Life Cycle Cost Analysis (LCCA)

Introduction

The SHRP2 R-23 Guidelines provide a number of possible alternative designs using either rigid of flexible pavements. There is usually not a single design that meets the design criteria but a number of alternative designs that can be considered as viable solutions. The method of selecting the best possible approach may consist of an economic evaluation, a decision matrix, or a combination of those approaches. There are several types of economic or criteria based evaluations that can be carried out as part of conducting a life cycle cost analysis (LCCA): cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis, risk-benefit analysis, etc. At one extreme lies the purely multi-criteria analysis, which employs weights from a variety of sources that contain a large degree of subjective assessment. At the other extreme lies the purely cost-benefit analysis that exclusively employs monetary valuation and has generally more explicitly defined criteria. Most Highway Agencies have established some form of selection process and it is expected that those Agencies will apply those to select between different options. For those Agencies who do not have a formal selection procedure in place, the following guidance for conducting life cycle cost analysis is provided and recommended to aid the selection process.

LCCA Procedure

Most agree that life-cycle cost analysis can be carried out using a few standardized steps. The process of a typical LCCA can be divided into the following:

- Establish strategies for a 50-year service period.
- Establish activity timing.
- Estimate agency costs.
- Estimate user costs.
- Develop expenditure streams.
- Compute net present value (NPV).
- Conduct risk analysis.
- Reevaluate strategies.

These steps will be explained more fully in the content that follows.

Establish Strategies for a 50 year Service Period

The primary purpose of an LCCA is to quantify the implications of initial pavement design decisions regarding the future costs of maintenance and rehabilitation activities over 50 years. This assumes that a high level of service is maintained to preclude the use of full depth patching and other major repairs. Having a clear picture of the performance of the pavement over that period is critical to the selection of the most cost efficient alternative for that particular location and project. The timing of needed minor repairs, which if properly managed, will efficiently preserve the pavement condition over the 50 year design period at what would be expected to be the lower total cost.

It is anticipated a 50-year analysis period will be long enough to incorporate multiple rehabilitation activities repeated through the service period. Figure 1 shows a typical analysis period for a given pavement design alternative. Guidelines for the preservation of long life pavements is included in these guidelines based on the work performed in SHRP 2 Project R-26 "Preservation Approaches for High Traffic Volume Roadways." Preservation treatments and approaches recommended in those guidelines should be considered in the re-accruing maintenance or preservation costs associated with each design alternative. A simplified illustration of the activity and timing is illustrated in Figure 1.

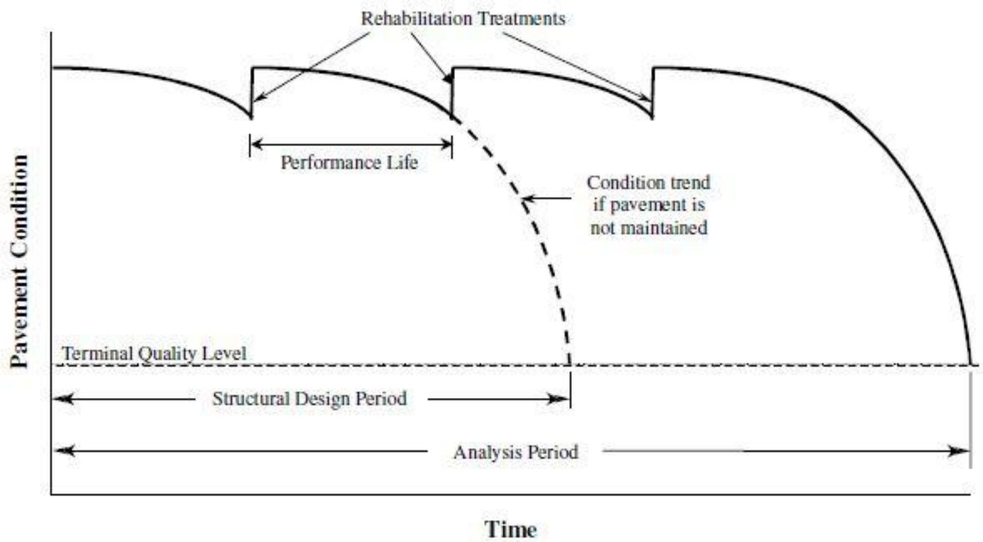


Figure 1. Example of Pavement Performance Life (WSDOT, 2010)

Typically, each design alternative will have an expected initial design life, periodic maintenance treatments and rehabilitation. In terms of the LCCA, it is important to identify the developing distress condition, timing, and cost of the key activities. SHAs have historically planned to employ a variety of rehabilitation strategies to keep highway facilities in a functional condition. For example, Table 1 shows the Washington State Department of Transportation's (WSDOT) maintenance and rehabilitation framework representing a conventional approach to maintain new and reconstructed pavements over a 50 year period in their LCCA procedure (WSDOT Pavement Guide Volume 1 2009).

