ENGINEERING BULLETIN

Life-Cycle Cost Analysis:
A Tool for Better Pavement Investment and Engineering Decisions

EB011

AMERICAN CONCRETE PAVEMENT ASSOCIATION

Life-Cycle Cost Analysis: A Tool for Better Pavement Investment and Engineering Decisions

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ACPA is the premier national association representing concrete pavement contractors, cement companies, equipment and materials manufacturers and suppliers. We are organized to address common needs, solve other problems, and accomplish goals related to research, promotion, and advancing best practices for design and construction of concrete pavements.

KEYWORDS: cement, concrete, concrete pavement, concrete pavement preservation (CPP), construction, cost, discount rate, equivalent uniform annual cost, escalator, inflation rate, initial cost, interest rate, life-cycle cost analysis (LCCA), life cycle, maintenance, preservation, net present value, overlay, pavement, paving, PCCP, performance, present worth, probabilistic analysis, reconstruct, rehabilitation, residual value, salvage value, user cost

ABSTRACT: This engineering bulletin presents the concepts of life-cycle cost analysis (LCCA) for the purpose of comparing equivalent competing pavement design alternatives on an economic basis. All of the factors that should be considered in an economic analysis are explained, and guidance is given on the selection of values for LCCA-sensitive factors. Single-project LCCA examples are provided for a local road, a highway and an airfield. Advanced LCCA topics also are discussed, including, probabilistic analysis, the impact of pavement service life on a roadway network, the role of LCCA in pavement type selection and consideration of material price volatility.

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Executive Summary

Life-cycle cost analysis (LCCA) is an analysis technique, based on well-founded economic principles, used to evaluate the overall long-term economic efficiency between competing alternate investment options. LCCA is typically used as a means to evaluate and then compare the cost to the agency of any number of alternate pavement alternatives, including variations of concrete and asphalt pavement solutions. When done correctly, a life-cycle cost analysis of pavement design or preservation/rehabilitation strategy alternatives identifies the strategy that will yield the best value by providing the desired performance at the lowest cost over the analysis period.

> "Economic principles tell us that if we want to minimize the cost of a durable good that requires repair, maintenance and replacement over time, we must minimize present value of those costs, not minimize initial costs. If the myopic strategy is adopted to accept the lower up-front price despite higher [present value], the buyers are actually made worse off."
>
> – Dr. William Holahan
> *Chair and Professor*
> *Department of Economics*
> *University of Wisconsin–Milwaukee*
> (Holahan 2007)

This document focuses specifically on the inputs to an LCCA, and involves the following steps in a typical life-cycle cost analysis of pavement design or rehabilitation alternatives:

1. Select the analysis period.
2. Select a discount rate.
3. Estimate initial agency costs (A).
4. Estimate user costs (B).
5. Estimate future agency costs (C).
6. Estimate residual value.
7. Compare alternatives.

The analysis period selected should be sufficiently long to encompass the initial new design or preservation/rehabilitation performance period and at least one major follow-up preservation/rehabilitation activity for each alternative. For this reason, ACPA recommends an analysis period of 45-50+ years.

The discount rate selected should reflect realistic expectations about future trends in appropriate interest and inflation rates. The appropriate interest rate to be used for analysis of pavement alternatives depends on the type of entity funding the project and the method(s) used to raise funds. The appropriate inflation rate to be used depends on how construction or specific material costs are expected to increase in the future, which may require the use of different inflation rates for different materials.

The types of agency and user costs that should be considered in a proper life-cycle cost analysis of pavement alternatives are described in this bulletin. Selection of activities, assigning their timing, and estimating their performance lives for each of the strategy alternatives are also discussed, as are options for quantifying the residual value of an alternative at the end of the analysis period.

Investment alternatives such as pavement strategies are most commonly compared on the basis of present worth (also called net present value) or annual worth (also called equivalent uniform annual cost). For strategies compared over a common analysis period, the present worth method and annual worth method will always yield the same result in terms of which strategy is most cost-effective. Real-world pavement life-cycle cost analysis examples of a local road, a highway, and an airport are presented along with detailed commentary on issues that might affect the results.

This bulletin also discusses some applications of LCCA of pavement alternatives, including network-level service life and economic analysis, material price forecasting, sustainability in the context of an LCAA, the role of LCCA in pavement type selection, the total cost of ownership, and the potential impact of material quantity specifications on LCCA results.

Chapter 1. Introduction

Life-cycle cost analysis (LCCA) is an analysis technique, based on well-founded economic principles, used to evaluate the overall long-term economic efficiency between competing alternate investment options. LCCA is typically used as a means to evaluate and then compare the cost to the agency of any number of alternate pavement alternatives, including variations of concrete and asphalt pavement solutions. When done correctly, a life-cycle cost analysis of pavement design or rehabilitation alternatives identifies the strategy that will yield the best value by providing the expected performance at the lowest cost over the analysis period.

Figure 1-1 illustrates the need for LCCA to determine which of two competing pavement alternatives has the lower overall cost; because different pavement types perform differently over time and because equivalent designs are not always achievable during initial construction, a comparison of the total discounted cost of each design over a specific analysis period is necessary to minimize the financial burden of the section of roadway on taxpayers.

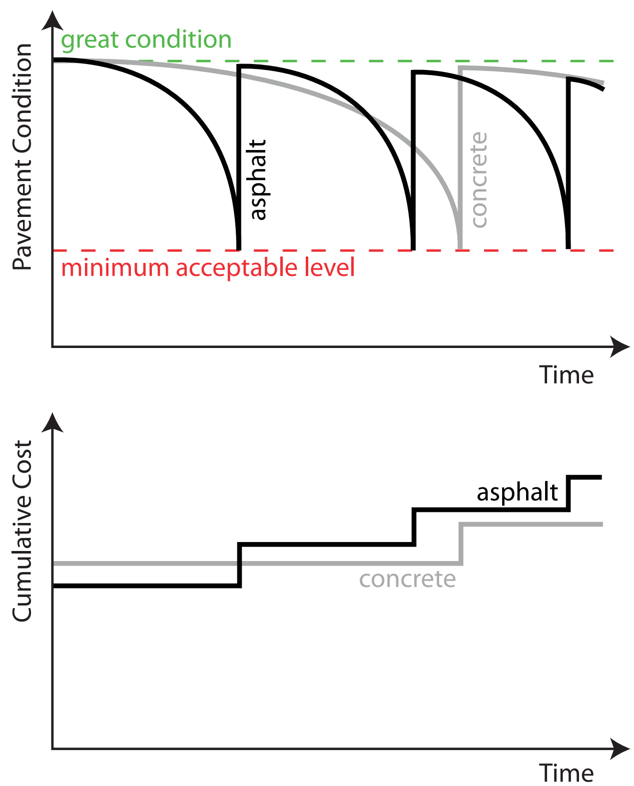


Figure 1-1.Generalized illustration of pavement condition over time and the financial implications of such through the calculation of total cost.

Because much of our pavement network consists of either asphalt or concrete pavement, this document focuses on LCCA of these two alternates and their subsequent comparison. However, LCCA could just as well be used to evaluate and compare the economic worth of two concrete alternatives or three asphalt alternatives.

The general trends between Average Annual Daily Traffic (AADT) and initial construction cost in Figures 1-2 and 1-3 were developed in 2003 by the Louisiana DOT (Temple et al. 2004). The concrete alternate has a significantly higher initial agency cost until the asphalt and concrete initial costs converge at around 35,000 AADT (Figure 1-2). However, when life-cycle costs are considered, the concrete alternate becomes the more cost-effective of the two at a much lower traffic level, around 10,000 AADT (Figure 1-3). It is important to note that these figures were developed in 2003 when oil was trading at just $30 per barrel. The advantage of concrete will only be more pronounced at current prices.

If the Louisiana DOT considered only the initial cost in all cases, the agency (and, thus, the taxpayers) would almost always select the asphalt alternate, forcing substantial future expenditures to be committed when the concrete alternate would, in most cases, save the agency money in the long run.

LCCA has applications for many areas of interest, including (FHWA 2003a):

- Designing, selecting, and documenting the most affordable means of building a project.
- Evaluating pavement preservation strategies.
- Value engineering.
- Project planning and implementation (e.g., work zone timing).

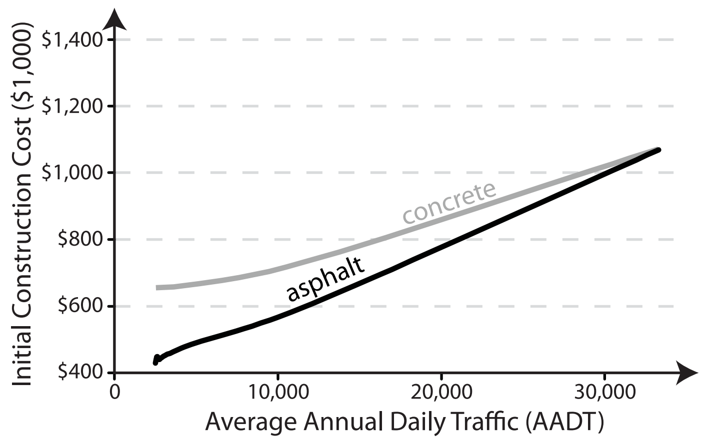


Figure 1-2.Louisiana DOT general trend for initial construction cost of concrete and asphalt pavements (after Temple et al. 2004).

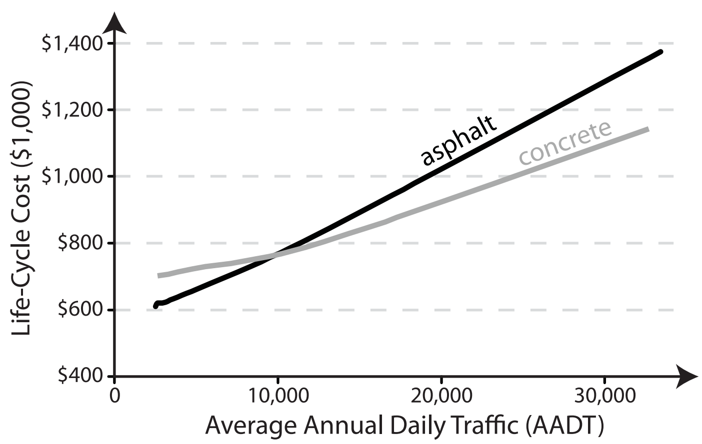


Figure 1-3.Louisiana DOT general trend for life-cycle cost of concrete and asphalt pavements (after Temple et al. 2004).

Life-cycle cost analysis is not an engineering tool for determining how long a pavement design or rehabilitation alternative will last or how well it will perform; rather, LCCA is an economic analysis procedure that uses engineering inputs. The quality of the results of an LCCA depends on economic inputs and the quality of the engineer's inputs, including the expected lives (for both initial construction and rehabilitation activities) of the alternatives considered.

This document focuses on the inputs to an LCCA and presents the following steps in a typical LCCA of pavement design or rehabilitation alternatives:

1. Select the analysis period.
2. Select a discount rate.
3. Estimate initial agency costs (A).
4. Estimate user costs (B).
5. Estimate future agency costs (C).
6. Estimate residual value.
7. Compare alternatives.

The FHWA identifies the following procedural steps involved in conducting an LCCA (FHWA 1998):

1. Establish alternative pavement design strategies for the analysis period.
2. Determine performance periods and activity timing.
3. Estimate agency costs.
4. Estimate user costs.
5. Develop expenditure stream diagrams.
6. Compute net present value.
7. Analyze results.
8. Reevaluate design strategies.

While ACPA agrees with the FHWA's suggested procedural steps (and, in fact, each of the ACPA's seven steps can be rolled up into just a few of these FHWA steps), the intent of this document is to focus on the individual inputs of an LCCA more than the LCCA process itself. The ACPA seven steps also assume that equivalent alternate pavement designs are selected as a prerequisite to conducting an LCCA of the alternates. As will be discussed in more detail later, design tools such as DARWinME™ can be useful in establishing equivalency in the design of pavement alternates.

Another facet of an LCCA framework that needs consideration but is not included as part of the ACPA's seven steps is the approach to risk and uncertainty that is inherent in any LCCA (NCHRP 2004).

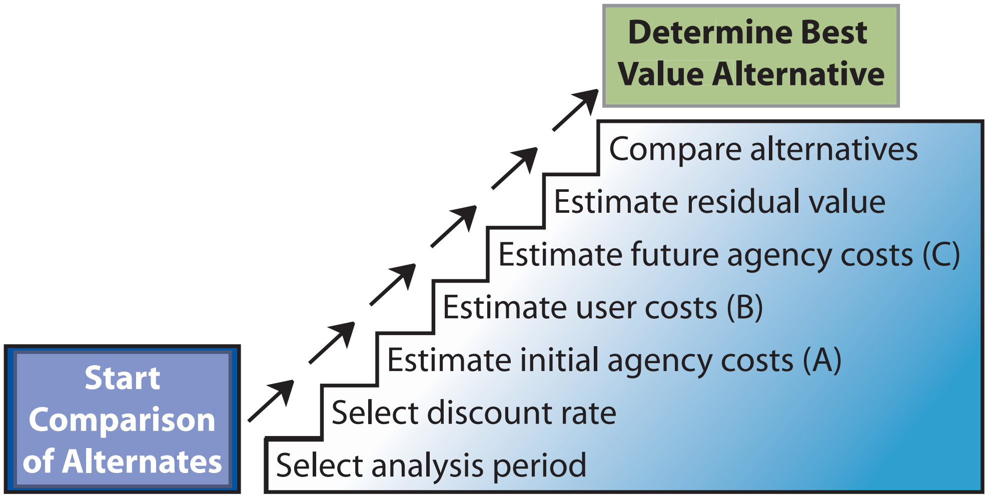
Each of the seven LCCA steps and the issue of risk/uncertainty are described in Chapter 2 of this document and examples employing these steps are presented in Chapter 3.

Chapter 4 discusses more advanced topics in life-cycle cost analysis of pavement alternatives, including:

- Network-level analyses,
- Sustainability in the context of a life-cycle cost analysis,
- The role of LCCA in pavement type selection,
- A detailed example of a total cost of ownership analysis, and
- The potential impact of material quantity specifications on LCCA results.

The appendices include a worksheet for simple deterministic LCCAs, a discussion on historic oil prices (and the impact such prices have on asphalt pavement costs), and all current federal policies on pavement type selection.

Although this document focuses primarily on LCCAs as they pertain to highways, streets, and roads, an example for an airport is included in Chapter 3. Detailed guidance for LCCAs of airfields and military construction is also available elsewhere (AAPTP 2011; ARMY 1992; FAA 2009).



Chapter 2. Basic Steps in a Life-Cycle Cost Analysis (LCCA) for a Single Project

Performing an LCCA is not complicated. It is simply a mathematical calculation of the value of anticipated expenditures over time. Though computer programs (e.g., ACPA's StreetPave) and spreadsheets (e.g., FHWA's RealCost) are useful in performing the calculations, they are not necessary.

Step 1 – Select the Analysis Period

The **analysis period** is the timeframe over which the alternative strategies/treatments are compared. This timeframe must be long enough to reflect significant differences in performance among the alternatives being compared. This is best accomplished by selecting an analysis period that encompasses the initial performance period and at least one major follow-up preservation/rehabilitation activity for each strategy.

For this reason, the Federal Highway Administration's (FHWA's) policy statement on LCCA recommends an analysis period of at least 35 years for all pavement projects (FHWA 1996). In line with this recommendation, typical analysis periods for pavement LCCAs of highways, streets, and airports are 40+ years (Table 2-1). ***ACPA recommends an analysis period of 45-50+ years so that at least one major rehabilitation effort is captured for each alternate because common practice in many states is to design the concrete pavement alternate for 30+ years.*** It is worth noting that, in some cases, the analysis period can be significantly shorter if the focus of the LCCA is to evaluate and compare shorter-term pavement alternates, such as thin concrete overlays and asphalt overlays.

One or more of the alternates being compared also may have a performance life that extends beyond the end of the chosen analysis period. For these alternates, the pavement structure presumably would have some remaining service life (RSL). The RSL can be included in the LCCA in a variety of ways, as discussed in Step 6.

Table 2-1. Summary of the LCCA Analysis Period Used by Various U.S. State Highway Agencies (after MDOT 2009 and Rangaraju, et al. 2008)

Analysis Period (yrs)	Percent of Responding Agencies	State Agency
< 30	4%	AL
30	11%	NC, SC, WY
35	18%	AK, AR, ID, MT, OH
40	**39%**	CO, FL, GA, IA, IN, KS, KY, LA, MD, MS
45	7%	IL, MO
50+	21%	MN, NE, NY, VA, WA, WI

Step 2 – Select a Discount Rate

The term **real discount rate**, also known as the real interest rate, is commonly used in engineering economics to refer to the rate of change over time in the true value of money, taking into account fluctuations in both investment interest rates and the rate of inflation. This value differs from a nominal discount rate, which reflects expected inflation and is used to discount inflated dollars or nominal benefits and costs (e.g., real discount rate ≈ nominal discount rate – inflation rate). That is to say, today's costs can be used as proxies for future costs only if the real discount rate is used in the LCCA. All state highway agencies currently use today's costs (e.g., non-inflated dollars) and real discount rates in their LCCAs.

The real discount rate is given by the following equation (Thuesen and Fabrycky 1984):

$$d = \frac{1 + i_{int}}{1 + i_{inf}} - 1 \qquad \text{[Eqn 2-1]}$$

where:

d = the real discount rate, %
i_{int} = the interest rate, %
i_{inf} = the inflation rate, %

For example, for an interest rate (i_{int}) of 10% and an inflation rate (i_{inf}) of 6%, the real discount rate is:

$$d = \frac{1.10}{1.06} - 1 = 0.038 \textit{ or } 3.8\%$$

If the interest rate exceeds the inflation rate, the following approximation may be used:

$$d \approx i_{int} - i_{inf} \qquad \text{[Eqn 2-2]}$$

For the previous example, the approximated real discount rate is 10% – 6% = 4%, slightly greater than the more precisely calculated real discount rate of 3.8%.

Through application of an appropriate real discount rate (which may differ for alternates with different material inflation rates), the worth or value of all initial and future costs can be expressed in terms of **constant dollars**, (i.e., in terms of the costs of those items as if they were incurred in the year in which the life-cycle cost analysis is conducted).

High real discount rates tend to reduce the impact that high future expenditures have on the net present value or the alternate. Thus, it can be said that high real discount rates favor alternates that have low initial costs and high future costs, while low real discount rates favor alternates with higher initial costs and lower future costs. As an example, consider Figure 2-1, which shows the present worth (discussed in Step 7) of $1 spent in various years under various real discount rates. If the real discount rate is 2%, a dollar spent in year 30 is worth 55 cents today; if the real discount rate is 6%, that same dollar in year 30 would be worth just 17 cents today. Thus, the higher real discount rate would more greatly discount future costs and could result in the selection of an alternate with much higher maintenance costs even if the initial cost is only slightly lower.

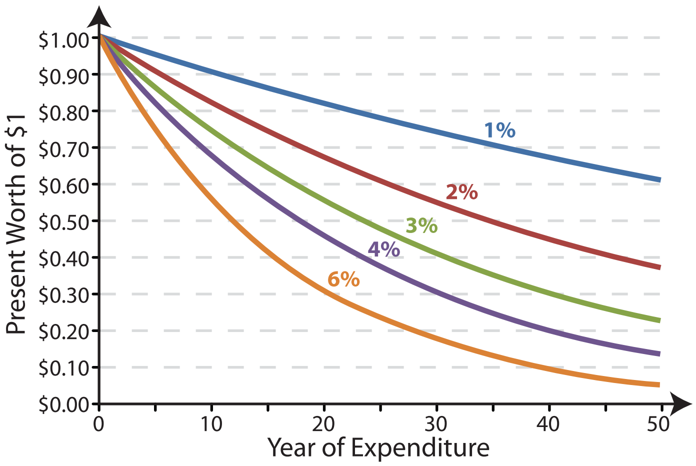


Figure 2-1. Present worth of $1.00 spent in various years at various real discount rates.

Interest rates and inflation rates fluctuate over time, but the relative difference between them, while not constant, is less variable. The real discount rate selected should take into account past trends in appropriate interest and inflation rates over relatively long time periods, as well as future economic projections.

The appropriate interest and inflation rates to use in calculating the real discount rate for the evaluation of public-sector investments, such as road projects, are the subject of much debate for the reasons discussed in the rest of this section. Oftentimes, a single "standard" real discount rate might be used to avoid the complexities in calculating a local or material-specific real discount rate, but this practice can lead to the selection of an alternate that is not the most cost-effective (Snyder 2008).

The real discount rate also must be routinely updated to reflect current and forecasted economic conditions. The practice of using a single "standard" real discount rate does not allow for such consideration. The use of the United State's Office of Management and Budget (OMB) real discount rate, which is updated annually, does, however, account for such changes in economic conditions. If local interest and inflation rates are not readily available to develop and regularly update a local real discount rate, ACPA supports the use of this OMB real discount rate.

The following sections discuss how to establish appropriate interest and inflation rates. Guidance is then provided on how best to determine the real discount rate.

Selecting an Interest Rate

An abundance of conflicting opinion and guidance exists on the subject of choosing an interest rate for use in LCCA of pavement alternatives. Funds for paving projects are obtained by 1) levying taxes, 2) borrowing money (i.e., selling bonds), and/or 3) charging users for services (e.g., toll revenue). The interest rate assumed for the LCCA of a project should reflect the type of entity raising the money and the method(s) used to raise it.

Public entities (e.g., local, State, and Federal agencies) fund projects by borrowing money through the sale of bonds and/or levying taxes. Opinions differ on whether the interest rate that applies to a public agency's analysis of project alternatives should be based on an assumption of financing by borrowing, financing by taxes, or a combination of the two. Another school of thought considers the interest rate to be a reflection of "opportunity or investment foregone" (i.e., money spent on one activity is money that cannot be spent on another activity or investment that might also produce revenue or benefit).

If project(s) will be funded by the sale of bonds, money is available at attractive, relatively low interest rates. While government bonds are in direct competition with other investment opportunities, they are presumed to be lower-risk than private investments because governments are better positioned to cope with risk. Bonds sold by government agencies are backed by the issuer's credit and taxing power – i.e., the "full faith and credit" of the government agency, which constitutes an unconditional commitment to pay interest and principal on the debt. For analyses of projects to be financed by the Federal government, the appropriate interest rate generally is taken to be the rate on long-term (30-year) U.S. Treasury bills (OMB 1992). State and municipal bonds typically carry somewhat higher risk and, thus, higher interest rates (Thuesen and Fabrycky 1984).

If project(s) will be funded with tax revenues (especially dedicated revenues, such as highway user fees, tolls or fuel taxes that cannot be used for other purposes), the owner-agency does not finance the revenue and there is no "opportunity cost" associated with it. Therefore, the interest rate for the use of the money must be zero (e.g., i_{int} = 0%). The use of a zero interest rate results in undiscounted (or negatively discounted) future expenditures, making future, relatively uncertain costs just as important (if not more so) to the decision as today's well-known costs (Thuesen and Fabrycky 1984). While this is contrary to current practice and the assumptions made in calculation of the OMB real discount rate, this viewpoint is gaining popularity and legitimacy among transportation economists.

State and local agencies typically cannot finance all of the roadway projects necessary to keep their network in ideal condition using only tax revenues. Thus, these agencies routinely sell bonds to supplement tax revenues. This can result in an ever-increasing backlog of projects that cannot be programmed with currently available funds because more and more money must be dedicated to paying out interest on the bonds. In this scenario, the most realistic interest rate may be a weighted average of the interest rate associated with tax revenues (e.g., 0%) and the interest rate associated with the bonds sold (Snyder 2008).

Quasi-private entities (e.g., toll authorities) fund projects by borrowing money through the sale of bonds; user fees (tolls) are charged to pay off those bonds and cover annual operating costs. New bonds might necessarily be issued periodically to raise capital for major construction projects. Because bonds issued by a quasi-private entity are backed solely by the toll revenue to be generated by the project(s) being financed, such bonds typically have higher interest rates than those issued by less-risky public entities. If no tax revenues will be used to fund the project, the interest rate used should be that of the bonds issued by the quasi-private entity for construction of the project(s).

Private entities (e.g., concessionaires) can neither levy taxes nor sell their own bonds, so they must raise capital from their own investments. For example, they might borrow money from private investors or use income from other investments to fund their construction projects. The appropriate interest rate for analyzing projects built by private entities can vary widely, but is often taken as that of a long-term corporate bond rate.

Selecting an Inflation Rate

The inflation rate chosen for use in a life-cycle cost analysis of pavement alternatives may be 1) a single value if it is assumed that all components of future costs inflate at a uniform rate or 2) several different values for various cost components when there are significant differences in inflation among the cost components.

Several general inflation indices are compiled regularly by the Bureau of Labor Statistics (BLS) in the U.S. Department of Labor, including:

- The Consumer Price Index (CPI), which represents the change in retail prices for a selected set of purchases of clothing, food, housing, transportation, medical care, entertainment, education, and other items throughout the U.S. The CPI serves to quantify the effect of retail price changes on a fixed standard of living for the "average" consumer, serving as a general barometer of inflation in the U.S. (Thuesen and Fabrycky 1984; Riggs and West 1986).
- The Highway and Street Construction (BHWY) Producer Price Index (PPI), which tracked the cost of materials used in highway construction. PPIs reflect changes over time in the prices received by domestic producers for goods and services. The BHWY PPI was, however, discontinued in 2010. The PPI for all commodities (WPU000000) also can be used as a general inflation index or combined with the BHWY PPI to extend the BHWY PPI from 2010 to present.

The FHWA compiled, for many years, an index it called the Bid Price Index (BPI) to track the prices of several installed components of highway construction (thus including labor, overhead, and material costs). Due to issues related to the quality of the data underlying the computation of the FHWA BPI, it was discontinued in 2006 (FHWA 2006 and 2007a). In 2010, the FHWA replaced the BPI with a National Highway Construction Cost Index (NHCCI), with data starting in 2003 (FHWA 2010a). Rather than tracking individual components as the BPI did, the new index is an aggregate of all highway construction costs, similar to the BLS's BHWY PPI. It is important to note, however, that neither of these indices includes the cost of price escalation clauses (e.g., material price escalators). Therefore, these indices can greatly underestimate a material's inflation rate in states where material price escalators are used. See Step 3 for more information on material price escalators.

To compare all of these general inflation indices, Figure 2-2 shows the BLS's BHWY PPI, the FHWA's BPI, the BLS's CPI and the FHWA's NHCCI (NOTE: the BHWY PPI started in 1986, making 1986 the earliest starting point for comparison, and the FHWA NHCCI index was started in 2006 at the end value of the FHWA BPI). Across the 24 years shown, the average compound annual growth rate (CAGR) for each index was:

- BLS's BHWY PPI: 3.25%
- FHWA's BPI + NHCCI: 2.34%
- BLS's CPI: 2.90%

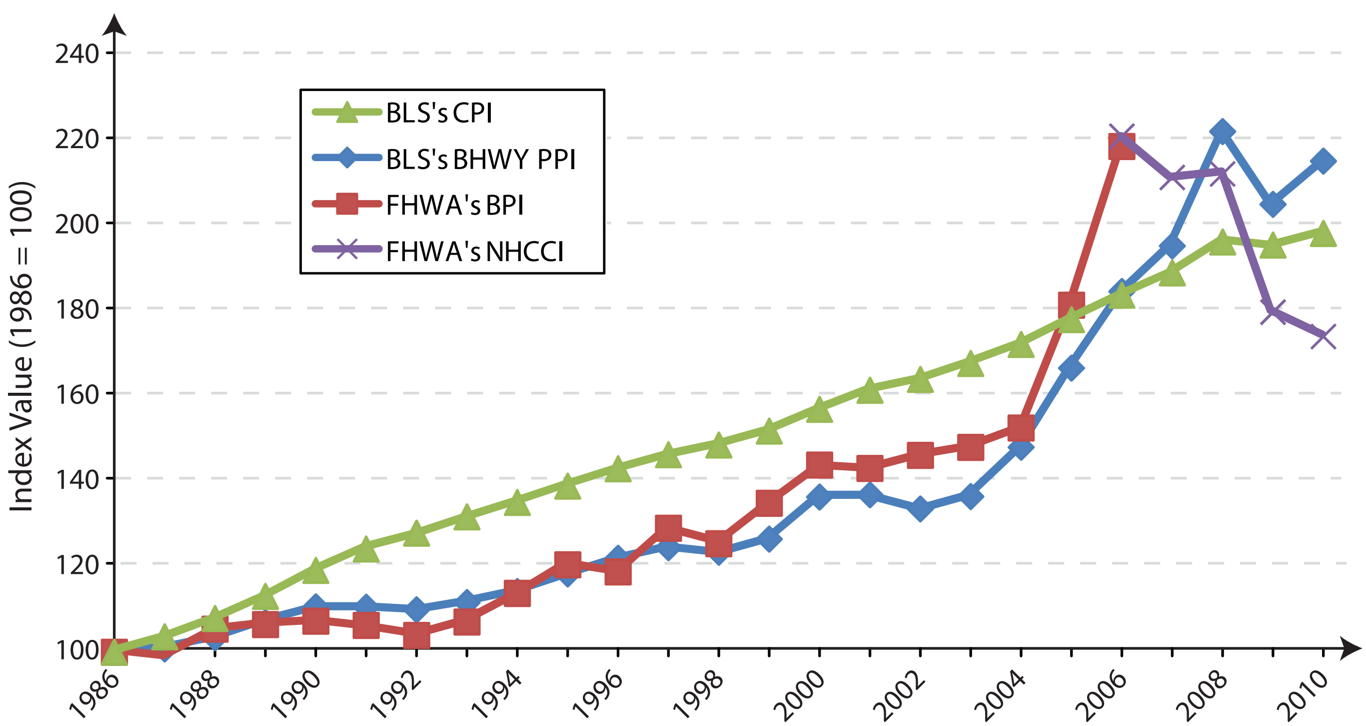


Figure 2-2. The BLS's BHWY PPI, the FHWA's BPI, the BLS's CPI, and the FHWA's NHCCI from 1986 to 2010 (FHWA 2007a and 2011a; BLS 2011).

Figure 2-3 shows the annual (e.g., year-over-year) inflation rates for the indices shown in Figure 2-2. As shown, the highway construction cost-specific indices are more volatile than the much more general CPI. Despite their increased volatility, the construction cost indices have had CAGRs comparable to that of the more general CPI over the last 24 years and, in fact, the construction cost indices were inflating at a rate that was significantly less than that of the CPI until 2004. The construction cost indices have increased sharply since that time and have become much more volatile.

According to the FHWA, **these recent surges** are due primarily to the **escalating costs of commodities** such as steel, asphalt, cement, and crushed stone (FHWA 2007a). These unprecedented construction cost increases may have potentially significant impacts on state agencies, the highway industry and the general public (FHWA 2011a). Thus, while a very general inflation index such as the BLS's CPI could be used in LCCAs, it is clearly not representative of historic or present price fluctuations in the highway and road sector. The importance of recent increases in material/commodity costs, as noted by the FHWA, underscores the importance of accounting for individual cost components in a pavement LCCA when there is significantly different inflation among cost components between alternates.

Material-specific inflation rates can be developed to forecast prices for various materials by considering their respective historic prices and trends. While current material costs can be known with a relatively high degree of reliability, forecasting future material costs for the purposes of an LCCA requires special consideration (MIT 2011a).

Figure 2-4 shows index values of the BLS's PPIs for concrete products and asphalt paving mixtures and blocks for the last 54 years (NOTE: the asphalt paving mixtures and blocks PPI started in 1958, making 1958 the earliest starting point for comparison; this also is a reasonable investigation timeframe when using previous trends to forecast future prices in an LCCA with an analysis period of 40+ years). Also shown are the BLS's CPI and standard deviation rates of monthly values within each year.

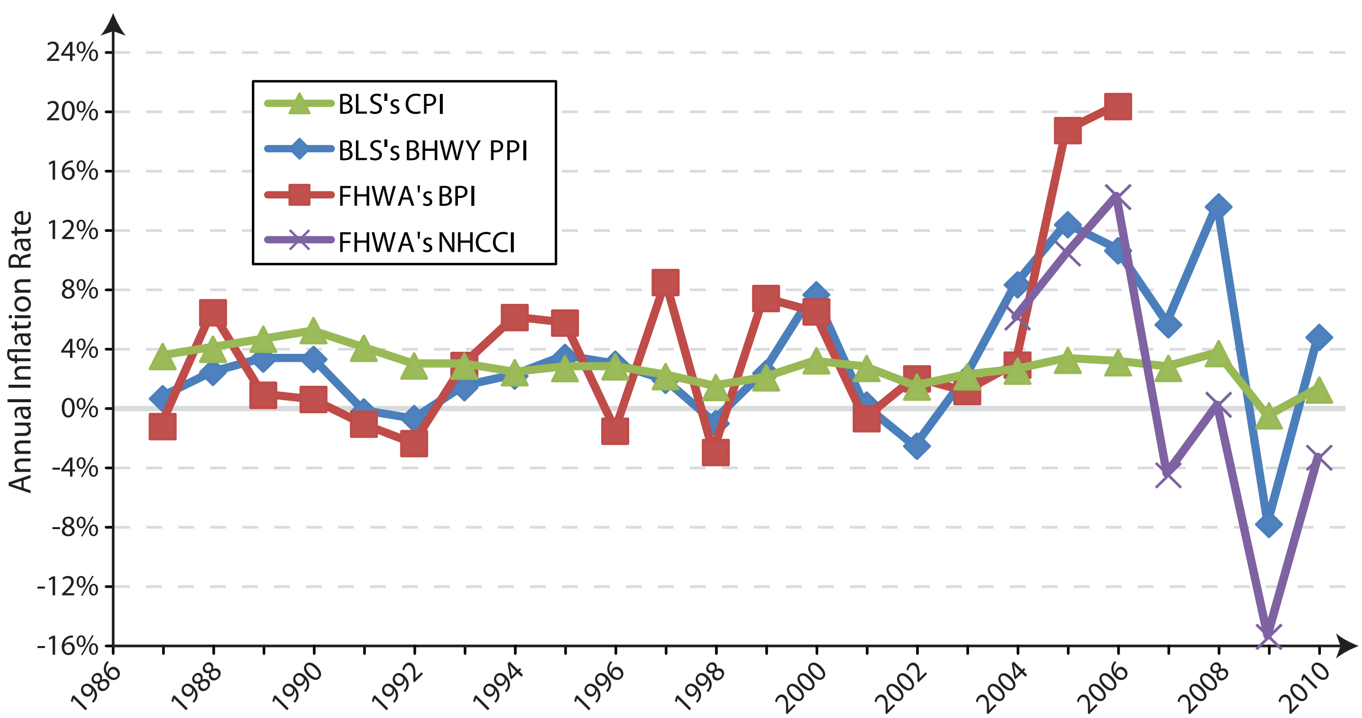


Figure 2-3. Annual (year-over-year) inflation rates for the BLS's BHWY PPI, the FHWA's BPI, the BLS's CPI, and the FHWA's NHCCI from 1986 to 2010 (FHWA 2007a and 2011a; BLS 2011).

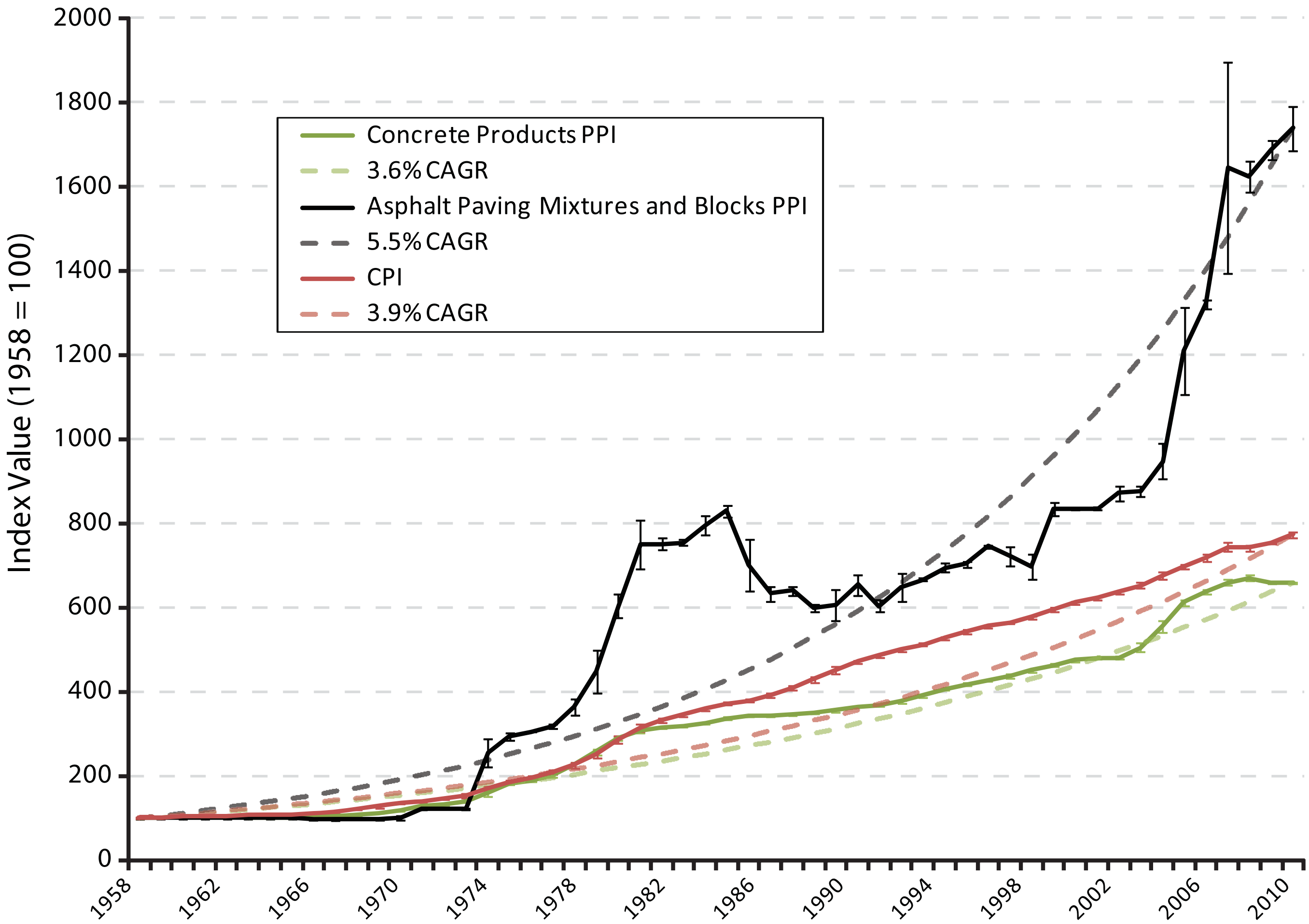


Figure 2-4. The BLS's PPI for concrete products (WPU133) and asphalt paving mixtures and blocks (WDU13940101/ WPU13940113), and the BLS's CPI, from 1958 to 2011 (BLS 2011), showing standard deviation rates of monthly values within each year and trendlines corresponding to each index's compound annual growth rate (CAGR).

The PPI for concrete products has tracked relatively closely to the CPI, but the asphalt paving mixtures and blocks PPI shows significantly different inflation. Table 2-2 presents a summary of some of the general trends for the last 54 years, of note:

- The concrete products PPI has had a lower average yearly standard deviation than that for the CPI (e.g., 2.9 versus 4.2). Thus, concrete prices are very stable and easy to forecast into the future.
- While concrete prices and the CPI have increased by about 500% to 700% in the last 54 years, asphalt paving mixture prices have increased 1,640%.
- The CAGR of the concrete products PPI and the CPI over this timeframe are similar (3.6% and 3.9%, respectively), while the inflation rate of the asphalt paving mixtures and blocks PPI is significantly higher (5.5%). This difference in inflation between materials is significant enough that it should be accounted for in a comprehensive LCCA.

Table 2-2. Summary of Concrete Products PPI, Asphalt Paving Mixtures and Blocks PPI, and CPI Trends from 1958 to 2011

Index	Average Yearly Standard Deviation	Index Increase (1958 to 2011)	Compound Annual Growth Rate (CAGR)
Concrete Products PPI	2.9	560%	3.6%
Asphalt Paving Mixtures PPI	**20.9**	**1,640%**	**5.5%**
CPI	4.2	674%	3.9%

The variability (or volatility) of these indices is as important as the overall historic increase. Figure 2-5 shows the annual (e.g., year-over-year) inflation rate for the concrete products PPI, the asphalt paving mixtures and blocks PPI, and the CPI. The annual inflation rate of the concrete products PPI follows very closely that of the CPI; the asphalt paving mixtures and blocks PPI, however, is much more volatile, increasing by over 20% year-over-year 7 different times (13% of the 54 years) and increasing by over 100% once (see Appendix 2 for comments on why the asphalt paving mixtures and blocks PPI is so volatile). Variability such as this can be accounted for in an LCCA through the use of a probabilistic analysis (see Step 7).

