Life-Cycle Cost Analysis Primer

U.S. Department of Transportation

Life-Cycle Cost Analysis Primer

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NOTE FROM THE DIRECTOR

Office of Asset Management, Infrastructure Core Business Unit, Federal Highway Administration

The Federal Highway Administration's (FHWA's) Office of Asset Management is pleased to present this *Life-Cycle Cost Analysis Primer*. This Primer is intended to provide sufficient background for transportation officials to investigate the use of life-cycle cost analysis (LCCA) to evaluate alternative infrastructure investment options. Additionally, the Primer demonstrates the value of such analysis in making economically sound decisions.

LCCA is an engineering economic analysis tool useful in comparing the relative merit of competing project implementation alternatives. By considering all of the costs—agency and user—incurred during the service life of an asset, this analytical process helps transportation officials to select the lowest cost option. Additionally, LCCA introduces a structured methodology that accounts for the effects of agency activities on transportation users and provides a means to balance those effects with the construction, rehabilitation, and preservation needs of the system itself.

LCCA's value as a decision-support tool is contingent upon its proper use. While the economic concepts that support this type of analysis are fairly straightforward, their application presents a number of challenges. Frequently there are uncertainties as to when and how LCCA should be employed and what assumptions should be made during the course of the analysis. By carefully describing the LCCA methodology and process and by addressing the uncertainties, this Primer is intended to encourage a broader application of this important investment tool.

FHWA has pursued a policy of promoting LCCA for transportation investment decisions since the Intermodal Surface Transportation Equity Act of 1991. Throughout the 1990s FHWA investigated LCCA. In Fall 1996, FHWA initiated a technology transfer effort under Demonstration Project 115, "Life-Cycle Cost Analysis in Pavement Design." This project resulted in an LCCA instructional workshop that has since been delivered to more than 40 State transportation agencies. In 1998, FHWA issued an Interim Technical Bulletin on LCCA, *Life-Cycle Cost Analysis in Pavement Design.* FHWA is currently developing instructional software and will continue to provide technical assistance and training to assist individual transportation agencies as they explore the use of LCCA for pavement design decisions.

Tommy L. Beatty
Acting Director, Office of Asset Management

WHAT IS LIFE-CYCLE COST ANALYSIS?

Life-cycle cost analysis (LCCA) is an evaluation technique applicable for the consideration of certain transportation investment decisions. Specifically, when it has been decided that a project will be implemented, LCCA will assist in determining the best—the lowest-cost—way to accomplish the project.

The LCCA approach enables the total cost comparison of competing design (or preservation) alternatives, each of which is appropriate for implementation of a transportation project. All of the relevant costs that occur throughout the life of an alternative, not simply the original expenditures, are included. Also, the effects of the agency's construction and maintenance activities on users, as well as the direct costs to the agency, are accounted for.

A "project" is a transportation investment that fulfills the agency's requirements to provide a given level of performance to the public. A "project alternative" is a proposed means to provide that performance. As the level of performance is defined by the project, and all alternatives meet the requirements of the project equally, the economic difference between alternatives is dictated by total cost.

LCCA is reasonably straightforward to understand and perform. It incorporates both the transportation agency's institutional knowledge and the application of sound economic analysis techniques.

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

The predicted schedule of activities and their associated agency and user costs form the projected life-cycle cost (LCC) stream for each design alternative. Using an economic technique known as "discounting," these costs are converted into present dollars and summed for each alternative. The analyst can then determine which alternative is the most cost-effective. A more thorough description of the LCCA process is provided in the methodology section of this Primer.

It is important to note that the lowest LCC option may not necessarily be implemented when other considerations such as risk, available budgets, and political and environmental concerns are taken into account. LCCA provides critical information to the overall decision-making process, but not the final answer.

LIFE-CYCLE COST ANALYSIS STEPS

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

LCCA AND BENEFIT-COST ANALYSIS

Life-cycle cost analysis (LCCA) is a tool used to compare the total user and agency costs of competing project implementation alternatives. LCCA is a subset of benefit-cost analysis (BCA), an economic analysis tool that compares benefits as well as costs in selecting optimal projects or implementation alternatives. Because the distinction between LCCA and BCA can be confusing in day-to-day practice, the differences between LCCA and BCA, and their appropriate applications, are discussed below.

The agency that uses LCCA has already decided to undertake a project or improvement and is seeking to determine the most cost-effective means to accomplish the project's objectives. LCCA is appropriately applied only to compare project implementation alternatives that would yield the same level of service and benefits to the project user at any specific volume of traffic. LCCA, for instance, is an appropriate tool to use when comparing two alternatives to replace a bridge that has reached the end of its service life, where each design alternative will result in the same level of service to the user. Costs measured in LCCA typically include expenses to the State or local agency, such as construction, operation, and maintenance costs. As a matter of best practice, LCCA should also include costs accruing to the users of the project facility, especially costs associated with increased congestion and reduced safety experienced during project construction and maintenance.

Unlike LCCA, BCA considers the benefits of an improvement as well as its costs and therefore can be used to compare design alternatives that do not yield identical benefits (e.g., bridge replacement alternatives that vary in the level of traffic they can accommodate), as well as to compare projects that accomplish different objectives (a road realignment versus a widening project). Moreover, BCA can be used to determine whether or not a project should be undertaken at all (i.e., whether the project's life-cycle benefits will exceed its life-cycle costs).

Benefits measured in BCA are typically those associated with the desired results of the project (i.e., the reasons for undertaking the project), and may include shorter travel distance or time, reduced vehicle operating costs, improved safety, and other benefits to facility users. Other effects of a project that may be considered involve emissions and noise, which affect project nonusers as well as users, and are often referred to as "externalities."

In summary, LCCA is a cost-centric approach used to select the most cost-effective alternative that accomplishes a preselected project at a specific level of benefits that is assumed to be equal among project alternatives being considered. BCA is the appropriate tool to use when design alternatives will not yield equal benefits, such as when unlike projects are being compared or when a decision-maker is considering whether or not to undertake a project. The elements typically included in LCCA and BCA are listed below.

COMPARISON OF ANALYSIS ELEMENTS: LIFE-CYCLE COST ANALYSIS VERSUS BENEFIT-COST ANALYSIS

Project Element	LCCA	BCA
Agency construction, rehabilitation, and maintenance expenditures	Yes	Yes
User costs during construction, rehabilitation, or maintenance	Yes	Yes
User costs during normal operations	Yes	Yes
User benefits resulting from project	No	Yes
Externalities resulting from project	No	Yes

WHY USE LCCA?

