IMPROVING THE REHABILITATION TIMING AND SELECTION IN A PAVEMENT LIFE CYCLE COST ANALYSIS

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LIFE CYCLE COST ANALYSIS IS PROJECT ANALYSIS TOOL THAT QUANTIFIES THE TOTAL “COSTS OF OWNERSHIP”
Accounts for initial costs and discounted future rehabilitation costs

LCCA compares different options for a given project and determines which pavement design is most cost effective over the analysis period

NPV = Initial Cost + \sum \text{Rehab cost} \times \frac{1}{(1 + d)^{n_k}} - \text{Salvage Value} \times \frac{1}{(1 + d)^{n_k}}

Where
NPV = Net Present Value
\(d\) = real discount rate
\(n_k\) = year of expenditure
TO GET CREDIBLE AND RELIABLE LCCA RESULTS
The Process and the Engineering & Economics Inputs need to be correct

1. **Process** needs to well-structured and follows best practices

2. **Engineering** must be fundamentally sound and pertain to **that specific** design for a particular project
   - Equivalent designs with similar performance
   - Realistic rehabilitation strategies for each particular design

3. **Cost Estimates** need to be based on good economic principals and expected rehabilitation strategy for **that specific** design
   - Must accurately represent – as best as possible – the Agency’s probable expenditures

The LCCA must be based on the designs “Being Proposed” for the Project (Not on a “Average or Standard Pavement”)

FHWA HAS A WELL STRUCTURED FRAMEWORK AND 5-STEP PROCESS FOR PERFORMING A LCCA

Establish LCCA Framework
- Establish analysis period
- Establish how inflation will be treated (nominal or real)
- Establish discount rate to be used (nominal or real)

Perform LCCA
1. Establish Alternative Pavement Designs
2. Determine Timing of Required Rehabilitation Activities
3. Estimate Agency and User Costs (often considered optional)
   - Initial Construction Costs
   - Rehabilitation Costs
4. Compute Life-Cycle Costs
5. Analyze the Results

State DOTS and the Concrete & Asphalt Industries generally agree with this Structure and Process
WHILE THERE IS GENERAL AGREEMENT ON THE PROCESS

There is disagreement and “lack of trust” in the results because of arguments are about the “correctness” of the inputs.

Sources of Uncertainty & Variability

1. Temporal - Timing of Rehabilitation Activities
   - Initial Performance
   - Rehabilitation Performance

2. Scenario – Which rehabilitation activities are done
   - Preservation Options
   - Overlay Options

3. Measurement - Cost
   - Inflation
   - Price Adjustment Clauses
   - Unit Price
   - Material Quantities
   - Bidding Practices
     (Incentives/Disincentives, SY vs Tons, etc.)

Goal is to develop a Robust Process to reflect the broadest sets of activities for each specific alternative being evaluated.
AGENDA

Improving “Timing of Rehabilitation Activities”

Improving “Which rehabilitation activities are done”

Case Study – Ohio Example
MANY AGENCIES USE HISTORICAL PERFORMANCE
Need to be aware that design features impact the pavement performance

Average Time to First Major Rehabilitation of Concrete Pavement in Georgia

Historical performance must be based on data from “like roadways” to avoid biasing the results

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1. Georgia Concrete Pavement Performance and Longevity, Final Report, GDOT Research Project No. 10-10, Task Order No. 02-74
   Dr. James (Yichang) Tsai, P.E., Yiching Wu, Chieh (Ross) Wang, Georgia Institute of Technology, February 2012.
   Note: Overall Avg Time to 1st Rehab = 17 years. Projects carried 17-30 million ESALs, which is 2-4 times the designed ESALs, before 1st rehabilitation

2. Time to 1st Rehabilitation in GDOT LCCA procedure = 20 years, time to 2nd Rehabilitation = 40 years
PAVEMENT–ME DEFINES A SPECIFIC PAVEMENT’S PERFORMANCE
State-of-the practice design procedure that predicts performance for key distresses