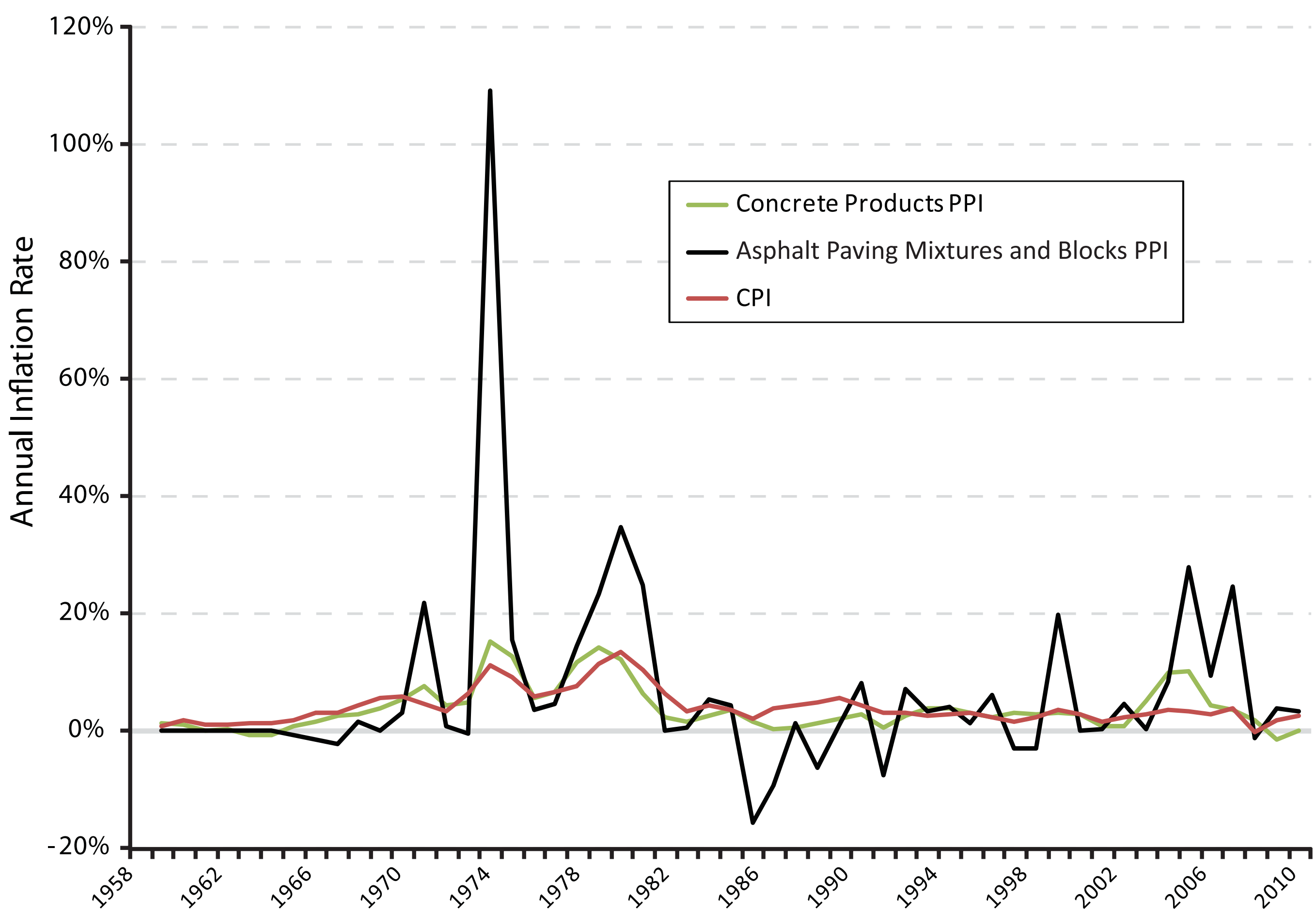


Figure 2-5. Annual inflation rate of the BLS's PPIs for concrete products (WPU133) and asphalt paving mixtures and blocks (WDU13940101/WPU13940113), and the CPI, from 1958 to 2011 (BLS 2011).

As noted, the CPI's CAGR from 1986 to 2010 was 2.90%. The higher CPI CAGR of 3.9% from 1958 to 2011 is more in line with the commonly quoted 4% general long-term inflation in the U.S. This emphasizes the importance of timeframe in LCCA.

The need to discern between materials with significantly different inflation rates is becoming more important as state agencies apply LCCAs to more and more paving projects and technologies advance to ease such calculations. One method of doing this, as noted previously, is to utilize different real discount rates for materials whose inflation rates differ significantly from the general inflation rate used in the LCCA. For example, if a 4% general inflation rate is used, based on the CPI of the last 50+ years, the concrete inflation rate might be assumed to be the same (though it is slightly lower over the same timeframe) and an asphalt inflation rate of 5.5% might be used. Another means of accounting for the difference is by applying an escalating factor to future costs before discounting all costs for all alternates at the general discount rate (MIT 2011a and Mack 2011); this method, which can also capture the impact of volatility in pricing, often is preferred by economists and is discussed more in Step 7.

Calculating the Real Discount Rate

As discussed, more than one real discount rate may be necessary if different elements of the LCCA have significantly different inflation rates and future costs are not escalated, when necessary, to account for the different inflation rates. Consider first the calculation of a general or standard real discount rate.

As an example of the calculation of a general real discount rate, consider Figure 2-6, where historical values for the 30-year Treasury bond yield are used as the interest rate, year-over-year change in the CPI is used as the inflation rate, and the real discount rate is calculated using Equation 1. While the interest and inflation indices used for calculation of the real discount rate can and should vary, the average real discount rate obtained from the use of the 30-year Treasury bond as the interest rate and BLS's CPI as the inflation rate averaged 2.1% over the last 5 years of data shown in Figure 2-6.

This average rate agrees fairly well with the real discount rates used by various state highway agencies across the U.S. (Table 2-3), recent OMB real discount rates, and the 2% to 4% range that FHWA recommends (FHWA 2008).

Table 2-3. Summary of the Real Discount Rates Used by U.S. State Highway Agencies in Their LCCAs (after Mack 2011; MDOT 2009 and Rangaraju, et al. 2008)

Real Discount Rate (%)	Percent of Responding Agencies	State Agency
< 3	18%	MI*, MN*, MO*, NV*, OH*, SC*, WV*
3	15%	GA, IA, IL, KS, MD, MT
3 to 4	10%	AR, CO*, FL, NE
4	**49%**	AK, AL, CA, CT, DE, ID, IN, LA, MS, NC, NJ, NM, NY, PA, TN, UT, VA, WA, WY
4 to 5	3%	SD
5	5%	KY, WI

* Denotes a state whose real discount rate is based either on the OMB or a moving average of the OMB.

There have been times in the history of the U.S. that, even when both the inflation and interest rates were positive, the real discount rate was negative because the rate of inflation was higher than interest rates (see Figure 2-6). **Thus, a negative real discount rate may exist even when both the inflation and interest rates are positive**.

To avoid all of the complexities in calculating a real discount rate for general use in LCCAs, many state agencies elect to use real discount rates published annually by the United State's Office of Management and Budget (OMB). Current OMB real discount rates are available online (OMB 2011).

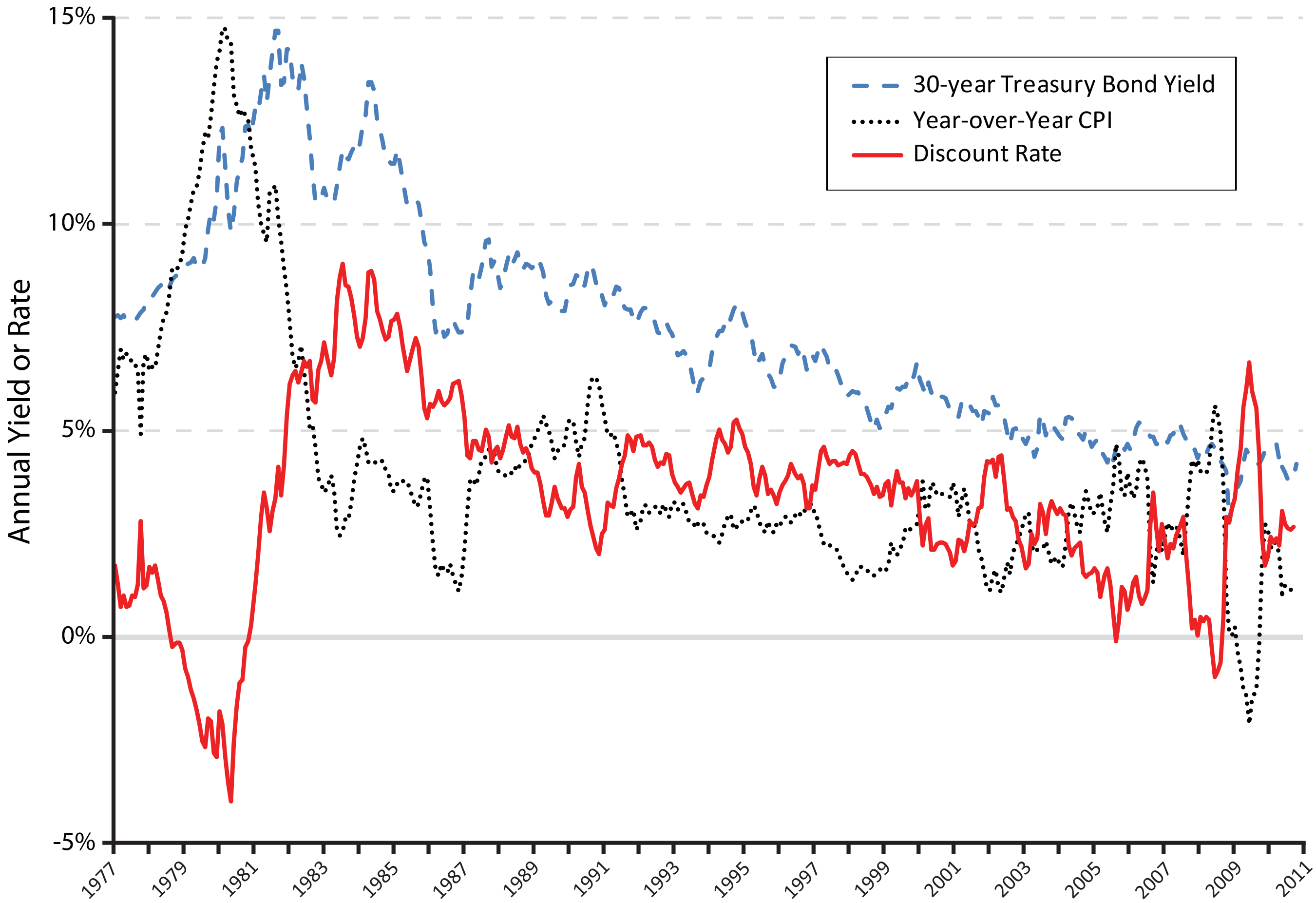


Figure 2-6. 30-year Treasury bond yield, year-over-year change in consumer price index (CPI) and real discount rate calculated from the two (BLS 2011; Federal Reserve 2010).

If local interest and inflation rates are not readily available to develop a local real discount rate, ACPA supports the use of the OMB real discount rate. If there is concern with the variability in OMB real discount rates, a moving average of the value can be considered. Figure 2-7 shows OMB real discount rate and a real discount rate calculated from the average annual CPI and 30-year Treasury rates from 1979 (the first year OMB data was available) to 2011. As shown, these values track relatively well in recent times.

As mentioned previously, uncertainty in material prices translates into increased risk for a roadway agency. This presents a challenge not only to developing accurate LCCAs, but also in accurately predicting future material costs and budgeting for roadway improvement projects. Coupled with a degradation of purchasing power, the impact can stifle needed maintenance and capacity improvements unless accounted for properly during pavement LCCAs. The best way of preventing such problems is by accounting for differences in material price inflation in current LCCAs.

Figure 2-7. Yearly real discount rates calculated from the CPI and the 30-year Treasury bond yield and those set by the OMB (BLS 2011; OMB 2011; Federal Reserve 2010).

If material-specific real discount rates are calculated, the interest rate should be that which is used in the calculation of the general real discount rate. The inflation rates, however, are those for each material whose price trends differ greatly from that of general inflation. For example, if the interest rate is 7% and the concrete and asphalt material inflation rates are 3.6% and 5.5%, respectively, as they were (on average) from 1958 to 2011 (see Table 2-2), the concrete and asphalt real discount rates would be 3.3% and 1.4%, respectively. Note that the asphalt PPI is for asphalt paving mixtures, so this rate would only apply to asphalt-based items in the bids (e.g., paving mixtures, sealers, etc.) and the general real discount rate would be used on other items (e.g., subbase/base, pipe culverts, striping, etc.).

If it is determined that the use of different discount rates for different materials is too cumbersome, other methods exist to account for significant differences in material inflation by escalating future material prices before discounting all future costs using a single real discount rate (see Step 7).

The Total Cost of Ownership

State agencies typically have a set amount of money that can be allocated towards new construction and preservation/restoration of pavements each year. Because of the magnitude of lane-miles of pavements already in existence in the U.S., **the alternative to not constructing or rehabilitating a new section of highway is not to invest the money in an interest-bearing account or the stock market**; the alternative is to allocate the money towards the construction, reconstruction, or preservation/ rehabilitation of another section. Thus, excess money is not invested and the case can be made that, to consider the true total cost of ownership of pavement alternatives to the owner/agency and ultimately to taxpayers, an interest rate of 0% should be used. **The total cost of ownership is, essentially, the inflated costs that the agency will spend over the life of the pavement.** Thus, an alternate means of calculating the total cost of ownership is to directly inflate all future costs by the appropriate inflation rate and summing the values for each alternate.

If the interest rate (i_{int}) is 0%, an inflation rate (i_{inf}) of 4% would yield a real discount rate of:

$$i_{disc} = \frac{1 + 0.00}{1 + 0.04} - 1 = -3.85\%$$

While it may seem erroneous to apply a **negative discount rate** to LCCAs of pavements, it is mathematically the same as inflating all future costs, the other means by which the true cost of alternate pavement designs can be calculated.

The total cost of ownership calculation is not presented here as an alternate method of calculating the LCCA of pavement alternatives. Rather, it is presented as another method of analyzing the future financial impact of the alternatives. Viewing the data is this manner can help provide perspective on future outlays and present the data in a format that might help with minimizing future budget deficit contributions.

Step 3 – Estimate Initial Agency Costs (A)

Agency costs are all the costs incurred by the agency over the analysis period. These costs include:

- Initial design and construction/inspection costs,
- Preservation/rehabilitation costs (including engineering and traffic control),
- Operation and maintenance costs (including staffing),
- Either demolition/removal costs or the residual value of the pavement structure,
- Costs associated with material price escalators, and
- Direct savings associated with sustainable benefits of a particular pavement type.

This section (Step 3), however, is focused on the initial design and construction/inspection costs exclusively, which are commonly referred to as the A component in LCCA methods that employ the A+B+C bid method nomenclature (TDOT 2007); other agency costs are addressed later in this document.

Initial Agency Cost Estimation

Only those initial agency costs that are different among the various alternatives need to be considered for reasonably similar alternates. Engineering and administrative costs (public hearings, informational meetings, permits, real estate and land development, legal fees, etc.) may be excluded from the initial agency cost if they are the same for all alternatives.

Initial agency costs can be divided into pavement and non pavement costs:

- Pavement costs include items such as subgrade preparation costs; base, subbase, and surface material costs; associated labor and equipment costs; etc.
- Non pavement costs are costs that affect the overall cost of the project but are not directly related to the pavement structure, such as extra fill or cut due to different grade elevations, traffic control, median and fill slopes, utilities, guardrail and sign adjustments, lighting requirements, overhead structures, at-grade structures, culvert extensions, associated labor and equipment costs, etc.

When historical bid prices are used to estimate the initial agency cost of current designs, it is important to consider the impact of material price escalators, payment practices (e.g., payment for concrete in fixed quantities, such as square yards, versus payment for asphalt by the ton, which may result in overages), and bidding practices (e.g., bid shifting to lower costs of some items [pavement items] while artificially increasing other costs [non-pavement items] to cover the difference). Past bid prices may not accurately represent final project costs if escalators significantly increased the actual construction cost of the project or if material quantity estimates were low. Thus, all project costs (pavement and non-pavement) from past projects must be examined to include any cost overruns when using past projects for current initial agency cost estimates.

Material price escalators (also known as price adjustment clauses or indexing) were originally established on transportation construction projects as a means to address price volatility in oil-based products like fuel and asphalt; such price escalators were developed in the 70s and 80s in response to significant and quick changes in oil-based product pricing (see Figure 2-4 and Appendix 2). The concept is simple: rather than have bidders cover their risk of price increases between the times of bidding and construction with higher bid prices, the agency assumes the risk of price increases by promising to pay for the difference (or to get a credit) in material costs between the times of bidding and construction. While most state highway agencies have escalators on fuels and asphalt, a few have also established escalators for other materials such as steel and cement.

Escalators do not eliminate the material price fluctuations discussed in Step 2. Instead, they simply transfer the risk of the high material cost variability from the contractor to the agency. When one alternate utilizes an escalator and another does not, the alternate with the escalator may be given an artificial advantage. For this reason, ***FHWA states that price adjustment clauses (e.g., material price escalators) should not be used in alternate bidding scenarios*** (FHWA 1981a).

Initial agency costs can account for 50 to 90 percent of the project LCCA cost, depending on the pavement type (JPCP, CRCP, full-depth asphalt, etc.) and preservation/ rehabilitation activities chosen. Another consideration is the pavement cost as a percentage of the total initial project cost, which typically ranges from 25 to 50 percent, but can be higher, depending primarily on construction type (overlay versus new construction), location (urban versus rural) and application (Figure 2-8). On projects where the initial costs of pavement construction are a relatively small portion of the overall project costs (e.g., urban highways), a long-term pavement solution is best because it limits future disruptions to users. Therefore, it is important that the designer chooses pavement features that can be expected to result in the desired performance without needlessly increasing the cost of the pavement (e.g., costs are considered alongside required pavement thickness and rehabilitation, preservation, and reconstruction activities to optimize the design of each alternate).

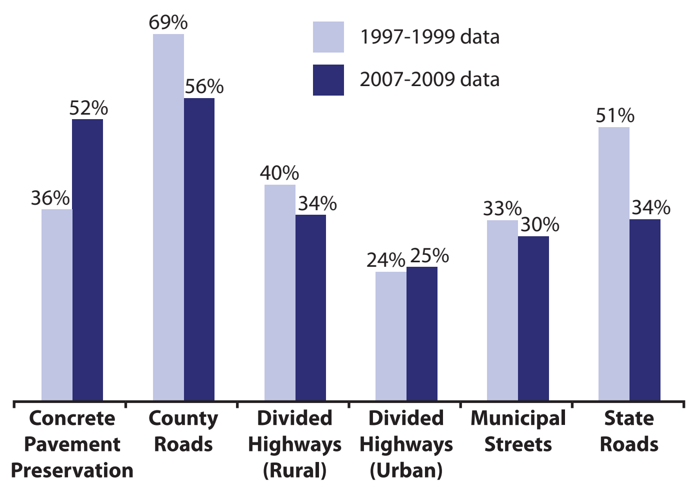


Figure 2-8. Pavement construction costs as a percentage of project construction costs (Mack et al. 2011).

Pavement thickness design software capable of generating equivalent concrete and asphalt pavement alternates include AASHTO's DARWin-ME^{TM} and ACPA's StreetPave software. In generating equivalent (and optimized) alternates, design elements other than the surface course thickness should be considered. For example, some states have used alternate subbase types (e.g., cement-treated subbase [CTB], asphalt-treated subbase [ATB]) and/or subbase thicknesses within a particular alternate pavement type (possibly with different pavement surface course thicknesses for each subbase alternate) in an attempt to reduce project construction costs.

It is important to analyze a realistic and well-developed design section for all pavement types considered. Some features or design components have a dramatic impact on the total initial construction cost. If these features do not enhance performance significantly, they may not be cost-effective and should not be included in the designs evaluated in the LCCA.

The performance value of a feature should be established through a benefit/cost analysis. Such an analysis can be supplemented with local experience or data from historical records of agencies with similar geological and climactic conditions.

Optimizing Concrete Pavement Designs

The effects of individual concrete pavement feature costs on overall initial cost have been studied in terms of relative costs (Cole and Smith 1997 and ACPA 2010a). There are three advantages to using relative costs rather than actual costs in comparing pavement design features:

- Costs can be compared across the United States, regardless of regional variations in labor and material costs, contractor equipment and capabilities, project size, etc.
- General comparisons of one feature to another are easily made, which helps in assessing their relative cost-effectiveness.
- The effects of interest and inflation rate fluctuation are diminished, allowing the same information to be used year after year.

To estimate the relative costs of various concrete pavement design and construction features, concrete paving contractors across the U.S. were surveyed and asked to provide the cost to build a "reference section," which was assigned a relative cost of 100. Next, a specific pavement feature (e.g., pavement thickness or dowel diameter) was changed, and the contractors determined the relative cost of the modified section (i.e., the index or multiplier to apply to the reference section to obtain the modified section). The following design features were evaluated during the ACPA's 2010 Relative Cost study:

- Slab thickness,
- Shoulder thickness and material,
- Subbase thickness and material,
- Subgrade improvement options,
- Surface texture methods,
- Curing methods,
- Use of dowel bar inserter (DBI),
- Use of widened lane,
- Joint design and sealant types,
- Smoothness, and
- Dowel bar features.

The final report and results of the ACPA's 2010 Relative Cost study are available in an interactive format as the Relative Cost Analyzer App in the ACPA's online application library at www.apps.acpa.org. This online tool not only allows users to select what to use as the "reference section" for comparisons of design features but also allows the comparison of the impact of multiple design features on the relative cost of the entire pavement section simultaneously, which allows agencies to quickly evaluate the estimated additional costs of using enhanced concrete pavement designs that will result in improved performance or to develop a concrete pavement alternate that will satisfy the design requirements at the lowest initial construction cost.

As an example, consider Figure 2-9, which was developed for a specific set of data using the ACPA Relative Cost Analyzer App and shows the relative cost impact of pavement thickness in terms of total pavement cost. If the basis for comparison is a 10-in. (250-mm) thick concrete pavement, 8-in. (200-mm), 12-in. (300-mm), and 14-in. (350 mm) thick concrete pavements would cost 87%, 112%, and 128%, respectively, of the cost of the 10-in. (350-mm) thick concrete pavement.

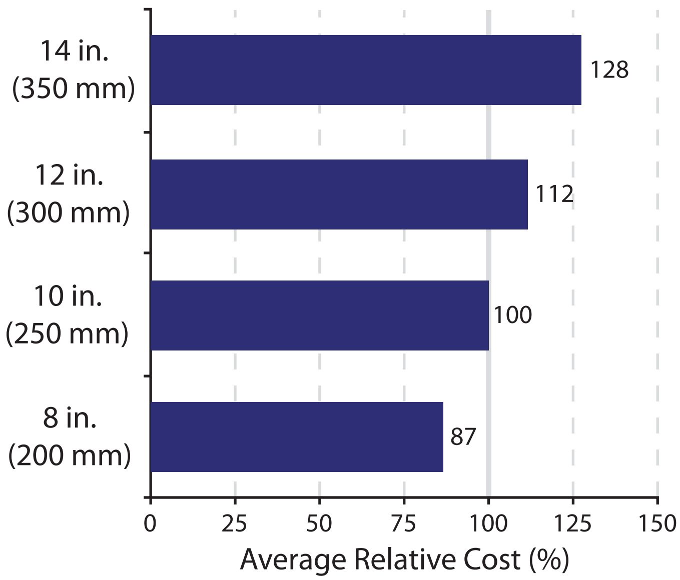


Figure 2-9. Example use of ACPA's Relative Cost Analyzer App to illustrate the effect of pavement thickness on average relative construction cost using a baseline thickness of 10 in. (250 mm).

When viewing results from this Relative Cost Analyzer, it is important to remember that the results represent initial construction cost only. As such, the "value" of a given design feature needs to be assessed based on the initial construction cost, the impact on pavement performance, and its life-cycle cost over the evaluation period. It also is important to note that the relative costs reported by the tool represent "national" costs for generalized conditions in 2010 and are intended only to provide relative comparisons; the real relative cost for local concrete paving jobs may be slightly different and the values should be expected to change over time. Thus, the reported relative costs should not be used as actual construction costs or as accurate representations of local bid conditions.

This tool is only useful in estimating initial agency costs; a true optimization of the system should consider all of the initial and future agency and user costs and how the alternate pavement design features impact these values. Detailed guidance on optimizing concrete pavement design/cost using design tools such as AASHTO's 1993 Design Guide and DARWinME™ and LCCA principles is outside of the scope of this document, but more information is available elsewhere (Mack et al. 2011, ACPA 2006a, ARA 2011).

Step 4 – Estimate User Costs (B)[1]

User costs are commonly used as the B component in LCCA methods that employ the A+B+C bid method nomenclature (TDOT 2007). These costs are intentionally separated from other bidding components because user costs are not agency costs and should not be treated as such (e.g., user costs have a discount rate based on user interest and inflation rates). User costs tell a different story than the other components and oftentimes are weighted differently than agency costs in the pavement type selection process. If user costs are significantly larger than other cost components, the agency should investigate why this is the case.

User costs are all those costs associated with the alternative that are incurred by users of the roadway over the analysis period. The users to be considered are both the actual users and the would-be users; that is, those who cannot use the roadway because of either a detour imposed by the highway agency or the user's self-imposed selection of an alternate route.

[1] Although the calculation of user costs (B) depends on decisions made in determining both the initial agency costs (A) and future agency costs (C), user costs are presented before future agency costs in this document to stay consistent with the A+B+C bid method nomenclature. User costs can only be calculated after all other initial and future agency cost details, like maintenance and rehabilitation/preservation schedules, have been determined.

The user costs incurred during lane closures and other periods of construction, preservation/rehabilitation, and maintenance work are termed **work zone user costs**; note that the impact of future activities that require work zones can significantly impact the work zone user cost if traffic is assumed to increase over time. The user costs incurred during the normal use of the roadway are **vehicle operating costs**. There are also user costs associated with **delays due to capacity issues** and with **accidents**.

The value of road users' time is the subject of considerable debate. In general, user delay costs vary by vehicle class, trip type (urban or interurban), and trip purpose (business or personal). Details on calculating delay costs are available elsewhere (NCHRP 2004) and free software called Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) is available to help owners assess the impact of various use delay configurations on user costs (Caltrans 2011a).

Any user costs that differ significantly among the alternatives being compared should be considered alongside the agency costs in an LCCA. However, each agency must decide which user cost components it expects to differ among different alternatives, and which it is able to estimate reasonably well. Even if the user costs are considered equivalent between alternates, the time value of money and frequency of future activities cause the net result of work zone user costs to be different between alternates. Because of the complexities in predicting user costs with a high degree of accuracy, some state highway agencies do not currently consider user costs in their LCCAs (Table 2-4).

Failure to consider user costs may lead in some cases to the selection of undesirably short-lived alternatives. For example, it is not good practice to recommend major rehabilitation of a busy urban freeway every seven years; traffic handling and delays in the future might be a significantly greater cost than constructing a long-lived alternative now. Without quantitative consideration of work zone user costs, however, it may be difficult to determine that a long-lived solution is best in such a scenario.

Table 2-4. Summary of U.S. State Highway Agency Practices Concerning the Inclusion of User Costs in Their LCCAs (after NCHRP 2011a; Shah, et al. 2011; MDOT 2009 and Rangaraju, et al. 2008)

User Costs Considered	Percent of Responding Agencies	State Agency
Yes	42%	AK, AZ, CA, CO, CT, DE, GA, KS, KY, LA, MD, MI, NM, PA, SC, VT, WA
No	**58%**	AL, AR, FL, IA, ID, IL, IN, MN, MO, MS, MT, NC, NE, NJ, NV, NY, OH, SD, TN, UT, WI, WV, WY

Work Zone User Costs

Factors that influence the work zone user costs include the work zone length, number and capacity of open lanes, duration and timing of closures, speed restrictions, and the availability and capacity of alternate routes (FHWA 1998). It should be noted that some state agencies have found full roadway closures preferable to lane reductions, both because of favorable user perception and because faster project completion can result in a lower overall work zone user cost and a lower initial construction cost.

Vehicle operating costs (see next section) tend to be higher in work zones and detours due to additional speed changes, stopping and starting, greater travel lengths, etc. Work zone vehicle operating costs may differ significantly for different alternatives if they have different traffic control plans associated with them. Information on vehicle operating costs associated with stopping and starting, speed changes, and idling is available elsewhere (FHWA 1998; Curry and Anderson 1972; and Winfrey 1969).

Work zone user delay costs may vary among the alternatives being considered, depending on the traffic control plans and construction methods associated with the alternatives.

For example, and despite common perceptions, placing (constructing) a concrete pavement can be faster than constructing an asphalt pavement because the asphalt must be placed in multiple layers and repeatedly compacted, while the concrete pavement is typically placed in one layer. Concrete pavements can then be open to traffic within hours or days if a fast-track concrete mixture is used.

While asphalt can be constructed using staged construction techniques that allow traffic on the pavement before the final design thickness is constructed, it is important to ensure that the base and subgrade layers do not have stresses/strains that are beyond their elastic limit or permanent deformation will occur (design tools such as AASHTO's DARWinME™ can now model the impact of staged construction of asphalt on the total asphalt thickness requirement). Allowable construction practices such as these and other issues such as allowable construction timeframes (e.g., weekday/ weekend or day/night) need to be considered in the specifications because they will impact both the initial agency cost and work zone user delay costs.

Vehicle Operating Costs

All costs related to **consumption of fuel/oil and wear on tires and other vehicle parts** are considered vehicle operating costs. Vehicle operating costs are primarily a function of pavement serviceability (i.e., roughness) and rigidity of the surface. It is sometimes thought that vehicle operating costs can be eliminated from consideration in a pavement LCCA because such costs are essentially the same for all alternatives. While this might be the case for vehicle operating costs such as wear on tire and other vehicle parts, research has shown this assertion to be false with regard to fuel consumption.

Several studies have investigated the **impact of pavement roughness on vehicle fuel consumption**, with results indicating that trucks use 2.5% to 4.5% less fuel on smooth pavement than on rough roadways (FHWA 2000 and MoDOT 2006). NOTE: Both of the referenced studies compared a new asphalt overlay against existing, deteriorated asphalt or composite pavement. With the increasing use of smoothness as an acceptance criterion, both concrete and asphalt pavements are regularly constructed to even the tightest of smoothness specifications. While initial construction smoothness is important, roughness progress (e.g., profile durability) over time is arguably more important because it is this characteristic that defines the vehicle-pavement interaction over the activity life of the pavement surface course. An analysis of FHWA's Long-Term Pavement Performance (LTPP) data revealed that although asphalt pavements had superior initial smoothness when compared to concrete pavements, roughness of the asphalt pavements increased 69.9% over the 8 to 9 year evaluation period compared to just a 3.7% increase in roughness for the concrete pavements (Transtec 2006).

Regarding the **impact of the rigidity of the surface on vehicle fuel consumption**, the hypothesis is that because trucks cause more deflection on flexible pavements than on rigid pavements, more of the energy intended for propelling the truck is "absorbed" due to the higher deflection of asphalt (flexible) pavements (Figure 2-10).

Several statistically rigorous studies have investigated the relationship between rigidity and vehicle fuel consumption, including:

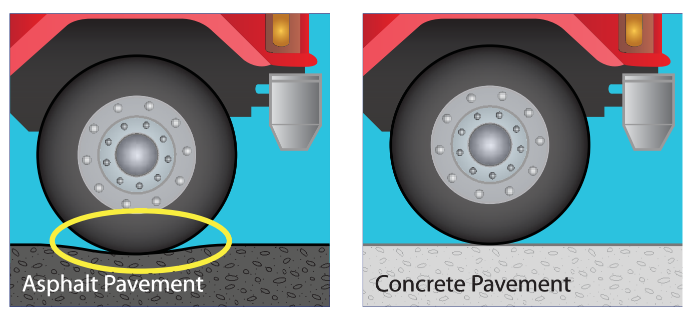


Figure 2-10. Illustration of the differences in energy-consuming pavement deflection and deformation for asphalt (left) and concrete (right) pavements under heavy truck loads.

- A National Research Council Canada (NRC) study that concluded that fully loaded tractor-trailers traveling on concrete pavements have statistically significantly lower fuel consumption than those traveling on asphalt pavements throughout the summer to winter temperature range (e.g., International Ride Index [IRI] < 120 in./mi [1,900 mm/km]) (Figure 2-11) (Taylor and Patten 2006). Fuel consumption for two common truck types—tractor tanker semi-trailer and tractor van semi-trailer—were **an average of between 1% to 6% lower on concrete versus asphalt pavement**, depending on truck type and vehicle speed.
- A Swedish study that investigated fuel consumption of passenger vehicles on different pavement types at highway speeds of 55 mi/h (90km/h). The study indicated a statistically **significant improvement in fuel consumption of 1.1%** (at a 95% confidence level) **on the concrete pavement tested versus the equivalent asphalt sections** (Jonsson 2008).
- A University of Texas at Arlington study that examined the effect of pavement type on fuel consumption for city driving (roughly 30 mi/h [50km/h]) in lower-weight vehicles (e.g., a passenger van). This study found that the fuel consumption rates were lower on the concrete sections, regardless of the test section, driving mode (acceleration vs. constant speed), and surface condition (dry vs. wet). In all cases, the differences were found to be statistically significant (at a 90% confidence level). On average, the **fuel consumption rates were between 3.2% and 4.7% lower on the concrete city streets** (Arkedani and Sumitsawan 2010).
- A study in Japan that concluded that heavy-duty vehicles have statistically **significantly better fuel consumption rates of between 0.8% and 3.4% lower at low speed and 1.4% to 4.8% lower at a constant speed of 50 mi/h (80 km/h) on concrete versus asphalt** (Yoshimoto, et al. 2010).

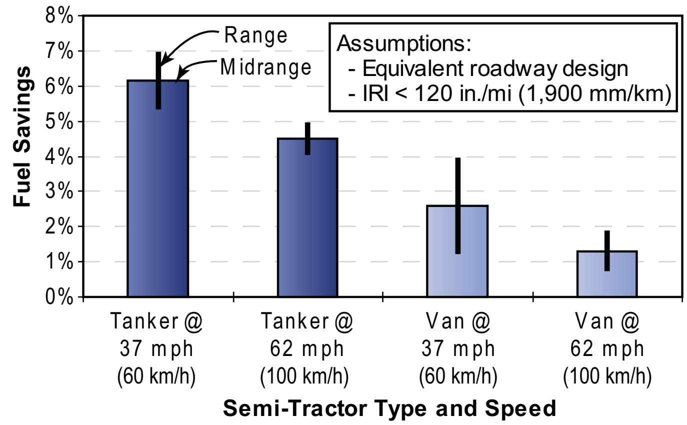


Figure 2-11. Fuel consumption savings on concrete versus asphalt pavements (after Taylor and Patten 2006).

Although the fuel consumption reductions on concrete versus asphalt in all of these studies are only about 1 to 6% (similar to the magnitude of potential benefits due to pavement smoothness), the **impact of a single 1.0% reduction in fuel consumption** can result in large vehicle operating user cost savings (Figure 2-12) and, thus, such differences between pavement types should be accounted for in a comprehensive LCCA. For example, each 1% reduction in fuel consumption on an average minor arterial with 7,500 ADT, 2% traffic growth, and assuming the average fuel economy of 23.7 mpg (10.2 l/100 km) for all vehicles, yields a savings of almost **50,000 gallons (189,000 liters) of fuel per mile (1.6 km)** of roadway in 30 years. (NOTE: Greenhouse gas emission reductions accompany such reduction in fuel consumptions and are accounted for in a life-cycle assessment.)

Among the **tools available for estimating vehicle operating costs** are the ACPA's Green Street Calculator (www.pavements4life.com/greenstreets/), the World Bank's Highway Design and Maintenance Standards Model (World Bank 2001), the FHWA's Revised Highway Investment Analysis Package (HIAP) (FHWA HIAP), the Texas A&M Research Foundation's MicroBENCOST (TAMRF 1993), the AASHTO Red Book (AASHTO 1977), CA4PRS (Caltrans 2011a), and others described in NCHRP Synthesis 269, Road User and Mitigation Costs in Highway Pavement Projects (Lewis 1999). For more details on pavement-vehicle interaction see MIT 2011b.

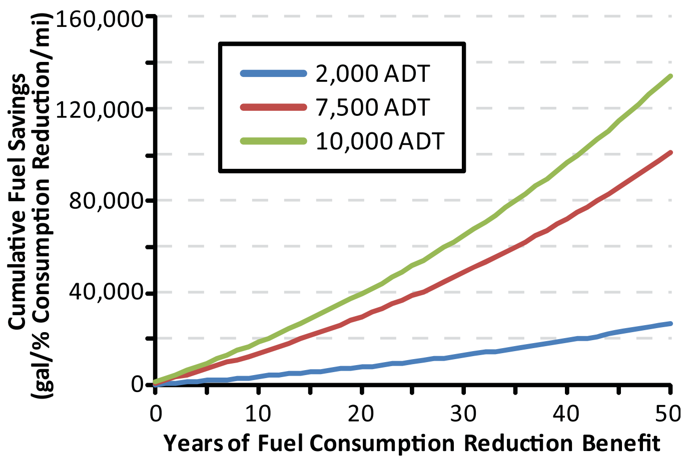


Figure 2-12. Marginal fuel consumption per mile of roadway with 1.0% improvement in fuel economy [assumed average fuel economy of 23.7 mpg (10.2 l/100 km) and 2% traffic growth per year].

Delay Costs due to Capacity Issues

In service user delay costs are primarily a function of demand for use of the roadway with respect to roadway capacity, and thus are only likely to differ among the alternatives being considered in an LCCA if the alternatives will have different effects on the capacity of the roadway.

Accident Costs

Damage to the user's vehicle and/or other vehicles and/or public or private property, as well as costs associated with injury to the user and others, are known as accident costs or crash costs.

Information on **in-service crash rates** for different roadway functional classes and accident types (fatal, nonfatal) are available elsewhere (FHWA 1998). Accident costs are calculated by multiplying the unit cost per accident type, the crash rate per vehicle-miles travelled, and the vehicle-miles travelled (traffic per analysis period multiplied by project length).

Work zones crash rates are higher than in-service accident rates, with research indicating that crash rates in work zones are anywhere from 7% to 119% higher than the pre-work zone period (Kattak, et al. 2002).

An alternate that requires a longer construction window and/or more frequent maintenance and preservation/rehabilitation activities will have a higher work zone accident cost. However, only limited information is currently available concerning the relationships between work zone accident rates and traffic control specifics, such as lane narrowing, use of cones or other barriers, crossovers, etc. Currently available information on daytime versus nighttime work zone accident rates is also limited.

Because in-service accident costs depend primarily on the functional class of the roadway, they are not likely to differ significantly among alternatives being considered in a pavement LCCA unless an optimized texture with excellent profile durability is to be used to prevent hydroplaning on one alternate but not the other. Work zone accident costs, however, may differ significantly among alternatives, depending on their respective traffic control plans, construction methods, and day versus night or weekend allowable construction timeframes.

Step 5 – Estimate Future Agency Costs (C)

Future costs to be incurred by an agency during the analysis period are commonly used as the C component in LCCA methods that employ the A+B+C bid method nomenclature (TDOT 2007). The future costs generally are divided into two parts: 1) maintenance and operations costs and 2) preservation or rehabilitation costs.

While the initial agency costs can exclude cost components that are similar for each alternate being considered, **all cost components must be considered in future agency costs** because the present value of costs associated with engineering, administrative, and traffic control (detours, lane closures, work hours, etc.) in the future are impacted by when the costs are projected to take place and by the selected discount rate (which may vary with paving material type).

Future activities are dependent on the initial pavement design. Thus, both (and their cost impact on each other) must be considered when designing the pavement structure. For example, concrete pavements can be built slightly thicker than is necessary for structural reasons to accommodate future diamond grinding activities (FHWA 2010b); if this is considered in the long-term design of the pavement structure, diamond grinding can be programmed for the structure instead of planning a more costly overlay of the structure because there is insufficient thickness for diamond grinding. Depending on rounding of the design thickness, this may or may not affect initial agency costs.

Maintenance and Operation Costs

The daily costs associated with keeping the pavement at a given level of service are termed maintenance and operating costs. These include contracts, materials and equipment, deicing, staff salaries, etc. for the maintenance of the pavement surface, shoulders, striping, drainage, etc.

