LCCA Overview

Eric Ross
Federal Highway Administration
Goal

Provide an understanding of Life-Cycle Cost Analysis
Overview

- LCCA in MAP-21
- Definition
- Process
- Current issues
- Alternative bidding
- Probabilistic approach
- RealCost
- Resources
The Link Between MAP-21, Transportation Performance Management, Asset Management and LCCA

Nathaniel Coley Jr.
Federal Highway Administration
MAP-21 Transportation Law

Created the National Highway Performance Program

❖ Performance Goals and Measures
❖ Performance Reports
❖ State Asset Management Plan (AMP)
  ❖ Life-cycle cost and risk management analysis
  ❖ Investment strategies.
❖ Other Performance Based Plans
What is Transportation Performance Management at FHWA?

- It is a systematic approach to making investment and strategic decisions using information about the condition and performance of the system and developing an approach to achieve a desired set of national goals.
Transportation Performance Management
Performance Measure Categories in MAP-21

<table>
<thead>
<tr>
<th>MEASURE CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Serious Injuries per VMT</td>
</tr>
<tr>
<td>• Fatalities per VMT</td>
</tr>
<tr>
<td>• Number of Serious Injuries</td>
</tr>
<tr>
<td>• Number of Fatalities</td>
</tr>
<tr>
<td>• Pavement Condition on the Interstates</td>
</tr>
<tr>
<td>• Pavement Condition on the Non-Interstate NHS</td>
</tr>
<tr>
<td>• Bridge Condition on NHS</td>
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<tr>
<td>• Traffic Congestion</td>
</tr>
<tr>
<td>• On-road mobile source emissions</td>
</tr>
<tr>
<td>• Freight Movement</td>
</tr>
<tr>
<td>• Performance of Interstate System</td>
</tr>
<tr>
<td>• Performance of Non-Interstate NHS</td>
</tr>
</tbody>
</table>

FHWA Office of Infrastructure
Transportation Performance Management

- National Goals
- Performance Measures
- Performance Targets
- Performance Plans
- Target Achievement
- Performance Reporting

Special Performance Rules Apply
Targets set by States & MPOs

FHWA Office of Infrastructure
Why Is it Important?

- Provide link between goals and specific actions
- Guide decisions on best use of available resources
- Evaluate the effectiveness of policies, plans, programs and projects
- Track system performance over time
- Communicate results to internal and external audiences
- Strengthen accountability
What is Asset Management?

- It is a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost.

(23 U.S.C. 101(a)(2), MAP-21 § 1103)
LCCA is the link between TPM and AMP

- Transportation Performance Management considers the broad offerings by Transportation Agencies
- AMP addresses the life-cycle of physical assets
- LCCA is a tool for linking performance trends to expected resources
Thank You

Nathaniel Coley Jr.
Structural Engineer/Economist
Federal Highway Administration
NColey@dot.gov
202-366-2171

http://www.fhwa.dot.gov/infrastructure/asstmgmt/economic.cfm
LCCA Process

Luis Rodriguez
Federal Highway Administration
Presentation Outline

- Life Cycle Cost Analysis Definition
- Structured Approach to LCCA
- LCCA Five Steps Process
Life-Cycle Cost Analysis Definition

- **A process** for evaluating the total economic worth of a usable project segment by analyzing **initial costs and discounted future costs**, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the **life of the project segment**.

Source: Transportation Equity Act for the 21st Century
LCCA Defined

An analytical tool
to provide a cost comparison
between two or more competing design alternatives
producing equivalent benefits
for the project being analyzed.
Structured Approach to LCCA

Before the Process Begins
• Establish LCCA Framework
• Establish Project Criteria when LCCA is warranted

Prepare Alternatives
• Determine Project Scope
• Establish Alternatives
• Determine Timing of Required Activities
• Estimate Agency and User Costs

Preferred Alternative
• Compute Life-cycle Costs
• Analyze the Results
• Apply Selection Criteria
Establish LCCA Framework

- Establish analysis period
- How inflation will be treated
- Establish discount rate to be used
  - Historically the Discount Rate has ranged from 3% to 5%
- Establish Economic Analysis Indicator
  - Net Present Value (NPV)
  - Equivalent Uniform Annual Costs
Determine Project Scope

- Specific Roadway Geometry
- Traffic Data
  - Work Zone
- Agency Cost Data
- User Cost Data
- Service Life Data
- Type of Alternative
  - Flexible vs. Rigid
  - New Construction vs. Rehabilitation
Sample Project-Level Data

- Specific roadway geometry
  - Number of lanes in each direction
  - Lane widths
  - Work zone lengths

- User cost data
  - Vehicle operating cost rates
  - Added vehicle operating cost and time
  - Value of user time delay
    - Passenger cars, single unit, comb. unit
Sample Project Level Data (Cont.)

