LIFECYCLE COST ANALYSIS

GOAL

Determine the lifecycle cost for the roadway project to aid in decision-making.

REQUIREMENTS

Perform a life cycle cost analysis (LCCA) of the roadway project. LCCA must contain at least agency costs (listed below) and workzone user costs.

LCCA can be performed with manual calculations or by using recommended software (noted below for pavements and bridges). Initial values for calculations should be consistent with existing owner agency policies and **software should report probabilistic rather than deterministic results**. Where no owner agency policy exists for LCCA, do one or more of the following to determine input values for software:

- Justify the use of any default inputs
- Use historical data as representative values where available
- Use engineering estimates
- Use values recommended for select software where noted below

For projects with pavements:
Perform a LCCA of the project's pavement structure (comparison of multiple design alternatives is encouraged but not required) in accordance with the method described in the FHWA's Interim Technical bulletin, *Life-Cycle Cost Analysis in Pavement Design* (1998, currently being revised). This may be completed manually or by using the FHWA's RealCost software available for free at:
http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm

Use parameters for the LCCA that are consistent with existing owner agency policies. If no owner agency policy exists, use recommended values shown in Table PR-2.1 for the FHWA's *RealCost* software.

For projects with bridges:
Perform a LCCA of the project's bridges (comparison of multiple design alternatives is encouraged but not required) according to the guidance in the National Cooperative Highway Research Program (NCHRP) Report 483 (Hawk, 2003) and the software (called *BLCCA*) developed for this study. The report provides standard input values for a wide range of potential bridge projects and referenced sources for other input data. Other lifecycle cost analysis software may also be used at the discretion of the project manager, including *RealCost,* with some minor adjustments to the spreadsheet. A BLCCA may also be completed by hand. Table PR-2.1 may provide some useful inputs for user costs and traffic data.

- Use agency and user cost parameters that are consistent with agency policy, if one exists (though according to the body of research such policies for bridges are rare.)
- Use the same number of years for service life that is used for design of structural members subject to long term loading effects.

PR-2

REQUIRED

RELATED CREDITS

- ✓ PR-3 Lifecycle Inventory
- ✓ EW-4 Stormwater Cost Analysis
- ✓ MR-1 Lifecycle Assessment

SUSTAINABILITY COMPONENTS

- ✓ Economy
- ✓ Extent
- ✓ Expectations

BENEFITS

- ✓ Reduces Lifecycle Cost
- ✓ Improves Accountability

For projects with additional features:
Perform a LCCA of the project's major features (comparison of multiple design alternatives is encouraged but not required) in accordance with generally accepted engineering economics practices. Major features may include tunnels, retaining walls and other items.

Details

Typical LCCAs and BLCCAs include agency and user costs, defined below. Occasionally, third-party costs (such as monetized environmental damages or hazards) are included, but are not required for this Project Requirement. A cost-benefit analysis (CBA) that includes the minimum components below is acceptable. Assumptions used for agency and user costs should be consistent in each analysis for projects with multiple major features.

Agency Costs. Costs from the planning, construction and operation of the roadway and structures.

- **Preliminary Engineering.** Planning and design costs.
- **Contract Administration.** Bidding and contract oversight.
- **Initial construction.** Costs incurred during the initial construction.
- **Construction Supervision.** Construction management, inspections, and
- **Maintenance.** Pothole patching, crack sealing, restriping, etc.
- **Rehabilitation.** Costs to maintain and rehabilitate or retrofit an asset throughout its service life.
- **Administrative Costs.** Cost of pavement management and other administrative costs.
- **Salvage value.** Expected value of materials and equipment at end of service life.

User Costs. Those who use the facility incur costs during normal operation and during construction periods (e.g., time, safety, fuel and other vehicle operating costs).

- **Normal Operation.** Often ignored in LCCA, as they may be the same between alternatives.
- **Work Zone.** Costs incurred by the user from work zone delays.

The Federal government mandated LCCA in the National Highway System Designation Act of 1995 but then changed it to a voluntary standard in TEA-21. Section 1305(c) states that LCCA is not required but tasks the "…Secretary shall develop recommendations for the States to conduct life-cycle cost analyses." Most recently, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) set a funding threshold that mandates the use of LCCA or other value engineering tools for bridge projects US$20 million or more. Another mandate threshold is set at US$25 million for any federal aid project (Federal Highway Administration, n.d).