Red Line - Defined Distress Limit. When major rehabilitation is needed (i.e. patching & DG or overlay).
Black Dashed Line - The actual (most likely) level of distresses predicted
Blue Dotted Line - The predicted distresses at the given reliability level (i.e. 90%). Designs are based on when this line hits the defined distress limit

Design life is when the Blue Reliability curve hits red Predefined Distress level
PAVEMENT-ME PROVIDES A PROCESS TO COMPARE DIFFERENT DESIGNS / DIFFERENT FEATURES

Standard Design

- 8.0” JPCP w/ Dowels
  Spacing = 15 ft
- 3.0” AC Base
  (SuperPave 19.0)
- 12” Graded Agg
  Base Course
- AASHTO
  Class A-7-5

Optimized Design

- 8.0” JPCP w/ Dowels
  Spacing = 12 ft
- 6” Graded Agg
  Base Course
- AASHTO
  Class A-7-5

Pavement-ME gives a repeatable, non-biased, scientific process to determine how a specific pavement design will perform.
THERE ARE 4 WAYS TO ESTIMATE REHABILITATION PERFORMANCE PERIODS

Procedures

1. Use standard rehabilitation performance lives based on historical performance of similar rehabilitation activities in the area.

2. Assume all rehabilitation activities carry the same amount of traffic as the original pavement.

3. Run Pavement-ME to evaluate the performance of rehabilitated pavements using the predicted condition and increased traffic levels.

4. Adjust Pavement-ME performance curves for the amount of distress repaired and assume that performance curves follow the same curve prior to the rehabilitation.
A common practice is to assume each rehabilitation activities last the same amount of time.

Pavement condition vs. age

Myth

INCREASING TRAFFIC AND DAMAGE MEANS THAT REHABILITATION TIMING DECREASES

Pavement condition vs. age – Actual Performance

The same, standard fix can not last the same time frame (eg 10 years)
Need to increase structure or decrease performance period

DETERMINING REHABILITATION PERFORMANCE
Using Traffic Counts

Process
1. Determine life of the original pavement using Pavement-ME
2. Determine how many vehicles are carried in that time.
3. Assume that each major rehabilitation will carry that same amount of traffic
4. Determine life of each rehabilitation by matching traffic.

Example
- Pavement-ME says original pavement lasts 24 years
  - Carries 62 million vehicles
  - Growth is 3%
- To carry the next ~62 million vehicles takes 13 years
  - Rehab year = 37
- To carry 3rd 62 million vehicles takes 9 years
  - Rehab year = 46

Simple, but cannot distinguish long term impacts of different designs
DETERMINING REHABILITATION PERFORMANCE
Running Pavement-ME in Rehabilitation Mode for each additional Activity

1. When curve hits "predefined" distress, record traffic and distress values
2. Run Pavement-ME in Rehabilitation Mode for the remaining years in the analysis period (e.g., 25 years)
   • Update traffic
   • Add rehabilitation activities
3. When adjusted curve hits "predefined" distress again, record traffic and distress values and repeat
4. Continue repeating the process thru analysis period

The most rigorous procedure and can account for structural changes (i.e., overlays) (but requires great care to make sure all inputs match (traffic, bonding, materials, etc.).
DETERMINING REHABILITATION PERFORMANCE
Running Pavement-ME in Rehabilitation Mode for each additional Activity

Performance criteria is 20-year faulting below 0.12 inches
Performance criteria is 20-year cracking below 10% of slabs

1st Rehabilitation was controlled by IRI, 2nd Rehabilitation controlled by Cracking
1. When curve hits “predefined” distress, repair pavement to original condition (IRI = 70 in/mile)
2. Assume new, adjusted curve follows same slope of the original curve
3. When adjusted curve hits “predefined” distress again, repair pavement
4. Continue repeating the process thru analysis period

\[ D'_{Rtn} = D_o + (D_{Rtn} - D_{Rtn-1}) \]

* \( D'_{Rtn} \) is Adjusted Distress Level at any time after rehabilitation
* \( D_o \) is Starting Distress Level
* \( D_{Rtn} \) is Predicted Distress Level from original Pavement-ME Curve
* \( D_{Rtn-1} \) is Distress Level at time of rehabilitation (amount of repair).