Decisions related to implementation of a transportation improvement generally require that several alternatives be considered. Many factors contribute to an agency's decision to select a particular option, although initial project costs may dominate this decision.

Initial agency costs, however, tell only part of the story. The design alternative selected will commit the agency to future expenditures for maintenance and rehabilitation actions over the life cycle of the project. Furthermore, the selected alternative will accrue costs to facility users through project activities that directly impact the traveling public.

LCCA provides the means to include total cost to both the agency and the user in the investment decision. Additionally, the structure and documentation of the LCCA process provide the transportation agency with the ability to enhance its stewardship of the public's investment. Documentation is also a resource that the agency can use in educating newer employees and maintaining the agency's institutional knowledge.

LIFE-CYCLE COSTS

The idea behind LCCA is that transportation investment decisions should consider all of the costs incurred during the period over which the alternatives are being compared. Transportation investments are required to provide service for many years. The ability of a transportation asset to provide service over time is predicated on its being maintained appropriately by the agency. Thus the investment decision should consider not only the initial activity that creates a public good, but also all future activities that will be required to keep that investment available to the public. Those future activities are part of the alternative as much as the initial action is; without periodic maintenance and rehabilitation, the investment will not provide continued use to the public.

Specific future rehabilitation and maintenance activities are in large part dictated by the design alternative selected. For example, a steel girder bridge will require periodic painting whereas a concrete girder bridge will not. However, a concrete bridge might not have the span lengths that a steel bridge can have and may require construction of an additional column pier, with the additional construction and maintenance costs that it would engender. Future costs should be considered as relevant as initial costs to the investment decision.

USER COSTS

As transportation agencies are increasingly viewed as providers of mobility to the public, travel time, vehicle costs, and safety impacts become more important to investment decisions. Though these user costs are not directly borne by the agency, they affect the agency's customers and the customers' perceptions of the agency's performance.

The transportation network is aging, and agencies are focusing on maintenance and rehabilitation of existing infrastructure to a greater extent than ever before. Work on existing transportation assets, whether its purpose is to rehabilitate or to add capacity, requires the use of work zones to protect transportation users and construction workers. By reducing capacity, work zones often cause user costs to rise due to increases in travel time, vehicle operating costs, and possibly the number and severity of crashes. With existing transportation capacity already taxed, agencies need to be more concerned than ever about the effects of their work zones on users. The LCCA method provides a framework for considering trade-offs between user costs and additional agency expenses.

PRESERVATION

Preservation is a rapidly emerging concept in transportation. LCCA provides a method to evaluate the effects of preservation strategies. Preservation activities are different from traditional maintenance and rehabilitation activities: while traditional activities address existing deficiencies in transportation assets, many preservation activities are performed before deficiencies are visible or even detectable. By applying specific treatments before distress occurs, preservation activities delay the onset of deterioration and increase the useful lives of infrastructure investments, thereby reducing agency expenditures and lowering costs to users.

While preservation technologies offer the promise of extended service life, they themselves are not without cost. LCCA provides a means to judge the economic effectiveness of these activities through their effects on total life-cycle costs. The investment's reduced need for rehabilitation and other maintenance is weighed against the costs of the preservation treatments themselves. The debate over the value of preservation then moves from a qualitative discussion to a fact-based exercise.

STEWARDSHIP

Transportation officials strive to maximize the service of mobility to the public while minimizing agency and user costs. LCCA enables decision-makers to find the least-total-cost alternative while still satisfying the requirements of the investment. This allows money available for a given project to be spent in a fashion that produces the best long-term result, or the greatest "bang for the buck."

In the face of increasing public sophistication and interest, transportation agency officials are expected to explain and justify decisions concerning the expenditure of taxpayer dollars. Documentation associated with the LCCA process is a mechanism for transportation officials to demonstrate their good stewardship of the public's transportation infrastructure investment. Decision-makers have a record of their consideration of different assumptions and a formal analysis that supports the decision itself. These records are available to be revisited during or after the LCCA process.

LCCA documentation also serves to preserve the public's investment in transportation expertise. Transportation agencies regularly lose sources of information and expertise when personnel retire or move to other positions. The structure and documentation associated with the LCCA process provide a means to preserve institutional knowledge. This information is then available for experienced decision-makers and new employees to consult.

CONCLUSION

LCCA provides a means for transportation decision-makers to extend consideration of the merits of alternative projects beyond initial agency costs to include future agency and user costs. Additionally, LCCA documentation, as well as the analysis itself, can be used to demonstrate management's commitment to good stewardship and to making the analytical process more transparent and efficient.

THE LCCA METHODOLOGY

Once a decision has been made to undertake a project, LCCA provides a comprehensive means to select among two or more alternatives to accomplish the project. For LCCA to yield valid results, each project alternative considered must provide the same level of service or utility for a specific, given volume of traffic. In the event that the alternatives yield different levels of service or utility, then benefit-cost analysis (BCA), not LCCA, would be the appropriate decision tool. For example, the LCCA technique is not appropriate for contrasting competing projects where one project would add additional roadway lanes and another would rehabilitate existing pavements.

For transportation agencies, the use of LCCA allows different project alternatives to be compared not only when the initial costs differ, but when costs following the initial expenditure are expected to occur at different times and for varying amounts.

The LCCA process steps are listed below. The steps are ordered so that the analysis builds upon information gathered in prior steps.

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

The LCCA approaches and techniques outlined in this section are consistent with FHWA's LCCA Interim Technical Bulletin, *Life-Cycle Cost Analysis in Pavement Design*, which was published in 1998. The Interim Technical Bulletin provides a more detailed discussion of this methodology and its components, particularly with regard to user cost calculations and the treatment of uncertainty in an analysis.

STEP ONE: ESTABLISH DESIGN ALTERNATIVES

The LCCA process is initiated after an asset has been selected for improvement and a range of possible alternatives has been identified for accomplishing that improvement. At least two mutually exclusive options must be considered, and the economic difference between alternatives is assumed to be attributable to the total cost of each.

ANALYSIS PERIOD

Transportation assets are constructed to provide service for generations. Competing design alternatives may each have a different service life, which is the time period that the asset will remain open for public use. Life-cycle cost analysis (LCCA), however, uses a common period of time to assess cost differences between these alternatives so that the results can be fairly compared. This time period is termed the "analysis period." Allowing analysis periods to vary among design alternatives would result in the comparison of alternatives with different total benefit levels, which is not appropriate under LCCA.