- Traffic data
  - AADT
  - Annual traffic growth
  - Percent trucks
  - Hourly traffic distributions
  - Lane capacities
  - Queue dissipation capacities

- Agency cost
Sample Project Level Data (Cont.)

- Service life
  - Structural
  - Functional

- Work zone
  - Activity duration
  - Hours of operation
  - Capacities
  - Speeds
The LCCA Process

- **Step 1:** Establish alternatives
- **Step 2:** Determine timing of required activities
- **Step 3:** Estimate agency and user costs
- **Step 4:** Compute life-cycle costs
- **Step 5:** Analyze the results
Step 1: Establish Alternatives

- Activities to ensure performance
- Initial construction or rehabilitation activity
- Future rehabilitation and preservation activities
Step 2: Determine Activity Timing

Terminal Serviceability Index

Time

Service Life

Initial Activity → Activity One → Activity Two

Analysis Period

Long enough to capture differences between alternatives

When will the future preservation and countermeasure costs be incurred?
Step 3: Estimate Agency and User Costs

- Include cost elements that are different between alternatives
- Exclude cost elements that are the same between alternatives
  - Agency overhead costs
  - Real estate acquisitions
  - Normal operations user costs
Step 3: Estimate **Agency and User Costs**

- **Approach fundamentals**
  - Compare demand and capacity under normal operations and work zone conditions
  - Determine how traffic is impacted
  - Convert traffic impacts into costs
Cash Flow Diagram

Initial Activity
- Agency Costs
- User Costs

Preservation Activities
- Initial Activity Work Zone
- User Work Zones

Rehab 1
- Salvage or Remaining Value
Step 4: Calculate NPV of Life-cycle Costs

Net Present Value = \sum_{k=0}^{N} (Cost_k) \times \left( \frac{1}{(1 + d)^{n_k}} \right)

- Cost_k = cost of activity
- N = length of analysis period
- d = discount rate
- n_k = year of expenditure

Present Value Factor
Step 5: Analyze the Results

- How do agency costs compare?
- How do user costs compare?
- Can trade-offs be made?
Thank You

Luis Rodriguez
Federal Highway Administration
luis.rodriguez@dot.gov
404-562-3681

http://www.fhwa.dot.gov/resourcetcenter/
LCCA: Current Issues and Alternative Bidding

Eric Ross
Federal Highway Administration
Current Issues

- Analysis period
- Use of remaining value
- Discount rate and inflation
- Alt bidding
- Uncertainty
Analysis Period

The time horizon for the analysis

- Equal for all alternatives under consideration
- Not the same as the design life
- Rule of thumb: Long enough to include at least one major rehab
- Long enough to distinguish cost differences
- Should not influence the relative ranking
- Should not influence the results
Remaining Value and Salvage Values

Two concepts which are often confused...
Remaining Value

The value of potential service remaining at the end of the analysis period

- Accounts for end-of-analysis period "differences" between alternatives
- Removes economic bias between alternatives
Remaining Value

- Computed as an accumulated depreciation of the value of structural and functional activities occurring over the analysis period
- Also need to consider the user costs
- Assumes the asset remains in service beyond the analysis period
Salvage Value

The value of recovered or recyclable materials

- Assumes material is removed from service at the end the analysis period
- Salvage value is only realized when materials are actually reclaimed
Discounting/Inflation?

Discounting

- What a future sum is worth to us now regardless of inflation.
- What we require in return for forgoing other benefits.
- This is a spot rates if you borrow on "one year" based on what we know what rate would you give me rate now.
Discounting/Inflation?