Table 1. Rehabilitation Scenarios for HMA and PCC Pavements

Year	HMA Pavement	PCC Pavement
0	Construction or reconstruction	Construction or reconstruction
15	1.8 in. mill and HMA overlay	
20		Diamond grinding
30	1.8 in. HMA overlay	
40		Diamond grinding
45	1.8 in. mill and HMA overlay	
50	Salvage value (if applicable)	Salvage value (if applicable)

Establish Activity Timing

Performance life for the initial pavement design and subsequent rehabilitation activities has a major impact on LCCA results. It directly affects the frequency of agency intervention on the highway facility, which in turn affects agency cost as well as user costs during maintenance activities. State Highway Agencies (SHAs) can determine specific performance information for various pavement strategies through analysis of pavement management data and historical experience as a basis of calibration of performance-related models and tools. Operational pavement management systems can provide the data to evaluate pavement condition and performance to identify performance trends. Current FHWA efforts to analyze pavement performance data collected as part of the Long-Term Pavement Performance Program (LTPP) should provide an additional valuable resource to SHAs.

Work zone requirements for initial construction, maintenance, and rehabilitation directly affect highway user costs and should be estimated along with pavement strategy development. The frequency, duration, severity, and year of work zone requirement are critical factors in developing user costs for the alternatives being considered.

Estimate Agency Costs

Construction quantities and costs are directly related to the initial design and subsequent rehabilitation strategy. The first step in estimating agency costs is to determine construction quantities/unit prices. Unit prices can be determined from SHA historical data on previously bid jobs of comparable scale. Other data sources include the Bid Analysis Management System, if used by the SHA.

LCCA comparisons are always made between mutually exclusive competing alternatives only reflecting differential costs between alternatives. In other words, costs that are common to all alternatives will simply cancel each other out in the LCCA calculations. In the past many agencies did not include traffic control costs since they were relatively common to different approaches for new construction. The existing, high volume highway facilities considered in these guidelines, traffic management costs may be a large part of the total costs and significantly different between alternative designs. Traffic management costs should be considered in comparing alternative design costs.

Agency costs include all costs incurred directly by the agency over the life of the project. They typically include initial preliminary engineering, contract administration, construction supervision and construction cost, and the associated condition monitoring cost. Routine or preservative maintenance must be proactively rather than reactively applied in order to be effective in preserving the condition of the pavement. Even though, routine preservative-type maintenance costs are generally not excessively high, their role in maintaining a relatively high performance level cannot be over stated. Unfortunately, many SHAs may not have tracked routine maintenance timing or costs providing little data regarding the differences between most alternative pavement strategies. It may also be true that when discounted to the present, the direct routine maintenance and associated monitoring cost differences have negligible effects on net present value (NPV) and may perhaps be ignored. Nonetheless, when effectively employed, the routine maintenance may often indirectly affect the NPV due to the longer service life before more costly treatments are utilized.

Salvage value, which at times is included as a negative cost, represents value of an investment alternative at the end of the analysis period and consists of two fundamental components—residual value and serviceable life. Residual value refers to the net value from recycling the pavement. The differential residual value between pavement design strategies is generally not very large, and, when discounted over the performance period, tends to have little effect on LCCA results.

Serviceable life represents the more significant salvage value component and is the remaining life in a pavement alternative at the end of the analysis period. It is primarily used to account for differences in remaining pavement life between alternative pavement design strategies at the end of the analysis period. For example, over a 50 year analysis, Alternative A reaches terminal serviceability at year 50, while Alternative B requires rehabilitation at year 40. In this case, the serviceable life of Alternative A at year 50 would be 0, as it has reached its terminal serviceability. Alternative B may still have 5 years of serviceable life at year 50, the year the analysis terminates. The value of the serviceable life of Alternative B at year 50 could be calculated as a percentage of design life remaining at the end of the analysis period (5 of 15 years or 33 percent) multiplied by the cost of Alternative B's rehabilitation at year 40.