Tracking maintenance costs can be difficult because construction contracts are typically let for relatively short sections (e.g., 4 to 10 miles) and maintenance contracts typically cover more than one of these construction sections. Although maintenance contracts do have specific beginning and ending locations, some analysis is needed to properly assign costs. Many agencies assign in-house maintenance crews to corridors encompassing multiple sections, which can either further complicate the goal of tying the work to specific sections or, if there is exceptional communication within the agency, make such a process easier. More guidance on determining highway maintenance costs is available elsewhere (NCHRP 2011b).

Several billion dollars are spent each year on pavement maintenance by highway agencies in the U.S. As such, most state highway agencies include maintenance costs in their life-cycle cost analyses for pavements (Table 2-5).

Table 2-5. Summary of U.S. State Highway Agency Practices Concerning the Inclusion of Routine or Scheduled/Preventative Maintenance Costs in Their LCCAs (after ACPA 2011a and Rangaraju, et al. 2008)

Maint. Costs Considered	Percent of Responding Agencies	State Agency
Yes	**77%**	AK, AR, CA, CO, DE, GA, ID, IL, IN, KS, LA, MI, MN, MT, NC, NE, NM, NV, PA, TN, UT, VT, WI, WV
No	23%	AL, IA, MD, MO, OH, SC, WA

FHWA suggests that the difference in maintenance and operation costs between alternates is relatively small in comparison to initial construction and preservation/rehabilitation costs, and as such, this difference would have a relatively minor effect on LCCA results (FHWA 1998). The inclusion of maintenance costs is, however, required in LCCA calculations for FHWA approval of SEP 14 projects (FHWA 2008).

For large projects, where initial construction and preservation/rehabilitation costs are in the millions of dollars, FHWA's suggestion may be true. However, for smaller projects with lower initial costs (e.g., many rural and municipal roadways, parking lots, etc.), this is likely not to be true. This also may not be true if the project is in an urban area because lane reductions, even for the most minor of maintenance activities, can have very large user work zone costs.

Another consideration is whether the alternatives are long- or short-term solutions. Short-term solutions typically have significantly larger maintenance requirements than long-life solutions, regardless of the size of the project. Furthermore, large maintenance costs that result from the use of short-term solutions can consume funds that would otherwise be available for other projects.

Preservation and Rehabilitation Timing and Costs

Preservation/rehabilitation costs are large future agency costs associated with improving the condition of the pavement or extending its service life. Almost all state highway agencies include these costs in their LCCAs (Table 2-6).

Table 2-6. Summary of U.S. State Highway Agency Practices Concerning the Inclusion of Rehabilitation Costs in Their LCCAs (after ACPA 2011a and Rangaraju, et al. 2008)

Rehab. Costs Considered	Percent of Responding Agencies	State Agency
Yes	**97%**	AK, AL, AR, CA, CO, DE, GA, IA, ID, IL, IN, KS, LA, MD, MN, MO, MS, NC, NE, NM, NV, OH, PA, SC, TN, UT, VT, WA, WI, WV
No	3%	MI

Preservation and rehabilitation activities and their timing should be based on the distresses that are predicted to develop in the pavement. That is, in the design phase, the engineer should estimate the rates of distress development in the pavement (based on design considerations such as pavement structure, traffic, and environment), determine the years in which critical level of distress are reached, and assign the appropriate preservation or rehabilitation activities for those distresses at the appropriate times.

The best approach to developing pavement performance predictions is to rely on local performance history data to the maximum extent possible; pavement feedback loops are an ideal means of updating such predictions as better designs are created. Unfortunately, many U.S. state highway agencies still have relatively young formal pavement preservation programs (Table 2-7).

Table 2-7. Summary of the Age of Formal Pavement Preservation Programs at U.S. State Highway Agencies (after Shah, et al. 2011)

Age of Pavement Preservation Program	Percent of Responding Agencies	State Agency
1-10 Years	**46%**	AK, AR, IL, MD, MN, MO, MS, NY, OR, PA, WV
10-20 Years	29%	CO, IN, LA, MI, NM, NJ, TX
> 20 Years	25%	CA, FL, KS, ME, UT, WA

In the absence of good, local historical data upon which to develop performance predictions, tools such as AASHTO's DARWinME^{TM} can be used to develop reasonable performance predictions. Estimates based on future traffic projections might also be used as preservation/rehabilitation triggers. More information and guidance concerning the factors that affect the selection and timing of pavement preservation and rehabilitation treatments are available elsewhere (SHRP2 2011).

Two important cost components often overlooked when determining preservation/rehabilitation costs are **traffic control and engineering**. As noted, because different pavements deteriorate at different rates, the timing of such costs and any other incidental costs (e.g., striping) impacts their present value. Also, because of ever-increasing traffic, future work on a section may require more complicated traffic control.

The stream of preservation/rehabilitation activities used varies greatly from agency to agency. Many agencies apply a standard scheme and/or uniform preservation/rehabilitation lives to all pavements. There are, however, limitations to this approach, including:

- Standard preservation/rehabilitations may not address the causes of the problems and, therefore, may not be suitable for all pavement types at all times.
- Because traffic is always increasing, the expected performance life of any given preservation/rehabilitation activity can be expected to decrease over time (as traffic levels increase).
- For some types of preservation/rehabilitation, the original pavement may continue to deteriorate, so it is possible that the second or third rehabilitation will not last as long as the first.

Selection of preservation/rehabilitation activities should be based on the type, severity, and extent of distresses in the pavement. As a pavement deteriorates, the appropriate types and expected service lives of preservation/rehabilitation activities changes.

Accurate assessment of the service life for alternate pavement sections is necessary if the results of the LCCA are to be credible. The performance period for concrete pavements is typically assumed to be 20 to 40 years. However, many concrete pavements originally designed for 20 years have lasted longer and carried significantly more traffic than that for which they were designed. A study in Illinois found that the concrete interstate pavements in that state carried almost 4 times as much traffic as that for which they were design (Gharaibeh, et al. 1997). A similar study in New York state found that their concrete pavements carried 3.4 times as much traffic as that for which they were designed (Chen, et al. 1995). A study in Louisiana investigated original Interstate pavements constructed between 1963 and 1967 and found that concrete pavements that were still in service in 1989 had carried, on average, 0.98 to 2.58 times more traffic than that for which they were designed; the study also found that while 86% of the original Interstate concrete pavements built some 20 or more years earlier were still in service, only 23% of the asphalt pavements were (Temple and Boleware 1989).

Predicting the performance of preservation or rehabilitation activities involves, at a minimum, predicting the time (either in years or accumulated axle loadings) at which each strategy will reach a level of condition requiring follow-up preservation or rehabilitation. For example, pavement performance studies have demonstrated that diamond grinding can extend the service life of a concrete pavement by 8 to 20 years, and that most concrete pavements may be diamond-ground several times, further extending the pavement's service life (Rao, et al. 1999 and Stubstad, et al. 2005).

Typical expected performance period ranges for new construction and various preservation/rehabilitation activities are summarized in Table 2-8. These ranges are general estimates, expressed in years, for all levels of truck traffic and are intended to represent the "conventional wisdom" about the performance periods that may reasonably be expected of the different rehabilitation techniques. As noted previously, tools such as the AASHTO's DARWinME™ provide a means to estimate expected performance periods for both new construction and future maintenance and rehabilitation activates. Performance life estimates for other preservation/rehabilitation activities are available elsewhere (FHWA 2010c).

Concrete Pavement Preservation (CPP) Options

If an existing concrete pavement is still in fairly good condition, concrete pavement preservation (CPP) techniques may be used (ACPA 2008). CPP techniques can be used to repair isolated sections of deteriorated pavement, or may be used to prevent or slow overall deterioration, sometimes by reducing the impact of traffic loadings on the pavement.

Table 2-8. Typical Service Life Ranges for Various Highway Pavement Preservation/Rehabilitation Treatments (after ACPA 1990a, 1990b and 1993b; ADOT 1991; CS 1996; FHWA 2010c; Hall, et al. 2001; INDOT 1998; NYSDOT 1993; ODOT 1999; PennDOT 1999; Rao, et al. 1999; Rangaraju, et al. 2008; SHRP2 2011; UDOT 1998; VTrans 1999; WisDOT 1999; and WVDOT 1994)

Preservation/Rehabilitation Treatment	Expected Performance Period (years)
Reconstruction:	
Reconstruction with asphalt pavement	8 – 25
Reconstruction with concrete pavement	20 – 40
Asphalt pavement preservation/rehabilitation:	
Structural asphalt overlay of asphalt pavement	6 – 17
Structural concrete overlay of asphalt pavement	15 – 40
Surface recycling without overlay	3 – 8
Nonstructural asphalt overlay of asphalt pavement	3 – 8
Nonstructural concrete overlay of asphalt pavement	5 – 15
Asphalt patching without overlay	4 – 8
Concrete pavement preservation/rehabilitation:	
Structural asphalt overlay of concrete pavement	8 – 20
Concrete overlay of fractured concrete slab	15 – 40
Unbonded concrete overlay of concrete pavement	15 – 40
Nonstructural asphalt overlay of concrete pavement	1 – 8
Bonded concrete overlay of concrete pavement	15 – 30
Restoration without overlay	5 – 15
Diamond grinding of the concrete surface	8 – 20
Composite pavement preservation/rehabilitation:	
Structural asphalt overlay of composite pavement	8 – 20
Concrete overlay of fractured concrete slab	15 – 40
Unbonded concrete overlay of composite pavement	15 – 40
Surface recycling without overlay	3 – 8
Nonstructural asphalt overlay of composite pavement	3 – 8
Nonstructural concrete overlay of composite pavement	5 – 15

CPP techniques include:

1. Slab stabilization,
2. Edge drain retrofit,
3. Partial-depth repair (PDR),
4. Dowel bar retrofit (DBR),
5. Cross-stitching longitudinal joints and cracks,
6. Full-depth repair (FDR),
7. Retrofitting concrete shoulders,
8. Diamond grinding (DG),
9. Grooving, and
10. Joint and crack sealing.

The choice of which CPP activity or activities to implement depends on the distresses present in the pavement. For CPP to be most effective, proper engineering and repair timing are critical. For CPP to be most cost-effective, CPP activities should generally be performed in the order shown in the list above. More information on CPP activities is available elsewhere (ACPA 1993a, 1994, 1995, 1998a, 1998b, 1998c, 2000, and 2008).

Diamond grinding is an extremely cost-effective means of renewing a concrete pavement's surface. Based on a California Department of Transportation (Caltrans) study of 76 test sections nationwide (including pavements in freeze-thaw zones), the average longevity of a diamond-ground project is about 14 years. In California, this value was determined to be closer to 17 years (Stubstad et al. 2005).

Because concrete pavements typically are constructed slightly thicker than the design thickness and because the pavement structural capacity increases over time due to the continued hydration of the cement, **it typically is possible to diamond grind a candidate concrete pavement up to three times** without compromising its fatigue life; this can extend the service life of the pavement to more than twice its initial design life. It is worth noting that diamond grinding provides enhanced smoothness and longevity without extracting or processing additional raw materials, such as aggregates or binders.

A section of Interstate 10 (San Bernardino Freeway) just east of Los Angeles presents an excellent example of this preservation strategy. The section was originally constructed in 1946 as a part of historic Route 66. In 1965, it was diamond-ground to correct the considerable amounts of joint faulting that had developed during its more than 20 years of service. This first-ever continuous grinding project in North America provided 19 years of additional service. In 1984, this pavement got a third lease on life when Caltrans decided to restore the pavement again using diamond grinding. In 1997, the 51-year old pavement was ground a third time. Today, more than 60 years after it was constructed, this concrete pavement is still in service and is currently carrying more than 200,000 vehicles each day (ACPA 2006b).

Resurfacing of a concrete pavement (also known as overlaying) is used when a concrete pavement has medium-to-high levels of distress and CPP is no longer considered to be cost-effective or when traffic levels increase such that increased structural capacity is necessary. Concrete overlays fall into two basic categories: bonded and unbonded. Existing concrete, asphalt (Figure 2-13), and composite pavements can all be overlaid by a new concrete pavement. Concrete overlays have been constructed on highways, streets, roads, airfield pavements, parking lots, and industrial/ trucking facilities and their successes date back to the 1910s (NCHRP 1982). As shown in Table 2-8, the expected performance period may be different for bonded and unbonded concrete overlays. More information on concrete overlays is available elsewhere (ACPA 1990a, 1990b, and 2011b; Rasmussen and Rozycki 2004; NCHRP 1982 and 1994; and NCPTC 2008). The ACPA also has developed an interactive National Concrete Overlays Explorer (available at www.apps.acpa.org) that allows users to explore and learn about many of the existing concrete overlays across the U.S.

Figure 2-13. A 4-in. (100-mm) thick bonded concrete overlay on an existing asphalt pavement on a city street in Ogden, Utah.

Reconstruction is done when a pavement has high levels of distress and overlays are no longer feasible, and/or when necessitated by other concerns, such as a need for geometric and/or capacity improvements or to correct items such as subgrade and subbase deficiencies, roadside safety features, drainage, etc. Some of the advantages of reconstruction are that it controls the final pavement elevation and minimizes the need for roadside appurtenance adjustments. Furthermore, it gives the agency and contractor the option to recycle the old pavement into products that will be useful for the reconstruction or on other projects.

Step 6 – Estimate Residual Value

The **residual value typically is defined in one of three ways**: 1) the net value that the pavement would have in the marketplace if it is recycled at the end of its life (also known as **salvage value**), 2) the value of the **remaining service life (RSL)** at the end of the analysis, and 3) the value of the existing pavement as a support layer for an overlay at the end of the analysis period.

Whichever way residual value is defined for rehabilitation strategy alternatives, **it must be defined the same way for all alternatives**, and should reflect what the agency realistically expects to do with the pavement structure at the end of the analysis period. Residual value should be taken into account whenever the alternates are expected to have significantly different residual values at the end of the analysis period. Table 2-9 shows which state highway agencies include residual value in their LCCAs.

Table 2-9. Summary of U.S. State Highway Agency Practices Concerning the Inclusion of Residual Value in Their LCCAs (after ACPA 2011a and Rangaraju, et al. 2008*)*

Residual Value Considered	Percent of Responding Agencies	State Agency
Yes	**51%**	AK, AR, CA, CO, CT, GA, HI, ID, IN, KS, MD, MN, NE, NV, NY, VA, WI , WA
No	49%	AL, FL, IA, IL, KY, LA, MI, MO, MS, NC, OH, SC, SD, TN, UT, WV, WY

Residual Value through Recycling (Salvage Value)

Concrete pavement is 100% recyclable. At the ultimate end of its fatigue life, concrete pavement can be crushed and reused in many ways (e.g., subbase material for a new concrete pavement). A 2005 study conducted by the Construction Materials Recycling Association (CMRA) revealed that between 130 and 140 million tons (between 118 and 127 million metric tons) of concrete were crushed and recycled in 2004. **In fact, on a weight basis, concrete is the most recycled material in the U.S.** (CMRA 2010).

Virgin aggregate resources are vast, but finite; many high-quality, conveniently located virgin aggregate resources are being depleted rapidly. In addition, environmental regulations, land use policies and urban/suburban construction and settlement are further limiting access to known aggregate resources. Virgin aggregate costs can be expected to rise with scarcity and increasing haul distances. Thus, ***it seems likely that even agencies that do not recycle existing pavements likely will do so in the future at the end of a typical life cycle for a new pavement***.

If it is assumed that the pavement is to be recycled at the end of the analysis period, the salvage value is the monetary value of the recycled materials minus the costs of removal and recycling. The salvage value of the pavement structure as recycled materials may be different for the different alternates.

It is important to not double-count the salvage value; that is to say, it should not be included as both a residual value credit at the end of the LCCA of a pavement section and then as a reduction in cost at the beginning of the next LCCA on the same section. Thus, if the pavement is to be recycled, salvage value oftentimes is not considered at the end of the analysis period (where the value is extremely discounted) but rather is considered as a reduction in cost for a new pavement (where the value of the reduction is better known and fully appreciated) in the next LCCA of the section.

Residual Value through Remaining Service Life

The residual value of a pavement that is likely to be rehabilitated rather than demolished at the end of the analysis period can be based on its contribution to the structural capacity of the rehabilitated pavement structure.

The FHWA currently recommends that the residual value be determined as the portion of the cost of the last rehabilitation equal to the portion of the remaining life of the last rehabilitation (FHWA 1998). For example, if an overlay with a predicted life of 12 years is placed 8 years before the end of the analysis period, it has a remaining life of 4 years at the end of the analysis period, so the residual value would be defined as 33% (4/12) of the cost of the overlay. However, this method of defining residual value attributes worth only to the last rehabilitation application, rather than to the pavement structure as a whole. It may also have the undesired consequence of attributing greater worth to a pavement design or rehabilitation strategy alternative that costs more, performs poorly and requires frequent follow-up rehabilitation than to an alternative with better long-term performance that requires less frequent rehabilitation.

The FHWA is currently developing a remaining life depreciation method that will include consideration of both the last rehabilitation methods and the remaining pavement structure (NCHRP 2011a).

Residual Value as a Support Layer

When all alternatives are predicted to reach minimum acceptable condition at the end of the analysis period and require rehabilitation at that time, **another option is to determine what contribution the existing pavement structure will make to the structural capacity of the rehabilitated pavement structure**. The residual value of each alternative could be quantified as the portion of the future rehabilitation cost that will be reduced by the contribution of the existing pavement structure.

When one or more alternatives are predicted to reach minimum acceptable condition beyond the end of the analysis period, the residual values could be defined in terms of how long each alternative delays the next required rehabilitation. The residual value could be quantified as the difference between the cost of rehabilitation if it is performed at the end of the analysis period and the discounted cost of the same type of rehabilitation if it is deferred some years into the future. Thus, an alternative with more remaining structural capacity at the end of the analysis period would yield a larger difference between immediate and deferred rehabilitation costs, and therefore a higher residual value.

Step 7 – Compare Alternatives

Alternatives considered in an LCCA must be compared using a common measure of economic worth. The economic worth of an investment may be measured in a number of ways. Investment alternatives such as pavement strategies are most commonly compared on the basis of **present worth** (also called **net present value [NPV]**) or **annual worth** (also called **equivalent uniform annual cost [EUAC]**).[2] The majority of state highway agencies who perform LCCA for pavement type selection use NPV to compare alternatives (Table 2-10).

Table 2-10. Summary of U.S. State Highway Agency Practices Considering the Use of NPV, EUAC, or both in Their LCCAs (after NCHRP 2011a)

Calculation Method Used	Percent of Responding Agencies	State Agency
Net Present Value (NPV) Only	**66%**	AL, AR, AZ, CA, CO, KS, LA, MD, MN, MO, MT, NM, NV, OH, SC, UT, VT, WA, WV
Equivalent Uniform Annual Cost (EUAC) Only	17%	DE, IL, MI, NC, WI
Both NPV and EUAC	17%	GA, ID, IN, PA, TN

For the purposes of calculation, many state agencies classify and group the components of their LCCA as follows for the purposes of calculations:

- A – Initial Agency Costs (found in Step 3)
- B – User Costs (found in Step 4)
- C – Future Agency Costs (found in Step 5)

[2] Benefit-cost analysis is another economic analysis option. It is, however, generally more difficult to perform correctly because the comparison of alternates requires a multi-step, incremental analysis. All things equal, a benefit-cost analysis provides the same rank order of alternates as NPV or EUAC calculations.

This nomenclature, which gives rise to bid models commonly referred to as A+B, A+B+C, or A+C , aids in separating the various costs into functional groups for the purposes of conducting the LCCA calculations and comparing the results.

Again, there are opportunities to optimize both cost and pavement structural design using modern tools such as AASHTO's DARWinME™ software (Figure 2-14).

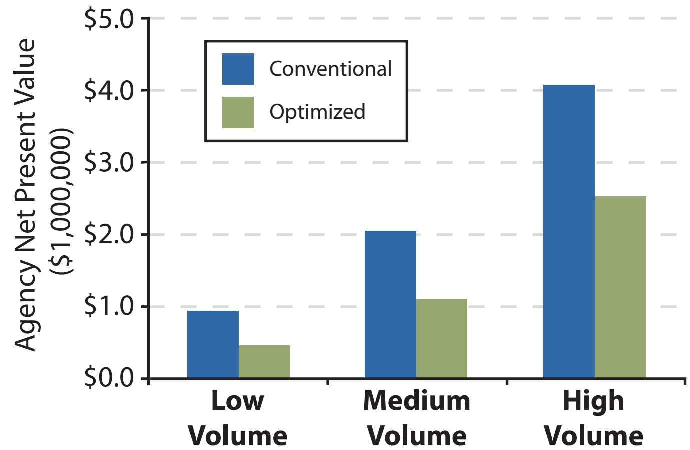


Figure 2-14. Concrete pavement designs optimized by MIT using DARWinME™ resulted in a reduced net present value (NPV) (MIT 2011c).

Cash Flow Diagrams

A cash flow diagram (Figure 2-15) helps in the development and visualization of strategies. A cash flow diagram shows the inflow and outflow of cash due to construction, maintenance, and preservation/rehabilitation, expressed in terms of either present worth or annual costs. Up arrows indicate major cash expenditures (e.g., construction, preservation, etc.) and down arrows show cash inflows (e.g., residual value). The length of the arrow indicates the magnitude of the expenditure.

For toll roads, where user fees are collected, there is a continuous inflow of funds, which should be taken into account in the analysis to the extent that the inflow will differ among the alternatives being considered. Lost revenues due to traffic disruptions or reduced usage during maintenance/rehabilitation work should also be taken into account to the extent that the lost revenue will differ among the alternatives being considered.

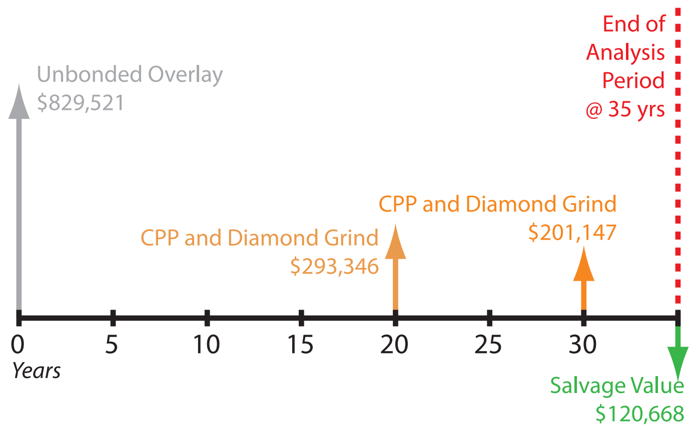


Figure 2-15. Example of a cash flow diagram for an unbonded concrete overlay.

Present Worth Calculations

All costs and benefits over the analysis period are expressed in terms of their equivalent (e.g., discounted) value at the beginning of the analysis period in a present worth style analysis. All initial agency costs are assumed to occur at time t = 0 and are not discounted (i.e., they are counted at full and actual value). All future costs (e.g., future maintenance and preservation/rehabilitation costs) and future benefits or reductions in cost (e.g., residual value at the end of the analysis period) are discounted to their equivalent present values and are summed with the initial costs to yield the **net present value (NPV)**.

NPV analyses are directly applicable only to mutually exclusive alternates each with the same analysis period; the use of residual values is a means of accommodating (to the extent possible) the fact that real-life alternatives do not typically have the same exact service lives.

The formula for the present value or worth ($P) of a **one-time future cost** or benefit ($F) is:

$$\$P = \$F \times \left[\frac{1}{(1+d)^t}\right] \qquad \text{[Eqn 2-3]}$$

where:

d = the real discount rate (e.g., 0.03 for 3 percent)
t = the year in which the one-time future cost or benefit occurs

Costs that are expected to accrue annually at a uniform value (e.g., routine maintenance costs) can also be expressed in terms of their present worth. Such costs should be taken into consideration in the LCCA whenever they are expected to differ significantly for the alternatives being considered (see Step 5).

The formula for the present value or worth ($P) of an **annual future cost** or benefit ($A) that first occurs in year 1 is:

$$\$P = \$A \times \left[\frac{(1+d)^n - 1}{d\,(1+d)^n}\right] \qquad \text{[Eqn 2-4]}$$

where:

d = the real discount rate (e.g., 0.03 for 3 percent)
n = number of years over which the annual future cost reoccurs

The conversion of nonuniform future annual costs requires:

1) Identification of subperiods during which the annual costs are uniform,
2) Converting these uniform annual costs to present worths in the beginning years of the subperiods, and
3) Converting these present worths in given future years to equivalent present worths at the beginning of the analysis period.

For example, suppose a uniform annual maintenance cost is expected to be incurred starting in year 16 of a 25-year analysis. The present worth incurred between years 16 and 25 would be calculated by first converting the annual maintenance costs in years 16 to 25 (N = 10) to an equivalent present worth at the beginning of year 16, which is also the end of year 15, and then discounting this equivalent present worth back 15 years to time zero.

Annual Worth Calculations

The value of all costs and benefits in a given analysis period can also be expressed in terms of an equivalent series of annual cash flows of uniform value over every year of the analysis period in an annual worth or equivalent uniform annual cost (EUAC) analysis.

The formula[3] for the **equivalent uniform annual value** ($A) of a cost ($P) incurred at the beginning of the analysis period (t = 0):

$$\$A = \$P \times \left[\frac{d\,(1+d)^n}{(1+d)^n - 1}\right] \qquad \text{[Eqn 2-5]}$$

where:

d = the real discount rate (e.g., 0.03 for 3 percent)
n = number of years over which the annual future cost reoccurs

To express a **one-time future cost** (e.g., follow-up preservation/rehabilitation) or benefit (e.g., salvage value) in terms of its equivalent uniform annual cost over the analysis period, it must first be converted to its equivalent present worth at t = 0, and then converted to its equivalent uniform annual cost.

Annual costs that are uniform throughout the analysis period require no conversion before being added to other equivalent uniform annual costs.

Annual costs that are not uniform over the analysis period (e.g., annual maintenance costs forecasted for some subperiod within the analysis period) must be:

1) Converted to present worth at the beginning of the first year of the subperiod,
2) Converted to a present worth at the beginning of the analysis period (e.g., t = 0), and
3) Converted to equivalent uniform annual cost over the entire analysis period.

Accounting for Material Inflation

Although asphalt cement makes up only about 5-8% of the weight of a typical asphalt paving mixture and cement comprises about 8 percent of a typical concrete paving mixture, the binders typically are the most expensive components of paving mixtures. Thus, a comprehensive LCCA comparing these two pavement types should consider any significant differences in inflation between these two materials.

The concept of accounting for expected differential price changes in an economic analysis such as an LCCA is a decades-old idea (Lee and Grant 1965). For much of the last 50 years, it has been argued that historic price trends did not justify accounting for material inflation. That may have been the case when considering concrete and asphalt prices from the early 1900s to about 1975. For the last 35 years (see Figure 2-4), however, concrete and asphalt prices have increased at significantly different rates.

As discussed, **material-specific real discount rates** are one method of accounting for situations when one or more materials are expected to inflate at a rate significantly greater (or less) than that of the inflation rate used in the calculation of the general real discount rate.

Other methods of accounting for differences in material inflation are 1) by escalating the future value of an item before calculating its present or annual worth or 2) adjusting the present or annual worth of the item.

For example, the Pennsylvania Department of Transportation recently began applying an Asphalt Adjustment Multiplier (AAM) to adjust asphalt bid prices to better reflect the price paid for asphalt over a life cycle; their current AAM factor is 1.7419 (PennDOT 2011a), which effectively inflates all future agency asphalt costs by almost 75% before the costs are discounted.

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[3] It should be noted that many pavement management and LCCA resources focused on pavements perpetuate an incorrect version of this formula, wherein the rate multiplier (d) is missing from the numerator.

Another method of escalating future costs has recently been suggested by researchers at MIT (MIT 2011a). Through stochastic simulation using the BLS's PPIs for steel, lumber, concrete, and asphalt and the CPI, they have proposed "real price" **escalation factors** that are dependent on the year in the LCCA in which the activity is conducted. These factors account for just the difference between the material inflation and general inflation so that the standard (e.g., not material-specific) real discount rate can still be used, making this process very easy to apply to individual expenditures. For example, and because inflation has outpaced the cost of concrete (see Figure 2-4), a concrete overlay in year 30 of an LCCA would be escalated by a "real price" adjustment of 87%, such that $1,000,000 of concrete overlay pavement today would have a real price of $870,000 30 years from now; this $870,000 at year 30 would then be used to calculate the present or annual worth of that activity using the standard real discount rate. Also see Mack 2011 for more details on accounting for material inflation through the use of escalation factors.

Analysis Methods

The present and annual worth calculations discussed thus far describe a **deterministic approach** to LCCA comparisons because **a single defined value is assumed and used for each activity** (e.g., initial construction cost, preservation/rehabilitation cost and timing, etc.).

There is, of course, **inherent variability** (and, thus, risk) in each and every input used in an LCCA (e.g., forecasted future material costs, forecasted activity timing, expected service life of preservation techniques, etc.) that is not accounted for in a deterministic analysis. Such variability can, however, be **accounted for through a probabilistic analysis**. Some states attempt to address this variability in a deterministic analysis by varying crucial inputs, such as the real discount rate, in a sensitivity analysis to investigate the impact that changes in these variables have on the results of the analysis. Such variability is, however, best accounted for in a probabilistic analysis.

Example of the Mathematical Equivalence of the Material-Specific Real Discount Rate and Escalation Factor Methods to Account for Material Inflation

This example illustrates how to account for material inflation on $25,000 of an expenditure at the end of year 10. Assume general interest and inflation rates of 8% and 4%, respectively. Consider a material inflation rate of 5.5%, slightly higher than inflation.

<u>Material-Specific Real Discount Rate</u>

1) Calculate the material-specific real discount rate:

$$\mathrm{d_{mat}} = \frac{1 + i_{int}}{1 + i_{mat-inf}} - 1 = \frac{1 + 0.08}{1 + 0.055} - 1 = 2.37\%$$

2) Discount the expenditure to its present worth:

$$\$P = \frac{\$F}{(1 + \mathrm{d_{mat}})^{t}} = \frac{\$25{,}000}{(1 + 0.0237)^{10}} = \$19{,}780.03$$

<u>Escalation Factor and General Real Discount Rate</u>

1) Calculate the general real discount rate:

$$\mathrm{d} = \frac{1 + i_{int}}{1 + i_{inf}} - 1 = \frac{1 + 0.08}{1 + 0.04} - 1 = 3.85\%$$

2) Calculate the escalation factor in a method comparable to the discount rate (e.g., the discount rate considers the difference between interest and inflation rates while the escalation factor considers the difference between material-specific and general inflation rates):

$$\mathrm{e} = \frac{1 + i_{mat-inf}}{1 + i_{inf}} - 1 = \frac{1 + 0.055}{1 + 0.04} - 1 = 1.44\%$$

3) Escalate the expenditure to its year 10 cost (Mack 2011):

$$\$F = \$P(1 + e)^{t} = \$25{,}000(1 + 0.0144)^{10} = \$28{,}849.03$$

4) Discount the expenditure to its present worth:

$$\$P = \frac{\$F}{(1 + \mathrm{d})^{t}} = \frac{\$28{,}849.03}{(1 + 0.0385)^{10}} = \$19{,}780.03$$

Both methods yield the same present worth. Thus, both are viable means of accounting for material inflation.

In a probabilistic approach to life-cycle cost analysis, the **variability of each input is accounted** for and used to generate a probability distribution for the calculated life-cycle cost. The spread of the probability distribution of the calculated life-cycle cost illustrates how much the actual life-cycle cost may vary based on the variability of the inputs (Figure 2-16).

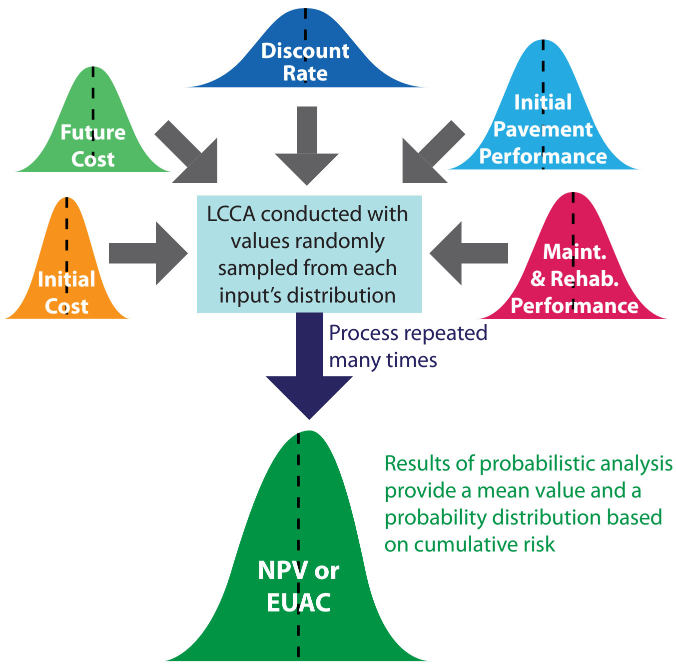


Figure 2-16. Schematic of a probabilistic analysis process (after NCHRP 2004).

Probabilistic LCCA is a relatively new concept for most state transportation agencies, but has become more practical in recent years due to advances in computer processing capabilities. FHWA has developed guidelines for probabilistic LCCAs (FHWA 2002). The FHWA's probabilistic LCCA procedure, as used in their **RealCost LCCA software**, relies on Monte Carlo simulations to select a random value for each input variable from its probability distribution and then compute the NPV or EUAC for the selected values. This process is repeated many times in order to generate a probability distribution of LCCAs for each alternative being considered. The **probability distribution of the NPV is characterized in the program outputs by the mean value and standard deviation**; minimum and maximum net present values also are reported.

Costs incurred closer to the beginning of the analysis period typically can be estimated with a higher degree of certainty than costs incurred later in the analysis period. Thus, initial costs can be estimated with a narrower probability distribution than future costs. These trends in probability distribution also hold true for other inputs and the outputted net present value distributions. A net present value probability distribution that is wider presents more risk than a narrow probability distribution (Figure 2-17).

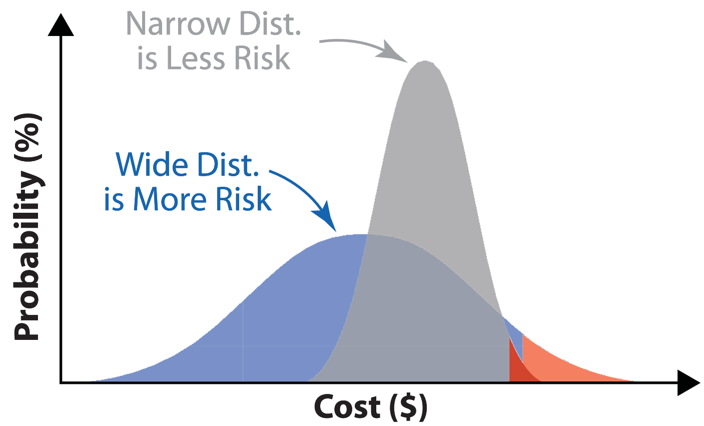


Figure 2-17. Illustration of how variability (e.g., width or standard deviation) of distribution is related to risk.

The majority of state highway agencies who perform LCCA for pavement type selection still either use deterministic analysis exclusively or use it alongside a probabilistic analysis (Table 2-11). Despite the complexities of a probabilistic analysis, many states who perform LCCA for pavement type selection have adopted such analysis methods to best account for the inherent variability/risk of an LCCA.

Analysis Tools

Most modern **spreadsheet software** include standard functions for calculating the present worth (e.g., PV() in Microsoft Excel) and annual worth (e.g., PMT() in Microsoft Excel) to aid in deterministic analysis.

Table 2-11. Summary of U.S. State Highway Agency Practices Concerning the Use of a Deterministic and Probabilistic Approaches in Their LCCA Calculations (after NCHRP 2011a)

Analysis Method Used	Percent of Responding Agencies	State Agency
Deterministic	**80%**	AL, AR, AZ, CA, GA, ID, IL, KS, LA, MI, MN, MO, MT, NC, NM, NV, OH, PA, TN, UT, VT, WI, WV
Probabilistic	10%	CO, IN, MD
Both Det. and Prob.	10%	DE, SC, WA

Table 2-12. Summary of U.S. State Highway Agency Practices Concerning the Use of State-Developed Tools, RealCost, or DARWinME™ to Conduct LCCA Calculations (after NCHRP 2011a)

LCCA Tool Used	Percent of Responding Agencies	State Agency
State-Developed Tool	**62%**	AR, GA, ID, IL, KS, MI, MN, MO, MT, NC, NM, NV, OH, PA, SC, TN, UT, WI
RealCost	41%	AZ, CA, CO, DE, IN, LA, MD, SC, TN, UT, VT, WA
DARWinME™	17%	AL, CO, TN, VT, WV

Proprietary software that can compute LCCAs include:

- AASHTO's DARWinME™ (deterministic)
- FHWA's RealCost (deterministic and probabilistic)
- ACPA's StreetPave (deterministic)
- Asphalt Pavement Alliance's (APA's) LCCA Original and LCCA Express (both deterministic)

Most state highway agencies are conducting calculations using a state-developed software/spreadsheet (Table 2-12). About 40% of surveyed state highway agencies currently use the FHWA's RealCost software and all responding states that conduct probabilistic analyses use RealCost either exclusively or with other LCCA software/spreadsheets. Many states have also developed their own customized version of the RealCost software, such as the California DOT's *RealCost v.2.2. – California Edition* (CALTRANS 2011b), while other states have state-customized spreadsheets, such as the Pennsylvania DOT's Life Cycle Cost Analysis spreadsheet (PennDOT 2011b).

Because of its ability to do both deterministic and probabilistic analyses and ease of use, RealCost is recommended by ACPA and is used alongside simple deterministic calculations in the examples in Chapter 3. The RealCost software and supporting documents, such as the User's Manual, several case studies, and the FHWA's LCCA Primer and Technical Bulletin, can all be downloaded for free from the FHWA's website (FHWA 2011b).

Comparison of Results

After the LCCA has been conducted for each alternate, it is necessary to analyze and compare the results. Because different components of the total life-cycle cost indicate different things about the alternates (e.g., the relative impacts of initial and future agency costs or user costs), the components typically are viewed both separately and together to aid in interpretation and evaluation of the results (NCHRP 2011a).

Probabilistic analyses provide a means of evaluating the relative economic (cost) risk of competing alternatives, but the process can be complex. **A simple way to examine the cost estimation risk** (i.e., variability in the estimated LCCA) of competing alternatives using only deterministic analysis techniques is to take the ratio of initial costs to the net present value (or EUAC) for each alternate[4]. Higher values of this ratio indicate that more of the LCCA is due to initial costs, which are relatively better known, so the reliability of the LCCA estimate is higher than for alternatives with lower values of this ratio.

When two alternatives have very similar net present values over the analysis period, it is advisable to choose the less risky alternative (i.e., the one with the higher proportion of the net present value attributable to initial costs). Depending on the level of cost estimation risk considered acceptable, it may even be preferable to select the alternative with the somewhat higher present worth of costs.

The examples presented in Chapter 3 illustrate the comparison of LCCA results for evaluating pavement alternatives.

Gaps between Actual Practice and State-of-the-Art of LCCAs

In 2004, researchers investigated trends in common LCCA practices among state highway agencies and found the following gaps between state-of-the-practice and state-of-the-art of LCCAs (Ozbay, et al. 2004):

- The statistical nature of the uncertain input parameters,
- The determination of the timing of future rehabilitation activities,
- The inclusion/exclusion of user and social costs, and
- The treatment of uncertainty.

The baseline against which state-of-the-practice activities was judged was that of the state-of-the-art in academic research and guidelines from groups such as the FHWA (e.g., RealCost) and the World Bank.

These differences between the state-of-the-practice and state-of-the-art are important to understand when attempting to conduct the most thorough and realistic LCCA possible.

Nature of Uncertainty

While discussed in some detail in previous section, this research identified that the majority of state agencies assume discrete values for inputs that have at least some uncertainty (e.g., timing of future activities), typically because the state agency was using a deterministic analysis.

It is noted by the researchers that **uncertain parameters are best accounted for in an LCCA through the use of probability distributions in a probabilistic analysis**. Readily available tools, such as RealCost, can be used to produce LCCA probability distributions from inputs for which probability distributions are known. Thus, the ability to account for the nature of uncertainty exists and such variability should be included in a comprehensive and realistic LCCA.

Determining Future Activity Timing

This difference is less about the ability to determine future activity timing and more about the method by which it is done.

[4] Because private entities (e.g., concessionaires) can neither levy taxes nor sell their own bonds, the opposite might be true for privately-funded projects. In such cases, the owner might want to minimize up-front costs as much as possible so they can either 1) borrow less money or 2) invest more of the money they have in other projects, the stock market, interest bearing bonds, etc.