Inflation

- General rise in prices due to more demand than supply.
- Measured by various “price indices” and effects purchasing power.
- Critical for budgeting exercises.
Present Value of the Future

- We are analyzing the returns to roadway users (taxpayers)
- Economists have determined that a discount factor of 3 to 5 percent is good practice to approximate the returns required by society
- Using this discount rate in the analysis is completely different from accounting for inflation in a financial analysis
- Objections good practice involves efforts to protect special interests
Inflation

- Change in price levels over time
  - Supply/demand pressures
- Derived from economic indicators
  - Ex: consumer price index (CPI)
- Should only be used to bring past values to present costs.
What is the FHWA position on alternate bidding for pavement type selection?

- FHWA considers alternate pavement type bidding a suitable approach for determining pavement type when engineering and economic analysis does not indicate a clear choice between different pavement designs.
Alternative Bidding Guidance

When is it use appropriate?

- Equivalent designs
- Discount rate determined from OMB guidance
- Consideration of uncertainty
- Maintenance and rehabilitation strategies
- Non-economic factors
- Appropriate application
- Work zone user delay costs
  - Within 20%
Alternative Bidding Guidance

Application

- LCCA bid adjustment
- Commodity price adjustments
  - If using for one – use for all
- Material quantities
- Approvals
- Change orders
Probabilistic LCCA and RealCost

Nadarajah Sivaneswaran (Siva)
Federal Highway Administration
LCCA and Uncertainty

- Many analytical models treat inputs as discrete fixed values but most inputs are uncertain. Economic models used in typical LCCA is no different.
- Almost all inputs in an LCCA are uncertain – includes both system’s inherent variability and uncertainty due to lack of knowledge.

Only certainty is that there is uncertainty!
Uncertain Inputs

- **Initial Agency Cost** = f(market conditions (competition, supply/demand imbalance etc.), bid cost, quantity, construction duration, etc.)

- **Future Agency Cost** = f(performance, discount rate, pavement technology improvements, agency policy changes, etc.)

- **Initial User Cost** = f(traffic volume and composition, road user behavior (no-show, detour, etc.), construction duration, etc.)

- **Future User Cost** = f(traffic projection, technology changes, discount rate, etc.)
Impact of Competition on Input

Comparison of the Low Bid vs. the Engineer's Estimate based on Number of Bidders (All Projects-16 Years)


Caltrans Example - Credit: Jack Young at the Minnesota Capacity Building Workshop in 2010 for Cost Estimation

\[ y = -0.2035 \ln(x) + 0.2276 \]
State of the Practice Approach

- **LCCA Approaches**
  - Deterministic
  - Probabilistic

- **Trend**
  - **2006** South Carolina Survey – **19% (4 out 21)** used probabilistic or a combination analysis
  - **2008** NCHRP 10-75 Survey – **33% (9 out 27)** conducting LCCA used probabilistic or a combination analysis
Deterministic Analysis

- Easy to understand and use
- Uses discrete fixed value, often best-guess for each input in arriving at a single outcome
- Best-guess from past experience, datasets or expert opinion
- Analysis results are easy to interpret
Limitations of Deterministic Analysis

- In the absence of “reliability” or “what-if-analysis”, the outcome may be misunderstood as the only answer
- Limited “what-if-analysis” such as one input at a time sensitivity analysis may still miss critical areas of uncertainty
- Endless debate over the selection of discrete fixed input value and what the outcome would be if a different discrete fixed input value is made

Engineer’s lack of confidence in the results he or she is to defend!
Challenges in Probabilistic Analysis

- Requires probabilistic characterization of uncertain inputs – **data intensive** that may not be readily available
- Often simulation-based - **computation intensive**
- Results **not as straight forward to interpret** as deterministic analysis
- **Managers or decision makers may still want a single number** and may not have the background to interpret probabilistic results
LCCA for Pavement Type Selection

- Lends well to probabilistic analysis as it has characteristics that simplifies its use
- LCCA is not a cost estimation tool but comparison tool – *items common to all alternatives need not be included*
- Of interest is not LCCA of each alternative but the *difference in LCC* between competing alternatives
LCCA for Pavement Type Selection (Cont.)

