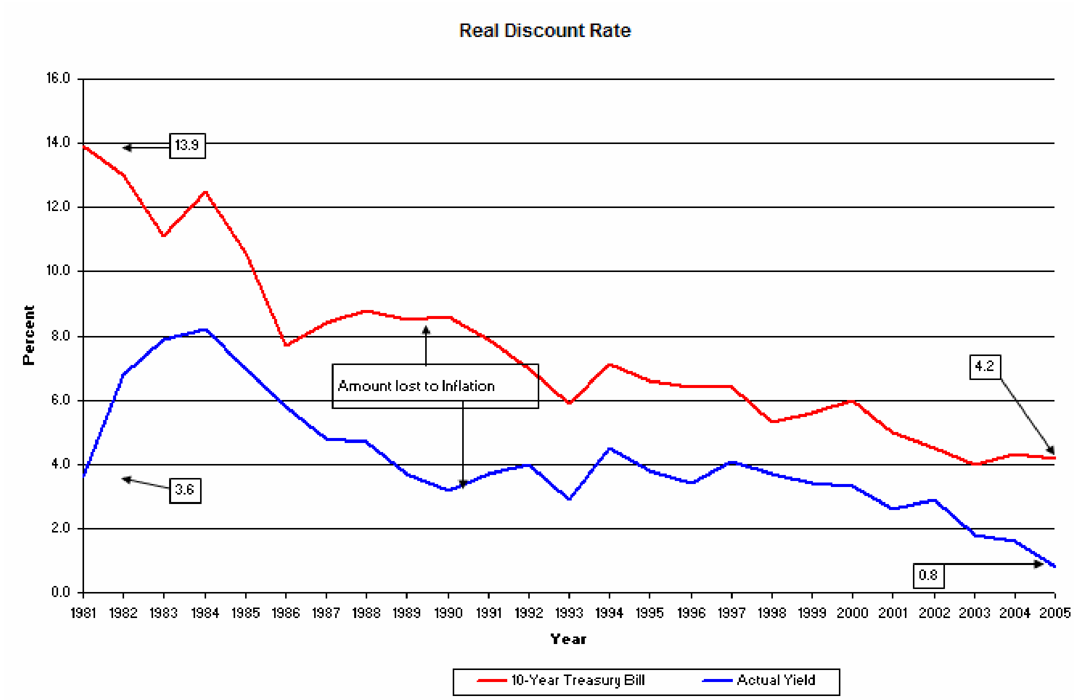

Figure 2

10 Year T-Bill vs. 10 Year Discount Rate

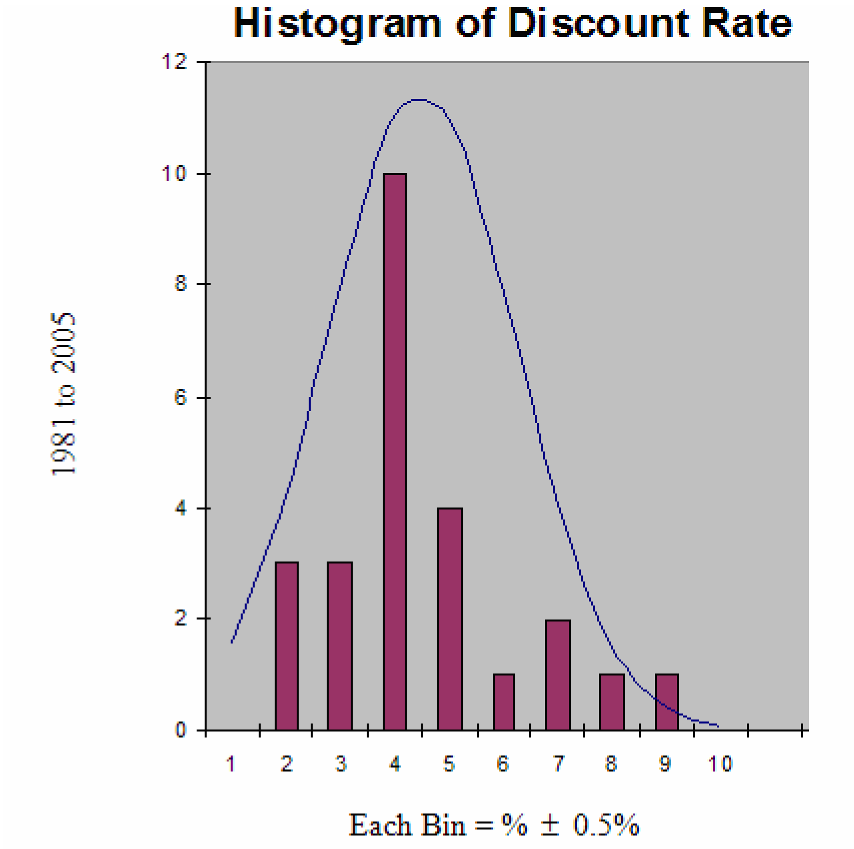

Figure 3

Histogram of the Real Discount Rate

Year	10-year T-Bills Interest Rate	Real Discount Rate	Deterministic (10 Year Average)
1980			
1981	13.9	3.6	
1982	13.0	6.8	
1983	11.1	7.9	
1984	12.5	8.2	
1985	10.6	7.0	
1986	7.7	5.8	
1987	8.4	4.8	
1988	8.8	4.7	
1989	8.5	3.7	
1990	8.6	3.2	
1991	7.9	3.7	
1992	7.0	4.0	
1993	5.9	2.9	
1994	7.1	4.5	
1995	6.6	3.8	4.1
1996	6.4	3.4	3.9
1997	6.4	4.1	3.8
1998	5.3	3.7	3.7
1999	5.6	3.4	3.7
2000	6.0	3.3	3.7
2001	5.0	2.6	3.6
2002	4.5	2.9	3.5
2003	4.0	1.8	3.4
2004	4.3	1.6	3.1
2005	4.2	0.8	2.8
	Avg.	4.1	2.8
	Std. Dev.	1.84	

Figure 4

Data Used to Calculate Log Normal Distribution and Deterministic Average Using 10 year Running Average

ANALYSIS OF DETERMINISTIC LCCA RESULTS

LCCA is used to compare the agency and user cost among alternatives. However, this comparison does not address the uncertainty contained in those outputs. Application of sensitivity analysis can reveal where analysis results may be subject to uncertainty. Deterministic sensitivity analysis is helpful in determining the “most likely” scenario where the selected input values are most likely to occur (based on objective data or expert opinions). Most likely to occur is a selection of a predetermined value. That predetermined value is called deterministic. Ideally, the “best” alternative will have the lowest PV in the most likely of “what-if” situations. The deterministic approach assigns each LCCA input variable a fixed, discrete value. The analyst determines the value most likely to occur for each input parameter. This determination is usually based on historical evidence or professional judgment. Collectively, these input values are used to compute a single LCC result. Traditionally, applications of LCCA have been deterministic ones. A deterministic LCC computation is straightforward and can be conducted manually using a calculator or automatically with a spreadsheet. However, it fails to convey the degree of uncertainty associated with the PV estimate. The results of deterministic analysis can be enhanced through the use of a technique called sensitivity analysis. This procedure involves changing a single input parameter of interest, such as the discount rate or initial cost, over the range of its possible values while holding all other inputs constant, and estimating a series of PVs (output values). Each PV result will reflect the effect of the input change. In this way input variables may be ranked according to their impacts on the bottom-line conclusions. This information is important to decision-makers who want to understand the variability associated with alternative choices. It also allows the agency to identify those input factors or economic conditions that warrant special attention in terms of their estimation procedures. To calculate a deterministic result in LCCA, CDOT has been using the software AASHTOWare DARWin™.