State agencies rely heavily on performance history records, expert opinions, etc. to estimate activity timing across the life cycle of each alternate. Thus, performance data is regularly revisited and estimates updated. This can, however, lead to the **problematic practice of systematically imposing standardized preservation/rehabilitation schedules** on a given pavement alternate type (see Step 5). The preservation/rehabilitation schedule developed for each competing project alternative should be custom-developed with consideration of variables such as expected initial pavement performance, traffic, climate conditions, etc.

Academia, on the other hand, generally relies on performance models, such as those included in DARWin-ME™, to estimate activity timing. While these models rely heavily on design inputs such as traffic, making the timing of future activities project-specific, the **performance models may not necessarily reflect the real-world performance** of each alternative in a specific location, even though the models were originally calibrated to field performance in some areas.

While each method of estimating future activity might yield slightly different results, using a probabilistic analysis with a varied timing for each activity likely helps to reduce differences between the two methods and provide more realistic performance expectations.

User and Social Costs

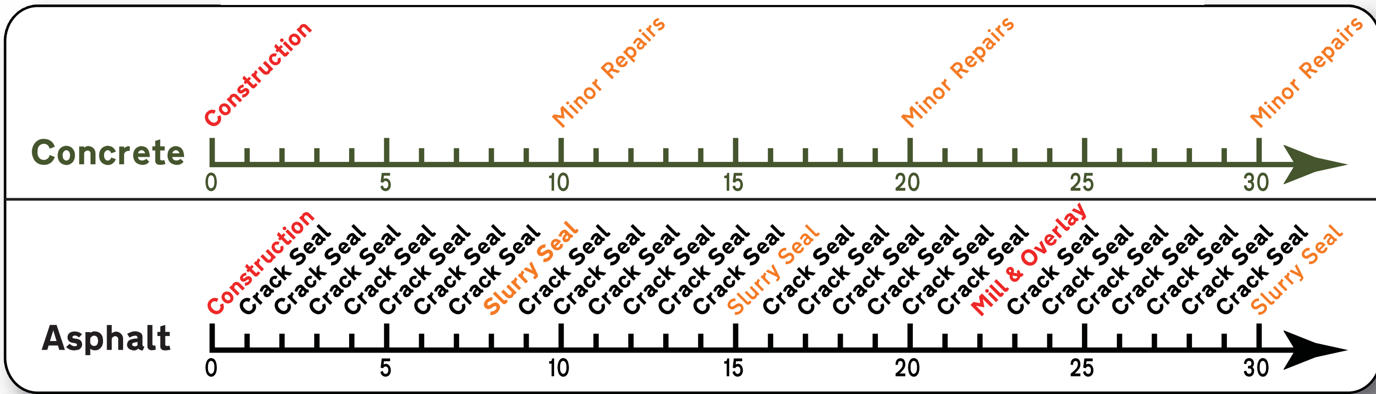
As discussed previously, most state agencies do not consider costs encountered by users (especially those incurred during the use-phase of the roadway) in LCCAs because (at least in part) they believe such costs to be similar for each alternate. However, **much research has been done on means to monetize and quantify user costs** for impacts ranging from work zone traffic delays to comfort, and even health effects. Such research increasingly shows that these are significant contributors to the overall cost of the roadway.

While some have argued that user costs are not real costs or such costs are too difficult to monetize, the **users are incurring these user costs just as they are incurring the total initial and future agency cost through taxes**, tolls, or other fees; thus, any and all quantifiable user costs should be considered in an LCCA.

Treatment of Uncertainty

Aside from a small percentage of state agencies who are utilizing probabilistic LCCAs, the vast majority of LCCAs currently being conducted are deterministic analyses that result in single-point estimates (or, at best, deterministic analyses with a simple sensitivity analysis that varies a few key inputs such as the real discount rate).

Although about 40% of surveyed state highway agencies use RealCost (Table 2-12), only 20% (Table 2-11) consider probabilistic analysis methods. Given the magnitude of taxpayer dollars spent each year on roadway projects and the increasing use of RealCost (a software that is simple to use and free for any agency, including cities, counties, etc.), **it is strongly recommended that the most advanced and sophisticated LCCA tools available be embraced and implemented** to account for the uncertainty that is inherent in any LCCA.



Pavement Management Plan from City of Leawood, Kansas

Chapter 3. Examples of Single-Project Life-Cycle Cost Analysis

Because of the ever-increasing use of LCCA and the level of transparency employed by most agencies when conducting LCCAs, many examples for specific projects are readily available.

This Chapter presents real-world LCCA examples for a local road, a highway and an airport. Because these are real-world examples, the cost data presented are valid only for the project described and in the year in which the project was constructed; the cost data presented in this Chapter should not be used as estimates for similar work because such costs are dependent on many more variables than just the pavement structural design (e.g., relative location of the contractor to the project, construction environment, required traffic management practices, etc.).

Each example begins with a deterministic analysis conducted using the equations from Step 7. RealCost is then used to conduct a probabilistic analysis for each example, assuming reasonable, simple variation in critical inputs such as the real discount rate, activity pricing, and activity timing. A comparison of the results is then presented along with further investigation and discussion on key issues. Note that while some examples will discuss similar concepts (e.g., the impact of real discount rate on results), other investigations are unique to specific examples because of the story the analysis/results tells; as such, if you are reading these examples for an understanding of methods to analyze LCCAs, all three examples should be read, regardless of whether you are conducting an LCCA for a local road, airfield, highway, industrial facility, or other type of project.

Local Road Example

General Details

Agency/Owner: Village of Whitefish Bay, WI
Year of LCCA: 2008
Design Method(s) Used: N/A; standard sections used
Location: Diversey Boulevard Street
Roadway Classification: Residential
Traffic: N/A

Project Scope: Reconstruction of approximately 10,000 SY (8,360 m^2) of pavement.

Other Project Details: The details of this LCCA example were taken from the Wisconsin Concrete Pavement Association's (WCPA's) report, *"The Selection of Concrete Pavement for Diversey Boulevard Street Reconstruction – Village of Whitefish Bay."*

The existing concrete pavement was built in 1928 (80 years old in 2008) and is still in good condition with no scheduled maintenance, rehabilitation or reconstruction planned (Figure 3-1). Immediately south of this section, an asphalt pavement was built in 1974 (34 years old in 2008) and has significant structural and material durability distresses (Figure 3-2).

Figure 3-1. Existing 80-year-old concrete pavement.

Figure 3-2. Existing 34-year-old asphalt pavement.

The project was originally bid in 2008 as 3 in. (75 mm) of asphalt atop 10 in. (250 mm) of granular base; the Village then planned to construct a 2-in. (50-mm) asphalt overlay one year after initial construction.

As part of the bidding package, the Village provided the contractor the opportunity to bid alternate pavement types.

Pavement Alternates: The concrete and asphalt alternates, based on the Village's standard pavement cross-sections, are shown in Figure 3-3.

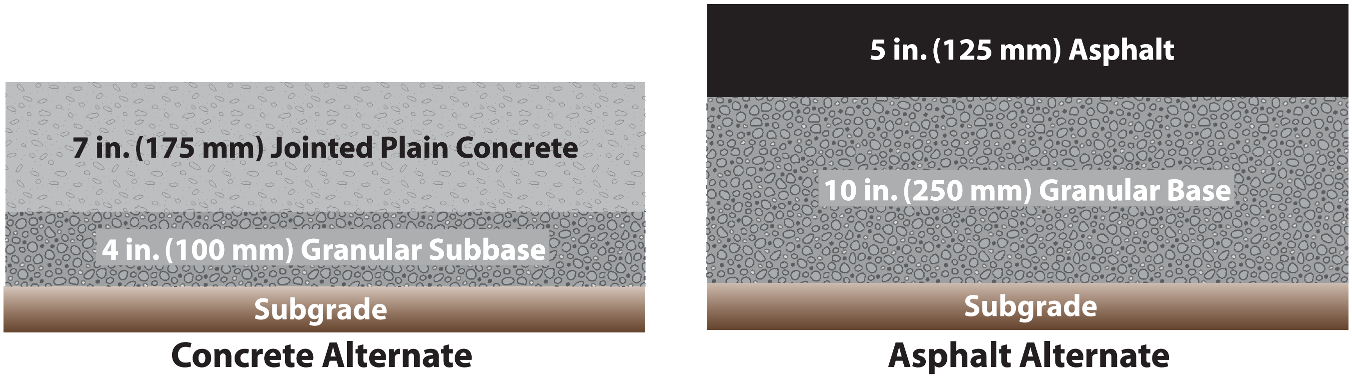


Figure 3-3. Village of Whitefish Bay's concrete and asphalt alternate pavement cross-sections for Diversey Boulevard Street in 2008.

Life-Cycle Cost Analysis

Step 1 – Select Analysis Period: 90 years
Step 2 – Select Real Discount Rate: 3%

Step 3 – Estimate Initial Agency Costs:

Concrete Alternate:

Table 3-1. Initial Agency Costs[5] for the Concrete Alternate

Description of Work	Quantity	Unit Price	Total Cost
7 in. Concrete Pavement	10,000 SY	$22.00/SY	$220,000
Concrete Curb and Gutter	5,580 LF	$11.00/LF	$61,380
4 in. Aggregate Subbase	3,120 Ton	$10.50/Ton	$32,760
Unclassified Excavation	4,600 CY	$13.00/CY	$59,800
	TOTAL INITIAL AGENCY COST:		$373,940

Asphalt Alternate:

Table 3-2. Initial Agency Costs[6] for the Asphalt Alternate

Description of Work	Quantity	Unit Price	Total Cost
2 in. Asphalt Surface Course	1,150 Ton	$48.42/Ton	$55,683
Tack Coat 2	250 gal	$1.25/gal	$313
3 in. Asphalt Lower Course	1,725 Ton	$42.10/Ton	$72,623
Tack Coat 1	200 gal	$1.25/gal	$250
Concrete Curb and Gutter	5,580 LF	$11.00/LF	$61,380
10 in. Aggregate Base	5,200 Ton	$10.50/Ton	$54,600
Unclassified Excavation	5,230 CY	$14.00/CY	$73,220
	TOTAL INITIAL AGENCY COST:		$318,068

NOTE: Initial agency cost for the asphalt alternate is 15% less than that of the concrete alternate.

[5] Costs are based wholly on the lowest concrete pavement alternate bid received by the Village.
[6] Costs are based on the lowest asphalt pavement alternate bid received by the Village except Tack Coat 2 and 2 in. Asphalt Surface Course, which were estimated costs for the surface course to be constructed after one year of service

Step 4 – Estimate User Costs: User costs were not considered. As originally bid with the 3-in. (75-mm) initial construction and 2-in. (50-mm) overlay after one year, user costs for the staged construction of asphalt pavement alternate would have been significantly more than those of concrete or asphalt placed in a single construction phase. Based on the activity timings in the next step, future user costs likely also are more for the asphalt alternate than the concrete alternate.

Step 5 – Estimate Future Agency Costs:

Concrete Alternate:

Table 3-3. Future Agency Costs for the Concrete Alternate

Year	Type of Work	Description of Work	Quantity	Unit Price	Total Cost
15	Maintenance	Joint Sealing (15%)	2,250 LF	$0.50/LF	$1,125
30	Maintenance	Joint Sealing (30%)	4,500 LF	$0.50/LF	$2,250
30	Preservation	Full Depth Repair (2% Panels @ 6 ft Repair)	40 CY	$180/CY	$7,200
30	Preservation	Partial Depth Repair (3% Joint Repaired)	180 LF	$15.00/LF	$2,700
45	Maintenance	Joint Sealing (30%)	4,500 LF	$0.50/LF	$2,250
60	Maintenance	Joint Sealing (30%)	4,500 LF	$0.50/LF	$2,250
60	Preservation	Full Depth Repair (4% Panels @ 6 ft Repair)	80 CY	$180/CY	$14,400
60	Preservation	Partial Depth Repair (6% Joint Repaired)	360 LF	$15.00/LF	$5,400
75	Maintenance	Joint Sealing (30%)	4,500 LF	$0.50/LF	$2,250

Asphalt Alternate:

Table 3-4. Future Agency Costs for the Asphalt Alternate

Year	Type of Work	Description of Work	Quantity	Unit Price	Total Cost
3	Maintenance	Crack Sealing	3,000 LF	$0.50/LF	$1,500
7	Maintenance	Crack Sealing	4,000 LF	$0.50/LF	$2,000
15	Preservation	Seal Coat	10,000 SY	$1.75/SY	$17,500
15	Maintenance	Crack Sealing	5,000 LF	$0.50/LF	$2,500
22	Maintenance	Crack Sealing	6,000 LF	$0.50/LF	$3,000
30	Reconstruct	Remove Pavement	10,000 SY	$2.00/SY	$20,000
30	Reconstruct	Pavement Replacement	1 LS	$318,068/LS	$318,068
33	Maintenance	Crack Sealing	3,000 LF	$0.50/LF	$1,500
37	Maintenance	Crack Sealing	4,000 LF	$0.50/LF	$2,000
45	Preservation	Seal Coat	10,000 SY	$1.75/SY	$17,500
45	Maintenance	Crack Sealing	5,000 LF	$0.50/LF	$2,500
52	Maintenance	Crack Sealing	6,000 LF	$0.50/LF	$3,000
60	Reconstruct	Remove Pavement	10,000 SY	$2.00/SY	$20,000
60	Reconstruct	Pavement Replacement	1 LS	$318,068/LS	$318,068
63	Maintenance	Crack Sealing	3,000 LF	$0.50/LF	$1,500
67	Maintenance	Crack Sealing	4,000 LF	$0.50/LF	$2,000
75	Preservation	Seal Coat	10,000 SY	$1.75/SY	$17,500
75	Maintenance	Crack Sealing	5,000 LF	$0.50/LF	$2,500
82	Maintenance	Crack Sealing	6,000 LF	$0.50/LF	$3,000

Step 6 – Estimate Residual Value: Residual value is assumed similar for both alternates at the end of 90 years. Thus, residual value is excluded from the LCCA. Even if residual values were considered, any remaining value for either alternate likely would not have significant present worth due to the length of the 90-year analysis period and the time value of money (see the section titled "Impact of Future Cost Predictions" on page 49).

Step 7 – Compare Alternatives: The alternates are first compared using a deterministic analysis to calculate the net present value of each alternate.

Concrete Alternate:

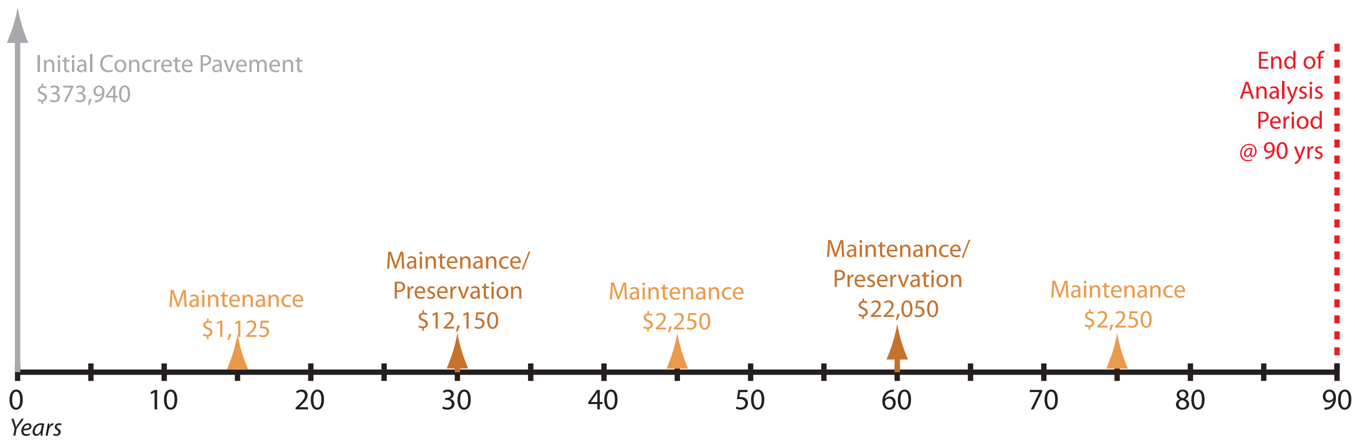


Figure 3-4. Cash flow diagram for the concrete alternate.

Table 3-5. Net Present Value Calculation for the Concrete Alternate (d = 3%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$373,940	$ 373,940
15	Maintenance	$1,125	$ 722
30	Maintenance/Preservation	$12,150	$ 5,006
45	Maintenance	$2,250	$ 595
60	Maintenance/Preservation	$22,050	$ 3,743
75	Maintenance	$2,250	$ 245
	TOTAL NET PRESENT VALUE:		**$ 384,250**

Asphalt Alternate:

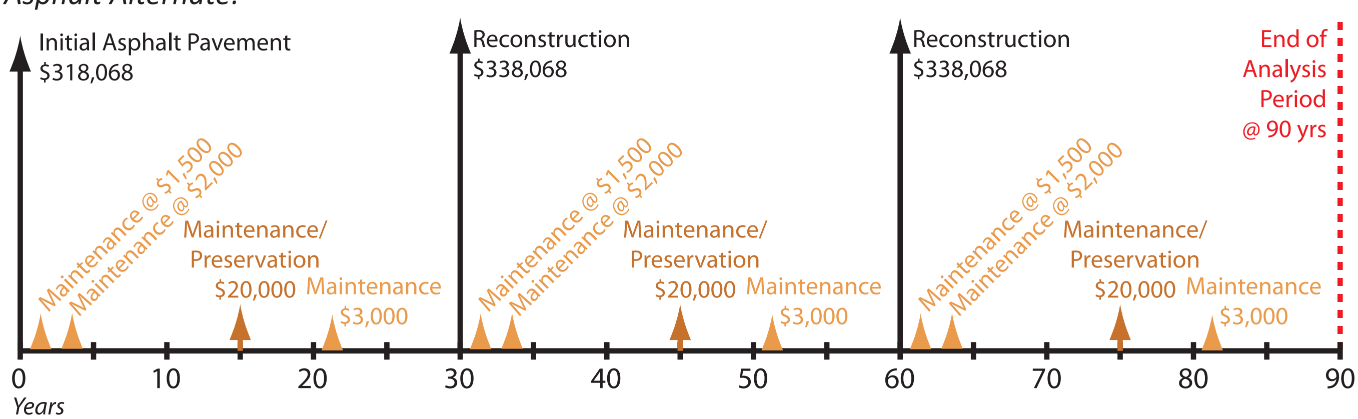


Figure 3-5. Cash flow diagram for the asphalt alternate.

Table 3-6. Net Present Value Calculation for the Asphalt Alternate (d = 3%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$318,068	$ 318,068
3	Maintenance	$1,500	$ 1,373
7	Maintenance	$2,000	$ 1,626
15	Maintenance/Preservation	$20,000	$ 12,837
22	Maintenance	$3,000	$ 1,566
30	Reconstruction	$338,068	$ 139,280
33	Maintenance	$1,500	$ 566
37	Maintenance	$2,000	$ 670
45	Maintenance/Preservation	$20,000	$ 5,289
52	Maintenance	$3,000	$ 645
60	Reconstruction	$338,068	$ 57,381
63	Maintenance	$1,500	$ 233
67	Maintenance	$2,000	$ 276
75	Maintenance/Preservation	$20,000	$ 2,179
82	Maintenance	$3,000	$ 266
		TOTAL NET PRESENT VALUE:	**$ 542,254**

The deterministic analysis shows that the concrete alternate will cost 29% less (in constant dollars) than the asphalt alternate over the analysis period investigated.

A deterministic analysis with RealCost confirms the previous calculations (Figure 3-6).

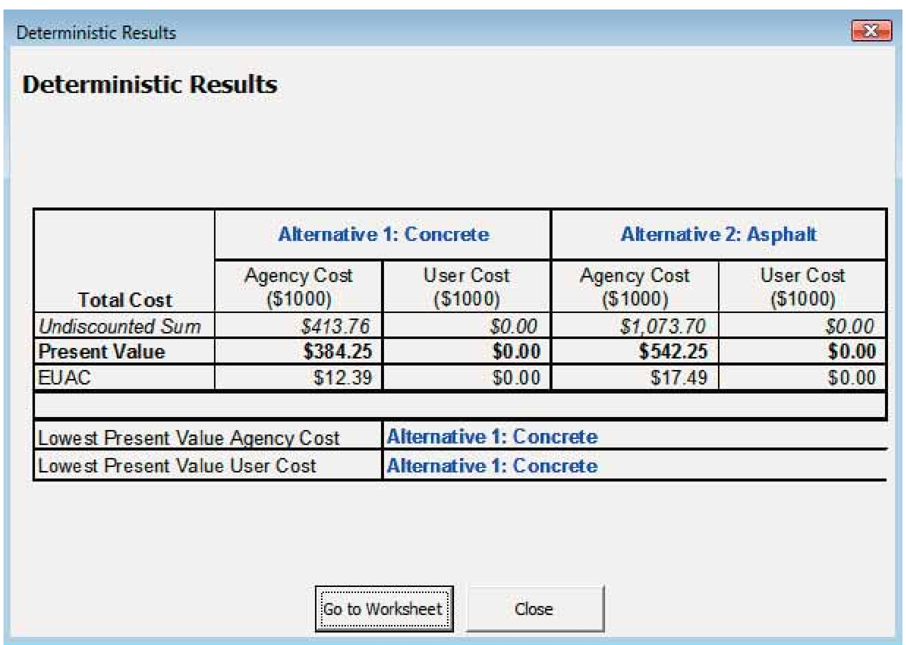
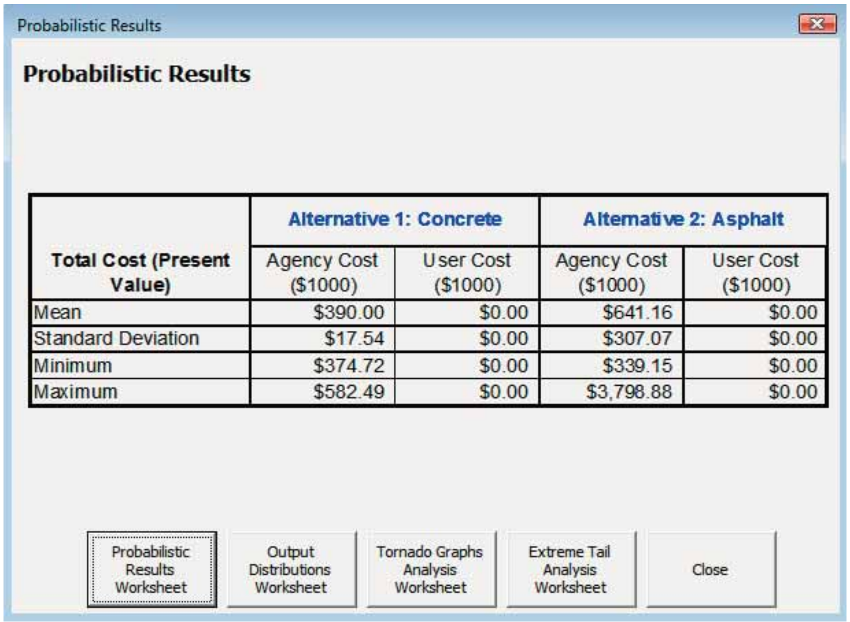


Figure 3-6. RealCost deterministic results for the concrete and asphalt alternates (d = 3%).

A probabilistic analysis also was conducted using RealCost and the software's default values for the sampling scheme, number of iterations, and tail analysis percentiles. The only input variability investigated in this probabilistic analysis was the real discount rate, which was set to a normal probability distribution with a mean value of 3 and a standard deviation of 2. Figure 3-7 shows the results of the probabilistic analysis.



Total Cost (Present Value)	Alternative 1: Concrete		Alternative 2: Asphalt	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Mean	$390.00	$0.00	$641.16	$0.00
Standard Deviation	$17.54	$0.00	$307.07	$0.00
Minimum	$374.72	$0.00	$339.15	$0.00
Maximum	$582.49	$0.00	$3,798.88	$0.00

Figure 3-7. RealCost probabilistic results for the concrete and asphalt alternates (d = 3% with normal standard deviation of 2%).

As shown, the mean net present values of the concrete and asphalt alternates in the probabilistic analysis are relatively close to the values obtained in the deterministic analysis. The asphalt alternate also has a significantly larger standard deviation, thus the net present value of the asphalt alternate is much more sensitive to the real discount rate, making this alternate much more prone to significant changes in magnitude due to changes in interest rates and/or material or general inflation rates.

A low real discount rate gives more weight (more importance) to future costs, and a negative interest rate further enhances this weighting. The high maximum net present values for both the asphalt and concrete alternates likely are a result of the use of the mean real discount rate of 3 and standard deviation of 2 with a normal probability distribution. Such a characterization of the real discount rate likely resulted in negative discount rates being used on the extreme left end of the normal probability distribution.

The cost estimation risk (e.g., ratio of initial agency cost to deterministic net present value) can be calculated for each alternate as a means of assessing the overall risk of each alternate.

Concrete Alternate:

$373,940 / $384,250 = 97%

Asphalt Alternate:

$318,068 / $542,254 = 59%

Because initial costs are much easier to estimate and the concrete alternate has a significantly higher cost estimation ratio, the concrete alternate is deemed the choice with the lower risk of higher-than-expected costs.

LCCA has shown the concrete alternative to be more cost-effective and to have a lower risk of unexpectedly high agency costs for variable discount rates.

Impact of Analysis Period

If the analysis period were less than 30 years, the asphalt alternate would have been the more cost-effective alternate (Figure 3-8). The difference between the two alternates increases, however, as the analysis period increases past 30 years. Thus, while the deterministically calculated net present values are dependent on the analysis period used, the results for this example show the concrete alternate to be more cost-effective solution for an analysis period of 30 years or more.

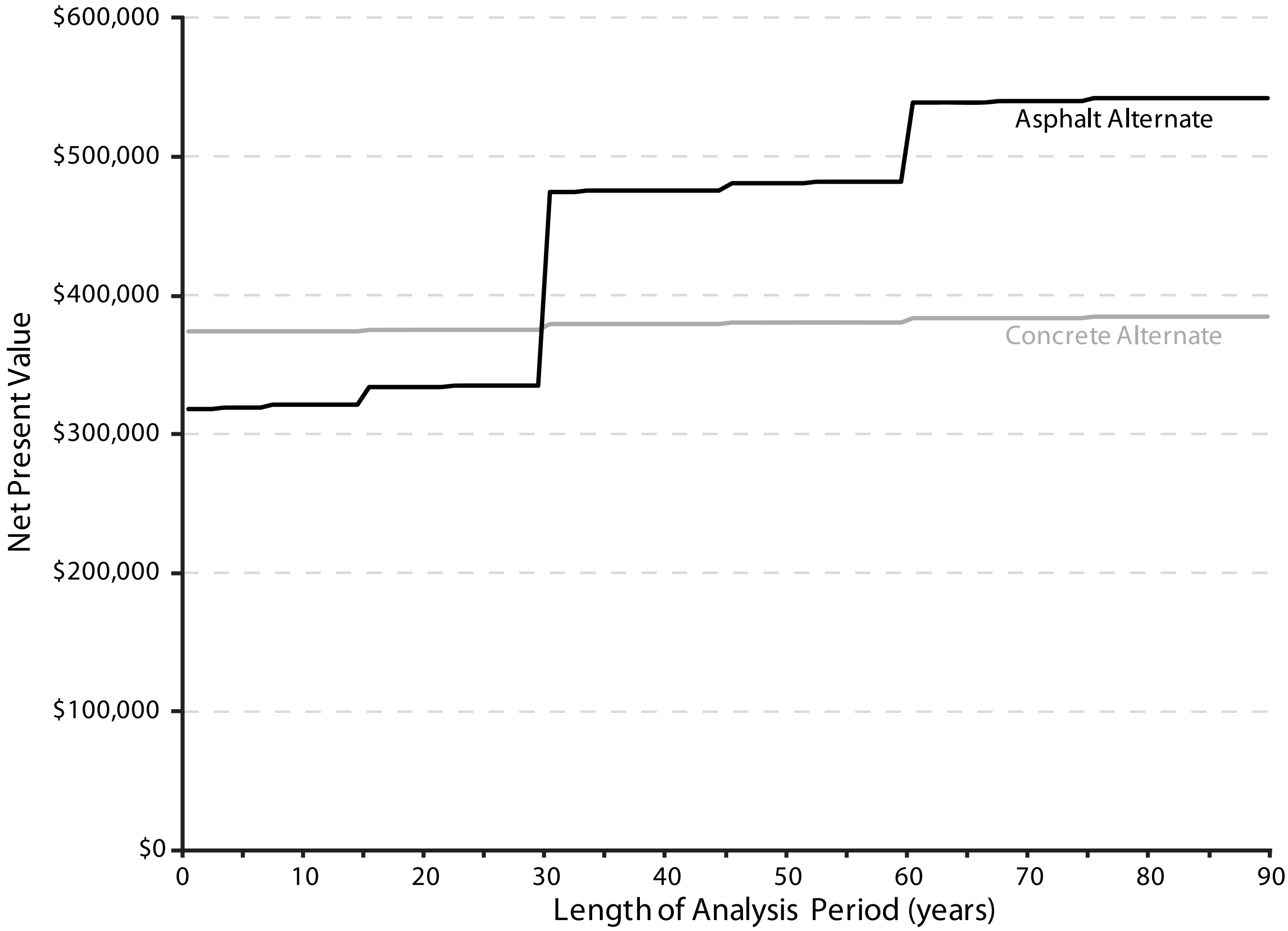


Figure 3-8. Deterministically calculated net present values for the concrete and asphalt alternates based on the length of the analysis period.

Impact of Real Discount Rate

The sensitivity of the real discount rate on net present value also was investigated in deterministic analyses (Figure 3-9).

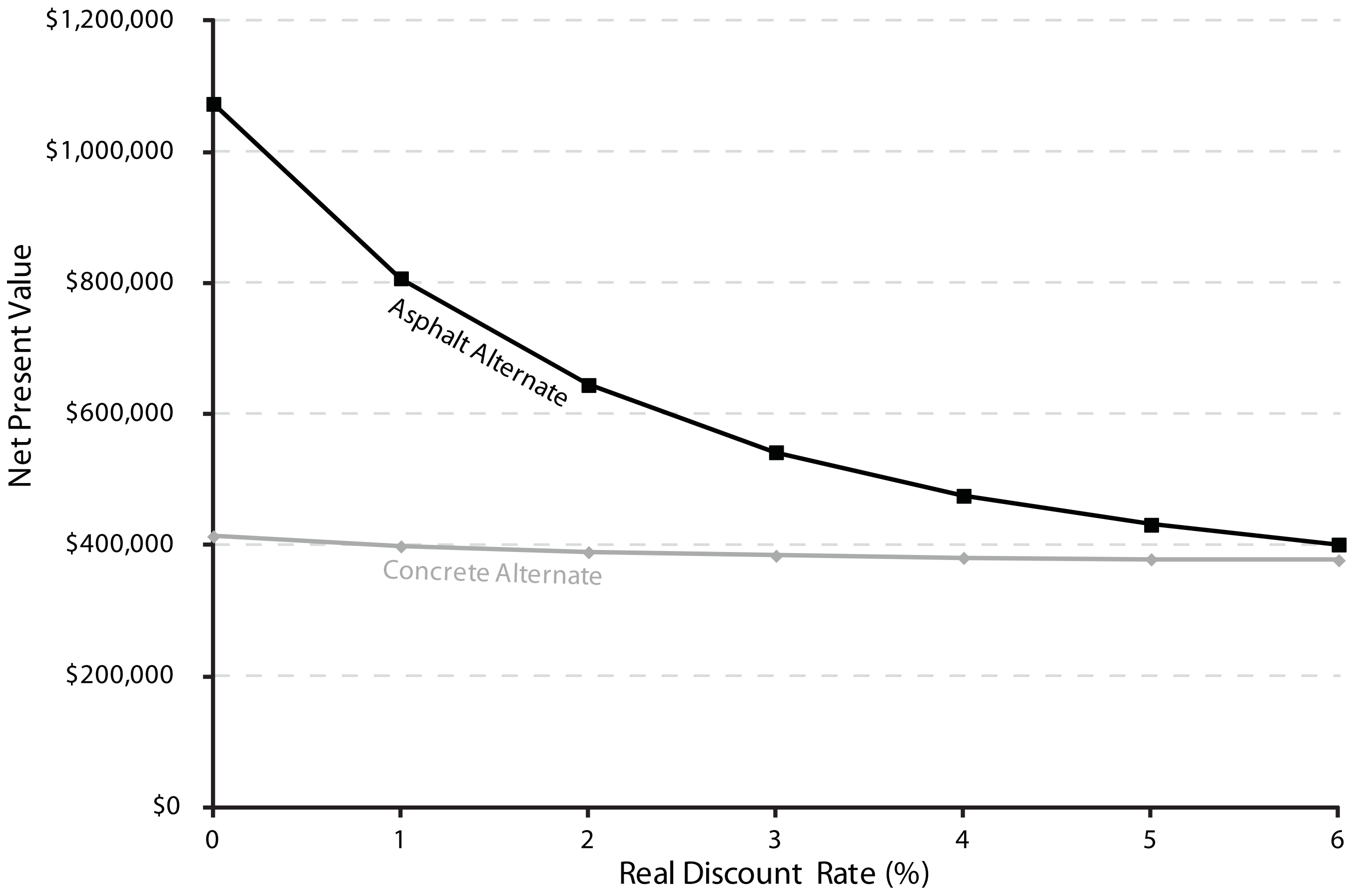


Figure 3-9. Deterministically calculated net present values for the concrete and asphalt alternates for varying real discount rates.

As shown, the concrete alternate becomes increasingly cost-effective as the real discount rate decreases. At a real discount rate of 6%, the net present value is almost identical for each alternate.

Impact of Material Inflation

Material-Specific Discount Rates

A material-specific real discount rate might be applied to the asphalt pavement portion of each reconstruction because asphalt inflates at a significantly different rate than other materials and items included in the bids. As shown in Step 2 of Chapter 2, the CAGR of asphalt was 5.5% over the past 54 years. If it is assumed the interest rate is 7% over the same time, the real discount rate for asphalt material would be 1.4%.

The reconstructions at years 30 and 60 include $20,000 for pavement removal and $318,068 for new construction, the same cost as the initial agency cost. Of this initial agency cost, about 40%, or $128,306, is for asphalt courses. Thus, $209,763 of each reconstruction can be discounted at the general real discount rate of 3% and the $128,306 that is asphalt paving materials should be discounted at the applicable real discount rate of 1.4%, as shown in Table 3-7.

Table 3-7. Net Present Value Calculation for the Asphalt Alternate (standard d = 3%; asphalt paving d = 1.4%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$318,068	$ 318,068
3	Maintenance	$1,500	$ 1,373
7	Maintenance	$2,000	$ 1,626
15	Maintenance/Preservation	$20,000	$ 12,837
22	Maintenance	$3,000	$ 1,566
30	60% Reconstruction – Non-asphalt	$209,763	$ 86,419
30	**40% Reconst. – Asphalt @ d = 1.4%**	**$128,306**	**$ 84,549**
33	Maintenance	$1,500	$ 566
37	Maintenance	$2,000	$ 670
45	Maintenance/Preservation	$20,000	$ 5,289
52	Maintenance	$3,000	$ 645
60	60% Reconstruction – Non-asphalt	$209,763	$ 35,604
60	**40% Reconst. – Asphalt @ d = 1.4%**	**$128,306**	**$ 55,714**
63	Maintenance	$1,500	$ 233
67	Maintenance	$2,000	$ 276
75	Maintenance/Preservation	$20,000	$ 2,179
82	Maintenance	$3,000	$ 266
		TOTAL NET PRESENT VALUE:	**$ 607,879**

The NPV of the asphalt alternate was $542,254 with everything discounted at a real discount rate of 3%. The inclusion of the asphalt-specific real discount rate on just 40% of the two reconstructions increased the total NPV of the asphalt alternate by over 12%! The concrete alternate NPV is 41% less than that of the asphalt alternate when accounting for the asphalt material's higher rate of inflation. This illustrates the importance of using realistic discount rates in the analysis of pavement alternates with significantly different material inflation rates.

Escalation Factors

Instead of using material-specific real discount rate(s), escalation factors may instead be used to account for the difference between material inflation rates and the general inflation rate. This allows all discounting to be done using the standard real discount rate.

As suggested by MIT researchers, the real price mean asphalt escalation factor for the BLS's Asphalt Paving Mixtures and Blocks PPI is 149.7% at year 30 (MIT 2011a). Based on extrapolation of the asphalt escalation factor trend presented in the MIT research (because the research only provides such escalation factors to 50 years), the asphalt escalation factor is 220.0% at year 60. Thus, the total cost of the asphalt pavement elements of the reconstructions at years 30 and 60 become $128,306*149.7% = $192,074 and $128,306*220.0% = $282,273, respectively. Using the standard real discount rate of 3% for all items, the total net present value is summed in Table 3-8.

The NPV of the asphalt alternate increased from $542,254 to $594,659, a 9.7% increase, with the asphalt material inflation accounted for in this manner. Again, as was shown with the use of the asphalt material-specific discount rate, this is a significant change in the total NPV, even though the escalation factors were only applied on a relatively small percentage of the future activity costs in just 2 of the 90 years in the analysis.

Table 3-8. Net Present Value Calculation for the Asphalt Alternate (d = 3%; future asphalt paving costs appropriately escalated)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$318,068	$ 318,068
3	Maintenance	$1,500	$ 1,373
7	Maintenance	$2,000	$ 1,626
15	Maintenance/Preservation	$20,000	$ 12,837
22	Maintenance	$3,000	$ 1,566
30	60% Reconstruction – Non-asphalt	$209,763	$ 86,419
30	**40% Reconst. – Asphalt Escalated**	**$192,074**	**$ 79,132**
33	Maintenance	$1,500	$ 566
37	Maintenance	$2,000	$ 670
45	Maintenance/Preservation	$20,000	$ 5,289
52	Maintenance	$3,000	$ 645
60	60% Reconstruction – Non-asphalt	$209,763	$ 35,604
60	**40% Reconst. – Asphalt Escalated**	**$282,273**	**$ 47,911**
63	Maintenance	$1,500	$ 233
67	Maintenance	$2,000	$ 276
75	Maintenance/Preservation	$20,000	$ 2,179
82	Maintenance	$3,000	$ 266
	TOTAL NET PRESENT VALUE:		**$ 594,659**

Impact of Future Cost Predictions

At a real discount rate of 3%, the sensitivity of the present worth of a $1,000 expenditure to the year of that expenditure is shown in Figure 3-10.

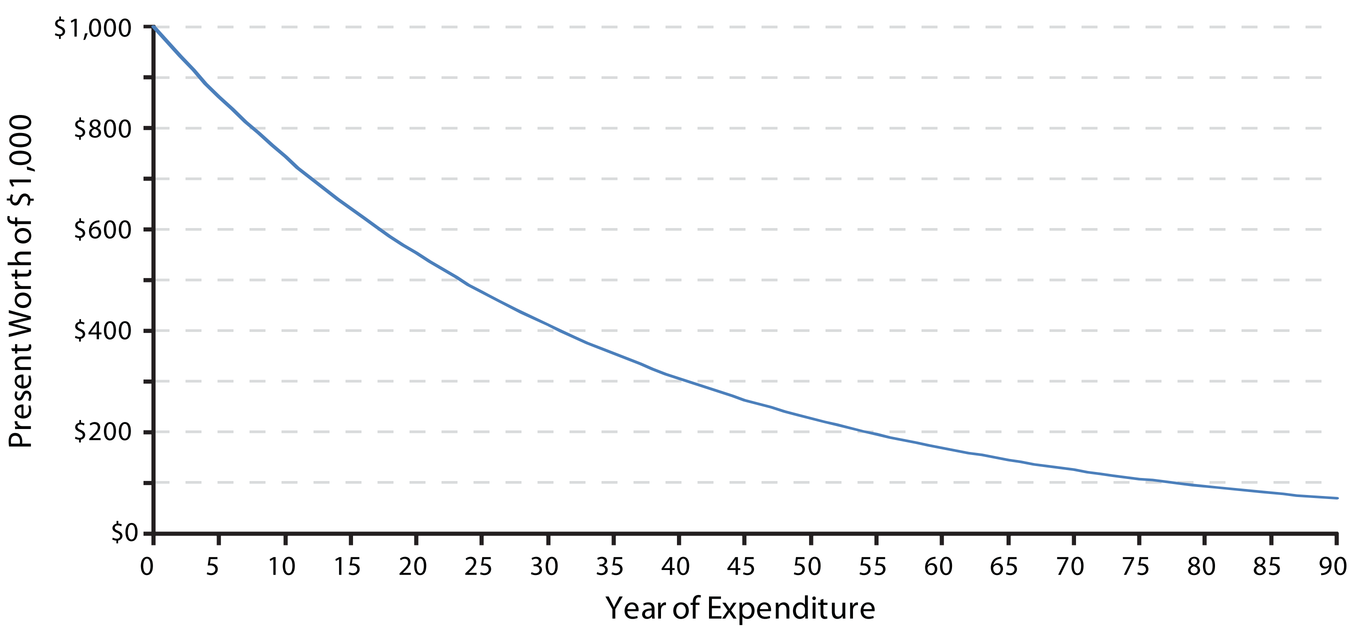


Figure 3-10. Present worth of a $1,000 expenditure based on the year of the expenditure and at a real discount rate of 3%.