The analysis period should demonstrate the total cost differences between the alternatives. Accordingly, the analysis period should be long enough to include the initial construction or major rehabilitation action and at least one subsequent rehabilitation action for each alternative. However, each alternative does not need to have the same number of maintenance or rehabilitation activities during the analysis period.

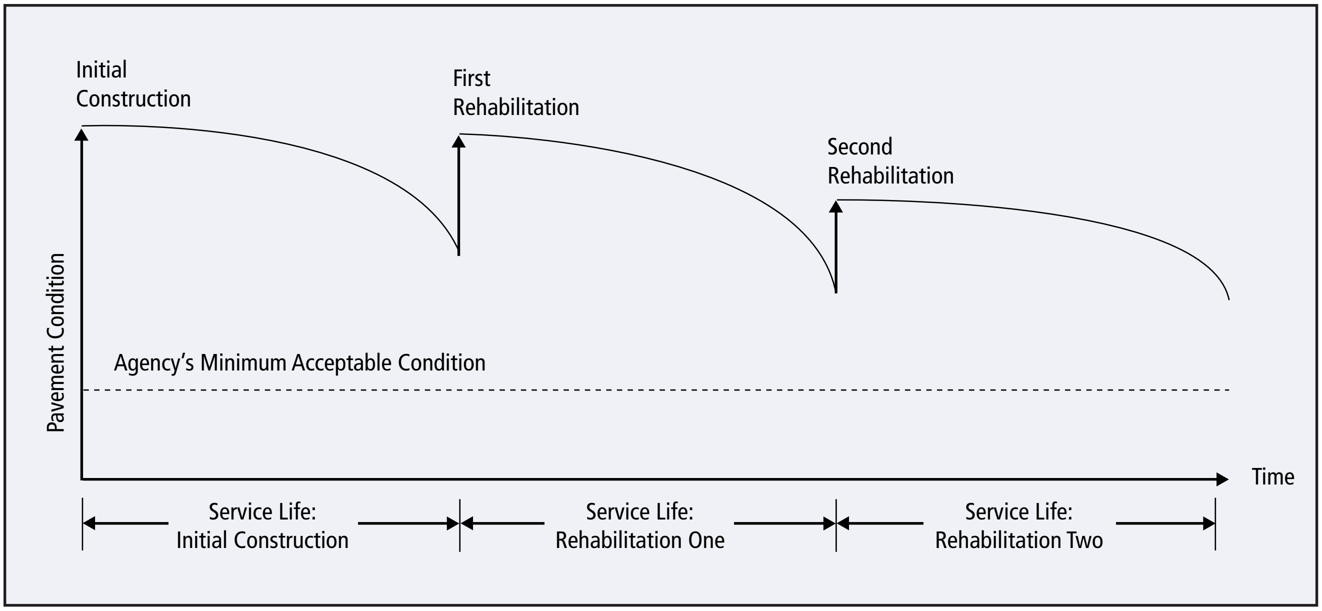


FIGURE 1. **EXAMPLE LIFETIME OF ONE DESIGN ALTERNATIVE**

In the first LCCA step, component activities for each alternative are detailed and the analysis period is defined. Each alternative is defined by the agency activities that create and maintain it. Initial construction or a major rehabilitation of an asset is only the first of these activities; periodic maintenance and subsequent rehabilitation are required for the alternative to provide a specified level of performance throughout its life. Different project alternatives will likely require different maintenance and rehabilitation activities. Typically, the identification of maintenance and rehabilitation activities is based on historical practice, research, and agency policies.

Important in this first step is defining the analysis period, the common timeframe for which initial and future costs will be evaluated for all alternatives being considered. In general, the analysis period should be long enough to include at least one major rehabilitation activity for each alternative being considered.

STEP TWO: DETERMINE ACTIVITY TIMING

After the component activities for each competing project alternative have been identified, each alternative's maintenance and rehabilitation plan is developed. Effectively, this plan results in a schedule of when the future maintenance and rehabilitation activities will occur, when agency funds will be expended, and when and for how long the agency will establish work zones.

When first constructed or substantially rehabilitated, transportation assets are in good condition and provide service as originally intended. Use, age, weather, and other factors cause assets to deteriorate, and deterioration causes the level of performance provided by the asset to fall. Periodic maintenance and rehabilitation activities will arrest deterioration and improve the asset's condition so as to maintain sufficient levels of condition, performance, and safety. Each agency decides when to perform these activities, usually based on the desired level of serviceability.

Figure 1 demonstrates the cycle of construction, deterioration, and rehabilitation that a typical transportation asset undergoes. As the asset's condition nears the agency's minimum acceptable condition, rehabilitation activities are conducted. The rate of deterioration, as influenced by pavement preservation practices, dictates the timing of future activities. Initial activities occur in the beginning of the analysis period, and future activities are shown in the years they are anticipated.

LCCA requires that the series of maintenance and rehabilitation activities forecasted for each improvement strategy be as accurate as possible because the expenses associated with these activities can account for a sizeable portion of a project's total LCC. The timing of rehabilitation activities should be based on existing performance records such as those available from an agency's pavement or bridge management system. This information may be supplemented with findings from outside research such as the national long-term pavement performance effort. Other data are available from local, regional, and national sources. When actual data are unavailable or not applicable, the judgment of experienced engineers may be particularly useful.

STEP THREE: ESTIMATE COSTS

Costs considered in LCCA include those accruing to highway agencies and to users of the highway system as a result of agency construction and maintenance activities.

LCCA does not require that all costs associated with each alternative be calculated. Only costs that demonstrate the differences between alternatives need be explored. This is an important distinction because it may simplify the analytical and data requirements considerably. In the case of agency costs, this means, for example, that rehabilitation activities should be included, but expenses common to all the alternatives (e.g., land costs) may be removed from the analysis. Although user costs may differ among alternatives over the entire analysis period, significant differences of importance to the LCCA process are usually associated with agency actions that require work zone activity.

When estimating future costs for an LCCA, it is appropriate to develop those costs in constant dollars. As is more fully explained in the Inflation and Discounting box on page 16, constant dollars do not include an inflation component. For example, the same material and labor costs used to price an activity in the base year of the analysis should generally be used to value them in any future year of the analysis.

