Improving Rehabilitation Selection for Pavement Life Cycle Cost Analysis

ACPA Mid Year Meeting
Applying Life Cycle Cost Analysis for Fair Pavement Type Selection Workshop

June 24, 2014

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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

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

Where
- \( NPV = \) Net Present Value
- \( d = \) real discount rate
- \( n_k = \) year of expenditure
WHILE PARTIES AGREE ON THE PROCESS, THERE IS DISAGREEMENT AND “LACK OF TRUST” IN THE RESULTS
Arguments are about the “correctness” of the inputs

Sources of Uncertainty & Variability

1. Temporal - Timing of Rehabilitation Activities
   - Historical vs Predicted

2. Scenario - What rehabilitation activities are done
   - Preservation Options
   - Overlay Options

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

Goal is to make sure “Uncertainty & Variability” are treated similarly so that “Risk Assumptions” in the LCCA are balanced
WHEN DETERMINING REHABILITATION TIMING

Need to develop reasonable performance period for each activity based on the **Given Design**

Performance periods describe the length of time from one pavement construction activity to the next.

- **Initial performance period** - Time from initial construction till the pavement undergoes its first rehabilitation.

- **Rehabilitation performance period** - Time between two consecutive rehabilitation activities (e.g. patching, asphalt overlays, etc).
AGENDA

Initial Performance Period

Rehabilitation Performance Periods

Rehabilitation Selection
INITIAL PERFORMANCE PERIOD USED BY STATE DOTS
Based on History or Pavement Design Life

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

Time to 1st Rehabilitation

Asphalt Pavements

- Max: 26
- Min: 10
- Avg: 15.4

Concrete Pavements

- Max: 40
- Min: 10
- Avg: 22.1

Red lines show the range of values for states that do not have fixed value.
WHEN USING HISTORICAL PERFORMANCE
Need to be aware that design features impact the pavement performance

Average Time to First Major Rehabilitation of Concrete Pavement in Georgia

1. Georgia Concrete Pavement Performance and Longevity, Final Report, GDOT Research Project No. 10-10, Task Order No. 02-74
2. Time to 1st Rehabilitation in GDOT LCCA procedure = 20 years, time to 2nd Rehabilitation = 40 years

Features

Non-doweled JPCP (20+ ft jts) on soil / soil Cement (circa 1960's)
Non-doweled JPCP (20+ ft jts) on GAB (circa early 1970's)
Doweled JPCP (20-ft jts) on GAB (circa late 1970 - 80's)
Doweled JPCP (15-ft jts & 13-ft WL) on AC Base over GAB (circa 1990+)

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

1. 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 PERFORMANCE PREDICTIONS DEFINE INITIAL PERFORMANCE PERIODS

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

As move “Time to first Rehab” across predicted time range, category of repair changes (in order):
1. Concrete Pavement Preservation
2. Overlays
3. Reconstruction

Amount to repair

Predicted Cracking PCC

Predicted Time Range for First Rehabilitation

Design Life (Rehab Required)
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 helps identifies “Design Risks” so the designer can mitigate their impacts.
REHABILITATION TIMING SHOULD BE BASED ON BOTH “MODELED PERFORMANCE” & “HISTORY”

Pavement-ME predicted performance
- Provides predicted performance of major structural distress
- Allows for comparison of design features

Pavement-ME does not Predict all Distress
- Use Historical Data for other potential distresses

Result:
- When used together, can minimize structural distress and while accounting for other non-Pavement-ME distresses
AGENDA

Initial Performance Period

Rehabilitation Performance Periods

Rehabilitation Selection
REHABILITATION PERFORMANCE PERIOD USED BY STATE DOTS

Asphalt Pavements

Concrete Pavements

- Age at 1st Rehabilitation
- Age at 2nd Rehabilitation
- Age at 3rd Rehabilitation
- Age at 4th Rehabilitation

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
A COMMON PRACTICE IS TO USE A STANDARD REHABILITATION ACTIVITY AND TIMEFRAME

Pavement condition vs. age

INCREASING TRAFFIC AND DAMAGE MEANS THAT REHABILITATION TIMING DECREASES
Pavement condition vs. age – Actual Performance

**THERE ARE 3 WAYS TO ESTIMATE REHABILITATION PERFORMANCE**

### Procedures

1. Assume all rehabilitation activities carry the same amount of traffic as the original pavement
   - Simple to use
   - Can not distinguish long term impacts of design features

2. Adjust Pavement-ME performance curves for the amount of distress repaired and assume that performance curves follow the same curve prior to the rehabilitation
   - Gives “reasonable” answers and does not require additional Pavement-ME runs.
   - Good for “preservation” activities. It can not account for the changes in structural capacity (increase of decrease of thickness)

3. Run Pavement-ME to evaluate the performance of rehabilitated pavements using the predicted condition and increased traffic levels
   - The most rigorous procedure
   - Can account for structural changes
DETERMINING PERFORMANCE FOR REHABILITATION ACTIVITIES
Procedure 1 - Using Traffic Counts

1. Estimate life of the original pavement
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
- Original Pavement is predicted to 24 years
  - Carries 3.0 million trucks
  - Growth is 3%
- To carry the next 3 million trucks takes 12 years
  - Rehab year = 36
- To carry 3rd 3 million trucks takes 8 years
  - Rehab year = 44
DETERMINING PERFORMANCE FOR REHABILITATION ACTIVITIES

Procedure 2: Adjust Performance Curves

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

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

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

Results are Similar running Pavement-ME (but much easier to do)

Can account for variation in sensitivity analysis
DETERMINING PERFORMANCE FOR REHABILITATION ACTIVITIES

Procedure 2: Adjust Performance Curves

Predicted Faulting

Performance criteria is 20-year faulting below 0.12 inches

Predicted Cracking

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

Controlling Distress for rehabilitation timing switched from IRI to Cracking
DETERMINING PERFORMANCE FOR REHABILITATION ACTIVITIES

Procedure 3: Run 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

Positives
   - Rigorous
   - Can account for thickness change
   - Can do overlays

Problems
   - Requires great care to make sure all inputs match (traffic, bonding, materials, etc.)