This plot illustrates that a $1,000 expenditure in year 0 will have a present worth of $1,000 whereas a $1,000 expenditure in year 60 will have a present worth of just $170 (verified in the asphalt alternate calculations where, at year 60, the ratio of present worth to total cost was $57,381/$338,068 = 17%). Thus, an expenditure of $1,000 60 years in the future will increase the net present value of the alternate by just $170.

This sensitivity plot illustrates the relative importance of under- or over-predictions of future costs. For example, consider a case where the $338,068 reconstruction expenditure at years 30 and 60 in the asphalt is under-predicted by 10%, or $33,807. The present worth of these activities (and, thus, the net present value of the alternate) will increase by $13,928 for the under-prediction at year 30 but only by $5,738 for the under-prediction in year 60. While these might not seem like significant values compared to the net present values of the alternates, it is the difference between net present values of the different alternates that is most important in the determination of which alternate is more cost-effective.

Another important observation is that the present worth of the $1,000 expenditure at the end of the 90-year analysis period is just $70. Thus, in this example, every $1,000 difference in any residual value between the two pavements would make only a $70 difference in the net present values between the pavements for the 90 year analysis period and a 3% real discount rate. In this case, any errors in estimates of residual value do not have as significant an impact on the net present values as do errors in the estimates of initial costs or other future costs. (NOTE: If the appropriate real discount rate is negative, as is the case if the inflation rate is greater than the interest rate, the opposite is true and expenditures in the very far future can have a very large impact on the total NPV).

It should be noted that the sensitivity of present worth on future cost predictions also is highly dependent on the real discount rate used in the LCCA (see Figure 2-1).

Ultimately, potential variations of future costs are best accounted for by the use of a probability distribution of each future activity's costs and timing through a probabilistic analysis.

Total Cost of Ownership

A total ownership cost analysis estimates actual expenditures that must be made by the owner in any given year over the life of the pavement. This cost can be calculated in one of two ways: 1) directly inflating all future costs by the appropriate inflation rate and summing the values for each alternate or 2) calculating net present value using a real discount rate that uses 0% interest rate and the appropriate inflation rate for each alternate.

Concrete Alternate:

Even though concrete prices have historically inflated at an average rate of about 3.6% (see Figure 2-4), the slightly higher general inflation rate of 4% is usually used for all paving alternatives. All of the concrete alternate's costs inflated at 4% annually (and, thus, the total cost of ownership) are shown and summed in Table 3-9.

If, instead, the interest rate is assumed as 0% and the inflation rate is again assumed to be 4%, the resultant real discount rate is -3.85%. If this discount rate is applied to the entire projected cash flow (using current cost values) the concrete alternate's net present value (and the total cost of ownership) can be computed as shown in Table 3-10. As shown, this method yields the same total cost of ownership over the analysis period as inflating all the concrete alternate's costs at 4% annually (see Table 3-9).

Table 3-9. Total Ownership Cost Calculation for the Concrete Alternate (i_{inf} = 4% and no discounting)

Year	Type of Work	Current Cost	Inflated Cost
0	Initial Construction	$373,940	$ 373,940
15	Maintenance	$1,125	$ 2,026
30	Maintenance/Preservation	$12,150	$ 39,407
45	Maintenance	$2,250	$ 13,143
60	Maintenance/Preservation	$22,050	$ 231,958
75	Maintenance	$2,250	$ 42,627
		TOTAL OWNERSHIP COST:	**$ 703,101**

Table 3-10. Total Ownership Cost Calculation for the Concrete Alternate (d = -3.85%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$373,940	$ 373,940
15	Maintenance	$1,125	$ 2,026
30	Maintenance/Preservation	$12,150	$ 39,407
45	Maintenance	$2,250	$ 13,143
60	Maintenance/Preservation	$22,050	$ 231,958
75	Maintenance	$2,250	$ 42,627
		TOTAL OWNERSHIP COST:	**$ 703,101**

Asphalt Alternate:

Again assuming an interest rate of 0% but this time using a general inflation rate of 4% and an asphalt material inflation rate of 5.5% (see Figure 2-4), the resultant real discount rates are -3.85% for the standard rate and -5.2% for the asphalt material. The asphalt alternate's net present value (and, thus, the total cost of ownership) is calculated as shown in Table 3-11.

Table 3-11. Total Ownership Cost Calculation for the Asphalt Alternate (standard d = -3.85%; asphalt paving d = -5.2%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$318,068	$ 318,068
3	Maintenance	$1,500	$ 1,687
7	Maintenance	$2,000	$ 2,632
15	Maintenance/Preservation	$20,000	$ 36,019
22	Maintenance	$3,000	$ 7,110
30	60% Reconstruction – Non-asphalt	$209,763	$ 680,345
30	**40% Reconst. – Asphalt @ -5.2%**	**$128,306**	**$ 639,471**
33	Maintenance	$1,500	$ 5,473
37	Maintenance	$2,000	$ 8,536
45	Maintenance/Preservation	$20,000	$ 116,824
52	Maintenance	$3,000	$ 23,060
60	60% Reconstruction – Non-asphalt	$209,763	$ 2,206,629
60	**40% Reconst. – Asphalt @ -5.2%**	**$128,306**	**$ 3,187,092**
63	Maintenance	$1,500	$ 17,750
67	Maintenance	$2,000	$ 27,686
75	Maintenance/Preservation	$20,000	$ 378,905
82	Maintenance	$3,000	$ 74,792
		TOTAL NET PRESENT VALUE:	**$ 7,732,077**

While these values might seem staggering at first glance, remember that these are the projected actual (inflation-adjusted) expenditures in any given year.

To validate these numbers, consider just the maintenance activity at year 82. The cost in terms of today's dollars is just $3,000 but in terms of dollars inflated for 82 years at an annual rate of 4%, the value becomes a much larger $74,792:

$$\$F = \$P * (1 + d)^t$$

$$\$F = \$3{,}000*(1 + 0.04)^{82} = \$74{,}792$$

While the LCCA showed the concrete alternate to be more cost effective by about 30% in terms of constant dollars, the true cost to the agency's budget over the 90 years is much more compelling. Even though the concrete alternate's initial cost is 17.6% greater than that of the asphalt alternate, construction with the longer-term solution, in this case, greatly reduces the magnitude of necessary future expenditures to the agency, and thus the taxpayers.

General Discussion/Conclusions

This case study illustrates the importance of selecting proper inputs for an LCCA. Specific conclusions for this case example include:

- While the relative cost-effectiveness of the concrete alternate increases over time, it is the more cost-effective solution as soon as one major rehabilitation activity takes place on the asphalt alternate (e.g., 30 years and on).
- Even though the concrete alternate had significantly lower life-cycle costs than the asphalt alternate for the assumed future activities used and the assumed real discount rate, the selection of a real discount rate of 6% would have resulted in much more similar life-cycle costs, and even higher discount rates would have favored the asphalt alternate. Use of such high discount rates is not justified by current inflation and interest rate trends.
- Activity timing and cost predictions can have a significant impact on the LCCA results.
- When historic material inflation rate trends are considered, with asphalt inflating at a significantly greater rate than concrete (as has been the case for the last 50+ years), the real cost-effectiveness of long-life, low-maintenance pavement solutions are apparent.
- The total cost of ownership analysis clearly shows significantly greater outlays over the analysis period for the asphalt alternative than for the concrete alternative.

Highway Example

General Details

Agency/Owner: Washington State DOT
Year of LCCA: 2006
Design Method(s) Used: Unknown
Location: I-90 Spokane West U.A.B to Viaduct
Roadway Classification: Interstate
Traffic: 42,726 2-way AADT; 15% trucks

Project Scope: Widening to three lanes and repair of existing two lanes.

Other Project Details: This project is the example case study that is included with the download of RealCost 2.5. All default inputs in this case study were used except when changes were made to bring the analysis more in line with current practices or to correct oversights/omissions in the input files; all such changes are described herein.

Pavement Alternates: Unknown, though the activity descriptions indicate that alternate 1 involves the use of asphalt paving and alternate 2 involves the use of concrete paving. Ultimately, the specific details of the alternates are not necessary to the understanding of the LCCA of the alternates.

Life-Cycle Cost Analysis

Step 1 – Select Analysis Period: 50 years; this was changed from the RealCost default value of 40 years to reflect the analysis period currently used by the Washington State DOT. Preservation and rehabilitation data used for years 40-50 are available in the RealCost files.

Step 2 – Select Real Discount Rate: 3% with a normal probability distribution and standard deviation of 2. This was changed from the default value of 4% with a uniform probability distribution from 3% to 5% to better reflect current trends in real discount rates; Figure 3-15 contains the sensitivity analysis for discount rate, showing net present values for deterministic analyses using real discount rates from 3 to 5%.

Step 3 – Estimate Initial Agency Costs:

Concrete Alternate: Given as $11,035,000 and characterized as having a normal probability distribution with a standard deviation of $1,104,000, or 10% of the initial agency cost (note that the standard deviation was changed from the default of $110,000, which appears to be a typo in the default files because all other agency costs have a normal probability distribution with a standard deviation equal to 10% of the cost).

Asphalt Alternate: Given as $7,411,000 and characterized as having a normal probability distribution with a standard deviation of $741,000, or 10% of the initial agency cost.

NOTE: Initial agency cost for the asphalt alternate is 33% less than that of the concrete alternate, which is a large difference.

Step 4 – Estimate User Costs: User costs are based on the value of time for passenger cars, single-unit trucks, and combination trucks and the construction work zone inputs, such as work zone length, capacity, duration, speed limit, number of lanes open, hourly distribution of traffic, and work zone hours. See the inputs used in the example provided with RealCost 2.5 for more details.

Step 5 – Estimate Future Agency Costs:

Concrete Alternate:

Table 3-12. Future Agency Costs for the Concrete Alternate

Year	Type of Work	Description of Work	Total Cost
20	Maintenance	Joint and Crack Sealing	$1,409,000
40	Maintenance	Joint and Crack Sealing	$1,409,000

Asphalt Alternate:

Table 3-13. Future Agency Costs for the Asphalt Alternate

Year	Type of Work	Description of Work	Total Cost
4	Maintenance	General Maintenance	$10,000
8	Maintenance	General Maintenance	$10,000
10	Preservation	2-in. Overlay	$1,563,000
14	Maintenance	General Maintenance	$10,000
18	Maintenance	General Maintenance	$10,000
20	Preservation	Grind and 2 in.-Overlay	$2,150,000
24	Maintenance	General Maintenance	$10,000
28	Maintenance	General Maintenance	$10,000
30	Preservation	2 in.-Overlay	$1,563,000
34	Maintenance	General Maintenance	$10,000
38	Maintenance	General Maintenance	$10,000
40	Preservation	Grind and 2 in.-Overlay	$2,150,000
44	Maintenance	General Maintenance	$10,000
48	Maintenance	General Maintenance	$10,000

Step 6 – Estimate Residual Value: Because the initial construction activities for both alternates have an activity service life of 50 years, the same as the analysis period, the "Include Agency Cost Remaining Service Life Value" and "Include User Cost Remaining Service Life Value" checkboxes were unchecked in the Analysis Options screen; this is a change in the file default settings that was made to simplify computations because RealCost does not parse residual value out from other costs.

Step 7 – Compare Alternatives: The alternates are first compared using a deterministic analysis to calculate the net present value of each alternate.

Concrete Alternate:

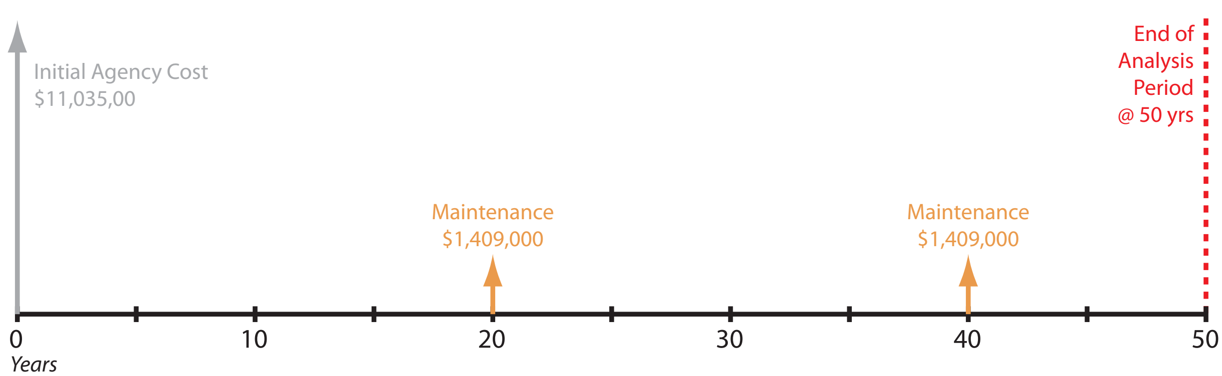


Figure 3-11. Cash flow diagram for the concrete alternate.

Table 3-14. Net Present Value Calculation for the Concrete Alternate (d = 3%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$11,035,000	$ 11,035,000
20	Maintenance	$1,409,000	$ 780,129
40	Maintenance	$1,409,000	$ 431,939
		TOTAL NET PRESENT VALUE:	**$ 12,247,068**

Asphalt Alternate:

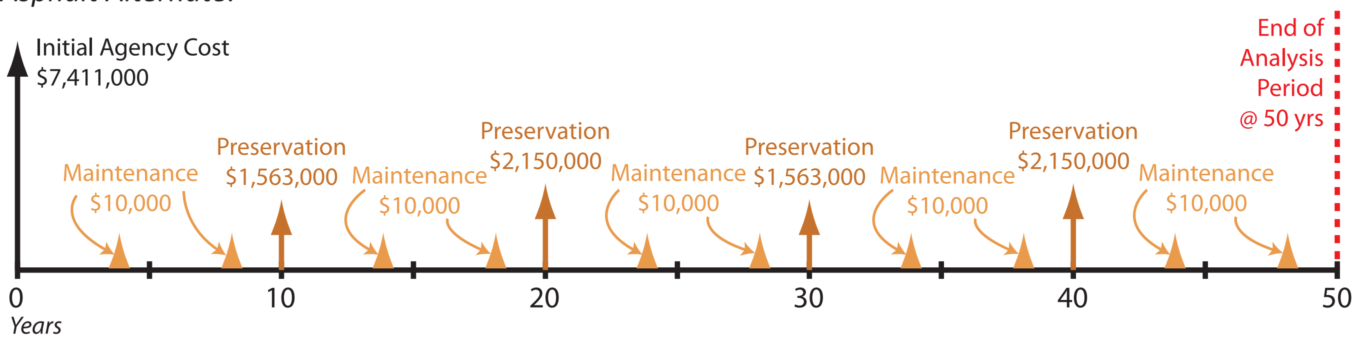


Figure 3-12. Cash flow diagram for the asphalt alternate.

Table 3-15. Net Present Value Calculation for the Asphalt Alternate (d = 3%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$7,411,000	$ 7,411,000
4	Maintenance	$10,000	$ 8,885
8	Maintenance	$10,000	$ 7,894
10	Preservation	$1,563,000	$ 1,163,019
14	Maintenance	$10,000	$ 6,611
18	Maintenance	$10,000	$ 5,874
20	Preservation	$2,150,000	$ 1,190,403
24	Maintenance	$10,000	$ 4,919
28	Maintenance	$10,000	$ 4,371
30	Preservation	$1,563,000	$ 643,935
34	Maintenance	$10,000	$ 3,660
38	Maintenance	$10,000	$ 3,252
40	Preservation	$2,150,000	$ 659,097
44	Maintenance	$10,000	$ 2,724
48	Maintenance	$10,000	$ 2,420
		TOTAL NET PRESENT VALUE:	**$ 11,118,065**

Considering only the agency costs (e.g., without user costs), the net present value of the asphalt alternate is 9.2% less than the concrete alternate. These results already tell a significantly different story about the relative costs of each alternate than that which is told by the 33% difference in initial costs. A deterministic analysis performed using RealCost confirms the previous agency cost calculations while also calculating the user costs (Figure 3-13).

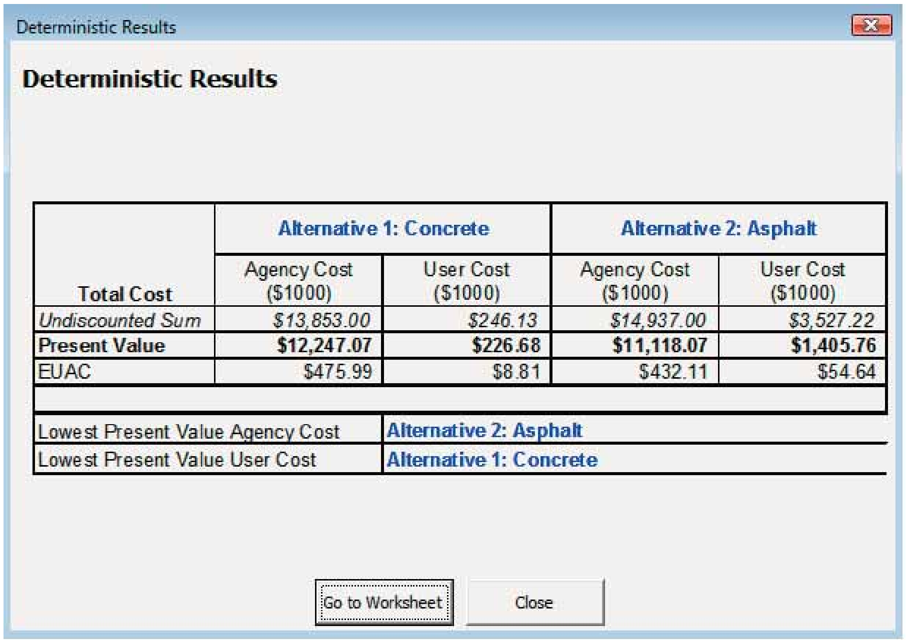


Figure 3-13. RealCost deterministic results for the concrete and asphalt alternates (d = 3%).

As discussed previously, the total net present value costs can be divided into initial agency costs (A), user costs (B), and future agency costs (C), as shown in Table 3-16.

Table 3-16. Total Net Present Value Cost Components for the Concrete and Asphalt Alternates

	Initial Agency Costs (A)	User Costs (B)	Future Agency Costs(C)	Total Net Present Value (NPV)
Concrete Alternate	$11,035,000	$226,680	$1,212,068	**$12,473,748**
Asphalt Alternate	$7,411,000	$1,405,760	$3,707,065	**$12,523,825**

The difference between the two alternates is now $50,077, just 0.4%; thus, the two alternates essentially have equivalent net present values. The B component (user cost) tells an interesting story in that the relatively frequent maintenance and preservation requirements of the asphalt alternate impose a significant cost to the roadway users. Any significant deviation from the single-point inputs used in this deterministic analysis would likely cause this too-close-to-call comparison one direction or the other.

Total cost, however, is not the only issue to consider in a thorough LCCA. Again, the cost estimation risk ratio can serve as a general indicator of the risk of significant variance in costs.

Concrete Alternate:

$11,035,000 / $12,473,748 = 88%

Asphalt Alternate:

$7,411,000 / $12,523,825 = 59%

The concrete alternate has a significantly higher ratio of initial cost to net present value and can, therefore, be deemed the option with the more reliable deterministic estimate of life-cycle costs.

A probabilistic analysis was run using RealCost default values (except those already described and except for activity three of alternate 2 (concrete pavement) being changed from a deterministic probability distribution of $1,409,000 to be a normal probability distribution with a mean of $1,409,000 and a standard deviation of $141,000 to make the input comparable in nature to all other activities having normal cost distributions with standard deviations of 10%). It should be noted that, by default, activity timings in RealCost are also assumed to be normally distributed with standard deviations of 20 percent of the mean (e.g., activities with a 10-year service life have a standard deviation of 2 years and activities with a 20-year service life have a standard deviation of 4 years); this was true for all activities except asphalt maintenance activates, which are, by default, assumed to occur in the year listed for each asphalt maintenance activity in Table 3-13. Variability also is considered, by default, in some user cost inputs. The results of the probabilistic LCCA are shown in Figure 3-14.

Probabilistic Results

Total Cost (Present Value)	Alternative 1: Concrete		Alternative 2: Asphalt	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Mean	$12,490.49	$229.16	$11,884.16	$2,001.85
Standard Deviation	$1,402.00	$11.97	$2,579.98	$1,520.68
Minimum	$7,996.27	$206.25	$7,186.11	$347.01
Maximum	$18,443.56	$310.24	$30,514.99	$17,827.31

Figure 3-14. RealCost probabilistic results for the concrete and asphalt alternates.

The mean total agency and user cost of the concrete alternate is $12,719,650, while the asphalt alternate is $13,886,010. The mean value for the concrete alternate is close to that found in the deterministic analysis because of the relatively high percent of initial agency costs to total costs for that alternate. The probabilistic analysis shows that, on average, the concrete alternate costs will be 8.4% lower than the asphalt alternate costs. These results again illustrate the great impact of frequent maintenance, preservation, and rehabilitation activities, and the variability in the costs of those activities, on the expected agency costs. Other results of the probabilistic analysis are that the concrete alternate has a potential total agency net present value cost ranging from $7,996,270 to $18,443,560, and the asphalt alternate costs range from $7,186,110 to $30,514,990. This large variability of the asphalt costs is reflected in the higher standard deviations present in the asphalt alternate's agency and user costs.

As with the last example, the high maximum net present values for both the asphalt and concrete alternates likely are a result of the use of the mean real discount rate of 3 and standard deviation of 2 with a normal probability distribution. Such a characterization of the real discount rate likely resulted in negative discount rates being used on the extreme left end of the normal probability distribution.

Based on thorough deterministic and probabilistic analyses of these two alternates, it appears that the concrete alternate should be chosen because it results in lower user costs and poses less risk of higher and unpredictable costs in the future – even though the asphalt alternate has a significantly lower initial cost.

Impact of Real Discount Rate

The sensitivity of the net present value to the selected real discount rate was investigated in deterministic analyses and the results are shown in Figure 3-15.

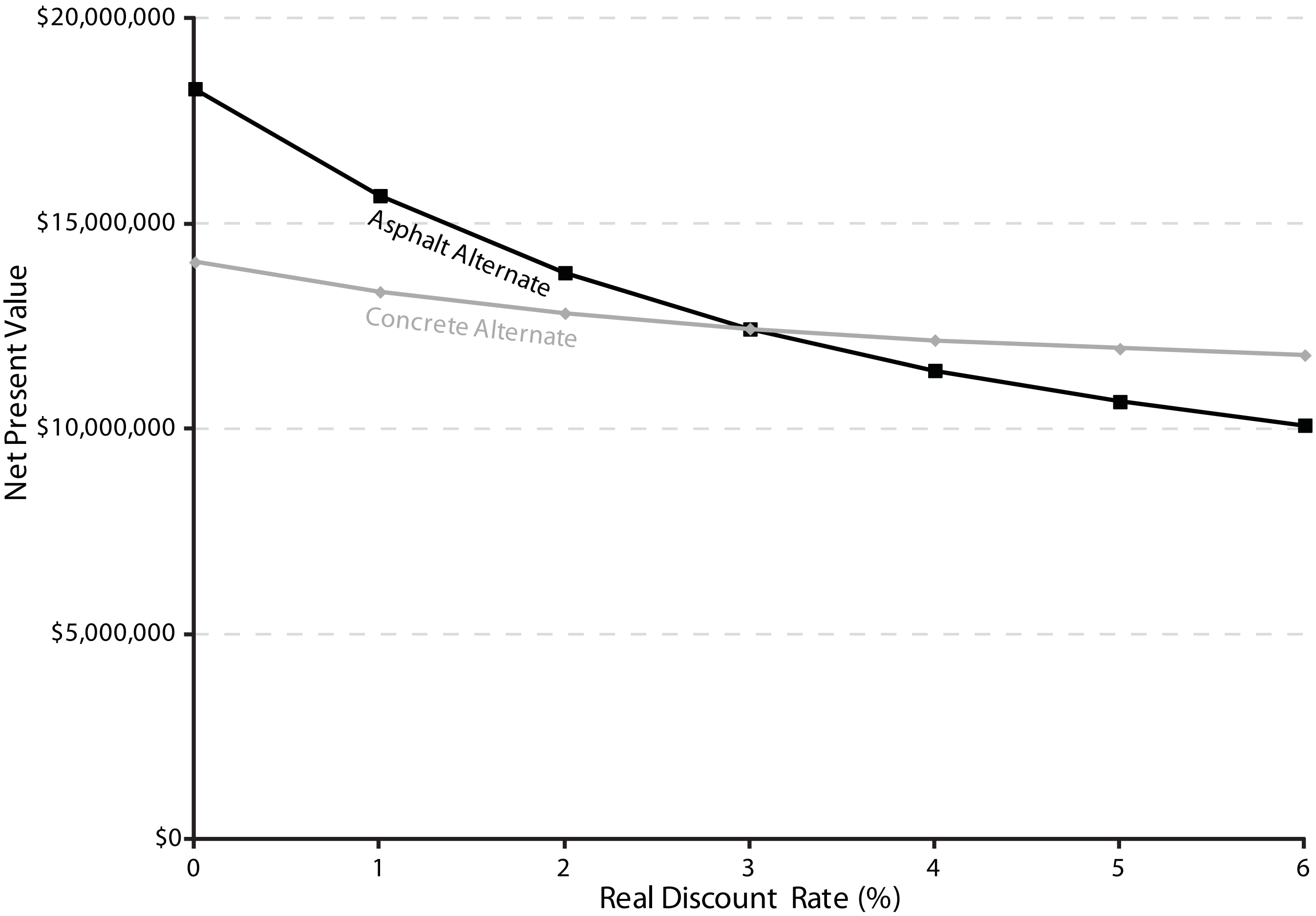


Figure 3-15. Deterministically calculated net present values for the concrete and asphalt alternates for varying real discount rates.

While the other two examples in this chapter show a convergence of the net present values of the alternates over the range of typical real discount rates used in practice, this example illustrates the great impact that the real discount rate can have. The plot also illustrates that the concrete alternate is much less sensitive to changes in the real discount rate.

Figure 3-16 shows the relative differences in NPV between the two alternates over the range of discount rates, assuming that the same real discount rate is used for each alternate.

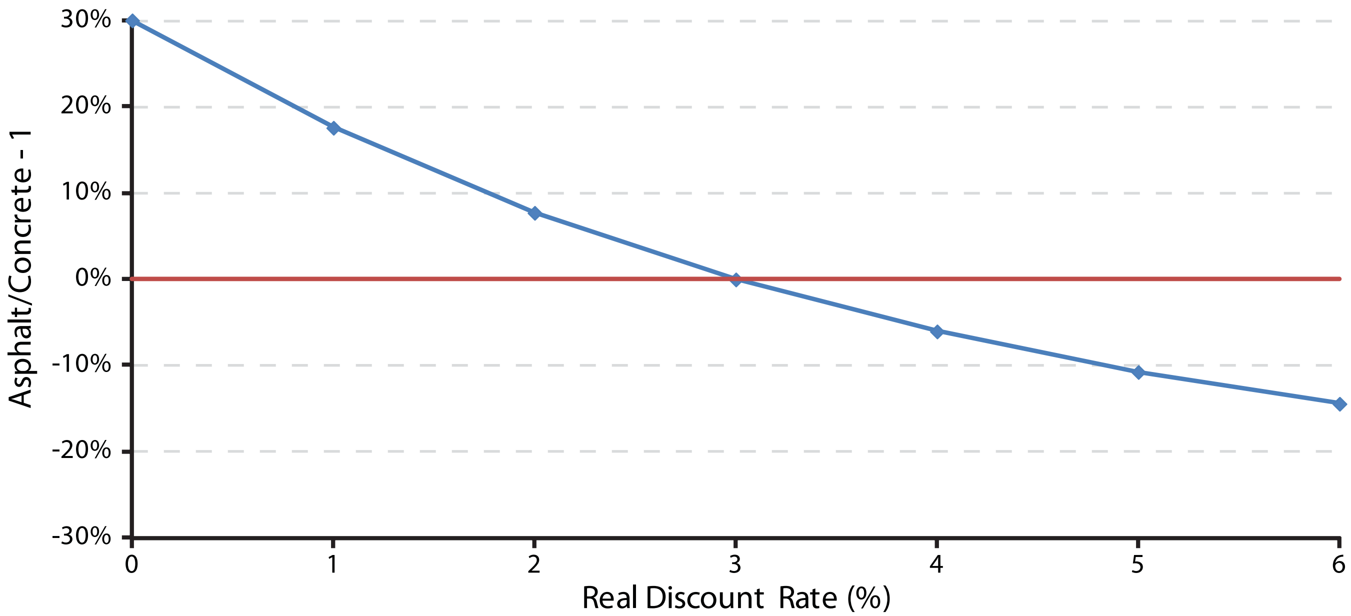


Figure 3-16. Relative difference in deterministically calculated net present values between the asphalt and concrete alternates, assuming the same real discount rate for each alternate.

Even across the small range of discount rates most commonly used in practice (i.e., 2% to 4%), the relative cost of the asphalt alternate with respect to the concrete alternate switches from being 8% more expensive to being 6% less expensive. Thus, this case example is extremely sensitive to the real discount rate used.

Impact of Future Activity Timing Predictions

Assuming a real discount rate of 3%, the sensitivity of NPV to future activity timing predictions is shown in Figure 3-17.

If the agency under-predicts the timing of a future expenditure by 5 years (e.g., the expenditure happens at 25 years instead of 20, 35 years instead of 30 years, etc.), the actual present worth of that activity will be just 86% of what was calculated in the incorrectly assumed year. If the expenditure timing is over-predicted by 5 years, the actual present worth will be 116% of the value calculated at the incorrectly assumed year. **This trend is independent of both year in which the expenditure is predicted and value of the expenditure**; all that is important is the difference between the predicted activity timing and when it actually occurs. Table 3-17 contains some example calculations to illustrate this point, assuming a real discount rate of 3%.

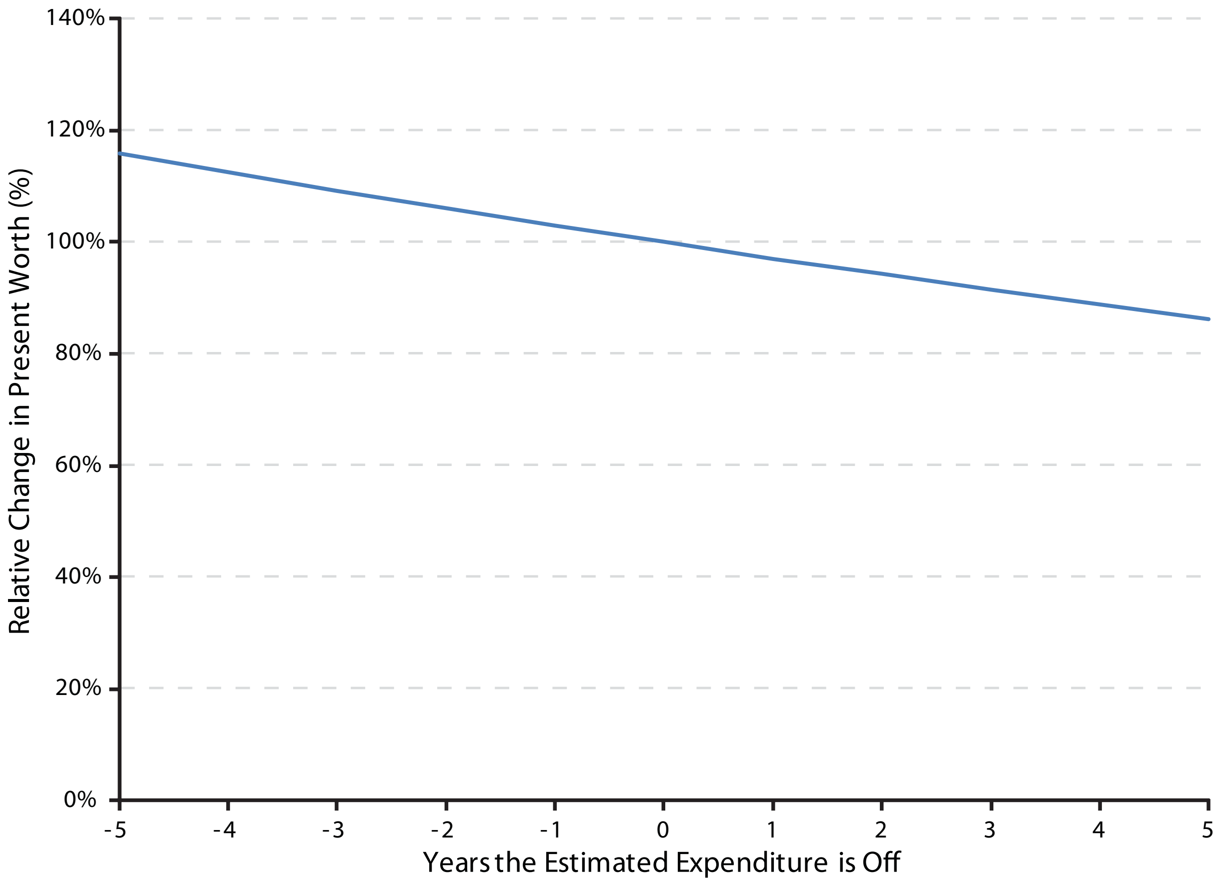


Figure 3-17. Relative change in present worth due to future activity timing errors, assuming a real discount rate of 3% .

Table 3-17. Relative Change in Present Worth Due to Future Activity Timing Errors at Different Planned Times and for Different Expenditure Values (d = 3%)

Timing	Year	Expenditure	Present Worth	% of 30 yr Value
- 5 years	25	$1,563,000	$ 746,498	116%
- 3 years	27	$1,563,000	$ 703,645	109%
- 1 year	29	$1,563,000	$ 663,253	103%
Planned	*30*	*$1,563,000*	*$ 643,935*	*100%*
+ 1 year	31	$1,563,000	$ 625,180	97%
+ 3 years	33	$1,563,000	$ 589,292	92%
+ 5 years	35	$1,563,000	$ 555,464	86%

Timing	Year	Expenditure	Present Worth	% of 48 yr Value
- 5 years	43	$10,000	$ 2,805	116%
- 3 years	45	$10,000	$ 2,644	109%
- 1 year	47	$10,000	$ 2,493	103%
Planned	*48*	*$10,000*	*$ 2,420*	*100%*
+ 1 year	49	$10,000	$ 2,350	97%
+ 3 years	51	$10,000	$ 2,215	92%
+ 5 years	53	$10,000	$ 2,088	86%

Despite having drastically different activity costs and timings, the relative change in present worth is identical for different deviations from the planned activity timing.

This trend is, however, highly dependent on the real discount rate used in the analysis (Figure 3-18).

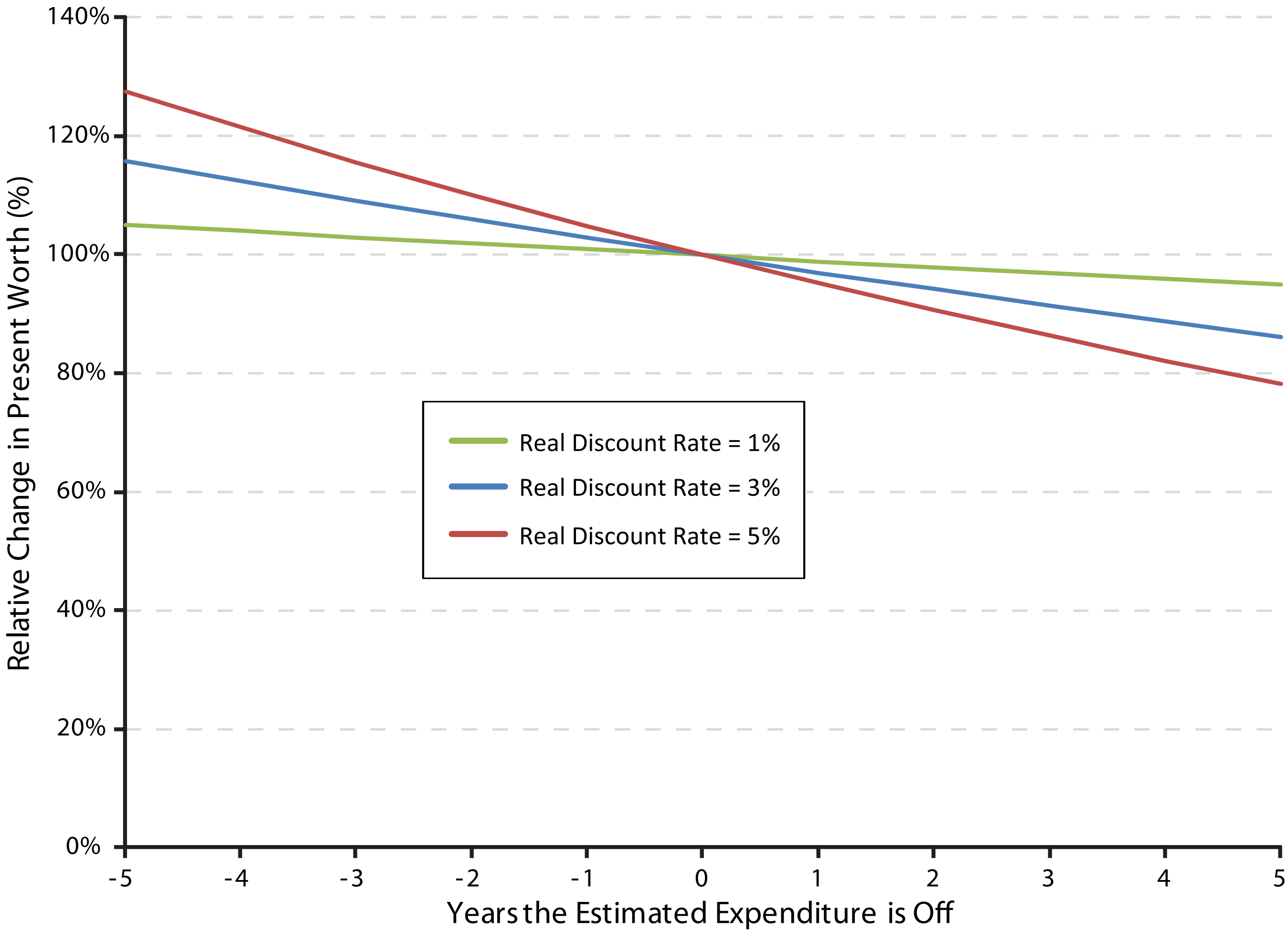


Figure 3-18. Relative change in present worth due to future activity timing errors for real discount rates of 1%, 3%, and 5%.

The net effective of poor predictions in activity timing can greatly impact LCCA results. For the $1,563,000 expenditure at year 30 of the asphalt alternate in this example, if the previous preservation were to underperform by 5 years and the expenditure had to be made in 25 years instead, the net present value of that alternate would have been $746,498 – $643,935 = $102,563 greater, a significant change to the net present value of that activity. Smaller expenditures, however, are not as problematic in this regard. Consider the $10,000 expenditure in year 48; had this been required 5 years earlier (in year 43), the impact on the net present value would only be $385. This difference resulting from such over- and under-predictions of performance also are larger if the expenditure is earlier in the life of the pavement structure.

Total Cost of Ownership

As discussed previously, the total cost of ownership is a calculation of the total inflated expenditures necessary for each alternate. Thus, it presents the total budgetary requirements of each alternate over its projected life using inflated dollars.

Concrete Alternate:

To calculate the total cost of ownership for the concrete alternate, a real discount rate of -3.85% is again used (Table 3-18).

Table 3-18. Total Ownership Cost Calculation for the Concrete Alternate (d = -3.85%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$11,035,000	$ 11,035,000
20	Maintenance	$1,409,000	$ 3,087,322
40	Maintenance	$1,409,000	$ 6,764,768
		TOTAL OWNERSHIP COST:	**$ 20,887,090**

Asphalt Alternate:

Similar to the values in the last example, it is assumed that 40% of the cost of each overlay activity in years 10, 20, 30, and 40 is asphalt material that should be discounted at the asphalt's material-specific real discount rate of -5.2%; all other items can be discounted at the general real discount rate of -3.85%. The asphalt alternate's net value (and, thus, the total cost of ownership) is calculated in Table 3-19.