Less rigorous than procedure 3, but it is simpler; gives reasonable answers; and does not require additional Pavement-ME runs.
DETERMINING REHABILITATION PERFORMANCE
Adjust Performance Curves

Predicted Faulting

Predicted Cracking

Performance criteria is 20-year faulting below 0.12 inches
Performance criteria is 20-year cracking below 10% of slabs

Controlling Distress for rehabilitation timing switched from IRI to Cracking
### COMPARISON LCCA TIMING USING THE DOT STANDARD POLICY VS. PAVEMENT-ME PREDICTIONS

<table>
<thead>
<tr>
<th>Pavement-ME</th>
<th>Run Pavement-ME in Rehab Mode</th>
<th>Adjust Performance Curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard DOT Policy</td>
<td>Based on Same Traffic</td>
<td>Standard</td>
</tr>
<tr>
<td>Initial Const.</td>
<td>Yr 0</td>
<td>Yr 0</td>
</tr>
<tr>
<td>Rehab 1</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Rehab 2</td>
<td>40</td>
<td>37</td>
</tr>
<tr>
<td>Rehab 3</td>
<td>46</td>
<td>45</td>
</tr>
</tbody>
</table>

1. Time to 1st rehabilitation is 4 years later than assumed LCCA schedule
2. Time to 2nd rehabilitation is close to the policy
   - Shorter for the standard design
   - Longer for the optimized design
3. Standard design requires a 3rd rehabilitation (not captured in policy LCCA)
AGENDA

Improving “Timing of Rehabilitation Activities”

Improving “Which rehabilitation activities are done”

Case Study – Ohio Example
MOST LCCA GUIDELINES PROVIDE A SINGLE SET OF ACTIVITIES

Rehab 1
Year 18 to 25
(Typical = Yr 22)

Rehab 2
Year 28 to 32
(Typical = Yr 32)

Initial PCC Construction → Diamond Grind → 4-7% FDR → 3 to 4” Asphalt Overlay → 2% FDR → NPV = $25,950,132

Question - is the selection of activities representative of the most likely set of activities for the pavement option?
THE FACT IS THERE ARE MANY POSSIBLE ACTIVITIES
Some agencies provide a series of activities, but still use a “standard”

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**Rehab 1**
Year 18 to 25
(Typical = Yr 22)

- Diamond Grind
- 2-4% FDR
- 4-7% FDR
- 7-10% FDR

**Rehab 2**
Year 28 to 32
(Typical = Yr 32)

- Diamond Grind
- 3 to 4” Asphalt Overlay
  - 1% FDR
  - 2% FDR
  - 3% FDR
  - 4% FDR

Decision Trees can evaluate the “Cost Impacts” of all Alternate Rehabilitation Options
DECISION TREE ANALYSIS IS A NUMERICAL ANALYSIS PROCEDURE

Accounts for all, or most, of the possible alternatives and results of a future course of action that requires various other decisions

A flowchart-like structure that shows the relationships among many courses of actions

Two kinds of nodes:

- Decision nodes – where an option is to be selected
- Chance nodes – where various future realizations along with some probability of occurrence are represented
  - Defines the likelihood that a specific activity will occur at that node
  - The combination of decision and chance nodes represents the outcome of the decision

As additional decisions about subsequent activities are made, the branches expand until the end of the analysis period is reached.