Estimate User Costs

User costs are an aggregation of three separate cost components: vehicle operating costs (VOC), user delay costs, and crash costs that are incurred by the highway user over the life of the project. In LCCA, highway user costs of concern are the differential costs incurred by the motoring public between competing alternative highway improvements and associated maintenance and rehabilitation strategies over the analysis period. In the pavement design arena, the user costs of interest are further limited to the differences in user costs resulting from differences in long-term pavement design decisions and the supporting maintenance and rehabilitation implications. There are user costs associated with both normal operations and work zone operations. In terms of long-life designs, user costs associated with *normal operations* pertain to service periods free of maintenance and/or rehabilitation activities that typically would limit flow capacity. User costs in these circumstances would be expected to be insignificant as they are mainly a function of pavement roughness which is anticipated to be maintained at a high level. During these operating conditions, there should be little difference between crash costs and delay costs resulting from pavement design decisions. Furthermore, it may be difficult to ascertain any difference between vehicle operating costs since roughness will be maintained at a low level.

Consequently, relative to the user costs associated with *work zone operations (*which pertain to user costs associated with periods of construction, maintenance, and/or rehabilitation activities) the only relevant cost would be those related to delay caused by monitoring or repair activities as these would be key to achieving the long performance life.

Pavement maintenance and rehabilitation alternatives are often selected based on LCCA evaluations. To make consistent and cost-effective decisions, LCCA should take into account all costs. Simple models to evaluate the additional road-user costs in work zones can be employed to assist in determining life-cycle costs of various repair alternatives. CA4PRS, discussed in Chapter 10 of the Project Assessment Manual in these Guidelines, can be used to do this and it gaining use among SHAs in the US.

There is a range for the dollar value of time delay used by various Agencies. The following table is the Recommended Dollar Value used by WSDOT in 2010 dollars (WSDOT Pavement Guide Vol 1 2009).

Table 2. Recommended Dollar Values per Vehicle Hour of Delay

Vehicle Class	**Value per Vehicle Hour**	
	Value	**Range**
Passenger Vehicles	$15.10	$13 to $17
Single Unit Trucks	$24.16	$22 to $26
Combination Trucks	$29.08	$27 to 31

Note: FHWA: adjusted to 2010 dollars (http://data.bls.gov/cgi-bin/cpicalc.pl)

Compute Net Present Value

In its broadest sense, LCCA is a form of economic analysis used to evaluate the long-term economic efficiency between alternative investment options. Economic analysis focuses on the relationship between costs, timing of costs, and discount rates employed. Once all costs and their timing have been developed, future costs are often discounted to the base year and added to the initial cost to determine the NPV for the LCCA alternative. As noted earlier, NPV is the amount at various points in time back to some base year:

$$NPV = InitialCost + \sum_{k=1}^{N} FutureCost_k \times \left[\frac{1}{(1+i)^{n_k}} \right]$$

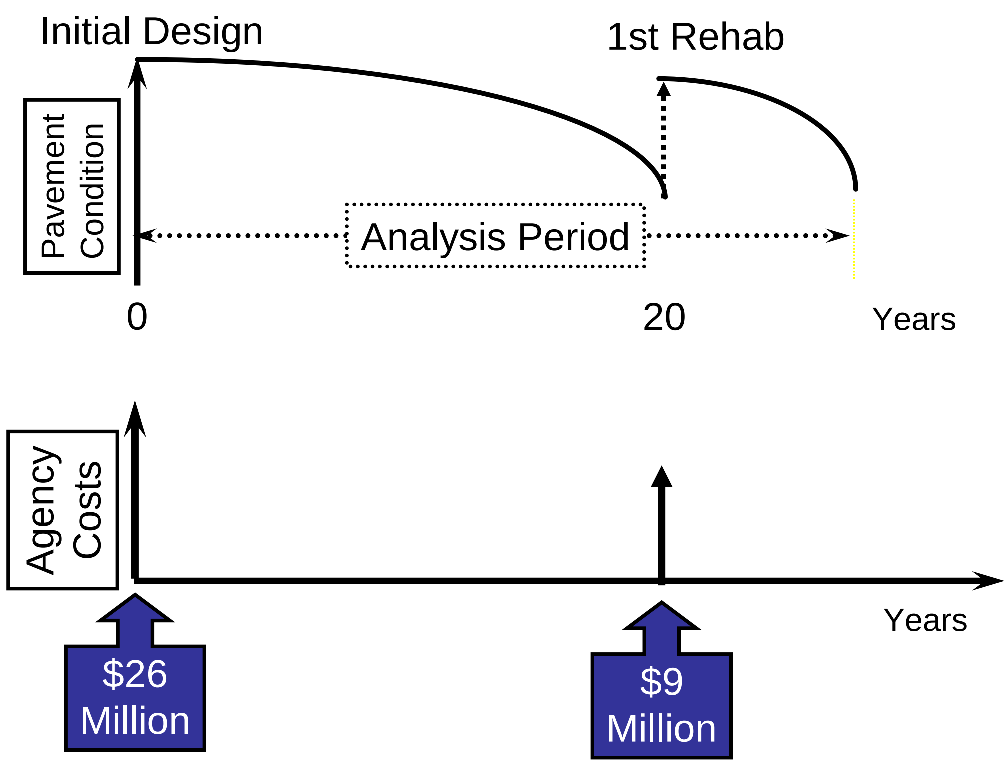
where:

i = Discount rate

n = Year of expenditure

The component within the bracket of the formula is referred to as the Present Value (PV) factor for a single future amount. PV factors for various combinations of discount rates and future years are available in discount factor tables (more commonly referred to as interest rate tables). PV for a particular future amount is determined by multiplying the future amount by the appropriate PV factor. For example, if the initial cost is $26 million and the future cost is $9 million, with a discount rate of 4 percent and if the year of expenditure is 20 years, the NPV will become $30.1 million by Equation 1 (as depicted by Figure 2). The NPV can be categorized in two ways: One being the agency NPV and the other the user cost NPV. Because user costs may dominate total NPV, agency costs and user costs must be computed separately.

Discount rates are typically set by a SHA and rarely changed; however, the federal Office of Management and Budget sets these rates annually via Circular A-94—and they do vary from year-to-year. For example, the real discount rates for 30 year + analyses have varied from a low of 2.7% (for 2009 and 2010) to a high of 7.9% (for 1982). On average the real discount rate over a span of about 30 years is 4.3%.



Source: J. Walls and M.R. Smith (1998), FHWA-SA-98-0**61**

Figure 2 Net Present Value Computation Example.

Risk Analysis

The concept of risk comes from the uncertainty associated with future events, i.e., the inability to know what the future will bring in response to a given action today. Risk can be subjective or objective. Subjective risk is based on personal perception, i.e., intuitively deciding how risky a situation may be. For example, you may view flying as more risky than driving. This perception of risk may be related to the consequences of failure as well as the inability to control the situation. Objective risk is based on theory, experiment, or observation. Because individuals' perceptions of risk vary, decisions incorporating risk management concepts will depend to a large extent on the decision maker's tolerance for risk.

Risk analysis is concerned with three basic questions: (1) what can happen, (2) how likely is it to happen, and (3) what are the consequences of its happening? Risk analysis attempts to answer these questions by combining probabilistic descriptions of uncertain input parameters with computer simulation to characterize the risk associated with future outcomes. It exposes areas of uncertainty typically hidden in the traditional deterministic approach to LCCA, and it allows the decision maker to weigh the probability of an outcome actually occurring.

Many analytical models treat input variables as discrete fixed values, as if the values were certain. In fact, the majority of input variables are uncertain. Economic models used in a typical LCCA are no exception. In conducting LCCA, it is important to be aware of the inherent uncertainty surrounding the variables used as inputs into the analysis. Uncertainty results from the assumptions, estimates, and projections made in conducting the analysis. Table 3 summarizes LCCA input variables and the general basis used to determine their values.