Table 3-19. Total Ownership Cost Calculation for the Asphalt Alternate (standard d = -3.85%; asphalt paving d = -5.2%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$7,411,000	$ 7,411,000
4	Maintenance	$10,000	$ 11,699
8	Maintenance	$10,000	$ 13,686
10	60% Preservation	$937,800	$ 1,388,180
10	**40% Preservation**	**$625,200**	**$ 1,067,935**
14	Maintenance	$10,000	$ 17,317
18	Maintenance	$10,000	$ 20,258
20	60% Preservation	$1,290,000	$ 2,826,576
20	**40% Preservation**	**$860,000**	**$ 2,509,287**
24	Maintenance	$10,000	$ 25,633
28	Maintenance	$10,000	$ 29,987
30	60% Preservation	$937,800	$ 3,041,702
30	**40% Preservation**	**$625,200**	**$ 3,115,996**
34	Maintenance	$10,000	$ 37,944
38	Maintenance	$10,000	$ 44,389
40	60% Preservation	$1,290,000	$ 6,193,436
40	**40% Preservation**	**$860,000**	**$ 7,321,538**
44	Maintenance	$10,000	$ 56,166
48	Maintenance	$10,000	$ 65,707
		TOTAL OWNERSHIP COST:	**$35,198,436**

While the concrete and asphalt alternates had practically identical agency costs (in constant dollars) in the original deterministic LCCA, the concrete alternate will cost the agency just 40% of the comparable asphalt alternate (in inflated or actual dollars) over 50 years if future asphalt and concrete costs inflate as they have for the past 54 years; the difference will be even larger if user costs are included.

General Discussion/Conclusions

This case study illustrates that:

- LCCA is not a decision tool in and of itself but, rather, it is a decision support tool that is part of the overall decision-making process. Because the results of an LCCA can be extremely sensitive to a few key inputs, such as is the case with the real discount rate in this example, a comprehensive LCCA requires more than just consideration of a deterministic analysis with single input values.
- When two or more alternates have very similar costs associated with them, assessment of the risk of cost volatility to the agency (and taxpayers) by means of evaluating the cost estimation risk ratio is a reasonable means of determining the alternate with the greatest probability of having the lowest life-cycle cost. Selection of an alternate with a lower ratio of initial-to-total costs leaves the agency exposed to a greater potential to increased future expenditures.
- The selection and consideration of appropriate inputs is key to the results. Because this example had considerably higher user costs associated with just one of the alternates, it was critical to consider the user cost component to get an accurate representation of which alternate is most cost-effective. As noted, while user costs can be controversial and difficult to quantify, users do incur these costs (as well as the entire agency cost, through taxes, tolls, etc.), so consideration of such values is justifiable.
- While it may seem as though it is not as critical to accurately predict future activity timings as the costs associated with them, under- or over-prediction of the life of such activities can have a significant impact on the net present value calculations, particularly early in the life-cycle of the alternate. Variability in future activity timings and other inputs is best accounted for through a probabilistic LCCA.
- Total ownership cost calculations, with consideration for materials that inflate at significantly different rates than those of general inflation, is the only means by which agencies can estimate their true expenditure requirements for any alternate over time.

Airport Example

General Details

Agency/Owner: Pensacola Regional Airport
Location: Pensacola, FL
Year of LCCA: 2006
Classification: Airfield Runway
Design Method(s) Used: FAA AC 150/5320-6D and LEDFAA
Traffic: Boeing 757 – 5,781 annual operations

Project Scope: Reconstruction of runway 17/35, approximately 7,000 ft (2,130 m) by 150 ft (46 m).

Other Project Details: The project was originally let in 2005, with a planned cost of $27 million. The original design was 12 in. (300 mm) of asphalt (P-401) atop 5 in. (125 mm) of granular subbase (P-154) atop 12 in. (300 mm) of compacted subgrade. 3 contractors submitted bids in the 2005 letting, one subsequently dropped out and the remaining two joined forces but submitted a bid that was $4 million over budget. As a result, the project was re-let with a concrete alternate and LCCA included.

Pavement Alternates: The concrete and asphalt alternates, based on the FAA AC 150/5320-6D and LEDFAA designs, are shown in Figure 3-19.

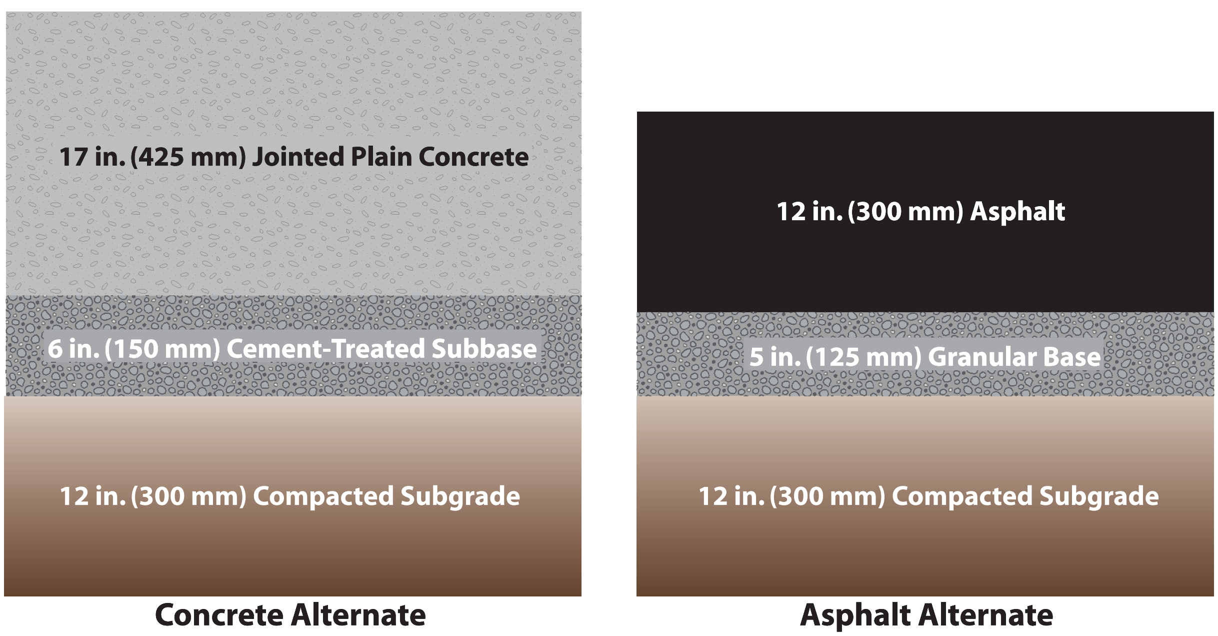


Figure 3-19. Pensacola Regional Airport's concrete and asphalt alternate pavement cross-sections for reconstruction of runway 17/35.

Life-Cycle Cost Analysis

Step 1 – Select Analysis Period: 20 years; this value was chosen because of an FAA requirement at the time of the LCCA, but, as recommended earlier, the analysis period should be long enough to encompass the initial performance period and at least one major follow-up preservation/rehabilitation activity for each strategy.

Step 2 – Select Real Discount Rate: 5%

Step 3 – Estimate Initial Agency Costs: The actual lowest bid prices of the concrete and asphalt alternates were used in the LCCA. Four concrete bids and two asphalt bids were submitted (Table 3-20).

Table 3-20. Concrete and Asphalt Bids Received by Pensacola Regional Airport in 2006 for the Reconstruction of Runway 17/35

As-Read Bid Results	Concrete Alternate	Asphalt Alternate
Bidder 1	**$23,591,682**	$22,019,551
Bidder 2	$26,245,084	**$21,767,513**
Bidder 3	$30,053,562	N/A
Bidder 4	$32,328,956	N/A

As noted, the single bid received in 2005 was $4 million over the $27 million budget; most of the bids submitted during the second letting were below the initial project budget. Thus, the stimulation of completion by the introduction of an alternate pavement type and LCCA on this project immediately saved the airport millions of dollars in initial construction costs.

Step 4 – Estimate User Costs: User costs were not considered.

Step 5 – Estimate Future Agency Costs:

Concrete Alternate:

Table 3-21. Future Agency Costs for the Concrete Alternate

Year	Type of Work	Description of Work	Quantity	Unit Price	Total Cost
15	Maintenance	Joint Resealing	113,233 LF	$1.70/LF	$192,496
19	Maintenance	Crack Sealing	130,309 SY	$1.30/SY	$169,402
20	Preservation	Slab Replacement (5% Panels)	6,515 SY	$100.00/SY	$651,545

Asphalt Alternate:

Table 3-22. Future Agency Costs for the Asphalt Alternate

Year	Type of Work	Description of Work	Quantity	Unit Price	Total Cost
6	Maintenance	General Maintenance	130,309 SY	$2.00/SY	$260,618
13	Maintenance	General Maintenance	130,309 SY	$2.00/SY	$260,618
15	Preservation	3-in. Mill & Overlay	130,309 SY	$15.12/SY	$1,970,272

Step 6 – Estimate Residual Value: A straight-line depreciation approach was used to calculate the residual value of each alternate.

Concrete Alternate:

The concrete alternate is assumed to have a 40 year design life (despite having a significantly thicker section than the asphalt alternate) so there are 20 years of remaining life after the 20-year analysis period.

$$Residual\ Value = \frac{Initial\ Agency\ Cost * Remaining\ Life}{Design\ Life}$$

$$Residual\ Value = \frac{\$23{,}591{,}682 * 20\ yrs}{40\ yrs} = \$11{,}795{,}841$$

Asphalt Alternate:

The initial asphalt alternate receives a 3-in. (75-mm) mill and overlay at year 15 and that system is assumed to have 10 years of remaining service life at the end of the 20-year analysis period. Thus, both the initial agency cost and cost associated with the mill and overlay contribute to the residual value (it is important to note that current FHWA recommendations state that only the residual value of the last rehabilitation activity should be considered).

$$\textit{Residual Value} = \frac{\textit{Initial Agency Cost} * \textit{Remaining Life}}{\textit{Initial Pavement Design Life}} + \frac{\textit{Overlay Agency Cost} * \textit{Remaining Life}}{\textit{Overlay Design Life}}$$

$$\textit{Residual Value} = \frac{\$21{,}767{,}513 * 10\ yrs}{30\ yrs} + \frac{\$1{,}970{,}272 * 10\ yrs}{15\ yrs} = \$8{,}569{,}352$$

NOTE: Even though the asphalt alternate has a major preservation/rehabilitation activity scheduled for year 15, the concrete alternate does not have one scheduled until year 40; thus, the analysis period for this example would more appropriately be 40+ years to ensure that the initial performance period and at least one major follow-up preservation/rehabilitation activity is included in the analysis for each strategy. Also, and although it was not a consideration in the analysis conducted for the airport, the concrete preservation activity at year 20 should have been included in the residual value at its full value because none of it will have been consumed at the end of year 20.

Step 7 – Compare Alternatives: The alternates are first compared using a deterministic analysis to calculate the net present value of each alternate.

Concrete Alternate:

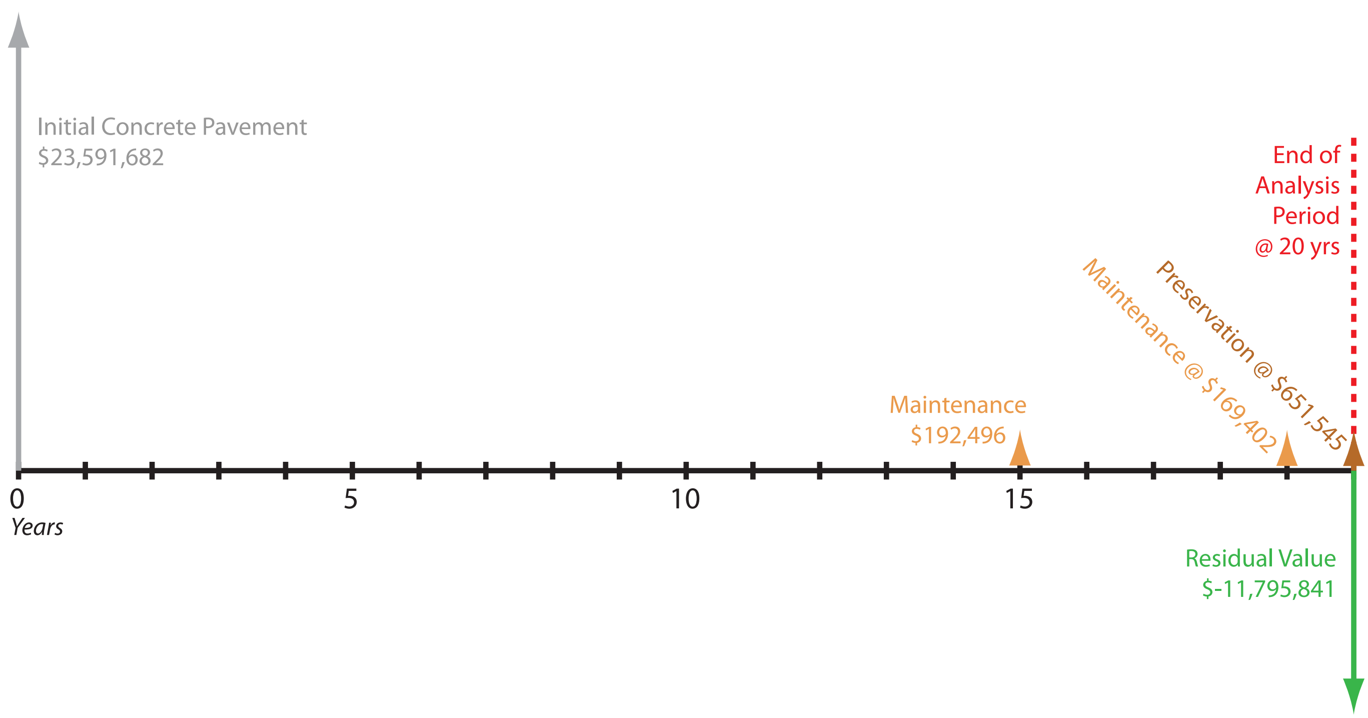


Figure 3-20. Cash flow diagram for the concrete alternate.

Table 3-23. Net Present Value Calculation for the Concrete Alternate (d = 5%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$23,591,682	$ 23,591,682
15	Maintenance	$192,496	$ 92,594
19	Maintenance	$169,402	$ 67,038
20	Preservation	$651,545	$ 245,560
20	Residual Value	($11,795,841)	($ 4,445,728)
		TOTAL NET PRESENT VALUE:	**$ 19,551,146**

Asphalt Alternate:

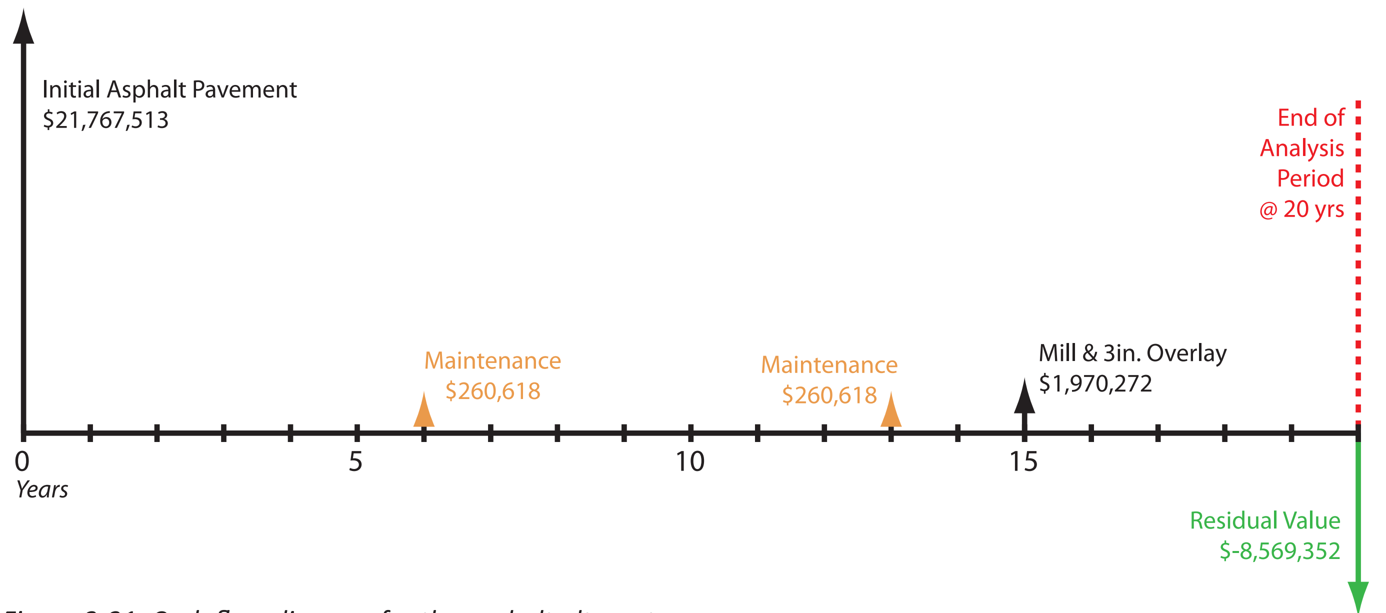


Figure 3-21. Cash flow diagram for the asphalt alternate.

Table 3-24. Net Present Value Calculation for the Asphalt Alternate (d = 5%)

Year	Type of Work	Total Cost	Present Worth
0	Initial Construction	$21,767,513	$ 21,767,513
6	Maintenance	$260,618	$ 194,477
13	Maintenance	$260,618	$ 138,211
15	Preservation	$1,970,272	$ 947,735
20	Residual Value	($8,569,352)	($ 3,229,699)
		TOTAL NET PRESENT VALUE:	**$ 19,818,237**

Although the initial agency cost for the asphalt alternate is 7.7% less than that of the concrete alternate, the concrete alternate life-cycle cost is 1.3% less than that of the asphalt alternate in this very short 20-year LCCA. The ratio of the initial agency cost to total net present value is 121% for the concrete alternate, while it is just 110% for the asphalt alternate (note that these values are greater than 100% because of the relatively short analysis period and large residual values); based on this, the concrete alternate has less risk of cost volatility associated with it.

Thus, the concrete alternate is more cost-effective and the associated costs are less subject to unexpected increase; for these reasons, the concrete alternate was chosen by the Pensacola Regional Airport for the reconstruction of runway 17/35.

RealCost confirms the deterministic calculations described above (note that the year 19 maintenance in the concrete alternate had to be given an activity service life of 0.9999 years for the 20 year preservation to be included in the calculations; typical LCCAs do not include expenditures in the final year of the analysis and if they occur in the final year of the analysis they are ignored by RealCost), as shown in Figure 3-22.

Deterministic Results

Deterministic Results

Total Cost	Alternative 1: Concrete		Alternative 2: Asphalt	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$12,809.28*	*$0.00*	*$15,689.67*	*$0.00*
Present Value	**$19,551.15**	**$0.00**	**$19,818.24**	**$0.00**
EUAC	$1,568.83	$0.00	$1,590.27	$0.00

Lowest Present Value Agency Cost	Alternative 1: concrete
Lowest Present Value User Cost	Alternative 1: concrete

Go to Worksheet | Close

Figure 3-22. RealCost deterministic results for the concrete and asphalt alternates (d = 5%).

A probabilistic analysis was run using RealCost, with each activity cost, timing, and structural life that factor into the remaining service life being assigned normal probability distributions having mean values equal to those used in the deterministic analysis and the standard deviations set to 10% the input mean values. The results of the probabilistic analysis are shown in Figure 3-23.

Probabilistic Results

Probabilistic Results

Total Cost (Present Value)	Alternative 1: Concrete		Alternative 2: Asphalt	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Mean	$19,437.92	$0.00	$19,883.27	$0.00
Standard Deviation	$1,985.84	$0.00	$2,036.73	$0.00
Minimum	$12,904.57	$0.00	$13,919.86	$0.00
Maximum	$26,867.05	$0.00	$27,330.11	$0.00

Probabilistic Results Worksheet | Output Distributions Worksheet | Tornado Graphs Analysis Worksheet | Extreme Tail Analysis Worksheet | Close

Figure 3-23. RealCost probabilistic results for the concrete and asphalt alternates.

Though not a significant difference, the mean net present value of the concrete life-cycle cost is 2.2% less than that of the asphalt alternate in the probabilistic analysis, up from 1.4% in the deterministic analysis. The results also show that the asphalt alternate life-cycle cost has a higher standard deviation and, thus, more risk of volatility associated with it (mostly due to the slightly higher costs being incurred later in the life of the pavement in this example).

As with the last two examples, the high maximum net present values for both the asphalt and concrete alternates likely are a result of real discount rate probability distribution.

Impact of Real Discount Rate

The sensitivity of the real discount rate on net present value was investigated in deterministic analyses (Figure 3-24).

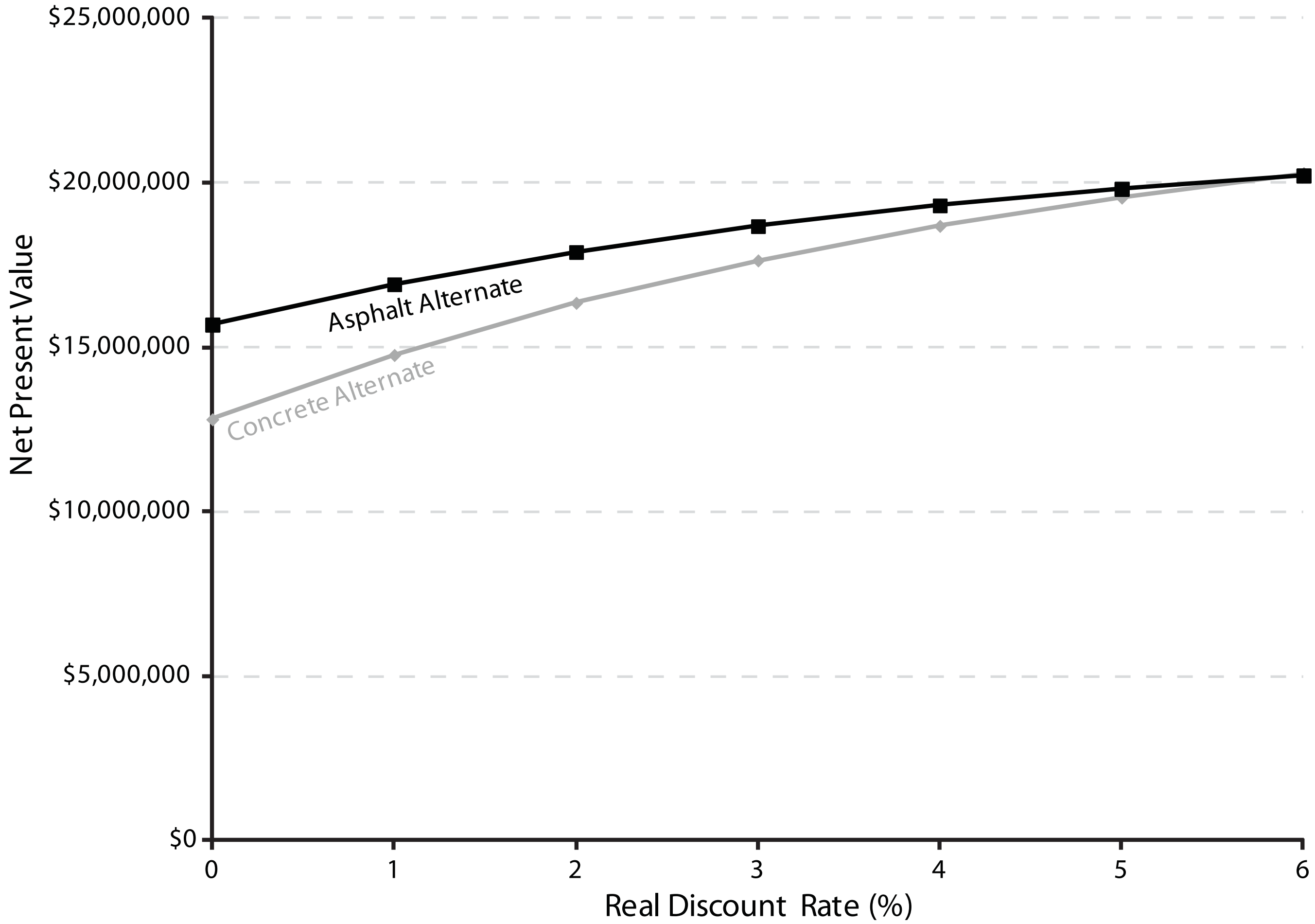


Figure 3-24. Deterministically calculated net present values for the concrete and asphalt alternates for varying real discount rates.

The trendlines shown in Figure 3-24 present a different result than those for the local road and highway examples. This is due to the relatively lower maintenance and preservation requirements scheduled for the asphalt alternate over this very short analysis period, the high percentage of total net present value represented by the initial cost for both alternates, the impact of the residual value, and the very short analysis period.

General Discussion/Conclusions

This case study illustrates the following:

- Concrete can be the most cost-effective paving solution even when the analysis period is relatively short because asphalt pavements often require significant and costly overlaying within a relatively short time-frame.
- Because the analysis period is relatively short in this case, the inclusion of the residual value is particularly important, as both pavement systems should be expected to perform for some time after the end of the 20-year analysis period. A better LCCA practice is to use an analysis period that is long enough to encompass the initial performance period and at least one major follow-up preservation/rehabilitation activity for each strategy.
- Variables such as residual value, activity timing, and analysis period can greatly impact the sensitivity of real discount rate on the LCCA results.
- The inclusion of the concrete alternate and LCCA in this example brought much competition and value to the owner, as is evident in the significant drop in asphalt bid prices from the original 2005 letting to the 2006 letting, an especially surprising result given that the average annual Asphalt Paving Materials and Blocks PPI increased 28% from 2005 to 2006.

Projects such as this have proven the value of LCCA for pavement type selection for airfield and military construction and guidance for such applications is increasingly available (AAPTP 2011; ARMY 1992; FAA 2009).

Chapter 4. Applications and Extensions of Life-Cycle Cost Analysis

Network-Level Service Life and Economic Analyses

This section discusses the impact of project-level LCCA-based decisions on network-level costs and performance measures. Viewed from a different (and probably more realistic) perspective, network-level constraints (e.g., limited funding) often lead to sub-optimal selections at the project level.

Network-level pavement management activities are part of the larger field of "asset management”. Comprehensive asset management software are available for Interstate highway systems and such advanced software and discussion on implementation of such tools are available elsewhere (NCHRP 2009).

An Introduction to Network-Level Analysis: The “Mix of Fixes” Concept

Strategic asset allocation is a well-established theory that is most notably applied in personal portfolio management. This method adheres to the **‘base policy mix’** principle, in which a combination of asset classes exists and the combined return is based on a proportional ownership and return of each individual asset. For example, if someone’s portfolio consists of 70% stocks yielding a 10% return per year and 30% bonds yielding a 5% return per year, the combined return is 8.5% per year (0.7*10% + 0.3*5% = 8.5%).

The application of strategic asset allocation principles to a pavement network allows the manager to maintain the network in the highest possible overall condition at any given constant level of dollar flow into the pavement network. Such a system is inherently dynamic, so reallocation is necessary at regular intervals to deliver a continuously optimized system. Thus, **the asset allocation mix will reflect the strategic goals for the system at any given time.**

The Federal Highway Administration (FHWA) publication "A Quick Check of Your Highway Network Health" states (FHWA 2007b):

> "By viewing the network in this manner [with each pavement as an asset in a collected network], there is a certain comfort derived from the ability to match pavement actions with their physical/functional needs. However, **by only focusing on projects, opportunities for strategically managing entire road networks and asset needs are overlooked.**"

By way of this statement, the **FHWA has advocated the implementation of asset allocation strategies in lieu of a traditional "bottom up" approach, in which the worst roadways receive attention first.**

Consider a hypothetical 3,000-mile (4,830-km) pavement network in the following condition:

- One-third (1,000 miles [1,610 km]) of the system consists of pavement that will require work in 5 years.
- One-third (1,000 miles [1,610 km]) of the system consists of pavement that will require work in 10 years.
- One-third (1,000 miles [1,610 km]) of the system is to be reconstructed immediately using either a short-term (anticipated service life of 15 years) or long-term (anticipated service life of 30 years) pavement solution.

To evaluate the effects of the reconstruction options, the average remaining service life (RSL) for each mile (km) of the network is calculated using the 'base policy mix' principle (Table 4-1). As shown, the selection of the long-term pavement solution adds 5 years to the average remaining service life of the network. Although this is a greatly simplified example, the principle that longer-life pavement solutions will always extend the average remaining service life of the overall network holds true in any case.

Table 4-1. Average Remaining Service Life (RSL) for a Hypothetical Network of 3,000 miles (4,830 km)

Short-Term Pavement Solution		
Segment Length, mi (km)	Time to Next Activity, yr	Remaining Years of Service in Segment, yr-mi (yr-km)
1,000 (1,610)	5	5,000 (8,050)
1,000 (1,610)	10	10,000 (16,100)
1,000 (1,610)	15	15,000 (24,150)
	Total:	30,000 (48,300)
Average Remaining Service Life for Each Mile = 30,000 yr-mi/3,000 mi = 10 yrs (= 48,300 yr-km/4,830 km = 10 yrs)		

Long-Term Pavement Solution		
Segment Length, mi (km)	Time to Next Activity, yr	Remaining Years of Service in Segment, yr-mi (yr-km)
1,000 (1,610)	5	5,000 (8,050)
1,000 (1,610)	10	10,000 (16,100)
1,000 (1,610)	30	30,000 (48,300)
	Total:	45,000 (72,450)
Average Remaining Service Life for Each Mile = 45,000 yr-mi/3,000 mi = 15 yrs (= 72,450 yr-km/4,830 km = 15 yrs)		

Though evaluating a current pavement network and alternative reconstruction options involves relatively simple calculations, making a decision based on which pavement preservation technique is most applicable on which pavement section and at what time is much more difficult and more significant to a pavement allocation program. Regardless of the pavement preservation method chosen for a road, timeliness is of utmost importance because of its implications on available funding and the future of the pavement system. Luckily, "**a palette of pavement preservation treatments, or 'Mix of Fixes', is available to address the network needs at a much lower cost than traditional methods**" (FHWA 2007b).

A means of quantifying network health, such as the RSL, can include all pavement distress modes and serviceability issues. FHWA has also recently developed a Pavement Health Track (PHT) Analysis Tool to aid in determining and reporting the health of pavement networks in terms of the pavement's RSL (FHWA 2010d). Once the method of quantifying the health of the network is determined, a computer-based pavement management system (PMS) must be implemented to guide the decision-making process. A PMS does not make the decisions, but rather provides valuable insight on applicable preservation options. Only with a fully-evaluated network and the aid of a PMS can the network decision-makers make the best decisions – decisions that will optimize the health or condition of their pavement network and save taxpayers money.

A Detailed Network Analysis

Lending credence to the concept of a "mix of fixes", the **FHWA has stated, "'remaining service life' (RSL) is the tool we need to apply"** (FHWA 2007b). More detailed network analyses are nothing more than extensions of this concept; although the metrics investigated may change, **long-term cost-effective solutions will always add the most value to the network**.

The example presented in this section consists of an existing pavement network with a total length of 1,000 miles (1,610 km), split into 200 numbered pavement sections in a spreadsheet program. The sections could each be 5 miles (8 km) long, but for greater realism, a normal distribution of lengths, with a target mean of 5 miles (8 km), was generated using a random number generator. Similarly, a normal distribution of ages for these 200 pavement sections, with a target mean age of 12 years, was also generated. It is assumed that each of the existing pavement sections has a 20-year service life, so each section will be reconstructed at age 20.

Thus, the largest number of projects must be reconstructed in 12 years and all will be constructed within 20 years. If reconstructions are completed using 20-year solutions, the cycle would will repeat itself every 20 years (Figure 4-1).

If, instead, 40-year solutions are used, the initial 20 year replacement cycle is the same as for the 20-year solution but the next cycle does not occur until year 40 (Figure 4-2).

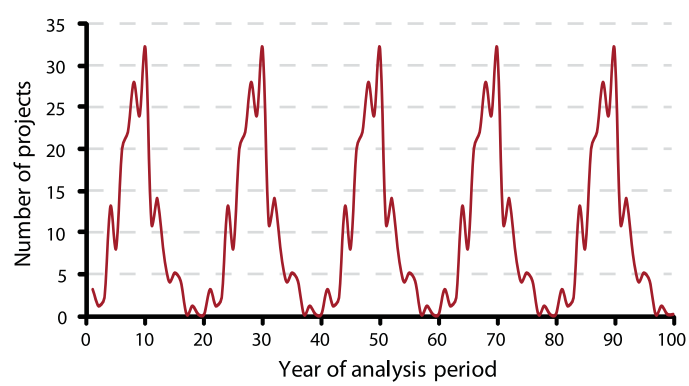


Figure 4-1. Reconstruction projects per year for 20-year reconstruction solutions over a 100-year period.

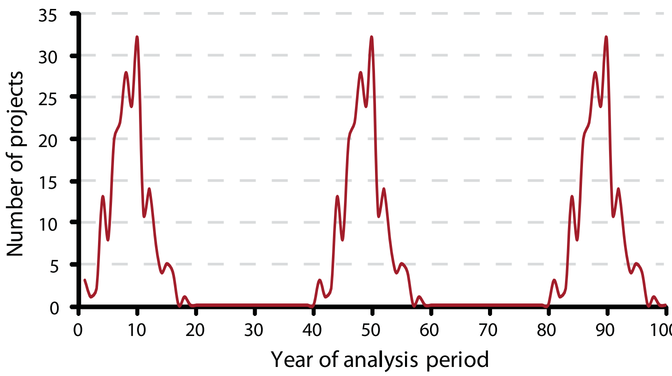


Figure 4-2. Reconstruction projects per year for 40-year reconstruction solutions over a 100-year period.

If even longer-term solutions can be found, the reconstruction cycle shifts even further into the future. For example, if 100-year solutions could be found, there would only be the first, 20-year long reconstruction cycle necessary over a 100-year period (Figure 4-3).

If 100-year service lives can be realized for all reconstructions, each of the 200 pavement sections in this example would only have to be reconstructed once; thus, there would only be a need for 200 project lettings, all within the first 20 years of the 100-year period. Reconstruction with 20-year solutions would require 1,000 project lettings (e.g., the 5 complete reconstruction cycles of all 200 projects shown in Figure 4-1). 40-year and 50-year reconstruction solutions would result in 600 and 400 projects, respectively, over 100 years.

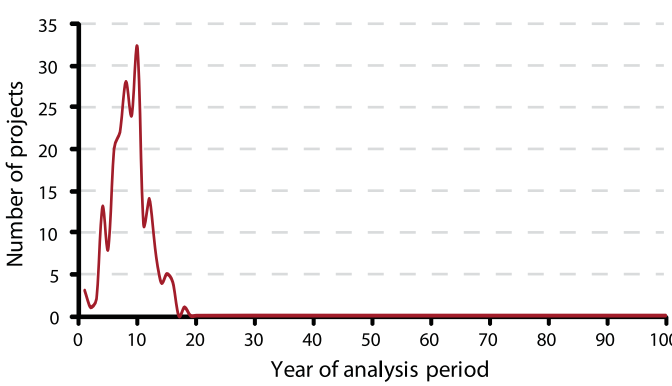


Figure 4-3. Reconstruction projects per year for 100-year reconstruction solutions over a 100-year period.

The RSL of this 1,000-mile (1,610-km) network can be calculated at any point in time for any assumed reconstruction solution service life. Using the assumptions presented in this example, this was done for 20-, 30-, 40-, 50-, and 100-year reconstruction fixes (Figure 4-4).

As shown, the 20-year reconstruction solutions never result in a network RSL larger than 15 years. As the service life of the reconstructions increases, so does the average network RSL, which is 10.5 years for the 20-year solution, 15.1 years for the 30 year solution, 20.9 years for the 40 year solution, 25.5 years for the 50 year solution, and 50.5 years for the 100 year solution. Although Figure 4-4 shows some years where longer-term solutions would result in a lower network RSL than shorter-term solutions, this is an artifact of the assumptions of this example; longer-term solutions will always add more service life to a network than shorter-term solutions, as is evident by the slope of each line within the first 16 years. Thus, **reconstruction with longer-term solutions, regardless of material used to achieve a longer service life, results in large increases in the RSL of the network**.

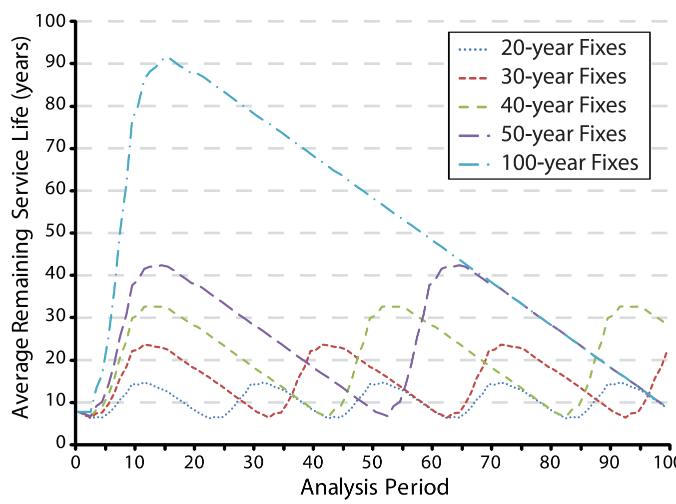


Figure 4-4. Network remaining service life (RSL) for 20-, 30-, 40-, 50-, and 100-year reconstruction solutions over a 100-year period.

Sustainability in the Context of a Life-Cycle Cost Analysis

The benefits of sustainable development are becoming increasingly important to public agencies. In the realm of highway and road construction, sustainable development involves being good stewards of the environment, balancing the needs of business, and providing societal benefits.

While an LCCA focuses on agency and user costs associated with pavement items, a **life-cycle assessment (LCA)** focuses on the environmental impact (e.g., carbon dioxide and other greenhouse gas emissions). While much has been done to quantify the economics of pavement alternatives through LCCAs and substantial research has been conducted in the arena of LCAs of alternate pavements, the direct connection between LCCAs and LCAs has not yet been well established in practice. Any direct cost impact from an LCA should, however, be considered in a thorough LCCA; some have suggested that direct sustainability-related cost saving be included as a D component in an A+B+C bid method nomenclature and that the strictly environmental impacts be included as an E component.

Not all pavement type selection decision factors are easily quantified in monetary terms and not all monetary factors bear equal weight in the decision process. For example, agency costs and user costs are typically viewed separately (e.g., broken out as part of the A+B+C bid method nomenclature) to aid the agency in appropriately weighing each factor. As such, integration of pavement sustainability into the A+B+C bid nomenclature as D and E components will allow such consideration for these components as well. Multi-factor decision matrices can then be used to aid in the decision making process.

Because pavement LCA is still a relatively new field of study, many researchers around the world are currently working to develop LCA models capable of estimating the environmental and monetary impacts of different pavement materials, designs, and construction techniques. See MIT 2011b and 2011c, and NCPTC 2012 for more details on pavement LCAs.

Concrete Pavement Sustainability Factors

The many aspects of concrete pavement design, construction, maintenance, and performance that relate to the objectives and goals of sustainable development include (Figure 4-5):

- Longevity,
- Reduced fuel consumption and emissions during construction and during use,
- Lower energy footprint,
- Reduced use of natural resources,
- Use of industrial byproducts,
- Pavement renewal,
- Optimized (e.g., quiet and safe) surface textures,
- Improved stormwater quality,
- Pavement recycling,
- And light colored and cool surface, which can reduce lighting requirements, mitigate urban heat island, and lead to global cooling.

The issue of vehicle fuel consumption (see Step 4), for example, is likely to become an increasing concerns as the steadily forward march of economic development confronts, and is potentially constrained by, the world's finite supply of fossil fuels. It is important to remember, however, that sustainability goes beyond mere fuel conservation; the goal of sustainability has been defined as "**meeting the needs of the present without compromising the ability of future generations to meet their own needs**," (WCED 1987), thus it extends to all facets of pavement design, construction, maintenance, and performance.