Agency Costs

Critical to an insightful LCCA are good estimates of the various agency cost items associated with initial construction and periodic maintenance and rehabilitation activities. Construction costs pertain to putting the asset into initial service. Data on construction costs are obtained from historical records, current bids, and engineering judgment (particularly when new materials and techniques are employed).

Similarly, costs must be attached to the maintenance and rehabilitation activities identified in the previous steps to maintain the asset above some predetermined condition, performance, and safety levels. These costs include those for preventive activities that are planned to extend the life of the asset, day-to-day routine maintenance intended to address safety and operational concerns, and rehabilitation or restoration activities.

Another consideration affecting total agency costs is the value of the alternative at the end of the analysis period. One type of terminal value is called "salvage value," usually the net value from the recycling of materials at the end of a project's life. A second type of terminal value is the "remaining service life" (RSL) value of an alternative (the residual value of an improvement when its service life extends beyond the end of the analysis period). The RSL value may vary significantly among different alternatives, and should be included in the LCCA. The RSL concept is more fully explored in the box on page 14.

User Costs

Best-practice LCCA calls for including both the costs accruing to the transportation agency, described above, and costs incurred by the traveling public. In LCCA, user costs of primary interest include vehicle operating costs, travel time costs, and crash costs. Such user costs typically arise from the timing, duration, scope, and number of construction and rehabilitation work zones characterizing each project alternative. Because work zones typically restrict the normal capacity of the facility and reduce traffic flow, work zone user costs are caused by speed changes, stops, delays, detours, and incidents. While user costs do result during normal operations, these costs are often similar between alternatives and may be removed from most analyses.

Incorporating user costs into LCCA enhances the validity of the results, but at the same time is a challenging task. Some of these challenges are discussed later in this Primer.

REMAINING SERVICE LIFE VALUE

Design alternatives should be evaluated over equivalent analysis periods in order to yield fair comparisons of life-cycle costs. However, in many cases, one or more alternatives will have service lives that exceed the analysis period. Any service life exceeding the analysis period is known as remaining service life (RSL). Failure to account for differing RSLs can result in an economic bias toward one or another alternative when using life-cycle cost analysis. The Federal Highway Administration's Interim Technical Bulletin recommends a means to value RSLs based on project cost and the percentage of design life remaining at the end of the analysis period.

RSL value is different from salvage value. RSL value exists only if the alternative will continue in operation after the end of the analysis period, whereas salvage value requires termination. Salvage value is obtained only when some actual value is realized from the sale or reuse of scrap materials. When applied at the end of the analysis period, RSL value and salvage value can generally be considered mutually exclusive.

STEP FOUR: COMPUTE LIFE-CYCLE COSTS

In previous steps, the alternatives were defined with respect to agency costs, user costs, and the time when these events will occur. At this point, the objective is to calculate the total LCCs for each alternative so that they may be directly compared. However, because dollars spent at different times have different present values, the projected activity costs for an alternative cannot simply be added together to calculate total LCC for that alternative. Economic methods are available to convert anticipated future costs to present dollar values so that the lifetime costs of different alternatives can be directly compared.

Expenditure Stream Diagrams

To assist the analyst in visualizing the quantity and timing of expenditures projected over the life of the analysis period, expenditure stream diagrams may be developed. An expenditure diagram (see Figure 2) depicts a design alternative's (1) initial and future activities; (2) agency and user costs associated with these activities; and (3) the timing of these activities and costs. Upward arrows on the diagram are expenditures with the relative costs reflected in the length of each arrow. The horizontal arrow segments show the timing of the work zone activities and the periods of normal operations between them. The RSL value (or the salvage value, if the asset is to be termi-

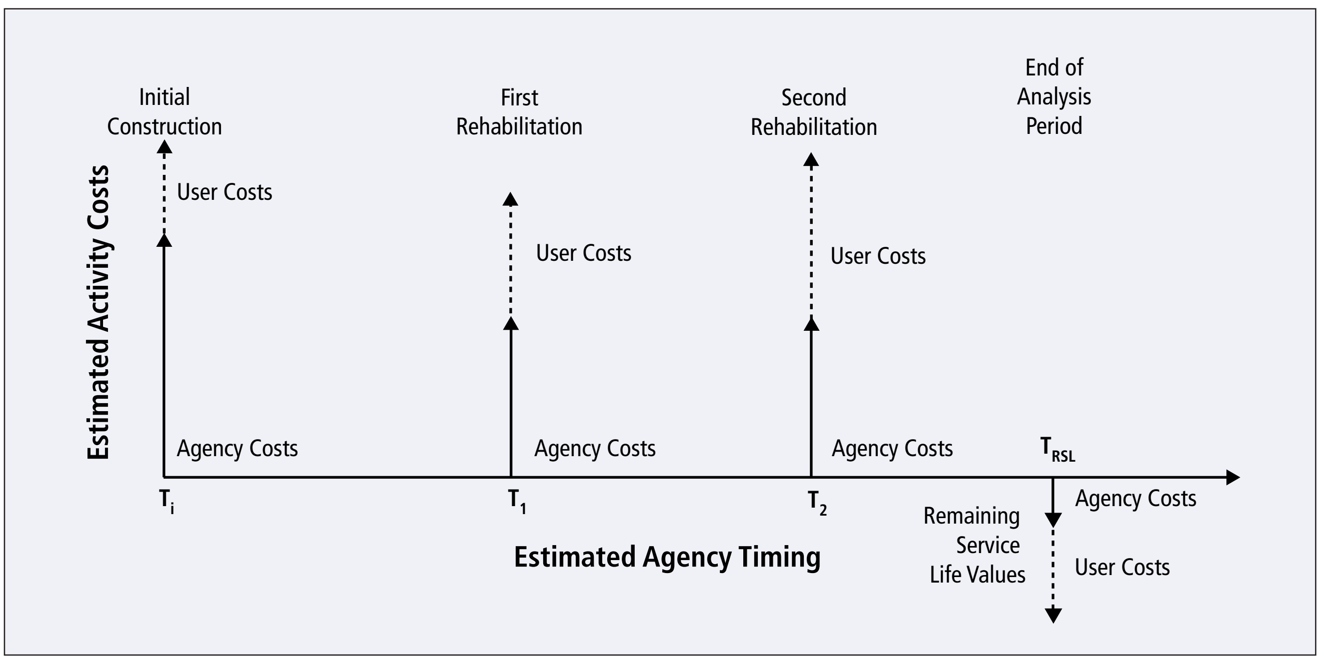


FIGURE 2. EXPENDITURE STREAM DIAGRAM, SHOWING ACTIVITIES, COSTS, AND TIMING

nated) is represented as a downward arrow and reflects a negative cost (or cost offset) accruing at the end of the analysis period. The value of an expenditure stream diagram is that it presents in a simple graphic all the cost and timing inputs required to perform an LCCA.