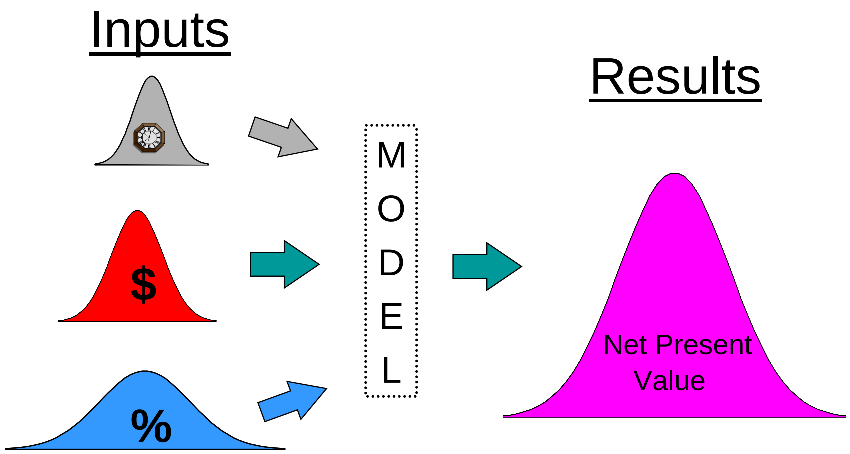
Table 3. LCCA input variables

LCCA Component	Input Variable	Source
Initial and Future Agency Costs	Preliminary Engineering	Estimate
	Construction Management	Estimate
	Construction	Estimate
	Maintenance	Assumption
Timing of Costs	Payment Performance	Projection
User Costs	Current Traffic	Estimate
	Future Traffic	Projection
	Hourly Demand	Estimate
	Vehicle Distributions	Estimate
	Dollar Value of Delay Time	Assumption
	Work Zone Configuration	Assumption
	Work Zone Hours of Operation	Assumption
	Work Zone Duration	Assumption
	Work Zone Activity Years	Projection
	Crash Rates	Estimate
	Crash Cost Rates	Assumption
Net Present Value (NPV)	Discount Rate	Assumption

This uncertainty is often ignored in an LCCA. For example, the analyst may make a series of best guesses of the values for each input variable and compute a single deterministic result. The problem with this approach is that it often excludes information that could improve the decision.

In some cases, a limited sensitivity analysis may be conducted whereby various combinations of inputs are selected to qualify their effect on analysis results. However, even with a sensitivity analysis, this deterministic approach to LCCA often conceals areas of uncertainty that may be crucial to the decision making process.

The need to make strategic long-term investment decisions under short-term budget constraints is encouraging SHAs to consider risk as a criterion for judging a course of action. Risk analysis exposes areas of uncertainty for the decision maker. Based on this information, the decision maker has the opportunity to take mitigating action to decrease exposure to risk. With the emergence of user-friendly computer software, a SHA should consider integrating quantitative risk analysis concepts into the decision making process (Figure 3).



Source: J. Walls and M.R. Smith (1998), FHWA-SA-98-061

Figure 3 Risk analysis approach.

Reevaluate Strategies

Once the NPVs have been computed for each alternative and limited sensitivity analysis performed, the analyst needs to and reevaluate the competing design strategies. The overall benefit of conducting LCCA is not necessarily to obtain LCCA results themselves, but rather to learn how the designer can use the information resulting from the analysis to modify the proposed alternatives and develop more cost-effective strategies.

For example, if user costs dwarf agency costs for all the alternatives, the analysis may indicate that none of the alternatives analyzed are viable. It could indicate that the designer needs to evaluate the current design strategies' impacts on future traffic maintenance and ensure that the design strategies reflect the need for additional capacity in the out-years to mitigate the impact on highway users. The solutions might include:

- The use of the shoulders in subsequent rehabilitation traffic control plans.
- Enhanced structural design of the mainline pavement to minimize the frequency of subsequent rehabilitation efforts.
- Reduction of the overall construction period.
- Restriction of contractor work hours or imposition of lane rental fees.
- Planning for additional lanes/routes and shifting to alternative modes of travel.

It is important to note that restricting the contractor's hours of operation or the number of work days allowed will increase agency cost.

LCCA results are just one of many factors that influence the ultimate selection of a pavement design strategy. The final decision may include a number of additional factors outside the LCCA process, such as local politics, availability of funding, industry capability to perform the required construction, and agency experience with a particular pavement type, as well as the accuracy of the pavement design and rehabilitation models. Chapter 3 of the 1993 *AASHTO Guide for Design of Pavement Structures* (AASHTO, 1993) discusses these other factors in greater detail. When these other factors weigh heavily in the final pavement design selection, it is imperative to document their influence on the final decision.

The accuracy of LCCA results depends directly on the analyst's ability to reasonably forecast such variables as future costs, pavement performance, and traffic years into the future. To deal effectively with the uncertainty associated with these forecasts, a probabilistic risk analysis approach is increasingly essential to quantitatively capture the uncertainty associated with input parameters in LCCA results.

References

Walls, J. and Smith, M.R. (1998) "Life Cycle Cost Analysis in Pavement Design," FHWA-SA-98-061, Federal Highway Administration, Washington DC.

WSDOT (2010), "Pavement Policy," Draft Document, Washington State Department of Transportation, January 2010, Olympia WA, January 2010.
URL: http://www.wsdot.wa.gov/biz/mats/Apps/DraftWSDOTPavementPolicy2-2-10.pdf

AASHTO (1993), "Guide for Design of Pavement Structures," American Association of State Highway and Transportation Officials, Washington DC.