Combined Pavement-ME Performance Curves with Rehabs

Time between rehabilitation changes with designs and decreases due to increasing traffic
DETERMINING PERFORMANCE FOR REHABILITATION ACTIVITIES

Procedure 3: Run Pavement-ME in Rehabilitation Mode for each additional Activity

Predicted Faulting

- Performance criteria is 20-year faulting below 0.12 inches

Predicted Cracking

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

1st Rehabilitation was controlled by IRI, 2nd Rehabilitation controlled by Cracking
### COMPARISON OF REHABILITATION PERFORMANCE USING THE DOT STANDARD POLICY VS. PAVEMENT-ME PREDICTIONS

Using Pavement-ME accounts for the performance / activities for a Given Design, which creates more realistic LCCA’s for comparison.

<table>
<thead>
<tr>
<th></th>
<th>Standard DOT Policy</th>
<th>Based on Same Traffic</th>
<th>Adjust Performance Curves</th>
<th>Run Pavement-ME in Rehab Mode</th>
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<td>Yr 0</td>
<td>Yr 0</td>
<td>Yr 0</td>
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<td><strong>Rehab 3</strong></td>
<td>44</td>
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</table>
When comparing alternatives, risk assumptions for rehabilitation timing need to be similar.

Concrete Designs have less risk on rehabilitation timing.

Asphalt Designs have greater risk on rehabilitation timing.

Proposed Rehabilitation Schedules for ALDOT LCCA Procedures: Asphalt based Auburn recommendation sand Concrete based on University of Alabama recommendations.
AGENDA

Initial Performance Period

Rehabilitation Performance Periods

Rehabilitation Selection
MOST LCCA GUIDELINES PROVIDE A SINGLE SET OF ACTIVITIES

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

Diamond Grind
4-7% FDR

Initial PCC Construction

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

3 to 4” Asphalt Overlay
2% FDR

= LCC

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

A “Robust LCCA” will evaluate the “Cost Impacts” of all Alternate Rehabilitation Options
USE PROBABILITY AND DECISION TREE ANALYSIS TO DETERMINE THE “MOST LIKELY” LIFE CYCLE COSTS

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

Initial PCC Construction

Diamond Grind
90%

25%

2-4% FDR

50%

4-7% FDR

50%

7-10% FDR

25%

3 to 6” AC Overlay

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

Diamond Grind

50%

25%

1% FDR

2% FDR

3% FDR

1% FDR

2% FDR

3% FDR

Asphalt Overlay

50%

25%

3 to 4”

No Mil

Mil

1.25” – 2” ACOL

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

Expected Value

(\[ EV_n = \text{Prob}_n \times \text{NPV}_n \] )

EV 1 = 

\[ \text{NPV} = \sum \text{EV} \]
USE PROBABILITY AND DECISION TREE ANALYSIS TO DETERMINE THE “MOST LIKELY” LIFE CYCLE COSTS

Expected Value
$(E_{vn} = Prob_{vn} \times NPV_{vn})$

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<th>Probability</th>
<th>NPV</th>
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<td>EV40</td>
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NPV = $25,306,023$

Initial PCC Construction

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

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

- 3 to 6” AC Overlay

- 1.25” – 2” ACOL

- No Mil

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

- Diamond Grind
  - 1% FDR
  - 2% FDR
  - 3% FDR

- 3 to 4” Asphalt Overlay

- 2-4% FDR
- 4-7% FDR
- 7-10% FDR

EV11 = Probability x NPV11 = (0.9 x 0.5 x 0.5 x 0.5) x ($25,950,132) = $2,919,390
SAME ISSUES AND PROCESSES ARE ALSO HOLD FOR ASPHALT

Initial AC Construction

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

1.25” – 2” AC Overlay

No Mill

Mill

2 to 3” AC Overlay

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

3-4” Mill/ACOL

Crack Seal

Microsurfacing

Mill / 1.5” ACOL

50%

25%

50%

25%

25%

25%

25%

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

4-6” Mill/ACOL

6-7” Mill/ACOL

No Mill

Mill

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
HOW 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” Intern. Typ A 19mm
  13” AC Base)
- 6” Aggregate Base
- Subgrade

Concrete Design
- 14.5” PCC 15-ft Joints w/ 1.5” Dia. Dowels
- 6” Aggregate Base
- Subgrade

Range of results addresses Risk Assumptions inherent in a standard LCCA

Asphalt
- $23.051
- $22.301
- $27.095
- Δ = 10.5%

Concrete
- $24.010
- $25.478
- $26.445

xxx = NPV from Standard LCCA
xxx = NPV range from Decision Tree Analysis
HOW PROBABILITY AND DECISION TREE ANALYSIS CAN MAKE LCCA RESULTS MORE ROBUST AND TRANSPARENT

Range of results addresses Risk Assumptions inherent in a standard LCCA
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 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