Development of New Life Cycle Cost Modeling

The University of Oklahoma

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** Currently with Iowa State University
Project Objective

• Conduct a comparative field evaluation of common methods to restore skid resistance
  – Surface treatments
  – Mechanical methods
• 23 asphalt and concrete test sections
  – Monthly testing of skid and macrotexture
  – Result will be deterioration models for each treatment
• Complete a life cycle cost analysis of each method in the study
Test Section Sponsors

- Blastrac, Inc. Edmond, OK
- Penhall Diamond Grinding, Anaheim, CA
- JLT Corp. Cushing, OK
- Ergon Emulsions and Materials, Austin, TX
- Skidabrader, Inc. Ruston, LA
- Polycon, Madison, MS
- Haskell Lemon & Hall Brothers, OKC, OK
- Pathway Services, Tulsa, OK
- Calumet Lubricants, Shreveport, LA
Background and Motivation

• ODOT latest APP: transportation system preservation - critical part of mission
• Economic Analysis: vital transportation decision-making component (sustainability)
• Substantial issues with LCCA theory when applied to preservation.

Sustainability - Triple Bottom Line, (AASHTO, 2009)
Current LCCA in Transportation

- Recommended by FHWA
- Limited application due to complexity
- Very sensitive to discount rate & analysis period
- Limited at project/implementation level
- No specific LCCA/PPT – adapted tool
- Network-level LCCA tool (FHWA CASE STUDIES):
  - not applied to PPT or needs to be customized for PPT
- Economic analysis tools still being developed (FHWA, 2007)
- No consensus among SHAs
- SHA to develop own tools (Hall et al, 2003)
- PPT alternatives, SL, cost and productivity data
LCCA

• Treatment cost-effectiveness evaluation based on engineering economic principles

FHWA LCCA procedures:
• 1. Establish design alternatives [and analysis period]
• 2. Determine [performance period and] activity timing
• 3. Estimate costs [agency and user]
• 4. Compute [net present value] life cycle costs
• 5. Analyze results
• 6. Reevaluate design strategies
Net Present Value AP Selection Methods

1. Establish [PPT] alternatives and analysis period:

   NPV: analysis period = a common period for all alternatives

   - set AP equal to the shortest life among alternatives
   - set AP equal to the longest life among alternatives
   - set AP equal to the least common multiple of the lives of the various alternatives
   - use a standard AP, such as 10 years
   - set the AP equal to the period the best suits the organization’s need for the investment
   - use an infinitely long AP

   (White et al, 2010)
FHWA LCCA procedure

1. Establish design alternatives [and analysis period]

<table>
<thead>
<tr>
<th>Time</th>
<th>Alternative</th>
<th>gap, Alt. A₂</th>
<th>residual value, Alt. A₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>A₁ (Majo)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B₁ (Reha)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Standard Analysis Period, One Major Rehabilitation Accommodated
LCCA
adapted to PPT alternative evaluation

Equivalent Uniform Annual Cost LCCA procedures:

1. Establish design alternatives
   \[ SL_{alt} = \text{analysis period}_{alt} \]
2. Determine [performance period and] activity timing
   \[ SL_{alt} = \text{MIN}\{\text{microtexture, macrotexture, expected}\} \]
3. Estimate costs [agency and user]
4. Compute [EUAC] life cycle costs
   \[ \text{EUAC}(i\%)_{alt} = \sum P \left( \frac{i(1+i)n}{(1+i)n-1} \right) \]
5. Analyze results
6. Reevaluate design strategies
Equivalent Uniform Annual Cost (EUAC)

1. Establish design alternatives

\[ \text{Analysis period}_{alt} = \text{SL}_{alt} \]

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Time ‘A’</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Time ‘B’</td>
</tr>
</tbody>
</table>

Equivalent Uniform Annual Cost for Unequal-Life Alternatives
2. Determine [performance period and] activity timing

\[ SL_{\text{alt}} = \text{MIN}\{\text{microtexture}, \text{macrotexture}, \text{expected}\} \]