Many roadway projects have both pavements and structures included in the scope of work. For such projects, the life cycle cost analysis prepared for this credit must reflect each substantial project feature for its entire service life. It may also be desirable to perform a LCCA on the entire roadway project (e.g., include all earthwork, traffic hardware, structures, etc.) but currently no straightforward means of doing this exists.

Many state departments of transportations (DOTs) already incorporate LCCA into a formal pavement type selection process or project alternative selection process, and thus already have a formal LCCA process in place for pavements. However, a formalized alternative selection process using BLCCA does not appear to be in widespread use for bridge or other structural projects (Özbay et al. 2004; Thompson, 2004).

DOCUMENTATION

- A copy of the LCCA and/or BLCCA calculations (if done by hand) or the report produced by the analysis software, including a summary of inputs and outputs.
- A link to or copy of agency policy on LCCA and/or BLCCA if one exists.
- A short 1-paragraph narrative describing which alternative was selected and the principal reasons for selection.

Table PR-2.1: Recommended LCCA Input Values for RealCost if No Standard Agency Policy Exists

Analysis Options	**Probability Distribution**	**Value**
Analysis period	NA	≥ 40 years
Discount Rate†	Triangular	min = 1.7%, most likely = 2.7%, max = 3.7%
Include agency cost residual value	NA	Yes
Include user costs in analysis	NA	Yes
User cost comparison method	NA	Calculated
Traffic direction	NA	Both or Inbound or Outbound
Include user cost residual value	NA	Yes
Traffic Data		
AADT	NA	Best estimate
Single unit trucks as % of AADT	NA	Best estimate
Combo unit trucks as % of AADT	NA	Best estimate
Annual growth rate of traffic	Normal	Best estimate
Speed limit under normal conditions	NA	Predominate speed limit in project
Lanes open in each direction under normal operation	NA	Best estimate
Free flow capacity	NA	Calculated by software
Queue dissipation capacity	Normal	average = 1818 vphpl, st. dev. = 144 vphpl
Maximum AADT both directions	NA	Best estimate
Maximum queue length	NA	Best estimate
Rural/Urban	NA	Best estimate
Value of User Time††		
Value of time for passenger cars	Triangular	min = $10, most likely = $11.50, max = $13
Value of time for single unit trucks	Triangular	min = $17, most likely = $18.50, max = $20
Value of time for combination trucks	Triangular	min = $21, most likely = $22.50, max = $24
Hourly Traffic Distribution		
Use default values if no region or project specific information available.		
Added Vehicle Time and Cost		
Use default values if no region or project specific information available.		
Alternatives		
Alternative description	NA	Fill in
Activity description	NA	Fill in
Agency construction cost	Normal	average = best estimate of cost st. dev. = 10% of the average
Activity service life	Triangular	Best estimate
Maintenance frequency	Triangular	Best estimate
Work zone length	NA	Best estimate
Work zone capacity	NA	Best estimate, if no data consider using Figure 3.4 in Walls and Smith (1998)
Work zone duration	NA	Best estimate
Work zone speed limit	NA	Posted value
Number of lanes open in each direction during work zone	NA	Best estimate
Work zone hours	NA	Planned hours

†Discount rate should be determined from most recent OMB Circular A-94. Appendix C contains real interest rates for treasury notes and bonds of various lengths. Treasury note maturity that most closely matches the project analysis period should be used. Use minimum and maximum values of ±1%.

††Dollar values in this table are taken directly from Walls and Smith (1998) and are given in August 1996 dollars. These values MUST be inflated to dollar values in the year that construction is scheduled to start using the U.S. Bureau of Labor Statistics (BLS) Consumer Price Index (CPI) U.S. city average for all urban consumers (not seasonally adjusted). The value for this index in 1996 was 156.9. The BLS CPI Inflation Calculator (http://www.bls.gov/data/inflation_calculator.htm) can be used to do this conversion quickly.