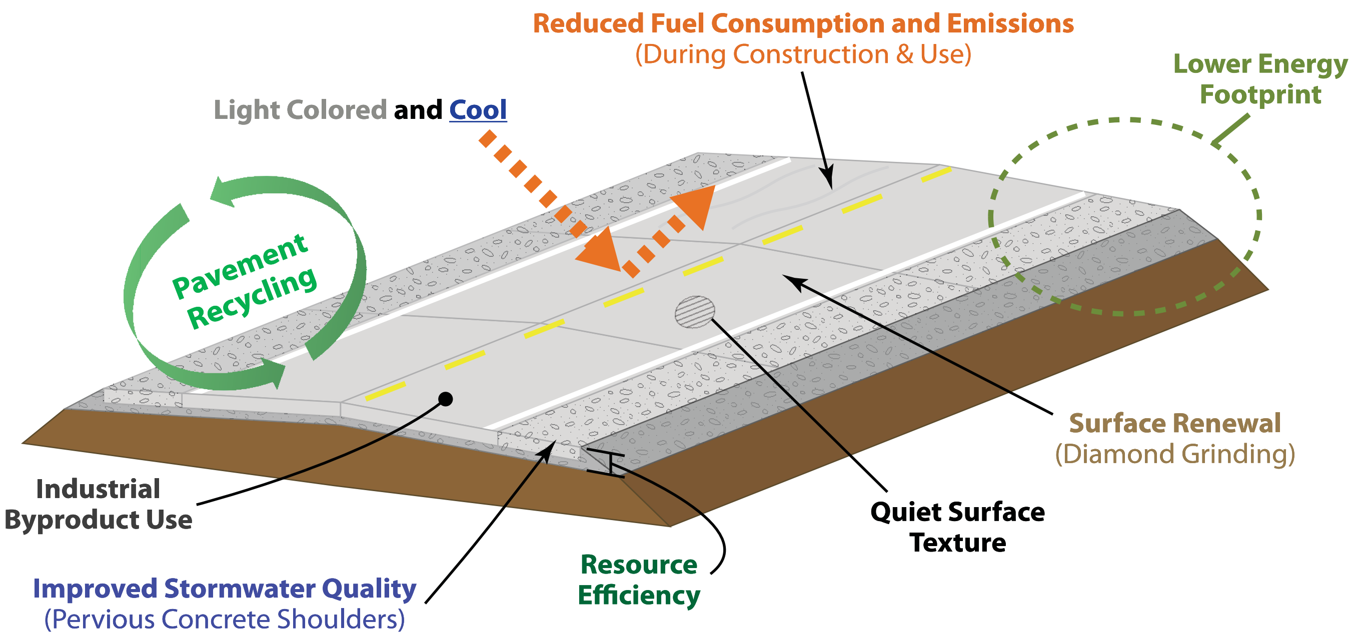


Figure 4-5. Concrete pavement sustainability opportunities that can be achieved through proper selection, design and/or mixture optimization.

Additional Details on Concrete Pavement Sustainability

A detailed discussion of each of the concrete pavement sustainability factors is outside of the scope of this document but more details are provided in the ACPA reports "Green Highways – Environmentally and Economically Sustainable Concrete Pavements" (ACPA 2011c) and "Sustainability Opportunities with Pavements: Focusing on the Right Things" (ACPA 2010b).

The Role of LCCA in Pavement Type Selection

As agencies face dwindling resources and ongoing cost increases, new approaches to pavement type selection may provide a viable solution to the challenge.

In simplest terms, **pavement type selection is the process by which pavement types or strategies are selected**. The decision is a challenging one because it involves balancing short- and long-term performance with initial and life-cycle costs.

Within highway agencies, the process of pavement type selection is typically a formal process, guided by policies or protocols. ***Although it is generally assumed that highway engineers and other transportation officials do not have a tool available to give an absolute and indisputable comparison of competitive pavement types for set conditions, this is no longer wholly true***. With the advent of AASHTO's DARWinME™ and other improved design methodologies, the pavement design community can design competing pavement alternate designs for similar performance. This **perceived** inability to provide equivalent designs is negatively impacting the implementation and embrace of LCCA and alternate design/alternate bidding (ADAB) practices. The great **benefit of such practices to agencies and taxpayers** cannot, however, be ignored. For example, the use of alternate bid processes by the Missouri DOT led to an increase in the number of bidders for each project, which resulted in a **5.1% reduction in asphalt unit prices on alternate bid projects when compared to those on non-alternate bid projects; similarly, concrete unit costs on alternate bid projects were 8.6% less than those on non-alternate bid projects** (MoDOT 2009).

A decades-old document provides some relevant guidance for current and future practices. "An Informational Guide on Project Procedures," produced by the American Association of State Highway Officials or AASHO (now the American Association of State Highway and Transportation Officials or AASHTO) in 1960 provides guidance that states "**any decision as to paving type to be used should be firmly based**" (AASHO 1960).

Despite its age, the document provides some useful and still-relevant information on the topic of pavement type selection. In fact, this little-known document is particularly relevant for federal aid projects because it is referred to in current federal policy on pavement type selection.

The document states that "judicious and prudent consideration and evaluation of governing factors will result in a firm base for a decision on paving type." According to the AASHO document, there are a host of these governing factors to consider, including ones pavement designers will easily recognize, such as traffic, soils, weather, past performance, and economic comparison. But, there are also several other governing factors that may no longer be that familiar to personnel involved in pavement type selection, such as conservation of aggregates, construction consideration, availability of local materials and **stimulation of competition**.

It is significant to note that these factors, which were obviously relevant in 1960, are still key considerations today. Of particular importance to note, the 1960 AASHO document also reveals that state agencies recognized the importance of **competition between industries**, both in terms of **spurring innovation and maximizing economic value to the owner**.

One of the governing factors noted above is economic analysis. Often, this is incorporated via some sort of LCCA to establish costs of the various pavement alternatives being considered. Even though this is an important factor to be considered in pavement type selection, it is not a replacement for pavement type selection (i.e., **LCCA is not synonymous with pavement type selection**). Instead, LCCA is simply a tool that should be used as part of the pavement type selection process.

In recent years, concerns have arisen about the equity and effectiveness of the pavement type selection process, particularly in our current climate of ever-increasing needs, construction cost inflation, and dwindling resources to address these challenges. A number of organizations are addressing the issue, including:

- The National Cooperative Highway Research Program (NCHRP), whose Project 10-75 resulted with the "Guide for Pavement-Type Selection" (NCHRP 2011a).
- The FHWA, which is examining its current guidance and is weighing whether to revisit it based on the recent NCHRP effort.

There are differences among states and how they address pavement type selection. For example, roughly one-third have no formal process in place; only some of the processes in place employ LCCA and, within the LCCA, only some consider user costs (Table 2-4). Some states make decisions on a project-by-project basis, others make decisions programmatically, while others still make decisions at the district level. Some states use formal selection panels, others do not. There are even some states that have begun to explore the use of the free market through the bidding process (e.g., alternate bidding or ADAB) to help decide pavement type, largely because of a concern about lack of equity and effectiveness of current selection processes.

Current Federal Policies

On a federal level, there are essentially two pavement-related policies currently in effect. The first is the October 1981 Pavement Type Selection Policy Statement (FHWA 1981b), which addresses four key issues. The second is the 1996 Pavement (Design) Policy (FHWA 1996), which essentially states that pavement should be designed to accommodate current and future traffic needs in a safe, durable and cost-effective manner.

The 1996 policy has no bearing on pavement type selection; its purpose is to set pavement design policy for federal-aid highway projects. The 1981 policy does, however, have a bearing on pavement type selection.

In broad strokes, the 1981 policy statement states that:

1) **Pavement type selection should be based upon an engineering evaluation** considering the factors contained in the 1960 AASHO publication (AASHO 1960),
2) **Pavement type determination should include an economic analysis** based on life-cycle costs of pavements,
3) **The economic analysis and pavement type selection should be updated just prior to advertising**, and
4) Where [appropriate], **alternate bids may be permitted** if requested by the contracting agency (provided the FHWA Division Administrator approves the equivalency).

A clarification issued in November 1981 states that ***price adjustment clauses (e.g., material price escalators) should not be used in alternate bidding scenarios*** (FHWA 1981a).

The 1960 AASHO guide referred to in section 1 of the FHWA 1981 policy mentions many guiding factors to be considered when making pavement type determinations, but of particular interest and significance today are the sections discussing "Cost Comparison" and "Stimulation of Competition." In today's economic environment, none of the other factors listed has such a pronounced effect on the ability of highway agencies to address the mounting infrastructure challenges with their severely limited resources – **competition is by far the most significant opportunity**.

In section V "Cost Comparison" of the document, the authors discuss the virtues of considering cost on the basis of service life or service rendered by a pavement structure, but cautions that:

> ***"…doubt as to the validity [of such analysis] arises in the case where on[e] type of pavement has been given monopoly status by the long-term exclusion of a competitive type."***

Finally, FHWA affirmed the 1981 pavement type selection policy in their 2008 clarification memo on alternate bidding (FHWA 2008).

See Appendix 3 for all current federal policy on pavement type selection.

The Role of Competition

The 1960 AASHO cost comparison quote above makes the point that **LCCA may not be meaningful where you only have one pavement type available** – the cost data are not meaningful. Moreover, it indirectly recognizes the value that competition between paving industries provides to owners. In section VI "Stimulation of Competition" of the AASHO document, the authors state:

> ***"It is desirable that monopoly situations be avoided, and that improvement in products and methods be encouraged through continued and healthy competition among industries involved in the production of paving materials."***

It is important to point out the context in which the highway officials serving on the Special Committee on Project Procedures in 1960 wrote this document. In the early days of the federal-aid highway program (Federal-Aid Highway Act of 1956) there were a few (but very public) instances of fraud and abuse related to the vast amounts of public funds expended (Weingroff 2006). Most of the fraud pertained to right-of-way acquisition, but there were also instances of collusion by industry and questions concerning monopolies and pavement type selection. As a result of the significant negative press surrounding these instances of neglect and abuse surrounding the "greatest public works project in history," the public and congress started losing confidence in the entire administration of the highway program. The Federal Bureau of Investigation (FBI), the General Accounting Office (GAO), and even the House Special Subcommittee on the Federal-Aid Highway Program (Blatnik Committee) were engaged in probing the various allegations of irregularities in the highway program. It was in this environment that the highway officials were charged with developing sound guidance regarding contract construction, pavement type selection and right of way acquisition. As the document notes:

> ***"It is imperative that all possible and proper measures be taken to ensure the tax payers of this country that they are receiving full value of every highway dollar spent… The recommendations included in this Guide are designed to keep the public confidence in the highway program at a maximum."***

It is safe to say that the guidance offered in the 1960 AASHO document which, again, is directly referred to in current federal pavement type selection policy, is purposefully "loose" to allow for proper consideration of all factors in pavement type determinations, including competition.

It is noteworthy that a few states recognize the benefit of competition between industries and incorporate it directly into their pavement type selection process. In some states, for example, the **watchword for competition is "balance"** (Fickes 2009).

A recent FHWA publication has this to say about competition (FHWA 2003b):

> "By standardizing its pavement design selection process with LCCA, PennDOT established clear benchmarks for pavement performance. The asphalt and concrete industries have met the challenge imposed by PennDOT and have adapted with better and lower cost products. ***Additionally, contractors have lowered their bid prices in order to remain competitive in a standardized environment***."

The impact of competition observed in Pennsylvania is not uncommon. An analysis of bid information for 14 states illustrates that a competitive market results in reduced bid prices for both concrete and asphalt pavements (Figure 4-6). In this analysis, the impact is larger on concrete bid prices than on asphalt bid prices; this illustrates that the bigger concrete pavement market allows the introduction of competition within the concrete industry.

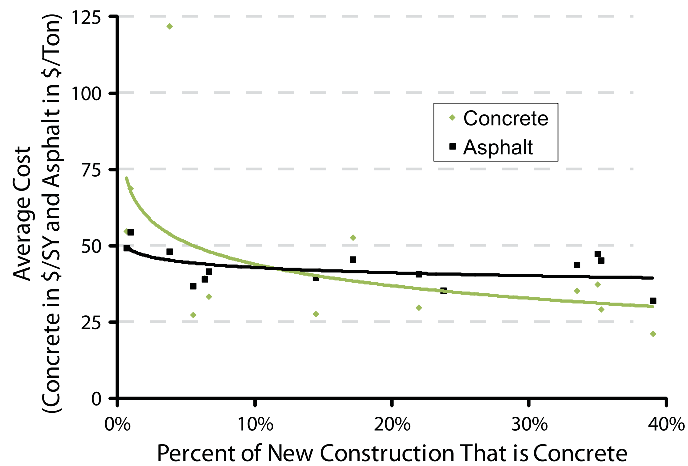


Figure 4-6. 2002-2006 average cost data for GA, IL, IN, KS, KY, MD, MO, NC, OH, PA, TN, VA, WI, and WV.

The approach of a balanced market not only fosters competition, it also helps **ensure healthy paving industries that can afford to invest in training, research, and quality control**. This in turn means better performing pavements being delivered to the agencies, and ensures that the **public receives the maximum value from their highway dollar**.

Regardless, today, **most highway engineers and administrators are not aware of the federal pavement type selection policy**, the 1960 AASHTO document it refers to, its background, or its intent. Conventional wisdom is that LCCA is the answer, but this, alone, does not properly account for the consideration of some of the very important non-economic factors.

Total Cost of Ownership Example – Mississippi Network of 36 Pavements

A practical application of LCCA is a total cost of ownership analysis. Essentially, total cost of ownership is the inflated costs that the agency will spend over the life of the pavement.

A 1985 report titled, "Pavement Selection Based on Life-Cycle Cost," by the Mississippi State Highway Department and FHWA detailed the actual initial, maintenance, and overlay costs of 36 paving projects in Mississippi, including:

- 4 full-depth asphalt pavement sections,
- 5 asphalt on stabilized base sections,
- 5 jointed plain concrete pavement (JPCP) sections, and
- 22 continuously reinforced concrete pavement (CRCP) sections.

Projects considered dated back to as early as 1960 and all costs were tabulated in original (e.g., as actual expenditure amount by the DOT, reflecting total ownership cost) and 1984 dollars for the purpose of comparison (Browning 1985).

Table 4-2 lists the actual average state DOT expenditures for the initial, maintenance, and rehabilitation (overlay) costs and the total expenditures per mile for each pavement type. As shown, the jointed plain concrete pavement is the most cost effective solution when looking at the true total ownership cost.

An inflation rate based on price trends in federal-aid highway construction and no interest rate was then used to adjust all costs to equivalent 1984 dollars (Table 4-3). Thus, the author calculated the true cost of ownership to the agency as a net present value. **Again, the jointed plain concrete pavement option is the most cost effective**.

The report concludes (Browning 1985):

> "**Sometimes asphalt pavements have been selected because they have a lower initial cost with the reasoning that the money saved can be spent on other projects or to pave additional roads… this can lead to a poor choice when future expenditures are also considered**. The results show that in the long run the jointed concrete pavements have the lowest average 1984 life-cycle cost per mile since 1960."

Table 4-2. All Original Expenditures per Mile of Pavement (Browning 1985)

Pavement Type	Average Initial Exp., $/mi	Average Maint. Exp., $/mi	Average Rehab Exp., $/mi	Average Total Exp., $/mi
Full-Depth Asphalt	$ 148,186.46	$ 1,872.82	$ 52,597.91	$202,657.19
Asphalt on Stabilized Base	$ 89,435.77	$ 2,895.79	$ 110,500.16	$202,831.72
Jointed Plain Concrete (JRCP)	$ 136,560.76	$ 1,393.60	$ -	$137,954.36
Continuously Reinforced Concrete (CRCP)	$ 208,959.12	$ 1,776.67	$ -	$210,735.79

Table 4-3. 1984 Value of All Expenditures per Mile of Pavement (Browning 1985)

Pavement Type	Average Initial Exp., $/mi	Average Maint. Exp., $/mi	Average Rehab Exp., $/mi	Average Total Exp., $/mi
Full-Depth Asphalt	$ 441,669.38	$ 2,967.44	$ 53,056.68	$497,693.50
Asphalt on Stabilized Base	$ 363,752.38	$ 3,945.46	$ 126,870.88	$494,568.72
Jointed Plain Concrete (JRCP)	$ 434,549.87	$ 1,746.51	$ -	$436,296.38
Continuously Reinforced Concrete (CRCP)	$ 481,614.09	$ 2,096.22	$ -	$483,710.31

The Potential Impact of Material Quantity Specifications on LCCA Results

Thickness requirements during construction typically are much more stringent for concrete pavements than for asphalt pavements. Thus, concrete contractors might place the concrete up to about ½" (13 mm) thicker than necessary to avoid penalties. This over-construction is not factored into the project costs if the concrete pavement is bid as $/SY, however, so a concrete pavement contractor must absorb it into his concrete pavement bid price.

Asphalt pavements, on the other hand, typically are paid for by the ton that is actually delivered and placed. Asphalt thicknesses are not watched as closely and the asphalt typically is just placed in reasonably close conformity with the grades, lines, thickness, etc. shown on the plans.

To understand the impact of this bias built into many specifications, consider how these bidding practices might impact the local road example from Chapter 3. The concrete alternate in that example was 7 in. (175 mm) thick at a cost of $220,000. If the concrete pavement must be built ½" (12.5 mm) thicker than necessary, the contractor has essentially included this into his cost (e.g., the $220,000 is really the price for a 7.5 in. (190 mm) thick concrete pavement). As such, the real price for the 7 in. (175 mm) thick concrete pavement might be $205,333. Thus, the real initial cost of the concrete alternate might actually be closer to that shown in Table 4-4.

On the asphalt side of the equation, any quantity overruns (e.g., if the asphalt material quantity that is delivered and placed is greater than the quantities specified in the plans) will be subsidized by the agency. Assume that the asphalt overruns to be 5%. The quantities from this example are 1,725 tons and 1,150 tons for the 3 in. (75 mm) and 2 in. (50 mm) asphalt lifts, respectively, so the required quantities would become 1,811 tons and 1,208 tons. The real initial cost of the asphalt alternate then become that shown in Table 4-5.

Table 4-4. Total Initial Agency Cost for Concrete Alternate from Local Road Example in Chapter 3 with Adjustment for Concrete Construction Thickness to Meet Specifications

Description of Work	Quantity	Unit Price	Total Cost
7 in. Concrete Pavement	10,000 SY	$22.00/SY	$205,333
Concrete Curb and Gutter	5,580 LF	$11.00/LF	$61,380
4 in. Aggregate Subbase	3,120 Ton	$10.50/Ton	$32,760
Unclassified Excavation	4,600 CY	$13.00/CY	$59,800
		TOTAL INITIAL AGENCY COST:	**$359,273**

Table 4-5. Total Initial Agency Cost for Asphalt Alternate from Local Road Example in Chapter 3 with Adjustment for Asphalt Quantity at Construction

Description of Work	Quantity	Unit Price	Total Cost
3 in. Asphalt Lower Course ***(w/ 5% overrun)***	1,811 Ton	$42.10/Ton	$76,243
2 in. Asphalt Surface Course ***(w/ 5% overrun)***	1,208 Ton	$48.42/Ton	$58,491
Tack Bid (.025 gal/SY)	200 gal	$1.25/gal	$250
10,000 SY Tack (.025 gal/SY)	250 gal	$1.25/gal	$313
Concrete Curb and Gutter	5,580 LF	$11.00/LF	$61,380
10 in. Aggregate Base	5,200 Ton	$10.50/Ton	$54,600
Unclassified Excavation	5,230 CY	$14.00/CY	$73,220
		TOTAL INITIAL AGENCY COST:	**$324,497**

Considering just this small difference in how material specifications are written, the initial agency cost for the asphalt alternate changes from 15% less to just 9.7% less than that of the concrete alternate. This impact would also affect the agency at future asphalt reconstructions, when the agency might then be liable for more material quantity overruns. Means of correcting this potential issue when bidding alternate pavements include balancing the specification by having the same thickness, subgrade, base/subbase, cross-slope, width, etc. requirements or paying for each alternate by the same metric (e.g., bid both in terms of SY or in terms of CY and SY).

Glossary

Accident or crash costs – costs associated with damage to the user's vehicle and/or other vehicles and/or public or private property, as well as injury to the user and others.

Activity – a specific action performed by the highway agency or the contractor, such as initial construction or a preservation/rehabilitation.

Administrative Costs – cost incurred in contract management administration overhead expenses.

Agency – a government organization responsible for initiating and carrying forward a highway program for the general public. May be federal, state department of transportation (DOT), metropolitan planning organization, local government, etc.

Agency costs – costs incurred by the agency over the analysis period.

Alternatives – the complete set of initial and future activities that will satisfy established pavement performance objectives of a project.

Analysis period – the timeframe over which the strategy alternatives are compared.

Annual worth or equivalent uniform annual cost (EUAC) – all costs over the analysis period expressed in terms of an equivalent annual value that is the same for every year of the analysis period.

Benefit-cost analysis – an analysis in which all consequences of the investment are measured in or converted to economic terms.

Benefit-cost ratio (B/C) – the ratio of a project's benefits (to the public) to its costs (to the government).

Bid Price Index (BPI) – the FHWA's index compiled to track the installed prices of several components of highway construction.

Concessionaire – the owner of a business that operates a facility under a contract a license with a government agency.

Concrete pavement preservation (CPP) – a set of nonoverlay techniques that repair isolated sections of deteriorated pavement, or prevent or slow overall deterioration, as well as reduce the impact of traffic loadings on the pavement; also known as preservation.

Constant dollars – costs of items as if they were incurred in the year in which the life-cycle cost analysis is conducted.

Consumer Price Index (CPI) – An inflation index compiled by the U.S. Department of Labor's Bureau of Labor Statistics (BLS) to reflect the change in retail prices for a selected set, or "market basket," of purchases of clothing, food, housing, transportation, medical care, entertainment, education, and other items.

Delay costs – costs to motorists due to reduced speeds and/or the use of alternate routes.

Design period – the period of time for which either a new pavement or a rehabilitation treatment is designed to serve.

Discount rate – in banking, the rate that commercial banks and other depository institutions are charged on loans from the Federal Reserve. In life-cycle cost analysis, the rate that reflects both the time value of money (interest rate) and the decrease in purchasing power (inflation rate) over time; also called the real discount rate.

Equivalent Uniform Annual Cost (EUAC) – see Annual worth.

Future costs – costs incurred after the beginning of the analysis period.

Incremental benefit-cost analysis – process by which a project is judged more favorable than another if the additional increment of benefit to be gained exceeds the incremental increase in cost.

Inflation rate – the rate of increase in prices; a measure of the decline of purchasing power.

Initial costs – costs incurred at the beginning of the analysis period.

In-service user costs – user costs associated with the normal use of the roadway.

Interest rate – the rate of return on an investment.

Life-cycle cost analysis – a procedure for evaluating the economic consequences of mutually exclusive project alternatives over a period of time.

Maintenance and operation costs – the daily costs associated with keeping the pavement at a given level of service.

Net present value (NPV) - The net value of all present and future costs and benefits converted to a single point in time using a real discount rate factor.

Network-level analysis – analysis of the condition and needs of an entire network of roadway sections.

Performance period – The best estimate of the expected life of a pavement or a rehabilitation treatment. For a newly constructed or reconstructed pavement, the performance period is the design period. For some rehabilitation treatments that are not designed for a specific time period or number of traffic loadings, the performance period must be estimated from field performance observations or empirical models developed from field performance data.

Present worth (PW) – the equivalent value at the present, based on the time value of money; the monetary sum equivalent to a future sum or sums when interest is compounded at a given rate; the discounted value of future sums.

Preservation – see Rehabilitation.

Private entity – a private owner of a roadway, such as a concessionaire.

Probabilistic analysis – an analysis in which the variability of each input is taken into account and used to generate a probability distribution for the calculated life-cycle cost.

Producer Price Index (PPI) – a family of Bureau of Labor Statistics indices that reflect changes over time in the prices received by domestic producers for a variety of goods and services.

Project-level analysis – analysis of the condition and needs of a single roadway section.

Public entity – a government (local, State, or Federal) owner of a roadway.

Quasi-private entity – a government-established entity such as a toll authority.

Real discount rate – see Discount rate.

Rehabilitation – the act of restoring a pavement to former condition.

Residual value – the cost recovered or that could be recovered from a used property when removed, sold, scrapped, or reused.

Salvage value – see Residual value.

User costs – costs incurred by users and would-be users of a roadway.

Vehicle operating costs – costs related to consumption of fuel and oil, and wear on tires and other vehicle parts.

Work-zone user costs – costs incurred during lane closures and other periods of construction, rehabilitation, and maintenance work.

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Appendices

Appendix 1 – Present Worth Calculations and Deterministic Analysis Worksheet

Present value/worth ($P) of a one-time future cost or benefit ($F):

$$\$P = \$F \times \left[\frac{1}{(1+d)^t}\right]$$

Present value/worth ($P) of an annual future cost ($A):

$$\$P = \$A \times \sum_{t=1}^{n}\left[\frac{1}{(1+d)^t}\right] = \$A \times \left[\frac{(1+d)^n - 1}{d\,(1+d)^n}\right]$$

Present value/worth ($P) of an annual future cost that escalates at a constant rate:

$$\$P = A_o \times \sum_{t=1}^{n}\left[\left(\frac{1+e}{1+d}\right)^t\right] = A_o \times \frac{(1+e)}{(d-e)} \times \left[1 - \left(\frac{1+e}{1+d}\right)^n\right]$$

where:

d = the real discount rate (e.g., 0.03 for 3 percent)
t = the year in which the one-time future cost or benefit occurs (t = 0 for initial costs)
n = number of years over which the annual future cost reoccurs
e = constant escalation rate (can be positive or negative)

The conversion of nonuniform future annual costs requires:

1) Identification of subperiods during which the annual costs are uniform,
2) Converting these uniform annual costs to present worths in the beginning years of the subperiods, and
3) Converting these present worths in given future years to equivalent present worths at the beginning of the analysis period.

The total net present value (NPV) is the sum of the present worths of the activities considered in the LCCA (e.g., initial agency costs (A), user costs (B), maintenance and preservation/repair costs (C), residual value, sustainability-related costs, etc.).

Deterministic Life-Cycle Cost Analysis (LCCA) Worksheet

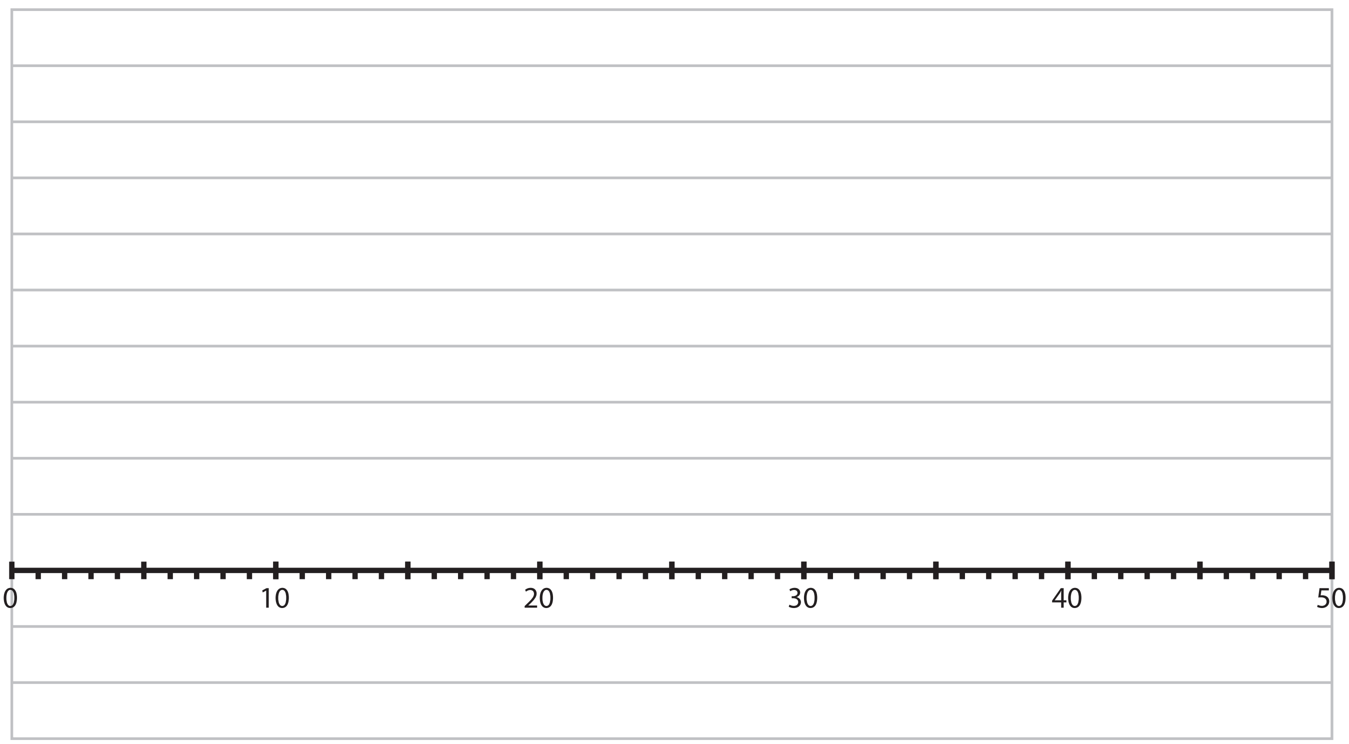
Project Name:

Project (Alternate) Description:

Analysis Period (yrs):

Real Discount Rate (%):

Cash Flow Diagram:



Year (t)	Activity	Cost ($F or $A)	For $A, Number of Years (n)	Present Worth ($P)
	Total Cost:		**Total NPV:**	

Appendix 2 – Historic Oil Price Trends and Volatility

Introduction
Asphalt cement is the by-product of petroleum refining – what is left over after all of the lower-molecular-weight fuels and lubricants, from jet fuel to gasoline to kerosene to petroleum jelly, have been boiled off and condensed. Being a by-product of petroleum refining, the price of paving-grade asphalt cement fluctuates with the price of crude oil. The two are not perfectly correlated, however. One reason for this is that changes in the price of asphalt cement tend to lag slightly behind changes in the price of crude oil. The other reason is that oil refiners, in an effort to maximize profits, can vary their distillation process to obtain relatively greater (or lesser) proportions of the various oil refinement products and by-products (e.g., though the use of "cokers").

When crude oil prices are high, refiners may strive to extract larger proportions of lighter-weight fuels. This may result in reduced asphalt cement quantity from a given volume of crude oil, and/or asphalt cement of lesser quality, which can result in a fundamental shift in the supply-demand curve for asphalt cement. As more and more refineries around the world install cokers in an attempt to maximize total profits, the price of asphalt will become even more dependent on the price of crude oil because as the price of crude oil increases the price of asphalt's source increases and, at the same time, less of it is manufactured.

Portland cement, on the other hand, has been manufactured in much the same manner for decades and it is not as dependent on oil prices. Recent advances in cement plant processes and the use of waste materials (e.g., tires) for fuel has decreased cement plant dependency on fuel as a source of energy over time.

Oil Price History
World oil prices are differentiated from U.S. oil prices in this discussion of trends in crude oil prices. The two are slightly different but follow the same trends. The U.S. oil price benchmark is that for West Texas Intermediate (WTI) crude oil (Figure A2-1), which tends to run about $2 per barrel higher than the price of the basket of crude oils controlled by the Organization of Petroleum Exporting Countries (OPEC). The crude oil price quoted on the New York Mercantile Exchange is the WTI price.

For about 25 years after the end of World War II, crude oil prices were very low and stable. Between the late 1940s and the early 1970s, crude oil prices ranged between about $2.50 and $3.00 per barrel (in nominal dollars; that is, based on the value of the U.S. dollar in each actual year, not adjusted for inflation).

A steep rise in oil prices in the early 1970s was triggered by the Yom Kippur War, which began in late 1973 with an attack on Israel by Syria and Egypt. In response, OPEC members reduced their oil production and imposed an oil embargo on the U.S. and other western countries that supported Israel in the war. Between 1972 and 1974, the nominal price of crude oil quadrupled from $3 per barrel to over $12 per barrel. Between 1974 and 1978, oil prices increased more slowly, actually declining during that period when adjusted for inflation.

Figure A2-1. Nominal price of West Texas Intermediate (WTI) crude oil from 1946 to 2011 (Source: Dow Jones & Company).

Oil prices shot up again in 1979 and 1980, due to the Iranian Revolution and the start of the Iran-Iraq War, which together resulted in a 10 percent decrease in worldwide oil production in one year. In mid-1980 the price of oil was just under $40 per barrel, well over $60 per barrel when adjusted for inflation.

Crude oil prices declined between 1980 and 1985, in both nominal and inflation-adjusted terms. Among the factors that contributed to this decline were improvements in energy efficiency in homes, factories, and automobiles, a global recession that reduced oil demand, and increased oil exploration and production by non-OPEC countries. For the first half of the decade, Saudi Arabia, the world's largest oil producer, frequently cut its production to compensate for the overproduction of other OPEC countries, in an attempt to halt the decline in oil prices. By 1985, Saudi Arabia tired of this role and began to increase its oil production too. The inflation-adjusted price of crude oil dropped to below $20 per barrel by 1988.

The invasion of Kuwait by Iraq and the start of the first Gulf War in 1990 caused a small spike in oil prices, but when the war ended oil prices began to decline. Oil prices rose again between 1994 and 1997, primarily due to a strong U.S. economy and strong economic growth in Asia. An economic crisis in Asia in the late 1990s led to a decline in Asian oil consumption (and OPEC made the mistake of increasing production at the same time) which led to another drop in oil prices. OPEC then cut production in response, and oil prices began to increase again in 1999.

Oil prices took a downward turn in 2001 due to weakening of the U.S. economy and increased oil production by non-OPEC countries, especially Russia. In addition, the September 11, 2001 terrorist attacks cause a sudden drop in oil prices. Throughout 2001 and 2002, OPEC attempted to bring oil prices up by imposing a series of production cuts on its members. These efforts were not very effective until several non-OPEC oil producers, including Russia, also agreed to production cuts. Oil prices have been rising fairly steadily ever since, with only one really notable drop from a recession, but oil prices have quickly risen back to pre-recession levels.

Oil Price Volatility and the Associated Risk

In addition to considerable recent increases, the price of oil is increasingly characterized by its volatility. In just the last few years, the price of oil has swung from as low as around $40/barrel to as high as nearly $135/barrel, having done so in under a year's time. Increasing volatility makes short-term and medium-term predictions of the price of oil increasingly difficult to make with confidence.

Some factors regularly affect the price of oil in fairly predictable ways. For example, it is normal for the price of oil to decline somewhat in the autumn, after the typical summer surge in gasoline consumption but before cold winter temperatures heighten demand for heating oil. Oil prices in the U.S. tend to decline during a mild hurricane season and rise during a strong hurricane season. Current events involving the world's major oil producers and/or oil consumers also influence the price of oil in predictable ways as well.

An economic downturn, as the global economy has experienced in 2008 and 2010, pushes oil prices down because a slower economy reduces oil demand. This may seem to be a boon to motorists, for example, because it brings down gas prices in the short term, but in fact oil price reductions due to economic recession are not healthy for the world's most productive economies (which are also the world's biggest oil consumers), nor for the world's developing economies or for the stability of countries whose economies depend heavily on the sale of oil.

The price of oil is becoming increasingly volatile (Figures A2-2 and A2-3), not only because of growing awareness that the world's supply of fossil fuel is finite, while the world's demand for oil to fuel economic growth and development is not, but also because of factors that had little or no influence on the oil market a decade or two ago.

One of these factors is the growing presence of non-OPEC countries (who are not bound by OPEC's internal agreements) in the oil market. Another factor is the growing influence of oil price speculation by investors.

In mid 2008, the Chicago Board Options Exchange (CBOE) introduced its Oil Volatility Index (OVX), to allow trading on the market's expectation of oil price volatility over the course of the coming 30 days. The OVX applies the methodology of CBOE's well-known Volatility Index (VIX), introduced in 1993, to analysis of options trading on the United States Oil Fund LP (USO), which is a commodity pool that invests in oil futures on the New York Mercantile Exchange, options on oil futures, and forward contracts. Trading on the volatility of commodities is, for better or for worse, a reality of the marketplace. The inevitable consequence is that future fluctuations in the price of oil will depend not only on the tradeoff between supply of and demand for real barrels of oil, but also on the trade in people's expectations about the price of oil.

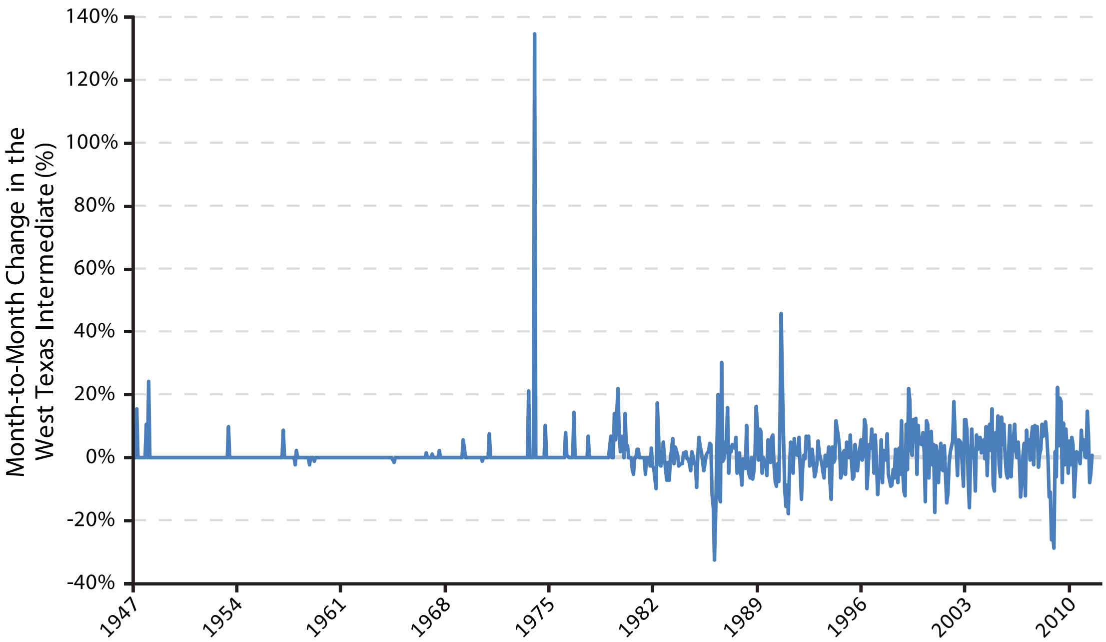


Figure A2-2. Month-to-month change in the nominal price of West Texas Intermediate (WTI) crude oil from 1946 to 2010 (Source: Dow Jones & Company).

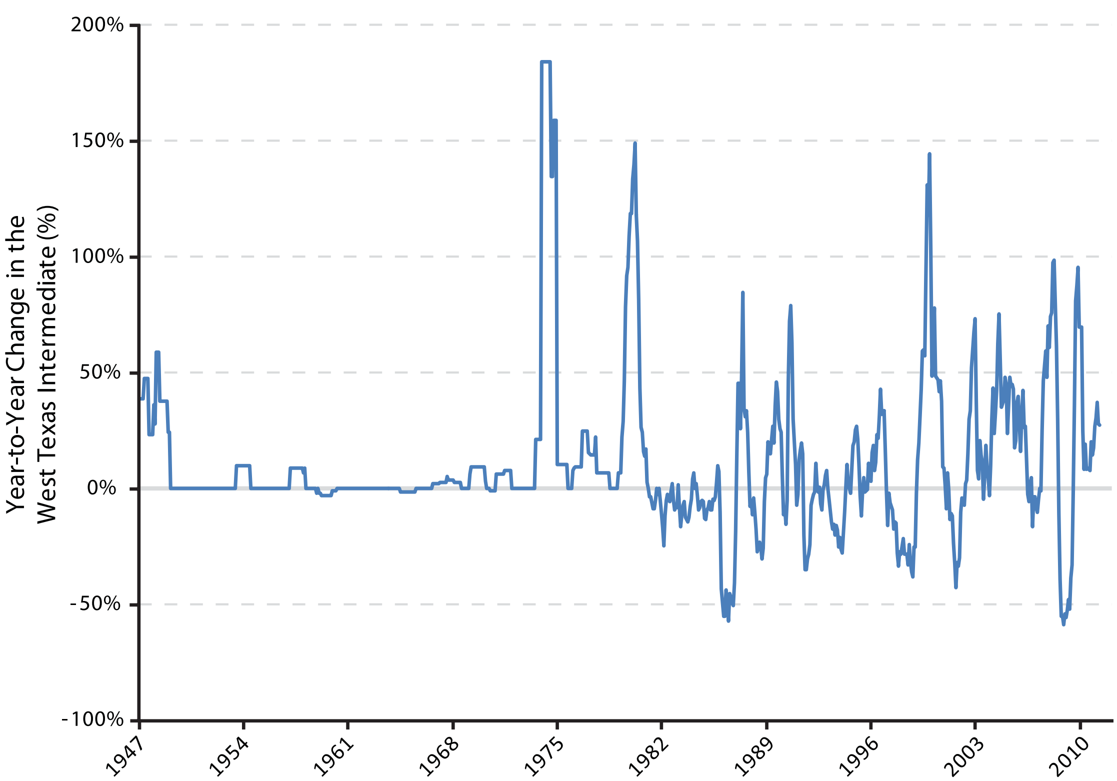


Figure A2-3. Year-to-year change in the nominal price of West Texas Intermediate (WTI) crude oil from 1946 to 2010 (Source: Dow Jones & Company).