- Field Trial Deterioration Models – Macrotexture, chip seal

\[ y = -0.004x^2 - 0.0012x + 2.5216 \]

\[ R^2 = 0.9687 \]

Coefficient of Determination: 0.9687
## EUAC for PPT evaluation

2. Determine [performance period and] activity timing

\[ SL_{alt} = \min\{\text{microtexture}, \text{macrotecture}, \text{expected}\} \]

<table>
<thead>
<tr>
<th>Pavement Preservation Treatment</th>
<th>Service Life (years)</th>
<th>Microtexture</th>
<th>Macrotecture</th>
<th>ODOT &amp; Lit. Review</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot; Hot Mix Asphalt Mill &amp; Inlay (HMA)</td>
<td>&gt; 10</td>
<td>N/A</td>
<td>10</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Open Graded Friction Course (OGFC)</td>
<td>&gt; 10</td>
<td>5.3 years</td>
<td>10</td>
<td></td>
<td>5.3</td>
</tr>
<tr>
<td>5/8&quot; Chip Seal</td>
<td>3.8</td>
<td>1.8</td>
<td>5</td>
<td></td>
<td>1.8</td>
</tr>
<tr>
<td>Pavement Retexturing, Abrading</td>
<td>&gt;5</td>
<td>N/A</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Pavement Retexturing, Shotblasting</td>
<td>&gt;5</td>
<td>N/A</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Treatment Service Life Based on Extrapolated Field Data
4. Calculate EUAC, (Continuous Mode)

\[ SL_{\text{alt}} = \min\{ \text{microtexture, macrotexture, expected} \} \]

**Initial Cost, SL:**
- Chip seal: $12.5k, 1.8y (macro)
- OGFC: $26.5k, 5.3y (macro)
- 1” HMA: $28k, 10y
EUAC (Continuous Mode)
Sensitivity Analysis

4. Calculate EUAC, (Continuous Mode)
[SL_{alt} = \text{MIN}\{\text{microtexture, macrotexture, expected}\}]

<table>
<thead>
<tr>
<th>ALT #</th>
<th>Description</th>
<th>EUAC</th>
<th>Rank</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bituminous ODOT Standard 5/8&quot; chip seal</td>
<td>4,696</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Bituminous Open Graded Friction Course (OGFC)</td>
<td>6,740</td>
<td>3</td>
<td>43.53%</td>
</tr>
<tr>
<td>3</td>
<td>Bituminous 1&quot; Hot Mix Asphalt mill &amp; inlay (HMA)</td>
<td>4,696</td>
<td>2</td>
<td>0.01%</td>
</tr>
</tbody>
</table>

\text{Initial Cost, SL:}
- Chip seal: $12.5 \text{ k, 3.8y (micro)}
- OGFC: $26.5 \text{ k, 5.3y (macro)}
- 1" HMA $28 \text{ k, 10y}
### EUAC (Continuous Mode)

**Sensitivity Analysis**

4. Calculate EUAC, (Continuous Mode) 
\[ SL_{alt} = \text{MIN}\{\text{microtexture, macrotexture, expected}\} \]

<table>
<thead>
<tr>
<th>ALT #</th>
<th>Description</th>
<th>EUAC</th>
<th>Rank</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bituminous</td>
<td>3,651</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ODOT Standard 5/8&quot; chip seal</td>
<td>4,460</td>
<td>2</td>
<td>22.15%</td>
</tr>
<tr>
<td>3</td>
<td>Bituminous</td>
<td>4,696</td>
<td>3</td>
<td>28.62%</td>
</tr>
</tbody>
</table>

**Initial Cost, expected SL:**
- Chip seal: $12.5 \text{k}, 5y
- OGFC: $26.5 \text{k}, 10y
- 1" HMA: $28 \text{k}, 10y
## EUAC-Continuous Mode
(same ranking as NPV, various AP)