Economic Analysis Technique

Important to understanding LCCA is the concept of the time value of money. A given amount of money received today has a higher value than the same amount received at a later date. One way to understand this concept is that funds received today may be invested and immediately begin to earn interest. The time value of money is germane to LCCA because costs included in the analysis are incurred at varying points in time.

For LCCA, costs occasioned at different times must be converted to their value at a common point in time. A number of techniques based on the concept of discounting are available. The FHWA recommends the present value (PV) approach (also known as “present worth”), but the equivalent uniform annual cost (EUAC) approach is also commonly used (see the box on this page). Either method is suitable as a measure of LCC. The PV approach brings initial and future dollar costs to a single point in time, usually the present or the time of the first cost outlay. The box on the next page discusses dollars, inflation, and discounting, and supplies the formula for calculating the PV of any cost component.

Computational Approach

There are two approaches to preparing an LCCA: deterministic and probabilistic. The methods differ in the way they address the variability and uncertainty associated with LCCA input parameters such as activity cost, activity timing, and discount rate.

Deterministic Approach. The deterministic approach assigns each LCCA input variable a fixed, discrete value. The analyst determines the value most likely to occur for each input parameter. This determination is usually based on historical evidence or professional judgment. Collectively, these input values are used to compute a single LCC estimate. Traditionally, applications of LCCA have been deterministic ones. A deterministic LCC computation is straightforward and can be conducted manually using a calculator or automatically with a spreadsheet. However, it fails to convey the degree of uncertainty associated with the PV estimate.

The results of deterministic analysis can be enhanced through the use of a technique called sensitivity analysis. This procedure involves changing a single input parameter of interest, such as the discount rate or initial cost, over the range of its possible values while holding all other inputs constant, and estimating a series of PVs (output values). Each PV result will reflect the effect of the input change. In this way input variables may be ranked according to their impacts on the bottom-line conclusions. This information is important to decision-makers who want to understand the variability associated with alternative choices. It also allows the agency to identify those input factors or economic conditions that warrant special attention in terms of their estimation procedures.

Deterministic sensitivity analysis is not well suited to measuring the impact that a simultaneous change of several inputs would have on a particular LCCA outcome. In addition, it does not give any information on the

EQUIVALENT UNIFORM ANNUAL COST ANALYSIS

The equivalent uniform annual cost (EUAC) analysis method produces the yearly costs of an alternative as if they occurred uniformly throughout the analysis period. The present value (PV) of this stream of uniform annual costs is the same as the PV of the actual cost stream. EUAC is another way to look at the results of a life-cycle cost analysis. Whether PV or EUAC is used, the decision supported by the analysis will be the same.

The decision to use EUAC or PV is up to the analyst. When decision-makers are accustomed to using annualized costs, EUAC may be a more useful form for the analysis results. Because it presents an annualized amount, EUAC may not emphasize the overall magnitude of the difference between alternatives as much as PV would and may convey an artificial evenness in cost flows. However, EUAC may present decision-makers with a feel for how a design alternative affects agency resources over the analysis period, particularly if the project in question will be bond financed.

INFLATION AND DISCOUNTING

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

- Inflation: Expenditures typically occur at various points in the past or future and are therefore measured in different value units because of changes in price (e.g., a 1980 dollar would, in general, have purchased more real goods and services in 1980 than would a 2002 dollar in 2002). A general trend toward higher prices over time, as measured in dollars, is called inflation. A general trend toward lower prices is called deflation. Dollars that include the effects of inflation or deflation over time are known as nominal, current, or data year dollars. Dollars that do not include an inflation or deflation component (i.e., their purchasing power remains unchanged) are called constant or base year dollars.

- Discounting: Costs or benefits (in constant dollars) occurring at different points in time—past, present, and future—cannot be compared without allowing for the opportunity value of time. The opportunity value of time as it applies to current versus future funds can be understood in terms of the economic return that could be earned on funds in their next best alternative use (e.g., the funds could be earning interest) or the compensation that must be paid to induce people to defer an additional amount of current year consumption until a later year. Adjusting for the opportunity value of time is known as discounting.

Analytically, adjusting for inflation and discounting are entirely separate concerns, and they should not be confused by attempting to calculate both at once. Instead, future costs and benefits of a project should be expressed in constant dollars and then discounted to the present at a discount rate that reflects only the opportunity value of time (known as a real discount rate). This is because public sector project benefits should be dependent only upon real gains (cost savings or expanded output), rather than purely price effects.

If future costs and benefits of a project are provided in nominal dollars, conversion of these nominal dollars to constant dollars can be accomplished through the use of applicable indexes as follows:

$$\textbf{Dollars}_{\text{base year}} = \textbf{Dollars}_{\text{data year}} \times \frac{\textbf{Price Index}_{\text{base year}}}{\textbf{Price Index}_{\text{data year}}}$$

Inflation indexes are available for every possible product and service. The choice among indexes from broad (e.g., Gross Domestic Product chain deflator) to intermediate (e.g., a consumption index such as the Consumer Price Index) to narrow sector or commodity (e.g., highway construction or resurfacing costs) depends upon how the results are to be interpreted.

Real discount rates used in life-cycle cost analysis typically range from 3 to 5 percent, representing the prevailing rate of interest on borrowed funds, less inflation. Because there is always an opportunity value of time, real discount rates will always exceed zero. Through the use of a real discount rate, the following transformations can be performed to facilitate comparison of the constant dollar costs of alternative transportation projects:

- Relocation in Time. A single figure can be "moved" (transformed into an equivalent value) backward or forward in time, without altering its real value, i.e., its present worth.
- Annualized Cost. A lump sum can be transformed into an equivalent multiyear flow (e.g., annualizing a capital cost).
- Present Value. Any combination of flows (finite or infinite) and lump sums can be summed into a single value at a single point in time.

continued

The formula to discount future constant value costs to present value is

$$\textbf{Present Value} = \textbf{Future Value x } \frac{1}{(1+r)^n}$$

where
r = real discount rate
n = number of years in the future when the cost will be incurred.