ANALYSIS OF PROBABILISTIC LCCA RESULTS

Probabilistic LCCA is a relatively new concept that utilizes the processing capabilities of today's computers to simulate and subsequently account for the simultaneous changes of input parameters. The probabilistic approach entails defining individual input parameters by a frequency (or probability) distribution, rather than by discrete values. It represents a risk analysis of the life cycle costs of a particular design alternative. For a given design strategy, sample input values are randomly drawn from the defined frequency distributions and the selected values are used to compute one forecasted life cycle cost value. The sampling process, which is commonly performed using Monte Carlo or Latin Hypercube techniques (details of these techniques are provided in the 1998 FHWA Interim Technical Bulletin), is then repeated hundreds or even thousands of times, thereby generating many forecasted life cycle cost values for the design strategy. The resulting forecasted costs can then be analyzed and compared with the forecasted results of competing strategies, so as to identify the most economical design.

Probabilistic LCCA attempts to model and report on the full range of possible PV outcomes. It also shows the estimated likelihood that any given outcome will actually occur. The engineer is able to array this information so that the underlying uncertainty inherent in each project alternative is reflected in the PV output results. This analysis also provides important statistical information to assist the decision-maker. As with deterministic LCCA, probabilistic LCCA can be enhanced by incorporating sensitivity analysis into the process. The sensitivity analysis will point to the variables most significant in influencing the LCCA results. Engineers must define the level of risk with which they are most comfortable. For example, those with a low tolerance for risk prefer less variability in the results, which may affect their selection between two or more options. In this case, the decision-maker may select an alternative with a somewhat higher PV but with much lower risk of cost overrun. When interpreting the probabilistic LCCA, CDOT defines the level of risk at 75% [(1)].

The type and range of each input sampling distribution are user-defined, and may be developed using either objective or subjective methods. The objective method uses hard data, such as bid price history or pavement survival distributions, to formulate the distribution, whereas the subjective method uses expert opinion. In most cases, a combination of the two must be used. For example, in the case of pavement performance, past service life information might be supplemented with expert opinion about the effects of incorporating new materials or technologies. Although many different types of frequency distributions exist, normal, log normal, and triangular are the most commonly used. Normal, log normal, and triangular distributions are used in the current version of the CDOT Pavement Design Manual (PDM) for calculating a probabilistic LCCA. These distribution types are fairly simple to apply and generally provide an adequate level of accuracy. As a minimum, LCCA should be performed deterministically with sensitivity analysis of key variables. However, the preferred approach to LCCA is the probabilistic approach. When properly applied, probabilistic LCCA provides a full view of the expected life cycle costs, because it takes into consideration the real-world tendencies of uncertainty and variation. In addition, it accounts for the simultaneous change of all input parameters and for the likelihood of a particular input value occurring. Every input into the LCCA is uncertain and may vary from the most expected value. In 2004, CDOT formed a task force to investigate which probabilistic LCCA software to use and FHWA's "RealCost" software was unanimously selected. RealCost calculates a probabilistic output for LCCA on roadways. [11]

REEVALUTE ALTERNATIVES

The LCCA concludes with a review of the findings to determine if adjustments or modifications to any of the proposed alternatives might be indicated prior to finalizing the alternative selection. Revisions might include design changes, newly defined work zone criteria for the contractors, or altered traffic plans to reduce high user costs. [2]

FINALIZE LCCA

Once all pertinent costs have been established and discounted to their present value, the costs can be summed to generate the total life cycle cost of the project alternative. After this has been done for all the viable project alternatives, a summary of the results should be prepared. The summary of project alternatives should compare the total life cycle costs of initial investment, operations, maintenance and repair, replacement, and residual value of all the project alternatives[1,2,3].

REFERENCES

1. The 2007 Colorado Department of Transportation Pavement Design Manual, Chapter 10, Pavement Type Selection.

2. Life-Cycle Cost Analysis Primer, U.S. Department of Transportation office of Asset Management August 2002.

3. User Benefit Analysis for Highways, American Association of State Highway and Transportation Officials (AASHTO), August 2003.

4. Life Cycle Costing for Design Professionals, 2nd Edition, McGraw-Hill, New York, 1995.

5. Civil Engineering Reference Manual for the PE Exam 6th Edition, Michael R. Lindeburg, P.E. Chapter 2 “Engineering Economic Analysis” 1997.