APPROACHES & STRATEGIES

- Complete the LCCA early enough in the project so that its results can be considered in selecting between project alternatives. This generally means it should happen during the planning stage and not the design or construction stage.
- Note that *RealCost* and *BLCCA* software are not required for this credit; however any other method used must conform to the FHWA's Interim Technical bulletin for pavements, *Life-Cycle Cost Analysis in Pavement Design* (Walls & Smith, 1998) and NCHRP 483 for bridges.
- Include LCCA considerations in the technical score of bidders for pavement projects in order for it to be considered in selecting a design alternative for Design-Build contract delivery methods. This is because the actual pavement design is often used as part of a design-build team's technical score in determining contract award, a LCCA of alternative designs cannot be performed by the agency until after the bid competition is complete. While this can be done, LCCA results should be properly weighted so that they influence contract award in a manner consistent with owner wishes. Unfortunately, Gransberg and Molenaar (2004) showed that design-build award algorithms often do not weight LCCA concerns heavily enough for them to be a significant factor in contract award.
- Incorporate results of other Related Credits, such as Project Development: Economy and Cost Benefit Analysis, into the LCCA for consistency across the whole project.

Example: Case Studies of LCCA

Rangaraju et al. (2008) report on LCCA efforts of the South Carolina DOT and list several case studies in Appendix E (page 117) that deal with the influence of discount rate and analysis period on LCCA outcomes.

The entire report, *Life Cycle Cost Analysis for Pavement* (Rangaraju et al. 2008) can be downloaded at: http://www.clemson.edu/t3s/scdot/pdf/projects/SPR656Final.pdf.

Example: Washington State Department of Transportation (WSDOT) LCCA Protocol

WSDOT follows a standard LCCA protocol when selecting pavement type for new facilities. This protocol is based on the FHWA's *Life-Cycle Cost Analysis in Pavement Design* (Walls and Smith, 1998) and uses RealCost software for calculations. It includes specified inputs for WSDOT analysis and how to consider results. Of note, cost difference between competing alternatives that are less than 15 percent are considered equal based on the uncertainty of input values.

The WSDOT *Pavement Type Selection Protocol* (2005) is available for download here: http://www.wsdot.wa.gov/biz/mats/Pavement/Technotes/PTSP_Jan2005.pdf.

Example: Caltrans LCCA Procedures Manual

Caltrans has developed a manual (Caltrans 2007) that describes LCCA procedures for use in Caltrans. The manual is based on RealCost software and provides standard input values for a wide range of potential projects. Caltrans has adopted an aggressive policy towards using LCCA mandating that it be used "…for all projects with include pavement work on the State Highway System regardless of funding source…" (Land 2007)

The manual can be downloaded at: http://www.dot.ca.gov/hq/esc/Translab/ope/LCCA.html.

POTENTIAL ISSUES

1. While LCCA is a fairly standard economic analysis tool, the potential exists to input incorrect or irrelevant numbers and misuse its results. Users should be familiar with the FHWA's *Life-Cycle Cost Analysis in Pavement Design* Interim Technical Bulletin (Walls and Smith 1998, currently being revised) before conducting an LCCA with *RealCost* or *BLCCA*.
2. A LCCA assumes that the benefits associated with project alternatives are equal. Thus, it only analyzes costs. Projects with different benefits between alternatives may desire a more comprehensive cost-benefit analysis.

3. The meaningfulness of LCCA outputs relies heavily on good estimates of future pavement life, rehabilitation costs and the interval between future rehabilitation efforts. These all rely on good engineering judgment and past history rather than economic theory or principals.
4. LCCA is based on estimated of total cost and can be easily manipulated by changing assumptions and input values. For this reason the results should not be weighted too heavily in the choice of design alternatives.
5. This credit does not contain a requirement to use or implement the lowest life-cycle cost project alternative. Therefore, it should be viewed as a credit that creates information that is useful in decision-making rather than a decision-making tool. It does not guarantee a lowest life-cycle cost decision.
6. This credit does not require the LCCA to be done during the planning stage where it would be most likely to influence project decisions. Therefore, it could be done late in design, or even during construction, meaning it would be undertaken for no other reason than to meet this credit, which misses the point.
7. Some rehabilitation efforts and even other efforts that take a systematic approach to choosing the proper project features (e.g., a pavement management system), there may not be a choice between two or more alternatives. This may be because such a system already incorporates a form of LCCA, or it may be because no other alternative is reasonably feasible.
8. Other prototype software programs for bridge life cycle cost analyses have been developed but do not appear to be in widespread use, such as the National Institute of Standards and Technology's *BridgeLCC* software which was last updated in 2003 (available at http://www.bfrl.nist.gov/bridgelcc/welcome.html). For purposes of this credit, any software can be used so long as the inputs and results are justifiable, reasonable, and validated by the professionals working on the project.