- By systematically working through all potential options for each rehabilitation cycle (i.e., each branch is expanded), all feasible rehabilitation activity paths can be mapped out
ASSIGN PROBABILITIES TO THE DECISION TREE TO DETERMINE THE “MOST LIKELY” LIFE CYCLE COSTS

Expected Value
\[ EV_n = \text{Prob}_n \times \text{NPV}_n \]

\[ EV_{11} = 0.9 \times 0.5 \times 0.5 \times 0.5 \times (\text{NPV}_{11}) \]

\[ \text{NPV} = \sum \text{EV} \]

PCC Rehab Schedule, Ohio DOT LCCA Manual

- 23 -
ASSIGN PROBABILITIES TO THE DECISION TREE
TO DETERMINE THE “MOST LIKELY” LIFE CYCLE COSTS

Expected Value
(EVₙ = Probₙ x NPVₙ)

|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| EV₁ | $675,271.93 |
| EV₂ | $1,358,096.10 |
| EV₃ | $682,824.17 |
| EV₄ | $715,921.76 |
| EV₅ | $1,439,395.76 |
| EV₆ | $723,474.00 |
| EV₇ | $1,370,843.01 |
| EV₈ | $2,755,790.50 |
| EV₉ | $1,385,947.49 |
| EV₁₀ | $1,452,142.67 |
| EV₁₁ | $2,919,389.81 |
| EV₁₂ | $1,467,247.14 |
| EV₁₃ | $695,571.08 |
| EV₁₄ | $1,398,694.40 |
| EV₁₅ | $703,123.32 |
| EV₁₆ | $736,220.91 |
| EV₁₇ | $1,479,994.05 |
| EV₁₈ | $743,773.14 |
| EV₁₉ | $193,607.52 |
| EV₂₀ | $194,033.81 |
| EV₂₁ | $195,039.77 |
| EV₂₂ | $21,342.90 |
| EV₂₃ | $21,390.77 |
| EV₂₄ | $21,502.54 |
| EV₂₅ | $346,262.88 |
| EV₂₆ | $347,034.48 |
| EV₂₇ | $348,222.85 |
| EV₂₈ | $85,894.53 |
| EV₂₉ | $86,084.46 |
| EV₃₀ | $86,531.55 |
| EV₃₁ | $152,413.90 |
| EV₃₂ | $152,739.98 |
| EV₃₃ | $153,522.39 |
| EV₃₄ | $64,813.10 |
| EV₃₅ | $64,954.37 |
| EV₃₆ | $65,289.69 |

EV₁₁ = Probability x NPV₁₁ = (0.9 x 0.5 x 0.5 x 0.5) x ($25,950,132) = $2,919,390

NPV = ∑ EV = $25,306,023
SAME ISSUES AND PROCESSES ARE ALSO HOLD FOR ASPHALT

Rehab 1
Year 10 to 15
(Typical = Yr 12)

Rehab 2
Year 18 to 25
(Typical = Yr 22)

Rehab 3
Year 28 to 34
(Typical = Yr 34)

EV12 = Probability x NPV12 = (0.9 x 0.9 x 0.5 x 0.5 x 0.5) x ($23,092,988) = $3,637,146

NPV = Σ EV = $24,210,615

AC Rehab Schedule, Ohio DOT LCCA Manual
AGENDA

Improving “Timing of Rehabilitation Activities”

Improving “Which rehabilitation activities are done”

Case Study – Ohio Example
PROBABILITY AND DECISION TREE ANALYSIS CAN MAKE LCCA RESULTS MORE ROBUST AND TRANSPARENT

LCCA Results

Asphalt Design
- 16" Total Asphalt Concrete
  - (1.5" Surf. Typ A 12.5mm, 1.5" Interm Typ A 19mm, 13" AC Base)
- 6" Aggregate Base
- Subgrade
- IC = $18.432 M

Concrete Design
- 14.5" PCC
  - 15-ft Joints w/ 1.5" Dia. Dowels
- 6" Aggregate Base
- Subgrade
- IC = $22.190 M