A Comparison of WTI to Asphalt and Concrete PPIs

Figure A2-4 shows indexed values of the WTI alongside the BLS's PPIs for asphalt paving mixtures and blocks and concrete products for approximately the last 50 years. As mentioned, asphalt trends tend to lag behind trends in oil prices (e.g., 1973 to 1985). At the same time, steep drops in oil prices don't necessarily translate to steep drops in asphalt prices (e.g., 1985 to 2000). Since 2000, both oil and asphalt prices have increased dramatically, with asphalt trends again lagging behind oil trends. The standard deviations on each year's data point also illustrates that asphalt and oil are both very prone to similar volatility within a given year, whereas the concrete yearly standard deviation is so low that it is very difficult to see on the figure. The differences in magnitude and standard deviation between the asphalt PPI and the WTI indices (e.g., asphalt PPI is up 1,640% and WTI is up 3,100% since 1958) are likely because the asphalt PPI is for asphalt block and paving mixtures, of which asphalt binder only composes about 5% of the volume; thus, the other components in the mixture (e.g., aggregate) also impact the asphalt PPI trends.

Some of the previously mentioned international political unrests that directly impacts oil prices have clearly also impacted asphalt prices in the U.S. Concrete prices, however, are relatively insensitive to such influences.

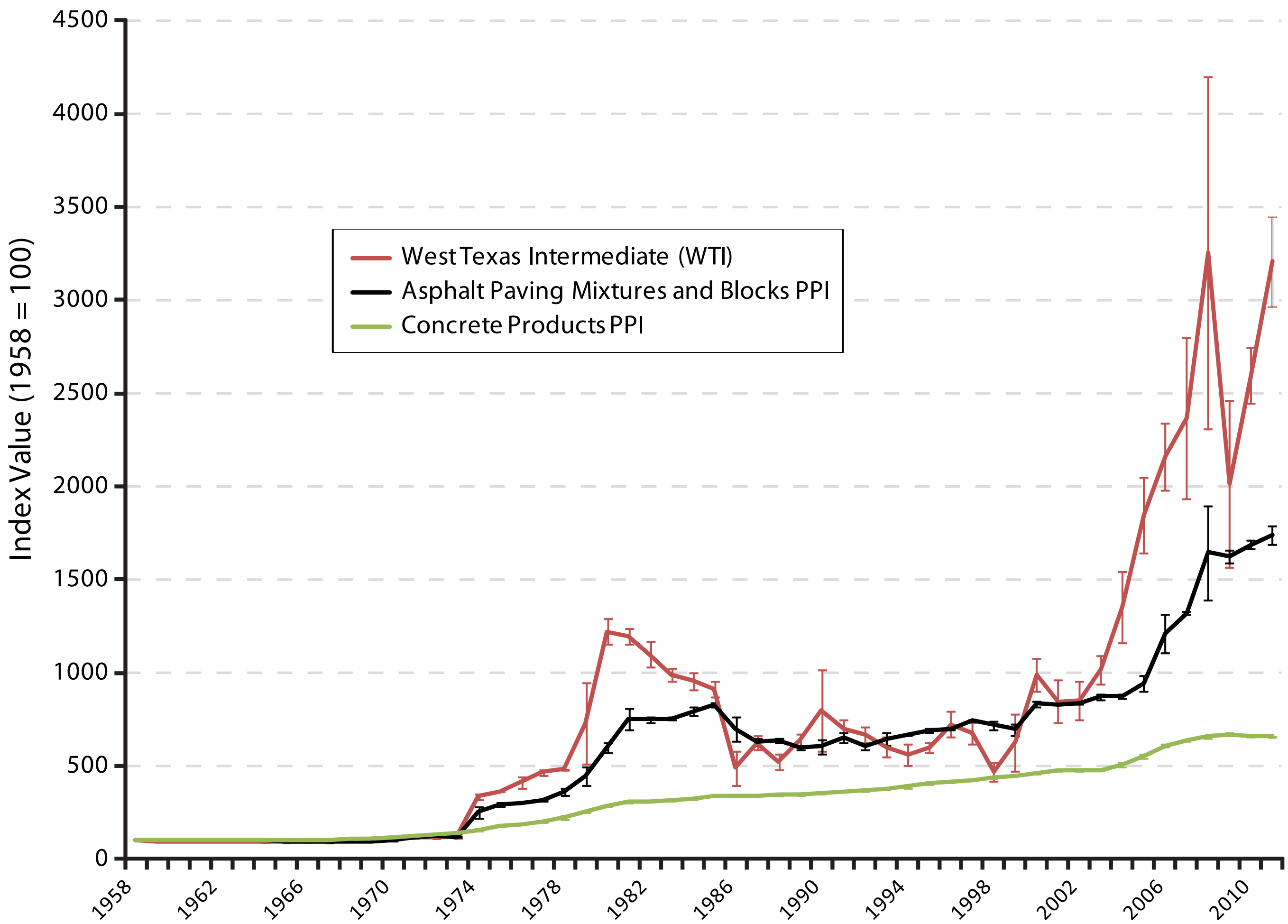


Figure A2-4. The BLS's PPI for concrete products (WPU133) and asphalt paving mixtures and blocks (WDU13940101/ WPU13940113), and the WTI, from 1958 to 2011 (BLS 2011), showing yearly standard deviation at each data point.

Forecasting Oil Prices

While market analysts may disagree on oil price movements in the short term, there is little disagreement with respect to the long-term direction of oil prices. Worldwide energy demand will continue to grow along with economic growth and industrialization, but the world's petroleum reserves are finite. If worldwide energy consumption were to remain at more or less current levels, which is unlikely, the world's proven petroleum reserves would last for another 30 to 50 years or so. The more energy consumption grows, the sooner the world's known supply of petroleum is likely to be exhausted. New oil discoveries, improvements in oil production efficiency, improvements in oil consumption efficiency, and energy conservation efforts may help to forestall the day of reckoning. It is nonetheless fairly well accepted that the world will run out of petroleum sometime in the middle of the 21st century, the same timeframe that many currently conducted LCCAs extend to.

It is reasonable to expect that the price of crude oil, and the prices of its refinement products and by-products, such as asphalt cement, will rise more or less steadily, and to their highest levels ever, in the coming decades. Increased efficiency in the production and consumption of other types of energy (natural gas, coal, nuclear power, water, wind, and others) will be necessary to fuel the world's continued economic growth and sustainable development, and mitigate the adverse economic effects of rising oil prices.

Appendix 3 – Federal Policy on Pavement Type Selection

This appendix contains relevant portions of the following documents:

AN INFORMATIONAL GUIDE ON PROJECT PROCEDURES

A Guide for the Reviewing of Certain Administrative, Inspection, and Documentation Practices in use by State Highway Departments

With Particular Attention to

CONTRACT CONSTRUCTION
PAVEMENT TYPE SELECTION
and
RIGHT OF WAY ACQUISITION

Prepared by the Special Committee on Project Procedures

Ordered Printed by the Executive Committee of the American Association of State Highway Officials as an Informational Guide

Published by the
American Association of State Highway Officials
917 National Press Building
Washington 4, D. C.

November 26, 1960

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PAVING TYPE DETERMINATION AND DOCUMENTATION

The highway engineer or administrator does not have at his disposal generally acceptable theoretical or rational methods that give an absolute and indisputable comparison of the competitive pavement types for set conditions.

Prerequisites for such an evaluation procedure would, of course, with other things, involve the development of improved scientific structural design methods for both rigid and flexible pavement structures to render comparable service under similar traffic and weather conditions.

It would also involve the availability of reliable cost accounting data on the maintenance costs of the two pavement types for those comparable conditions. Here again factual information in complete desirable form is not presently available. Even though information is being developed through research it will not be wholly applicable on a national basis without modifications to adjust for the various soil and climatic conditions encountered.

Past, current and proposed major research undertakings such as the Maryland Road Test, the WASHO Road Test and the current AASHO Road Test research project, and its proposed satellite projects, together with road life and maintenance studies underway in the several State highway departments all contribute to fill in, gradually, some of the gaps.

The AASHO Committee on Design is currently in the process of converting the basic scientific relationships of pavement performance and applied loads, as developed on the AASHO Road Test, into improved rational design methods for pavements.

Pending the development of better tools, the State highway departments must rely on those that are available. Certain assumptions must be made and an empirical approach used, based on the best professional highway engineering judgement and experience available.

In other words there is no magic formula, where certain figures can be inserted and a definite answer as to pavement type required will result.

Governing Factors

To avoid criticism, if that is possible, any decision as to paving type to be used should be firmly based. Judicious and prudent consideration and evaluation of the governing factors will result in a firm base for a decision on paving type.

A list of such factors comprises the following items:

1. Traffic
2. Soils characteristics
3. Weather
4. Performance of similar pavements in the area
5. Economics or cost comparison
6. Adjacent existing pavements
7. Stage construction
8. Depressed, surface, or elevated design
9. Highway system
10. Conservation of aggregates
11. Stimulation of competition
12. Construction considerations
13. Municipal preference and recognition of local industry

14. Traffic Safety
15. Availability of and adaptations of local materials or of local commercially produced paving mixes

In the following pages, these factors are discussed and grouped, one group including all those which may be considered to have major influence, and the second, those which have lesser, or only occasional influence. The order of magnitude of influence is to be considered interchangeable within the groups and between the groups, as no single order is held to apply in all cases.

PRINCIPLE FACTORS

I. Traffic

The volume of passenger cars generally affects only the geometric or lane requirement. The percentage of commercial traffic and frequency of heavy load application generally has the major direct effect on the structural design of the pavement. Existing heavy-duty highways constitute sufficient evidence that both flexible and rigid pavement designs can meet requirements under given conditions.

If a cost comparison between competitive paving types is to be of value, it is imperative that the structural designs compared have equal capacity to carry loads. Since the matter is one of basic economics, the cost comparison must also include not only the cost of original construction, but that of needed periodic repairs and routine maintenance over the service life of the pavement, and an estimate as to what its probable useable salvage value will be at the end of that time.

It must be conceded that in these important areas, some assumption still must be made pending the results of current and further research developments not already available in guide form. When such assumptions are made, they must be made by the best qualified personnel available.

Present legal load limits are, to all intents and purposes, frozen by the Federal-Aid Highway Act of 1956, and will remain until certain studies are presented to the Congress for its consideration and further action.

Even accepting this restriction, it is reasonable and proper to make allowances in the structural designs of pavements for possible future modest legal load increases as well as the occasional overloads, whether moving by special permit or illegally, that are likely to use the pavement.

Currently, the AASHO Transport Committee is preparing new proposed vehicle weights and size regulations for consideration of the various States from data received from the AASHO Road Test and other appropriate sources. The Transport Committee assignment is to develop recommended size and weights to give an optimum balance between the best highway use and maximum highway life, for roads and bridges that can be furnished with the funds available for highway purposes.

In the projection of the density and weight of future traffic that will likely use the pavement during its lifetime, it is essential that not only normal increases be anticipated, but that consideration be given to the possibility of additional traffic being generated by potential industrial development or changes in land use for the area served.

The construction of a modern highway may also divert large amounts of heavy traffic, from other routes in the same broad traffic corridor, that should be considered by the designer.

II. Soils Characteristics

Of paramount importance is the ability of a native soil, which forms the subgrade for the pavement structure in cuts and on embankments, to withstand applied loads. Even in given limited areas the inherent qualities of such native soils are far from uniform, and they are further subjected to variations by the influence of weather.

The characteristics of native soil not only directly affect the pavement structure design, but may, in certain cases, dictate the type of pavement economically justified for a given location.

The evaluation of the characteristics of soils is, axiomatically, a requirement for each individual pavement structure design.

III. Weather

Weather affects subgrade as well as pavement wearing course. The amount of rainfall, snow and ice, and frost penetration will seasonally influence the bearing capacity of subgrade materials. Moisture, freezing and thawing, and winter clearing operations will affect pavement wearing surfaces as to maintenance costs, etc. These surfaces, in turn, will have some effect on the ease of winter clearing operations due to differences in thermal absorption or to the ability of the pavement to resist damage from snow and ice control equipment or materials.

In drawing upon performance record of pavements elsewhere, it is most important to take into consideration the conditions pertaining in the particular climatic belt.

IV. Performance of Similar Pavements in the Area

To a large degree, the experience and judgment of the highway engineer is based on the performance of pavements in the immediate area of his jurisdiction. Past performance is a valuable guide, provided there is good correlation between conditions and service requirements between the reference pavements and the designs under study. This factor should not be allowed to develop into blind prejudice. Caution must be urged against reliance on short-term performance records, and on those long-term records of pavements which may have been subjected to much lighter loadings for a large portion of their present life. The need for periodic reanalysis is apparent.

V. Cost Comparison

In any cost comparison of paving types, the matter of availability of local or commercially produced materials, and the existence and proximity of manufacturing or processing plants will be of significant importance.

Unavoidably, there will be instances where the financial circumstances are such as to make first cost the dominant factor in paving type selection even though greater maintenance costs may be involved later. Where circumstances permit, a better and more realistic measure would be the cost on the basis of service life or service rendered by a pavement structure. Such cost computation should reflect original investment, anticipated life, maintenance expenditures, and salvage value.

Original cost can be fairly accurately estimated. Doubt as to validity arises in the case where on type of pavement has been given monopoly status by the long-term exclusion of a competitive type.

The highly desirable determination of cost on a service life basis is presently adversely affected by some incomplete areas in needed factual information. One such area is the life expectancy of different paving types, a second, the matter of maintenance costs, and a third, the salvage value of pavements.

With our present state of limited knowledge as to the effect of frequency of heavy load applications, it is difficult to conceive of anything but an empirical approach to the determination of life expectancy of a pavement. The Bureau of Public Roads report "Lives of Highway Surfaces-Half Century Trends" shows a difference in the probable life for rigid and flexible pavements. It is not known if these trends hold for the pavements currently being constructed for the modern heavier traffic loadings, such as will be involved for the National System of Interstate and Defense Highways. The experience of the individual states as to assignment of probable life expectancy of different paving types, under the pertaining conditions, must for the present be accepted.

Assigned maintenance costs will seriously affect the cost comparison. If these costs are to be considered wholly valid, they must be based on accurately kept, long-term maintenance records reflecting an established maintenance standard adhered to in practice. Since traffic and structural standards in the past have been such variables, it is difficult to accurately evaluate maintenance costs. This has not been a dereliction of the highway official.

It is urged that the individual states take the necessary steps to develop factual information from Interstate System of highways, which will be valuable in the years ahead. These highways are built to modern standards. Establishment of, and adherence to, a maintenance standard, supplemented by accurate cost recording, will produce for the future more reliable data on maintenance cost and life expectancy.

Salvage value to be ascribed to pavements is somewhat open to conjecture. As it were, a large proportion of highway reconstruction involves changes in alignment or gradient which negate the salvage value. Each project actually must be considered individually.

SECONDARY FACTORS

I. Adjacent Existing Pavements

Provided there is no radical change in conditions, the choice of paving type on a highway may be influenced by existing sections thereof which have given adequate service. This will result in a desirable continuity of pavement and consequent simplification of maintenance operations.

II. Stage Construction

Where financial circumstances dictate stage construction of the type of pavement, where a thinner wearing course is later brought up to design requirements by an additional course or courses of wearing course material, flexible design becomes mandatory.

III. Depressed, Surface, or Elevated Design

Depressed and surface design may involve a high water table which will influence the choice of paving type. Elevated design, as in the case of approaches to long bridges or viaducts with concrete decks, may influence the decision in favor of rigid pavement to preserve a desirable continuity of pavement surface. A depressed design, presenting some periodic possible drainage problems, may also indicate the use of one type of pavement over another.

IV. Highway System

It is not considered good practice to let a system designation influence the choice of paving type. Merits of the individual case and economics should prevail.

V. Conservation of Aggregates

This consideration may well have influence in choosing a paving type which will involve, in the total pavement structure, less of the scarce critical material than might be required by another type.

VI. Stimulation of Competition

It is desirable that monopoly situations be avoided, and that improvement in products and methods be encouraged through continued and healthy competition among industries involved in the production of paving materials.

VII. Construction Consideration

Such considerations as speed of construction, reduction of traffic maintenance during construction, ease of replacement, anticipated future widening, need for minimum of surface maintenance in highly congested locations, seasons of the year when construction must be accomplished, and perhaps others may have a strong influence on paving type selections in specific cases.

VIII. Municipal Preference, Participating Local Government Preference and Recognition of Local Industry

While these considerations seem outside of the realm of the highway engineer, they cannot always be ignored by the highway administrator, especially if all other factors involved are indecisive as to the pavement type to select.

IX. Traffic Safety

The particular characteristics of a wearing course surface, the need for delineation through pavement and shoulder contrast, reflectivity under highway lighting, and the maintenance of a non-skid surface as affected by the available materials may each influence the paving type selection in specific locations.

X. Availability of and Adaptation of Local Materials or of Local Commercially Produced Paving Mixes

The prevalence of adaptability of local materials may influence, or the availability of commercial produced mixes particularly on small projects, may influence the selection of pavement type.

Conclusion . . .

In the foregoing, there have been listed and discussed those factors and considerations which influence, to various degree, the determination of paving types. This has brought to the fore the need, in certain areas, for the development of basic information that is not available at present. It has also served to point out that, in general, conditions are so variable, and influences sufficiently different from locality to locality, to necessitate a study of individual projects in most instances.

The public, although a critical judge, cannot be expected to be aware of the variety of considerations which influence the decisions of a highway administrator.

Consequently, whatever factors control the selection of the pavement type should be made part of the project file and should carry the identity of the person or persons involved in the entire process of making recommendations and in making the final decisions. It is very important that the reasons for reaching the decision be fully documented in the project file.

The judgment of the decision may be disputed at some subsequent time, but if the reasons are fully outlined and documented, the matter becomes only a difference of opinion and the reasons of the person or persons, who are responsible for the decision, are a matter of record for any future review or investigation.

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number shall be coded identically on each invoice and on the worksheet.

PART 142—ENTRY PROCESS

1. Section 142.21(f) is revised to read as follows:

§ 142.21 Merchandise eligible for special permit for immediate delivery.

* * * * *

(f) *Release from warehouse followed by warehouse withdrawal for consumption.* Merchandise may be released from warehouse under a special permit—

(1) At the discretion of the district director when

(i) The warehouse is located a considerable distance from the customhouse and actual release of the merchandise from the warehouse may not be effected within the next full business day after the day of the payment of duty, and (ii) The district has sufficient manpower to permit such practice;

(2) The importer shall have on file one of the types of Customs bonds provided for in § 142.4; and

(3) The immediate delivery permit shall be annotated to state that a warehouse withdrawal for consumption will be filed for this merchandise.

* * * * *

2. Section 142.22(b) is revised to read as follows:

§ 142.22 Application for special permit for immediate delivery.

(a) * * *

(b) *Customs custody.* Merchandise for which a special permit for immediate delivery has been issued under §142.21 of this part shall be considered to remain in Customs custody until the filing of one of the following:

(1) An entry summary for consumption, with estimated duties attached, an entry summary for warehouse, or an entry summary for entry under a temporary importation bond, which may be filed in any of the circumstances under §142.21 of this part except for merchandise released from warehouse under §142.21(f) of this part;

(2) A withdrawal for consumption, with estimated duties attached, which shall be filed only for merchandise released from warehouse under §142.21(f) of this part;

(3) An entry for transportation and exportation, immediate transportation without appraisement, or direct exportation, which shall be filed in those circumstances under §142.21(b) and (e)(2) of this part; or entry for transportation and exportation, or direct exportation, which shall be filed in the circumstances under §142.28 of this part or

(4) An application to destroy, which shall be filed in those circumstances under §§142.21(b) and (e)(2), and §142.28 of this part.

(R.S. 251, as amended (19 U.S.C. 66), sec. 484, 552, 553, 557, 624, 46 Stat. 722, as amended, 742, as amended, 744, as amended, 759 (19 U.S.C. 1484, 1552, 1553, 1557, 1624); 92 Stat. 888, (Pub. L. 95-410), October 3, 1978)

[FR Doc. 81-29302 Filed 10-7-81; 8:45 am]

BILLING CODE 4810-22-M

DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

23 CFR Ch I

Pavement Type Selection; Policy Statement

AGENCY: Federal Highway Administration (FHWA), DOT.

ACTION: Notice of policy statement.

SUMMARY: This notice provides a statement of FHWA policy on how the type of materials used in the various pavement components of a Federal-aid project should be determined.

FOR FURTHER INFORMATION CONTACT: Mr. L. M. Noel, Pavement Branch, Highway Design Division, (202) 426-0327, or Michael J. Laska, Office of the Chief Counsel, (202) 426-0800, Federal Highway Administration, 400 Seventh Street, SW., Washington, D.C. 20590. Office hours are from 7:45 a.m. to 4:15 p.m. ET, Monday through Friday.

SUPPLEMENTARY INFORMATION: This notice establishes a policy on Pavement Type Selection pending completion of the rulemaking process initiated on August 21, 1980, with the issuance of an advance notice of proposed rulemaking (ANPRM) (FHWA Docket No. 80-14). This policy is based on an initial analysis of comments made to Docket No. 80-14. The policy is designed to provide the public with acceptable highway service at a minimal annual or life cycle cost while permitting maximum flexibility. The policy encourages the consideration of alternate designs and strategies in the type selection process. As used in this policy, pavement type includes both new and rehabilitated pavements including their components of overlays, shoulders, bases, and subbases.

The FHWA policy can be addressed under the following four key issues:

1. Pavement type selection should be based upon an engineering evaluation considering the factors contained in the 1960 AASHTO publication entitled "An Informational Guide on Project Procedures."

2. Pavement type determinations should include an economic analysis based on life cycle costs of the pavement type. Estimates of life cycle costs should become more accurate as pavement management procedures begin providing historical cost, serviceability, and performance data. States without this data are encouraged to obtain it.

3. An independent engineering and economic analysis and final pavement type determination should be performed or updated a short time prior to advertising on each pavement type being considered.

4. Where the analysis reflects that two or more initial designs and their forecasted performance are determined to be comparable (or equivalent), then alternate bids may be permitted if requested by the contracting agency. The Division Administrator shall review the analysis and concur in the finding of equivalency prior to PS&E approval. Price adjustment clauses where utilized would also have to be treated on an equal basis.

This policy is written with the intention of taking advantage of fluctuating material prices while not compromising good design and pavement management practices.

(Catalog of Federal Domestic Assistance Program Number 20.205, Highway Research, Planning, and Construction. The provisions of OMB Circular No. A-95 regarding State and local clearinghouse review of Federal and federally assisted programs and projects apply to this program.)

Issued: September 29, 1981.

R. A. Barnhart,

Federal Highway Administrator.

[FR Doc. 81-29181 Filed 10-7-81; 8:45 am]

BILLING CODE 4910-22-M

PENSION BENEFIT GUARANTY CORPORATION

29 CFR Part 2618

Allocation of Assets in Non-Multiemployer Plans

AGENCY: Pension Benefit Guaranty Corporation.

ACTION: Amendment to final rule adding Subpart C—Allocation of Residual Assets.

SUMMARY: This is an amendment to the regulation on the allocation of assets in terminating, non-multiemployer pension plans. This amendment prescribes rules for the distribution of any assets that remain after all plan benefits have been paid in terminating plans that close out

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effects of refilling the reservoir pursuant to repairs would be less problematic to the environment, although construction impacts are always important to consider. The effect of any reconstruction on migratory fish populations at the site of a breached dam is an additional factor to weigh in determining appropriate terms and conditions of exemption.

For the above reasons, any project which contains an impoundment which is at substantial variance from the historic, non-flood power generation level or, if no power was previously developed at the site, the impoundment level which the dam was originally designed to contain, will be scrutinized to determine whether the return of the impoundment level to its historic or power generation level would entail significant adverse environmental effects. If the Commission so finds, the project will not be considered "at the site of an existing dam."

II. Effective Date

Because this clarification does not change the Commission's exemption regulations or its policy regarding the application of those regulations, it will be considered effective as of November 7, 1980, the effective date of Order No. 106 (45 FR 76115, November 16, 1980). The Commission finds that notice and comment is unnecessary for interpretations of existing regulations such as this clarification.

(Federal Power Act as amended 16 U.S.C. 782–828c Public Utility Regulatory Policies Act of 1978, 16 U.S.C. 2601–2645, the Department of Energy Organization Act 42 U.S.C. 7101–7352, E.O. 12209, 3 CFR 142 (1978))

By the Commission.

Kenneth F. Plumb,

Secretary.

[FR Doc. 81–32455 Filed 11–6–81; 8:45 am]

BILLING CODE 6717–01–M

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18 CFR Part 282

[Docket No. RM80–18]

Treatment Under the Incremental Pricing Program of Natural Gas Used in the Manufacturing Process for Fertilizer, Agricultural Chemicals, Animal Feed or Food; Effective Date and Availability of Exemption Affidavits

Issued: November 2, 1981.

AGENCY: Federal Energy Regulatory Commission, DOE.

ACTION: Notice of effective date and availability of exemption affidavits.

SUMMARY: On September 24, 1981, the Federal Energy Regulatory Commission (Commission) issued a rule (46 FR 50060, October 9, 1981) under Title II of the Natural Gas Policy Act of 1978 (NGPA) providing an exemption from incremental pricing for natural gas used as boiler fuel in the manufacture of fertilizer, agricultural chemicals, animal feed or food. The rule was transmitted to Congress for review, as required by section 206(d) of the NGPA. During the period for Congressional review set forth in section 507(b) of the NGPA, neither House disapproved the submittal. The exemptive rule thus became effective on November 1, 1981, the day following expiration of the review period.

EFFECTIVE DATE: November 1, 1981.

FOR FURTHER INFORMATION CONTACT:

Barbara K. Christin, Office of the General Counsel, Federal Energy Regulatory Commission, 825 North Capitol Street, N.E., Washington, D.C. 20426, (202) 357–9370, or

Alice Fernandez, Office of Pipeline and Producer Regulation, Federal Energy Regulatory Commission, 825 North Capitol Street, N.E., Washington, D.C. 20426, (202) 357–9095

SUPPLEMENTARY INFORMATION: Affidavits for claiming an exemption from incremental pricing have been revised to reflect the subject exemption and are available through the Commission's Division of Public Information, Room 1000, 825 North Capitol Street, N.E., Washington, D.C. 20426, or from natural gas suppliers. By order issued November 2, 1981, the Commission waived its regulations in § 282.204(d)(7) (18 CFR Part 282) to provide that if the owner or operator of an industrial boiler fuel facility files, by November 25, 1981, an affidavit with the Commission claiming the subject exemption, and sends a copy to the facility's natural gas supplier, the facility shall be exempt from incremental pricing as of November 1, 1981.

Kenneth F. Plumb,

Secretary.

[FR Doc. 81–32456 Filed 11–6–81; 8:45 am]

BILLING CODE 6717–01–M

DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

23 CFR Ch. 1

Pavement Type Selection; Policy Statement; Clarification

AGENCY: Federal Highway Administration (FHWA), DOT.

ACTION: Clarification of policy statement.

SUMMARY: This notice provides a clarification to a statement of FHWA policy, published on October 8, 1981 (46 FR 49842), on how the type of materials used in the various pavement components of a Federal-aid project should be determined.

FOR FURTHER INFORMATION CONTACT: Mr. L. M. Noel, Pavement Branch, Highway Design Division, (202) 426–0327, or Michael J. Laska, Office of the Chief Counsel, (202) 426–0800, Federal Highway Administration, 400 Seventh Street, SW., Washington, D.C. 20590. Office hours are from 7:45 a.m. to 4:15 p.m. ET, Monday through Friday.

SUPPLEMENTARY INFORMATION: The notice published on October 8, 1981, established a policy on Pavement Type Selection designed to provide the public with acceptable highway service at a minimal annual or life cycle cost while permitting maximum flexibility. The policy encouraged the consideration of alternate designs and strategies in the type selection process.

The policy contained a provision in paragraph 4 that "price adjustment clauses where utilized would also have to be treated on an equal basis." It has come to the attention of FHWA that when price adjustment clauses are used, it is difficult, if not impossible, to administer equal treatment to alternate materials. Therefore, the policy is revised to discourage the use of price adjustment clauses with alternate bids.

The FHWA policy is revised as follows:

1. Pavement type selection should be based upon an engineering evaluation considering the factors contained in the 1960 AASHTO publication entitled "An Informational Guide on Project Procedures."

2. Pavement type determinations should include an economic analysis based on life cycle costs of the pavement type. Estimates of life cycle costs should become more accurate as pavement management procedures begin providing historical cost, serviceability, and performance data. States without this data are encouraged to obtain it.

3. An independent engineering and economic analysis and final pavement type determination should be performed or updated a short time prior to advertising on each pavement type being considered.

4. Where the analysis reflects that two or more initial designs and their forecasted performance are determined to be comparable (or equivalent), then

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alternate bids may be permitted if requested by the contracting agency. The Division Administrator shall review the analysis and concur in the finding of equivalency prior to PS&E approval. Price adjustment clauses should not be used when alternate bids are permitted.

This policy is written with the intention of taking advantage of fluctuating material prices while not compromising good design and pavement management practices.

(Catalog of Federal Domestic Assistance Program Number 20.205, Highway Research, Planning, and Construction. The provisions of OMB Circular No. A-95 regarding State and local clearinghouse review of Federal and federally assisted programs and projects apply to this program)

Issued on: November 2, 1981.

R. A. Barnhart,

Federal Highway Administrator.

[FR Doc. 81-32334 Filed 11-6-81; 8:45 am]

BILLING CODE 4910-22-M

DEPARTMENT OF DEFENSE

Department of the Navy

32 CFR Part 706

Certifications and Exemptions Under the International Regulations for Preventing Collisions at Sea, 1972

AGENCY: Department of the Navy, DoD.

ACTION: Final rule.

SUMMARY: The Department of the Navy is amending its certifications under the International Regulations for Preventing Collisions at Sea, 1972, (72 COLREGS) to reflect that the Secretary of the Navy has determined that USS CHANDLER (DDG 996) is a vessel of the Navy which, due to its special construction and purpose, cannot comply fully with certain provisions of the 72 COLREGS without interfering with its special function as a guided missile destroyer. The intended effect of this rule is to warn mariners in waters where the 72 COLREGS apply.

EFFECTIVE DATE: October 27, 1981.

FOR FURTHER INFORMATION CONTACT: Captain Richard J. McCarthy, JAGC, USN, Admiralty Counsel, Office of the Judge Advocate General, Navy Department, 200 Stovall Street, Alexandria, Virginia 22332, Telephone Number (202) 325-9744.

SUPPLEMENTARY INFORMATION: Pursuant to the authority granted in Executive Order 11964 and 33 U.S.C. 1605, the Department of the Navy amends 32 CFR Part 706. This amendment provides notice that the Secretary of the Navy has certified that USS CHANDLER (DDG 996) is a vessel of the Navy which, due to its special construction and purpose cannot comply fully with 72 COLREGS, Annex I, Section 2(f) pertaining to the placement of masthead lights over all other lights and obstructions; 72 COLREGS, Annex I, Section 3(a) pertaining to the placement of the forward masthead lights in the forward quarter of the ship; 72 COLREGS, Annex I, section 3(a) pertaining to the placement of the after masthead light; and 72 COLREGS, Rule 23(a)(ii) regarding the arc of visibility of the after masthead light, without interfering with its special function as a naval ship. The Secretary of the Navy has also certified that the aforementioned lights are located in closest possible compliance with the applicable 72 COLREGS requirements. Moreover, it has been determined, in accordance with 32 CFR Parts 296 and 701, that publication of this amendment for public comment prior to adoption is impracticable, unnecessary and contrary to the public interest since it is based on technical findings that the placement of lights on this ship in a manner different from that prescribed herein will adversely affect the ship's ability to perform its military function.

PART 706—CERTIFICATIONS AND EXEMPTIONS UNDER THE INTERNATIONAL REGULATIONS FOR PREVENTING COLLISIONS AT SEA, 1972

Accordingly, 32 CFR Part 706 is amended as follows:

§ 706.2 [Amended]

1. Table Five of § 706.2 is amended by adding the following naval ship to the list of vessels therein to indicate the certifications issued by the Secretary of the Navy:

* * * * * * *

TABLE 5.

Vessel	Number	Forward masthead light not required; height above hull. Annex I, Section 2(a)(ii), (c), (d)	Aft masthead light less than 4.5 meters above forward masthead light. Annex I, Section 2(a)(ii)	Masthead lights not over all other lights and obstructions. Annex I, Section 2(f)	Vertical separation of masthead lights used when towing less than required by Annex I, Section 2(a)(i)	Aft masthead lights not visible over forward light 1000 meters ahead of ship in all normal degrees of trim. Annex I, Section 2(b)	Forward masthead light not in forward quarter of ship. Annex I, Section 3(a)	After masthead light not less than ½ ship's length aft of forward masthead light. Annex I, Section 3(a)	Percentage horizontal separation attained
USS Scott	DDG 995	*	*	*	*	*	*	*	*
USS Chandler	DDG 996	–	–	X	–	–	X	X	44 6

2. Table Four paragraph 7 of § 706.2 is amended by adding to the list of vessels therein certifications issued by the Secretary of the Navy.

7. The arc of visibility of the after masthead light required by Rule 23(a)(ii) and Annex I; section 2(f) may be obstructed from right ahead on certain naval ships as follows:

* * * * *

USS Chandler (DDG 996) .... 0°28.8'

3. Table Four of § 706.2 is amended by adding to the lists of vessels therein certifications issued by the Secretary of the Navy:

17. On the following ships the arc of visibility of the after masthead light required by Rule 23(a)(ii) may be obstructed through 0°48.6' arc of visibility at the point 349° relative to the ship's head:

* * * * *

USS Chandler (DDG 996)

Dated: 27 October 1981.

Authority: Executive Order 11964; 33 U.S.C. 1605.

James F. Goodrich,

Acting Secretary of the Navy.

[FR Doc. 81-32306 Filed 11-6-81; 8:45 am]

BILLING CODE 3810-AE-M

U.S. Department of Transportation
Federal Highway Administration

Memorandum

Subject:	**INFORMATION**: Clarification of FHWA Policy for Bidding Alternate Pavement Type on the National Highway System	Date:	November 13, 2008
From:	Peter J. Stephanos Director, Office of Pavement Technology	In Reply Refer To:	HIPT
To:	Associate Administrators Chief Counsel Directors of Field Services Federal Lands Highway Division Engineers Resource Center Director Division Administrators		

Recent changes in pavement materials costs have impacted the competitive environment relative to the determination of the most cost effective pavement structure for a specific project. In response, State highway agencies (SHA's) have a renewed interest in using alternate pavement type bidding procedures to determine the appropriate pavement type. The FHWA policies relative to pavement design, pavement type selection, economic analysis, and alternate bidding procedures are distributed among several resources. The intent of this memorandum is to consolidate and clarify FHWA policy relative to alternate pavement type bidding procedures on National Highway System (NHS) projects. In accordance with Title 23 U.S.C. 109(o), contracting agencies may use State design and construction standards, including alternate pavement type bidding, for Non-National Highway System projects.

Guidance on alternate pavement type bidding procedures is contained in 23 CFR 626 Non-Regulatory Supplement. It states that "FHWA does not encourage the use of alternate bids to determine mainline pavement types primarily due to the difficulty in developing truly equivalent pavement designs". It further states that "In the rare instances where the use of alternate bids is considered, the SHA's engineering and economic analysis process should clearly show there is no clear cut choice between two or more alternatives having equivalent designs. Equivalent design implies that each alternative will be designed to perform equally, and provide the same level of service, over the same performance period, and has similar life-cycle costs."

The FHWA Pavement Type Selection Policy published in the Federal Register on November 9, 1981, states "Where (engineering and economic) analysis shows that two or more initial designs and their forecasted performance are determined to be comparable (or equivalent), the use of alternate bids may be permitted as requested by the contracting agency."

MOVING THE AMERICAN ECONOMY

There are several factors that should be considered prior to determining that alternate bidding procedures should be used. Additionally, there are several factors that should be considered once the determination has been made to utilize alternate bidding procedures for pavement type selection.

The factors that should be considered prior to making the determination to utilize alternate bidding procedures include:

Designs must be equivalent – The 23 CFR 626 Non-Regulatory Supplement defines "equivalent design" as a design that performs equally, provide the same level of service, over the same performance period, and has similar life-cycle costs. It is difficult for two pavement structures utilizing different materials to be truly equivalent, so engineering judgment is required in the determination of what is and what is not "equivalent design". The performance period (analysis period) should be long enough to cover at least one major rehabilitation cycle. Life–cycle cost should be considered similar when the Net Present Value (NPV) for the higher cost alternative is within less than 10 percent higher than the lowest cost alternative. This difference is appropriate due to the uncertainty associated with estimating future costs and timing of maintenance and rehabilitation. It should be highlighted that no design methodology or analysis procedures currently available will output "equivalent designs" using design lives and analysis periods typically used for high-type facilities.

Realistic discount rate – Discount rates have a significant impact on the determination of the Net Present Value (NPV) of alternate pavement designs. The Final Policy Statement on Life - Cycle Cost Analysis (LCCA), published in the Federal Register on September 18, 1996, recommends that future agency costs should be discounted to NPV or equivalent uniform annual costs using appropriate (real) discount rates. Discount rates should be consistent with OMB Circular A-94. The trend over the past 10 years indicates a discount rate in the range on 2-4 percent is reasonable.

Consideration of uncertainty – The impact of uncertainty in factors such as performance life, material costs, construction duration, and future actions should be considered in the determination of total life-cycle cost for each alternative. The RealCost Software Program (available for free download at http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm) is a useful tool to perform LCCA as well as quantify the uncertainty of future factors through a sensitivity or probabilistic LCCA.

Realistic rehabilitation strategy - The rehabilitation strategy selected for each "equivalent design" should accurately reflect current or anticipated owner-agency pavement management practices. If recent experience with a pavement design is limited, available "best-practice" guidance on pavement rehabilitation strategies should be utilized.

Subjective Considerations – Despite the outcome of an objective engineering and economic analysis, an owner-agency may consider non-cost related factors such as constructability, type of adjacent pavements, recycling, and conservation of materials when making the determination to utilize alternate bidding procedures for pavement type selection.

Appropriate application – Alternate pavement type bidding procedures should only be used where the pavement items impacted by the alternate bid are likely to influence the final determination of the lowest responsive bidder for the project. Projects with substantial bridge or earthwork items are generally not suited for alternate bids. Additionally, projects with substantial quantities of different pavement materials may not be suited for alternate bids due to equipment mobilization costs.

The factors that should be considered once a decision has been made to bid alternate pavement types include:

Commodity price adjustment factors – The Pavement Type Selection Policy, published in the Federal Register on November 9, 1981, specifies that price adjustment clauses should not be used when using alternate bidding procedures. Price adjustment clauses transfer some material cost escalation risk from the contractor to the owner agency. As it is very difficult, if not impossible, to administer equal treatment with price adjustment factors to alternate materials, using these clauses will result in different levels of materials cost risk being included in the bid for alternate pavement types.

Incentive/Disincentive (I/D) Provisions for quality - If quality based I/D provisions are included with alternate bidding procedures, the I/D provisions should provide comparable opportunity for each alternate.

Specifications of material quantities – Using different methods to specify/quantify alternate pavement types may result in different levels of materials quantity risk for the alternate pavement types. Owner-agencies should consider approaches that balance materials quantity risk between the alternate pavement types.

SEP 14 approval needed if using adjustment factors – Some States have utilized price adjustments to account for differences in life-cycle costs for the alternate pavement types to determine the lowest responsive bidder. If adjustment factors are used, approval under Special Experimental Project #14 (SEP14) is required. It is recommended that prior to utilizing any adjustment factors that appropriate stakeholders be provided an opportunity to provide input. Adjustment factors should include, at a minimum, anticipated maintenance costs, anticipated rehabilitation costs, and salvage value.

Approval Requirements - The Pavement Type Selection Policy, published in the Federal Register on November 9, 1981, specifies that the division administrator shall review the analysis and concur in the finding of equivalency, when bidding alternate pavement types, and no adjustment factors are used.

Guidance related to LCCA and pavement type selection is currently under review and development. Once completed, more comprehensive guidance relative to the alternative pavement type bidding procedures will be issued. If there are questions concerning bidding of alternate pavement types, please contact Mark Swanlund of my staff at (202) 366-1323 or via email at mark.swanlund@dot.gov.

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