The term $1/(1+r)^n$ is known as the discount factor and is always less than or equal to one. Using this formula, a $1,000 cost incurred in year 30, discounted to the present (year zero) at a 4 percent real discount rate, would have a present value of $308.

It should be noted that the term "net present value" (NPV) is sometimes used when referring to the present value of life-cycle costs. However, NPV is more appropriately used in benefit-cost analysis to convey the net difference between the present values of benefits and costs of an alternative or project.

likelihood that a selected input value will actually occur. Therefore, while a deterministic LCCA approach provides considerably more information about the economic reasonableness of a project than just its initial cost, it does not offer decision-makers a complete picture of the expected PVs.

Probabilistic Approach. With deterministic LCCA, discrete values are assigned to individual parameters. In contrast, probabilistic LCCA allows the value of individual analysis inputs to be defined by a frequency (probability) distribution. For a given project alternative, the uncertain input parameters are identified. Then, for each uncertain parameter, a sampling distribution of possible values is developed. Simulation programming randomly draws values from the probabilistic description of each input variable and uses these values to compute a single forecasted PV output value. This sampling process is repeated through thousands of iterations. From this iterative process, an entire probability distribution of PVs is generated for the project alternative along with the mean or average PV for that alternative. The resulting PV distribution can then be compared with the projected PVs for alternatives, and the most economical option for implementing the project may be determined for any given risk level.

Probabilistic LCCA accounts for uncertainty and variation in individual input parameters. It also allows for the simultaneous computation of differing assumptions for many different variables. It conveys the likelihood that a particular LCC forecast will actually occur. From the perspective of most transportation agencies, the application of probabilistic LCCA is relatively new. Probabilistic LCCA has been made more practical due to the dramatic increases in computer processing capabilities of the last two decades. Simulating and accounting for simultaneous changes in LCCA input parameters may now be accomplished easily and quickly.

STEP FIVE: ANALYZE THE RESULTS

Step five involves analyzing and interpreting the LCCA results. With the deterministic or probabilistic LCCs computed, the PVs of the differential costs may be compared across competing alternatives. Because the deterministic approach results in a single PV for each alternative and the probabilistic approach yields a distribution of PV results, the procedures used to analyze the results are different.

Although best-practice LCCA considers both agency and user costs, in actual practice many analysts are reluctant to assign the same level of validity to user costs that they assign to agency costs. Thus, alternatives are often compared chiefly on agency costs. User costs may be compared to see if an alternative has a disproportionately high or low impact on users compared to other alternatives. If the lowest-agency-cost alternative also has a disproportionately high user-cost impact, the analyst may use this information to revisit that alternative to mitigate user costs, or may recommend that an alternative with somewhat higher agency costs but much lower user costs be pursued in preference to the lowest-agency-cost alternative.

Analysis of Deterministic LCCA Results

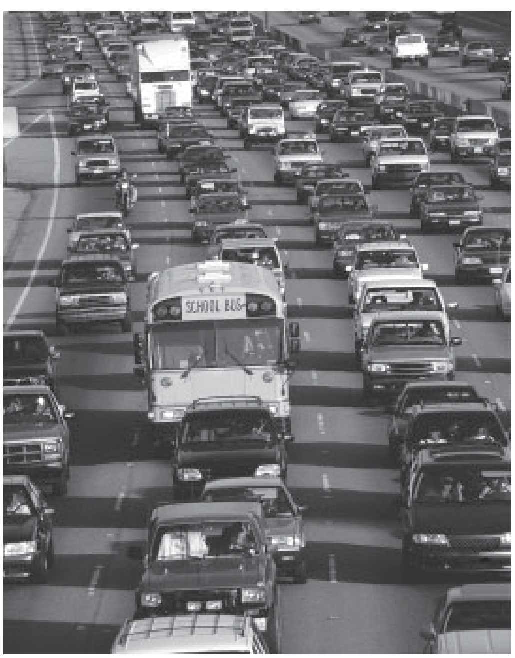
The most basic analysis of a deterministic LCCA is to compare the agency and user cost PVs among alternatives. However, this comparison does not address the uncertainty contained in those outputs.

As noted above, application of sensitivity analysis can reveal where analysis results may be subject to uncertainty. Deterministic sensitivity analysis is helpful in determining the "most likely" scenario where the selected input values are most likely to occur (based on objective data or expert opinions). Ideally, the "best" alternative will have the lowest PV in the most likely of "what-if" situations.

Analysis of Probabilistic LCCA Results

Probabilistic LCCA attempts to model and report on the full range of possible PV outcomes. It also shows the estimated likelihood that any given outcome will actually occur. The analyst is able to array this information so that the underlying uncertainty inherent in each project alternative is reflected in the PV output results. This analysis also provides important statistical information to assist the decision-maker.

As with deterministic LCCA, probabilistic LCCA can be enhanced by incorporating sensitivity analysis into the process. The sensitivity analysis will point to the variables most significant in influencing the LCCA results.



When interpreting the probabilistic LCCA, decision-makers must define the level of risk with which they are most comfortable. For example, those with a low tolerance for risk prefer less variability in the results, which may affect their selection between two or more options. In this case, the decision-maker may select an alternative with a somewhat higher PV but with much lower risk of cost overrun.

Reevaluate Alternatives

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

LIFE-CYCLE COST ANALYSIS (LCCA) EXAMPLE: DETERMINISTIC APPROACH

Presented here is an example of a deterministic LCCA comparing two alternative project strategies. Each alternative will supply the same level of performance or benefit, so application of LCCA is appropriate. Costs that are equal between alternatives have been removed from the analysis. The discount rate is 4 percent, and a 35-year analysis period is used.

Step One: Establish Design Alternatives

Alternative A is characterized by fewer construction and rehabilitation activities than is Alternative B, but the activities it requires are more extensive and cost more, per activity, than those of Alternative B. Alternative B requires more frequent use of work zones to maintain level of service, but these work zones last less time, per activity, than those of Alternative A.

Step Two: Determine Activity Timing

Year	Alternative A Activities	Alternative B Activities
0	Initial construction	Initial construction
12		Rehabilitation one (8-year service life)
20	Rehabilitation one (20-year service life)	Rehabilitation two (8-year service life)
28		Rehabilitation three (8-year service life)
35	End of analysis period—residual service life value if applicable.	

Step Three: Estimate Costs (Agency and User)

Agency and user costs for each activity are in constant, base year dollars. User costs are based upon user vehicle operating costs and traveler delay associated with work zone activities. User costs increase for similar work due to the increase in traffic over time. Costs for year 35 reflect the value of remaining service life for each alternative in year 35.