US $ M

Asphalt: $23.093  \( \Delta = 12.4\% \)
Concrete: $25.950

IC = $18.432 M IC = $22.190 M

Range of results addresses Risk Assumptions inherent in a standard LCCA

NPV results from Standard Rehabilitation Schedule

Ohio DOT
HAM-75-10.10 (PID 76256) Pavement Type Selection (March 2007)
PROBABILITY AND DECISION TREE ANALYSIS CAN MAKE LCCA RESULTS MORE ROBUST AND TRANSPARENT

LCCA Results

Asphalt Design

16” Total Asphalt Concrete
(1.5” Surf. Typ A 12.5mm
1.5” Interm Typ A 19mm
13” AC Base)

6” Aggregate Base

Subgrade

IC = $18.432 M

Concrete Design

14.5” PCC
15-ft Joints w/ 1.5” Dia. Dowels

6” Aggregate Base

Subgrade

IC = $22.190 M

US $ M

Asphalt

Concrete

$23.093

$27.095

$22.301

$24.010

$26.445

$25.950

$Δ = 12.4%

Range of results addresses Risk Assumptions inherent in a standard LCCA

IC = $18.432 M

IC = $22.190 M

NPV results from Standard Rehabilitation Schedule

Range of NPV results from DTA

Error bars represent the high and low value of DTA results

Ohio DOT
HAM-75-10.10 (PID 76256) Pavement Type Selection (March 2007)
PROBABILITY AND DECISION TREE ANALYSIS CAN MAKE LCCA RESULTS MORE ROBUST AND TRANSPARENT

LCCA Results

Asphalt Design
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- 14.5” PCC
  - 15-ft Joints w/ 1.5” Dia. Dowels
- 6” Aggregate Base
- Subgrade
- IC = $22.190 M

US $ M
- Asphalt: $23.093, $24.211, $22.301
- Concrete: $27.095, $25.950, $26.445

$23.093 $24.211 $22.301
$27.095 $25.950 $26.445

Δ = 4.5%
Δ = 12.4%

NPV results from Standard Rehabilitation Schedule
Range of NPV results from DTA
Error bars represent the high and low value of DTA results
EV NPV based on assumed probabilities

Range of results addresses Risk Assumptions inherent in a standard LCCA
PAVEMENT-ME PREDICTED PERFORMANCE IS HIGH
Faulting, Cracking, & IRI levels far exceed the 20 year Design Life

Pavement is over-designed because it does not need rehabilitation until the end 50 year analysis period
Creates the opportunity for project optimization
LCCA results indicate that Alternatives have similar costs, which means the Agency could benefit by doing Alternate Design / Alternate bid.
ALTERNATE DESIGN/ALTERNATE BID LOWERS PROJECT COSTS
Increases competition by bringing more contractors & industries to the bidding table

Alternate Design / Alternate Bid

- Bidding process where two equivalent pavement designs are developed
- Contractor then chooses on which pavement to submit for his bid.
- Alternative with lowest total “costs of ownership” wins.

Initial Cost is the Most Important Factor in a LCCA

- Account between 75-95% of Life Cycle Cost for Concrete (~55-75% for asphalt)
- Using ADAB lowers initial pavement unit costs

Lowers initial costs is an immediate decrease in Life Cycle Costs by approximately the same amount

Missouri DOT ADAB Results

124 Total Projects (41 Asphalt, 83 Concrete)
Total Value = $1,645 M

<table>
<thead>
<tr>
<th></th>
<th>Non ADAB Projects Unit Bid Price</th>
<th>ADAB Projects Unit Bid Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt ($ / ton)</td>
<td>$50.97</td>
<td>$45.78</td>
</tr>
<tr>
<td>Concrete ($ / CY)</td>
<td>$139.59</td>
<td>$126.75</td>
</tr>
</tbody>
</table>

No. of Bidders (2005) 3.9
No. of Bidders (2008) 4.2

3. Presentation by David Nichols, Missouri DOT at Mo Asphalt Pavement Assn 2009 Annual Conference, January 2009
CONCLUSIONS
LCCA needs to be reasonable and reflect the likely agency expenditures and performance of the specific pavement design being evaluated

1. Most agencies apply a single, standard, policy set rehabilitation scenario to all pavements
   - Assumes that the historical performance used in the analysis will be representative of the performance of the specific design being evaluated.
   - This is probably not true.