6. Life-Cycle Cost Analysis in Pavement Design, FHWA interim technical bulletin (FHWA-SA-98-079, 1998).

7. Transportation Equity Act for the 21st Century (TEA – 21), financial section.

8. Fundamentals of Engineering, the Most Effective FE/EIT Review, Dr. Merle C. Potter PhD, PE editor, 4th edition Chapter 5 1993.

9. Engineering Economy, 10th edition, E. Paul DeGarmo, William G. Sullivan, James A. Bontadelli, Elin M. Wicks 1997.

10. ACPA’s Definition of Discount Rate "Life Cycle Cost Analysis: A Guide for Comparing Alternate Pavement Designs," EB220P, American Concrete Pavement Association, Skokie, Illinois, 2002.

11. FHWA RealCost 2.2 User Manual Software 2006, page 7.

ADDITIONAL RESOURCES

Pavement Life-Cycle Cost Analysis Software User Manual, Version 2.1, United States Department of Transportation Federal Highway Administration August 2004.

Advanced Pavement Life-Cycle Cost Workshop, Showcasing FHWA RealCost Software Federal Highway Administration US Department of Transportation.

Life Cycle Cost Analysis in Pavement Design, Demonstration Project No. 115, U.S. Department of Transportation Federal Highway Administration, Participant's Manual.

2000 Transportation Research Board Highway Capacity Manual.

Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, 1-37A Appendix C.1, March 2004.

Engineer-In-Training Reference Manual 7th Edition, Michael R. Lindeburg, P.E. Chapter 13 "Engineering Economic Analysis" July 1990.

Life Cycle Cost Analysis: State-of-the-Practice, Jay Goldbaum, CDOT Report Number CDOT-R1-R-003, March 2000.

Life-Cycle Cost Analysis in Pavement Design Participant's Notebook Demonstration Project No. 115, Publication No. FHWA-SA-98-040 August 1998.

APPENDIX A - GLOSSARY

Analysis Period: period of time used in making economic comparisons between design alternatives. The analysis period should not be confused with the pavement design life (i.e., performance period).

Benefit Cost Analysis: process is often used where project evaluations where benefits and costs accrue to different segments of the community. With this method the present worth of all benefits (irrespective of the beneficiaries) is divided by the present worth of all costs. The project is considered acceptable if the ratio equals or exceeds 1.0 (i.e., $B/C \geq 1.0$). This will be true whenever $B\text{-}C \geq 0$.

Constant-Dollars: dollars that have uniform purchasing power over time and that are not affected by general price inflation or deflation.

Current-Dollars: dollars that do not have uniform purchasing power over time and that are affected by general price inflation or deflation.

Discount Rate: rate of interest that balances an investor's time value of money.

Inflation: an increase in the prices paid for goods and services bringing about a reduction in the purchasing power of the monetary unit, is a business reality that can affect the economic comparison of alternatives.

Initial Investment Cost: any cost of creation of a facility prior to its occupation.

Life Cycle Cost: a sum of all costs of creation and operation of a facility over a period of time.

Life Cycle Cost Analysis: a technique used to evaluate the economic consequences over a period of time of mutually exclusive project alternatives.

Maintenance Cost: any cost of scheduled upkeep of building, building system, or building component.

Nominal Discount Rate: a discount rate that includes the rate of inflation.

Operating Cost: any cost of the daily function of a facility.

Present Value (PV): an economic analysis method that requires converting all present and future costs and benefits to a single point in time (usually at or around the time of the first expenditure), using a discount rate factor.

Real Discount Rate: a discount rate that excludes the rate of inflation.

Replacement Cost: any cost of scheduled replacement of a building system or component that has reached the end of its design life.

Residual Value: value of a building or building system at the end of the study period.

Study Period: the time period over which a life cycle cost analysis is performed.

User Costs: costs incurred by highway users traveling on the facility and the excess costs incurred by those who cannot use the facility because of either agency or self-imposed detour requirements. User costs are typically comprised of vehicle operating costs and accident costs, and user delay costs.