RESEARCH

Lifecycle cost analysis (LCCA) is a process for evaluating the total cost of a project, facility or product over its useful lifetime. For roadway projects, this means accounting for initial construction costs, maintenance and rehabilitation costs, roadway user costs and third-party costs. LCCA can contribute to the sustainability of a roadway project by allowing project personnel to account for total life cycle costs when making key project decisions.

An important distinction must be made between LCCA and life cycle assessment (LCA) as these terms use confusingly similar acronyms. Both have similar utility in the decision-making process, but the underlying purpose, scope and mathematical model for each are different. For this reason, LCA is discussed in detail in other credits in the *Greenroads Manual* (see PR-3 Lifecycle Inventory and MR-1 Lifecycle Assessment) while LCCA is discussed here.

Lifecycle Cost Analysis Method

LCCA is simply a mathematical accounting tool that can be used to compare the value of money at different times. Underlying the LCCA process are basic principles of business finance, which uses compound interest formulas (and tables) and reasonable assumptions about the future to translate different economic values to an equal reference point in time. LCCA may be quite familiar to many transportation professionals in the form of cost-benefit analysis (CBA) or commonly just "engineering economics." The how-to of business finance and engineering economics can be found in a plethora of textbooks and will not be discussed in depth here.

LCCA is a useful process in roadway design because the results quantify the total long-term value of project alternatives. This process allows for straightforward comparisons, usually in terms of a total lifetime cost or a total lifetime benefits. The key role of the decision-maker in LCCA is determining appropriate assumptions and scope for the comparison, as well as interpreting and acting on the quantified results.

For a basic example, consider a roadway project with two design alternatives; one is a thin pavement section and the other has thicker section. The initial construction cost of the first alternative is lower than the second, but the first alternative requires additional, more frequent expenditures for maintenance throughout its lifetime. The project manager completes an LCCA on each alternative. The results show that while first alternative is less expensive for initial construction, the second alternative actually has a much lower long-term cost. The second alternative has a higher upfront cost for initial construction, but saves the project owner more money over time.

Because this comparison is not limited to upfront costs alone, a project manager can better understand how their design and construction choices contribute to the overall economic impact of the project.

Lifecycle Costing, Roadways and Sustainability

There is substantial writing to suggest that LCCA contributes to sustainability. Most efforts are centered on buildings; however, the FHWA does contribute some useful information. Considering buildings, the Federal Facilities Council recognized the relationship between life-cycle costing and sustainable development by stating:

> *"Guidance related to life-cycle costing and value engineering was recognized as being supportive of sustainable development, in particular when used in the conceptual planning and design phases of acquisition, where decisions are made that substantially affect the ultimate performance of a building over its life cycle (Federal Facilities Council, 2001)."*

In essence, they were concerned that features that enhanced sustainability would be excluded to save on initial costs without considering life-cycle costs that could show such features to be warranted. The FHWA believes LCCA should be used because "…transportation investment decisions should consider all of the costs incurred during the period over which alternatives are compared (FHWA, 2002)." This means considering the total cost to the owner, users and externalities rather than just the first, or construction, cost.

- **Initial construction.** Costs incurred during the initial design and construction.
- **Preservation.** Costs to maintain and rehabilitate an asset.
- **Users.** Those who use the facility incur costs during normal operation and during construction periods (e.g., time, safety, fuel and other vehicle operating costs).
- **Externalities**. Costs that indirectly impact the users or the environment due to, for example, air emissions or a natural hazard.