	Alternative A Activities		Alternative B Activities	
Year	Constant Dollar Agency Costs	Constant Dollar User Costs	Constant Dollar Agency Costs	Constant Dollar User Costs
0	$26,000,000	$11,000,000	$20,000,000	$8,000,000
12			6,000,000	10,000,000
20	15,000,000	30,000,000	6,000,000	16,000,000
28			6,000,000	28,000,000
35	(3,750,000)	(7,500,000)	(750,000)	(3,500,000)

Step Four: Compute Life-Cycle Costs

Using the discount factor, the present value (PV) is calculated for each of the agency and user costs (see the Inflation and Discounting box on page 16).

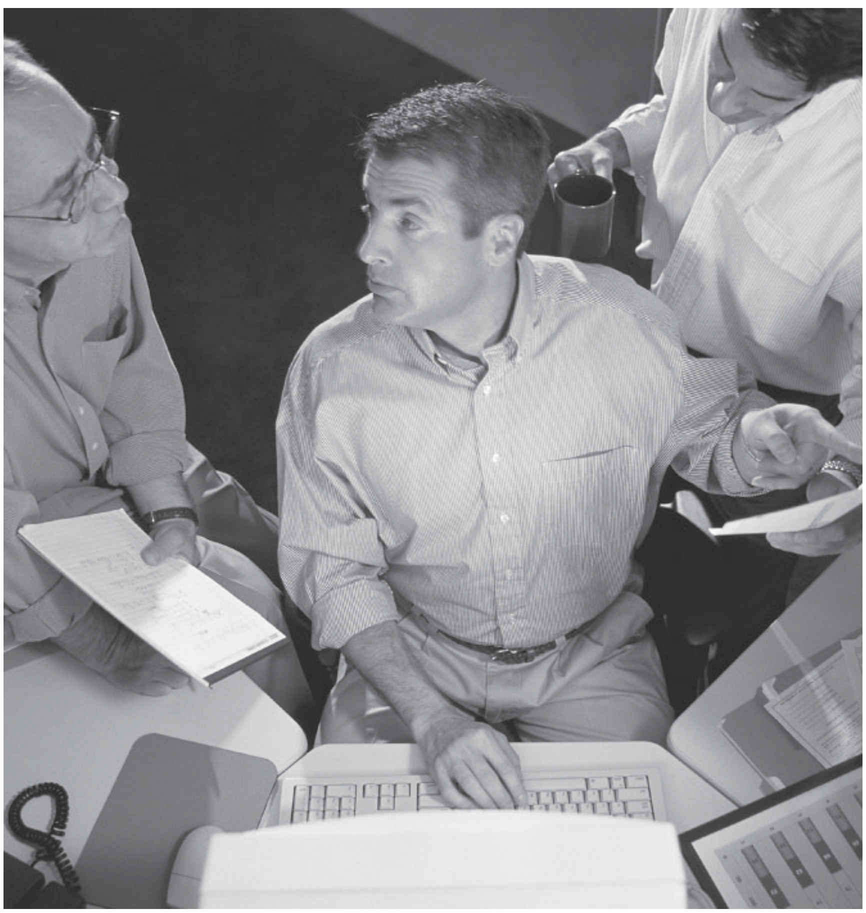
		Alternative A		Alternative B	
Year	Discount Factor	Discounted Agency Costs	Discounted User Costs	Discounted Agency Costs	Discounted User Costs
0	1.0000	$26,000,000	$11,000,000	$20,000,000	$8,000,000
12	0.6246			3,747,582	6,245,970
20	0.4564	6,845,804	13,691,608	2,738,322	7,302,191
28	0.3335			2,000,865	9,337,369
35	0.2534	(950,308)	(1,900,616)	(190,062)	(886,954)
Total Costs (PV)		**31,895,496**	**22,790,992**	**28,296,707**	**29,998,576**

Step Five: Analyze the Results

Alternative A has the lowest combined agency and user costs, whereas Alternative B has the lowest initial construction and total agency costs. Based on this information alone, the decision-maker could lean toward either Alternative A (based on overall cost) or Alternative B (due to its lower initial and total agency costs). However, more analysis might prove beneficial. For instance, Alternative B might be revised to see if user costs could be reduced through improved traffic management during construction and rehabilitation. Sensitivity analysis could be performed based on discount rates or key assumptions concerning construction and rehabilitation costs. Finally, probabilistic analysis could help to capture the effects of uncertainty in estimates of timing or magnitude of costs developed for either alternative.

LCCA ISSUES

LCCA provides a methodology for comprehensive analysis of an investment decision. It is reasonably easy to understand and perform, and its outputs are useful to decision-makers. However, it has yet to become a routine analysis tool in transportation project decision-making. This is due in part to a lack of understanding of its usefulness in support of investment decisions. It is also due to the belief that there are impediments to the proper use of LCCA. This section will discuss some of the issues that might be faced by transportation agencies that choose to incorporate LCCA into their investment decision process.



AGENCY DATA REQUIREMENTS

LCCA is data-intensive, and its value, as with any quantitative analysis technique, depends on the quality of the input data. Transportation agencies have been collecting data for years on their asset inventory and its condition. However, the inputs that LCCA requires (e.g., long-term maintenance data) are often not directly available from agency information systems and must be derived from multiple data sources. Unless an agency's data collection and storage have been specifically designed to support LCCA, it is unlikely that existing data sources will fit the exact needs of LCCA without further work.

The technological revolution of the last two decades has enabled many automated transportation data management systems. States that have invested in these systems, whether project information systems or bridge or pavement management systems, often have access to agency cost and service life data. Transportation agencies may find that developing inputs for LCCA is not a matter of finding enough input data but rather what to do with the myriad of possible values that present themselves.

Historical agency data are only one mechanism that may be used to feed LCCA input needs. The expert opinion of senior agency staff members can also provide a wealth of information for investment analyses, as can research conducted by industry and government. Still, the agency will have to devote resources toward the development and validation of data sources for LCCA inputs, as well as toward learning how to use those sources.