2. Pavement-ME can be used to improve the performance estimates / rehabilitation timing of different pavement designs
   - Accounts for different Design Features on performance
   - Can be used to account for increasing traffic and damage for rehabilitation activities

3. Decision Tree Analysis looks at all potential rehabilitation options and develops a range of Net Present Values (NPV) so that the associated “Risk Profile” of each alternative is defined

A “Robust LCCA” addresses the inherent uncertainty in LCCA’s to balance the risk assumptions to make them more transparent, credible, and defensible
INITIAL PERFORMANCE PERIOD USED BY STATE DOTS
Based on History or Pavement Design Life

Asphalt Pavements

Concrete Pavements

<table>
<thead>
<tr>
<th>Time to First Rehabilitation</th>
<th>Max</th>
<th>Min</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Pavements</td>
<td>26</td>
<td>10</td>
<td>15.4</td>
</tr>
<tr>
<td>Concrete Pavements</td>
<td>40</td>
<td>10</td>
<td>22.1</td>
</tr>
</tbody>
</table>

Red lines show the range of values for states that do not have fixed value.

1. 2007 National LCCA Survey by Mississippi DOT
2. National LCCA Survey Conducted by South Carolina DOT
3. State DOT Pavement Design and/or Pavement Type Selection Manuals
REHABILITATION PERFORMANCE PERIOD USED BY STATE DOTS

Asphalt Pavements

<table>
<thead>
<tr>
<th>State</th>
<th>Init</th>
<th>R-1</th>
<th>R-2</th>
<th>R-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>26</td>
<td>20</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Min</td>
<td>10</td>
<td>5</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Avg</td>
<td>15.4</td>
<td>11.4</td>
<td>10.5</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Concrete Pavements

<table>
<thead>
<tr>
<th>State</th>
<th>Init</th>
<th>R-1</th>
<th>R-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>40</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Min</td>
<td>10</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Avg</td>
<td>22.1</td>
<td>12.9</td>
<td>10.0</td>
</tr>
</tbody>
</table>

1. 2007 National LCCA Survey by Mississippi DOT
2. National LCCA Survey Conducted by South Carolina DOT
3. State DOT Pavement Design and/or Pavement Type Selection Manuals
PAVEMENT REHABILITATION DEFINITION

Pavement Rehabilitation consists of “structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Rehabilitation techniques include restoration treatments and structural overlays.”

Rehabilitation projects extend the life of existing pavement structures either by restoring existing structural capacity through the elimination of age-related, environmental cracking of embrittled pavement surface or by increasing pavement thickness to strengthen existing pavement sections to accommodate existing or projected traffic loading conditions. Two sub-categories result from these distinctions, which are directly related to the restoration or increase of structural capacity.

- Minor rehabilitation consists of non-structural enhancements made to the existing pavement sections to eliminate age-related, top-down surface cracking that develop in flexible pavements due to environmental exposure. Because of the non-structural nature of minor rehabilitation techniques, these types of rehabilitation techniques are placed in the category of pavement preservation.
- Major rehabilitation “consists of structural enhancements that both extend the service life of an existing pavement and/or improve its load-carrying capability.” Source: AASHTO Highway Subcommittee on Maintenance Definition.

Examples of “Major Rehabilitation” for concrete pavements include:

- full concrete pavement restoration (e.g. 1% full depth patching or more plus diamond grinding), asphalt overlay, concrete overlay, rubblized and asphalt overlays. Joint resealing, isolated areas of patching, and partial depth patching is not considered “major” rehabilitation.