- Not all inputs are equally significant – of interest are those inputs that impact the difference in LCC. May be different than those impacting LCC of individual alternatives

- Often only a handful of inputs with critical significance to change the outcome
FHWA’s RealCost for Probabilistic Analysis

- Analyze to identify project specific critical uncertain inputs – Tornado plots, Extreme Tail Analysis
- Invest resources to further study only those inputs to reduce uncertainty
  - **Example:** HMA bid cost – better estimate narrowed down by quantity involved, location of project, etc.
- Re-analyze to arrive at outcome with increased reliability
RealCost LCCA Software

- Microsoft Excel based application – existing user expertise and user customizable
- User interface – separates inputs from analysis methodology
- Offers both Deterministic and Probabilistic Analysis
- Available free of charge, regular enhancements and technical assistance from FHWA
RealCost

- Follows FHWA recommended process for LCCA in Pavement Design
- Developed with inputs from State DOTs, ACPA and NAPA
- Recommended by ACPA\(^1\), referenced in NAPA\(^2\) publications and NCHRP 1—75\(^3\) “Guide for Pavement-Type Selection”
- Easily customizable to meet agency specific requirements

\(^1\) ACPA Engineering Bulletin (EB011) *Life-Cycle Cost Analysis: A Tool for Better Pavement Investment and Engineering Decisions* states “Because of its ability to do both deterministic and probabilistic analyses and ease of use, RealCost is recommended by ACPA”

\(^2\) Asphalt Pavement Alliance *KEYS TO A SUCCESSFUL ALTERNATE BIDDING PROCESS*

\(^3\) TRB’s National Cooperative Highway Research Program (NCHRP) *Report 703: Guide for Pavement-Type Selection*
RealCost Use

- Several State DOTs have adopted RealCost for LCCA in their PTS process
  - AZ, CA, CO, DC, DE, FL, IN, LA, MD, SC, TN, UT, VT, WA, Quebec (per NCHRP 1-75 2009 survey) and others
- Included in the formal PTS policy or manual
  - CA\(^1\), CO\(^2\), FL, IN, WA\(^3\)
- Used exclusively by those using probabilistic analysis
  - CO, DE, IN, MD, SC, WA

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\(^2\) CDOT (2011) *Pavement Design Manual* “Federal Highway Administration (FHWA) RealCost software is to be used for probabilistic LCCA.”

\(^3\) WSDOT (2010) *Pavement Policy* “The pavement type selection, ... including the results of the RealCost evaluation..., all applicable RealCost input files and project specific details) shall be submitted electronically to the Pavement Design Engineer”
RealCost for Effective Probabilistic Analysis

- User worksheets and external data
- Incorporating variability based on bid items
- User defined output to develop distribution of PV differences of alternatives
- Use of Tornado graph to identify critical inputs
- Use of tail analysis to identify critical inputs influencing extremes
Agency LCC Difference

<table>
<thead>
<tr>
<th>Agency LCC ($1000)</th>
<th>Alt 1</th>
<th>Alt 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>$2,658.13</td>
<td>$2,858.32</td>
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<tr>
<td>Standard Deviation</td>
<td>$411.24</td>
<td>$297.41</td>
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<tr>
<td>Minimum</td>
<td>$1,614.60</td>
<td>$2,041.63</td>
</tr>
<tr>
<td>Maximum</td>
<td>$3,787.07</td>
<td>$3,772.61</td>
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</tbody>
</table>

Alt 1 agency LCC is lower than Alt 2 80% of the time
Use of Probabilistic Analysis
Tornado Charts

Agency LCC Difference (Alt 1 – Alt 2)

- HMA Bid Cost (TON)
- PCC Bid Cost (CY)
- Alternative 2: Activity 1: Service Life
- Alternative 1: Activity 1: Service Life
- Corrosion Resistant Dowel Bars Bid Cost (Each)

Correlation Coefficient

Most Sensitive Input (Change from Normal ($80, $20) to ($100, $20) +1 SD change)
# Tornado Charts

<table>
<thead>
<tr>
<th>Agency LCC Difference between Alternatives ($1000)</th>
<th>Probabilistic Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Base Case</td>
</tr>
<tr>
<td>Mean</td>
<td>-$200.2</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>$262.1</td>
</tr>
<tr>
<td>Minimum</td>
<td>-$984.12</td>
</tr>
<tr>
<td>Maximum</td>
<td>$674</td>
</tr>
</tbody>
</table>

Both alternatives are equally competitive!
### Probabilistic Comparison

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Alternative 2 Service Life 1 increase by 1 SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>-$200.2</td>
<td>-$174</td>
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<tr>
<td><strong>Standard Deviation</strong></td>
<td>$262.1</td>
<td>$263.7</td>
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<tr>
<td><strong>Minimum</strong></td>
<td>-$984.12</td>
<td>-$958.2</td>
</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>$674</td>
<td>$709.7</td>
</tr>
</tbody>
</table>

Changing Initial Service Life of Alt 2 by 1 SD did not have a significant impact.
Tornado Charts (Cont.)