UNCERTAINTY

When data are collected to support an LCCA, there may be uncertainty around assigning engineering and economic values to inputs and the resulting outputs. This is an issue because the level of confidence that decision-makers have in the analytical results is based upon their faith in the accuracy and precision of the data used to generate them. Confidence can be improved through education to explain the derivation of existing values and research to develop better values. As discussed previously, a number of techniques are also available to address the issue of uncertainty. However, the analysts and decision-makers must be comfortable with the concepts and techniques used to measure uncertainty. Again, education provides the solution, and will not only raise the comfort level, but will also increase the perception of LCCA as a rigorous and useful analytical tool.

USER COSTS

User costs may represent the greatest data challenge to LCCA implementation. When calculated, user costs are often so large that they may substantially exceed agency costs, particularly for transportation investments being considered for high-traffic areas.

Agencies have been reluctant to rely on user cost estimates for several reasons. Foremost, perhaps, is the difficulty in valuing user delay time. Although extensive literature on the value of traveler time exists, much of this time (other than business and professional travel) does not have a traded market value. Similarly, uncertainty exists about the effects of agency activities on crash rates and vehicle operating costs. The difficulty in assigning a hard number to user costs has made their comparison with actual agency budget figures problematic for many analysts.

Finally, user costs do not debit agency budgets as do agency costs. This fact, combined with uncertainty regarding actual values, may incline transportation decision-makers to give less credence to user costs than to their own agency cost figures, reducing their desire to make trade-offs between agency and user costs and restraining their ability to find the lowest total cost solutions. Nonetheless, as future traffic demand pushes user costs ever higher, it becomes increasingly important to include these costs in a total cost analysis.

FHWA'S ROLE AND FOCUS IN LCCA

Since the early 1990s, FHWA has pursued a policy of encouraging the use of LCCA for certain transportation investment decisions. The LCCA program is one of a number of initiatives being advanced under the broad engineering economic analysis (EEA) umbrella. FHWA's long-term goal is to fill an EEA "toolbox" with a variety of applications useful for project- or program-level evaluations.

FHWA ACTIVITIES

In 1993, FHWA and the American Association of State Highway and Transportation Officials jointly sponsored an LCCA symposium of senior transportation officials from FHWA and State transportation agencies. The symposium highlighted the need for total cost analysis in transportation decision-making and elevated the awareness of decision-makers about LCCA.

In 1998, FHWA published the LCCA Interim Technical Bulletin. In addition to detailing the LCCA mechanism, it describes how to derive user work zone delay costs through basic traffic information and addresses the uses of probability and risk analysis in LCCA. FHWA also produced Demonstration Project 115, which includes an instructional workshop based on the Interim Technical Bulletin. FHWA Resource Center personnel provide the workshop as well as support services in the application of LCCA.

Also in 1998, the Transportation Equity Act for the 21st Century was enacted. It required that a value engineering review be performed for any project greater than $25 million that has Federal involvement. A value engineering review looks at such things as constructability, design criteria, and cost estimates. FHWA recommends that LCCA be a part of value engineering reviews.

Within FHWA, the Office of Asset Management is charged with developing and improving the state of the art for LCCA tools. Most recently, the Office undertook development of an LCCA probabilistic software package and workshop. This software is instructional in orientation and has been designed to follow the LCCA methodology as outlined in the Interim Technical Bulletin. The new workshop will promote exploration of the use of LCCA in the project design decision process. The workshop and software will support agencies as they perform LCCA on pavement projects and will allow managers and their agencies to investigate the full range of effects on

project selection caused by discount rates, user costs, data uncertainty, and probability.

Although the Office of Asset Management is currently focusing on the application of LCCA to pavement design decisions, further work will include investment analysis for other transportation assets and will also explore the usefulness of LCCA for evaluating alternative maintenance and preservation strategies.

KEY LIFE-CYCLE COST ANALYSIS (LCCA) MILEPOSTS

1991—The Intermodal Surface Transportation Equity Act suggested that LCCA be considered in the design and engineering of bridges, tunnels, and pavements.

1995—The National Highway System (NHS) Designation Act mandated that States conduct LCCA on all high-cost projects (more than $25 million) constructed with Federal funding.

1996—The Federal Highway Administration (FHWA) produced Demonstration Project 115, "Life-Cycle Cost Analysis in Pavement Design," and by July 2002 had brought these techniques to more than 40 State transportation agency pavement design groups.

1998—The Transportation Equity Act for the 21st Century rescinded the LCCA mandate of the 1995 NHS Designation Act. States are no longer required to perform LCCA, but FHWA is directed to further develop the analysis methodology.

1998—FHWA published its pavement LCCA Interim Technical Bulletin, *Life-Cycle Cost Analysis in Pavement Design.*

ASSET MANAGEMENT AND LCCA

Asset Management is a strategic approach to managing transportation infrastructure. The goal of Asset Management is to get the best results and performance from the preservation, improvement, and operation of infrastructure assets with the resources available. LCCA provides decision-makers with the ability to determine the least-cost solution for a transportation investment requirement and is therefore a natural fit within the Asset Management framework.

CONCLUSION

The FHWA encourages the use of LCCA for certain transportation investment decisions. LCCA is an important analytical tool that is applicable to a broad range of routine decisions facing State and local transportation agencies. It is appropriately applied once a decision has been made to undertake a project or improvement but the specific design for accomplishing the project's objectives has not been chosen.

The LCCA methodology provides a structured approach to evaluating design alternatives. By focusing on the project life cycle, it prompts the analyst to address not only the initial costs of a project, but the timing, scope, and resources required for future rehabilitation and maintenance activities. Best-practice LCCA also directs the analyst to quantify and compare the effects of different project implementation options on highway users, who may experience significant costs due to congestion and safety issues associated with work zones.

By incorporating LCCA into standard agency practice, transportation officials are also able to demonstrate good stewardship of the public's transportation assets. The documentation associated with the LCCA process provides a clear record for each design decision in the event of future controversy. More importantly, the documentation helps to preserve important agency knowledge so that it may inform future analysts and decision-makers.

Implementation of LCCA for project evaluation may require education of staff and adjustments in the agency decision-making process. However, it clearly presents transportation agencies with a means of identifying the most cost-effective investment options. LCCA is an important tool, and one that may lead to the broader application of more comprehensive EEA tools. FHWA will continue to promote LCCA applications through its training efforts and the development and distribution of LCCA software.

For further information and additional copies of this document, contact:

Office of Asset Management (HIAM)
Federal Highway Administration
U.S. Department of Transportation
400 7th Street, SW, Room 3211
Washington, DC 20590

Telephone: 202-366-9242
Fax: 202-366-9981

U.S. Department
of Transportation

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