Prevalence of LCCA and BLCCA

According to the comprehensive state-of-the-practice review of the applications of lifecycle costing in practice by Özbay et al. (2004), LCCA has been in use to some extent for almost 40 years for pavement selection. The authors completed a three year study that surveyed the division at 39 state departments of transportation (DOTs) which used LCCA the most. The majority of respondents in the survey indicated that LCCA is applied by:

- Research and design division (68%)
- Materials and pavements division (37.5%)
- Bridge offices (12.5%)

Additionally, the authors found that all agencies surveyed use LCCA on some form of pavement projects. In fact, 60% of the responding agencies have adopted formal guidelines for pavement LCCA. However, only 25% of those surveyed by Ozbay et al. (2004) indicated that BLCCA might be used on bridge projects at their state agencies while 100% indicated that it might be used on pavement projects.

State of the Practice - Pavements

A more recent study for the South Carolina Department of Transportation (Rangaraju et al., 2008) found that most states (i.e. state departments of transportation) conduct LCCA but to varying degrees. Their survey, completed in 2005, had responses from 33 states and 2 Canadian Provinces and found:

- 94% (33 of 35) of the agencies use LCCA as part of their decision-making process. This appears to be an increase in percentage over an earlier limited 2001 survey that found 8 of 16 responding states used LCCA.
- 69% (24 of 35) of respondents include or are planning to include user costs in LCCA. Typically this is done by quantifying user delay costs during construction only.
- Few (only 2 out of 32) used a fully probabilistic approach to calculating life cycle costs while others did conduct sensitivity analyses to determine how changes in assumed parameters affected analysis outcome.

State of the Practice - Bridges

Ehlen (1997) provides a strong, practical argument for the utility of systematic application of BLCCA and Thompson (2004) also provides a good summary of the state of BLCCA in bridge practice. He notes that streamlined tools will expand application opportunities for BLCCA, especially in terms of network level bridge management systems, but much more refinement may be necessary for uncertainties and assumptions to be unified from project to project. Much of the lifecycle literature for bridges appears to be relevant to optimization of the project and network level bridge management systems. These references are discussed in more detail in PR-9 Pavement Management System.

However, to date, the most comprehensive work on BLCCA was completed as part of the National Cooperative Highway Research Program *Report 483: Bridge Life-cycle Cost Analysis* (Hawk, 2003). This report contains details on specific methodologies that may be relevant to bridge designers, as well as limitations, assumptions, examples, and a software tool called *BLCCA*.

Some of the most recent work that is relevant to sustainability includes early BLCCA work by Ehlen (1999), who attempts to account for third-party costs (which he defines as costs of environmental damages) due to the lifecycle of bridge projects. However, values of zero were used for these costs in his model. Lately, BLCCA literature has focused more on reliability studies for catastrophic and long-term environmental stressors including work by Lee, Cho, and Cha (2006), Hosser et al. (2008) and Padgett, Dennemann, and Ghosh (2010). The latter authors applied LCCA principles using a risk-based analysis of several bridge retrofit options subject to seismic hazards. The study may be particularly relevant to practitioners trying to model their bridge to determine an appropriate retrofit solution and maintenance schedule.

Impact of LCCA

Given that most states use LCCA in some form already this credit may have the largest effect in three areas:

1. **Local agencies or other owners who do not typically conduct LCCAs.** *RealCost* and *BLCCA* are fairly straightforward free software tools that should be able to provide answers with reasonable effort.
2. **State or federal projects considered too small for LCCA.** Some projects (e.g., overlays or other preservation efforts) are generally deemed too small for LCCA and have historically omitted this process in decision-making.
3. **Non-pavement projects.** This credit may encourage the wider adoption of lifecycle costing on non-pavement projects such as bridges and other major structures, intelligent transportation systems, or other types of assets where LCCA applications are not common practice.

GLOSSARY

Agency cost	A cost incurred by the agency of a roadway such as maintenance, repair, rehabilitation, improvement, and replacement (Thompson, 2004)
BLCCA	Bridge Life Cycle Cost Analysis
Externality	An indirect cost incurred by any party due to the project, such as damage to the environment, which is hard to quantify using traditional accounting.
LCCA	Life Cycle Cost Analysis
Salvage value	The estimated monetary value of an asset at the end of its useful life.
Third-party cost	See *Externality.*
User cost	A cost incurred by the users of a roadway such as collision risk, detours, and time delay (Thompson, 2004)

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