- Help in identifying those few key uncertain inputs that could significantly impact the decision being made from the many in the LCCA model.

- Total uncertainty includes both system’s inherent variability and uncertainty due to lack of knowledge. The uncertainty due to lack of knowledge can be reduced through further study.

- Once few key inputs that could significantly impact the decision have been identified, additional efforts can be allocated to better define them.
Tornado Charts (Cont.)

- Inputs not treated stochastically (probabilistically) will not show up in Tornado Chart and should not be incorrectly interpreted that those are insignificant. **No inference can be drawn regarding the significance of the inputs that are treated deterministically** from a Tornado Chart. The Tornado Chart only ranks those that are treated probabilistically within the range of variability considered.
The standard deviation or range assumed for an input has impact on the ranking. Unreasonably large or small standard deviation can misidentify key inputs.

Interrelated variables should be properly correlated. Treating highly positively correlated variables independently may results artificially smaller outcome uncertainty.
Extreme Tail Analysis

Alternative 1

Probability Scale

Agency LCC ($1000)
## Extreme Tail Analysis (Cont.)

<table>
<thead>
<tr>
<th>Input Variable</th>
<th>Extreme Tail Analysis – Alpha Values</th>
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<tbody>
<tr>
<td></td>
<td>Name</td>
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<tr>
<td>HMA Bid Cost (TON)</td>
<td>-1.74</td>
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<tr>
<td>Base Course Bid Cost (TON)</td>
<td>-0.91</td>
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<td>Alternative 1: Activity 1: Service Life</td>
<td>0.41</td>
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<td>Planning Bituminous Pavement-0.15-ft Bid Cost</td>
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<tr>
<td>Discount Rate</td>
<td>0.46</td>
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<td>Roadway Excavation for Full Depth Reconstruction Bid Cost</td>
<td>-0.39</td>
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<td>Alternative 1: Activity 1: Work Zone Duration</td>
<td>-0.13</td>
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<tr>
<td>Value of Time for SU Trucks</td>
<td>-0.12</td>
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<tr>
<td>Alternative 1: Activity 4: Service Life</td>
<td>0.07</td>
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<tr>
<td>Value of Time for Passenger Cars</td>
<td>-0.12</td>
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<tr>
<td>Alternative 1: Activity 2: Service Life</td>
<td>0.01</td>
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<tr>
<td>Annual Average Daily Traffic</td>
<td>0.11</td>
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<tr>
<td>Alternative 1: Activity 3: Service Life</td>
<td>-0.05</td>
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<tr>
<td>Queue Dissipation Capacity</td>
<td>0.05</td>
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<tr>
<td>Value of Time for Combination Trucks</td>
<td>0.02</td>
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</tbody>
</table>
Extreme Tail Analysis (Cont.)

Alternative 1

Agency LCC ($1,000)

Probability Scale

$1,000 $1,500 $2,000 $2,500 $3,000 $3,500 $4,000 $4,500 $5,000
### Extreme Tail Analysis – Effect of Key Input Variability on Output Extreme

#### HMA Bid Cost Variability on LCC

<table>
<thead>
<tr>
<th>Agency LCC ($1000)</th>
<th>HMA Bid Cost SD $20</th>
<th>HMA Bid Cost SD $10</th>
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<tbody>
<tr>
<td></td>
<td>Agency Cost ($1000)</td>
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</tr>
<tr>
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<td>$2,661.33</td>
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<tr>
<td>Standard Deviation</td>
<td>$411.24</td>
<td>$219.87</td>
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<tr>
<td>Minimum</td>
<td>$1,614.60</td>
<td>$2,050.73</td>
</tr>
<tr>
<td>Maximum</td>
<td>$3,787.07</td>
<td>$3,327.09</td>
</tr>
</tbody>
</table>
Thank You

Nadarajah Sivaneswaran (Siva)
Federal Highway Administration
n.sivaneswaran@dot.gov
202-493-3147

http://www.fhwa.dot.gov/research/
Thank You

Eric Ross
Federal Highway Administration
eric.ross@dot.gov
202-366-3975

http://www.fhwa.dot.gov/tpm/index.cfm