<table>
<thead>
<tr>
<th>PAVEMENT TREATMENTS</th>
<th>Agency Costs</th>
<th>Analysis Period</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EUAC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ODOT Standard 5/8&quot; chip seal (5-yr)</td>
<td>3,408</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>OGFC (10-yr)</td>
<td>4,150</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>1&quot; Hot Mix Asphalt mill/inlay (10-yr)</td>
<td>4,367</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td><strong>Present Value - Shortest Life</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ODOT Standard 5/8&quot; chip seal (5-yr)</td>
<td>15,172</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>OGFC (10-yr)</td>
<td>20,463</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>1&quot; Hot Mix Asphalt mill/inlay (10-yr)</td>
<td>21,343</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Present Value - Longest Life</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ODOT Standard 5/8&quot; chip seal (5-yr)</td>
<td>30,344</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>OGFC (10-yr)</td>
<td>33,663</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>1&quot; Hot Mix Asphalt mill/inlay (10-yr)</td>
<td>35,423</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td><strong>Present Value - Standard Period &amp; LCM</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ODOT Standard 5/8&quot; chip seal (5-yr)</td>
<td>60,688</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>OGFC (10-yr)</td>
<td>67,326</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>1&quot; Hot Mix Asphalt mill/inlay (10-yr)</td>
<td>70,846</td>
<td>20</td>
<td>3</td>
</tr>
</tbody>
</table>
EUAC
Terminal Mode

1. Establish design alternatives

[analysis period \( \tau_{alt} = SL_{alt} \)]
**EUAC**

**Terminal Mode, Expected or Truncated SL**

<table>
<thead>
<tr>
<th>ALTERNATE #</th>
<th>PAVEMENT DESCRIPTION</th>
<th>SERVICE LIFE</th>
<th>Anticipated Service Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 A Bituminous ODOT Standard 5/8&quot; chip seal</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>1 B Bituminous Open Graded Friction Course (OGFC)</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1 C Bituminous 1&quot; Hot Mix Asphalt mill &amp; inlay (HMA)</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

**PVEMENT TYPE**

<table>
<thead>
<tr>
<th>ALTERNATE #</th>
<th>PAVEMENT DESCRIPTION</th>
<th>Initial Construction Days**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 A Bituminous ODOT Standard 5/8&quot; chip seal</td>
<td>0.20</td>
</tr>
<tr>
<td>2</td>
<td>1 B Bituminous Open Graded Friction Course (OGFC)</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>1 C Bituminous 1&quot; Hot Mix Asphalt mill &amp; inlay (HMA)</td>
<td>0.28</td>
</tr>
</tbody>
</table>

**1.18 DISCOUNT RATE**

<table>
<thead>
<tr>
<th>Years until next Rehabilitation/Reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

****Days traffic impacted during initial construction project**

**From “Quantity” Worksheet**
Terminal Mode, Expected or Truncated SL

### Initial Cost, SL:
- **Chip seal**: $12.5 k, 5y (expected)
- **OGFC**: $26.5 k, 6y (truncated)
- **1" HMA**: $28 k, 6y

### ALTERNATE COMPARISON

<table>
<thead>
<tr>
<th>ALT #</th>
<th>Description</th>
<th>Construction</th>
<th>Maintenance</th>
<th>User Delay</th>
<th>Annual Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bituminous</td>
<td>2,799</td>
<td>609</td>
<td>243</td>
<td>3,651</td>
</tr>
<tr>
<td>2</td>
<td>ODOT Standard 5/8&quot; chip seal</td>
<td>5,036</td>
<td>517</td>
<td>206</td>
<td>5,759</td>
</tr>
<tr>
<td>3</td>
<td>Bituminous, Open Graded Friction Course (OGFC)</td>
<td>5,372</td>
<td>517</td>
<td>235</td>
<td>6,124</td>
</tr>
</tbody>
</table>

### EUAC
- **ALT # 1**: 3,651
- **ALT # 2**: 5,759
- **ALT # 3**: 6,124

### Rank Difference
- **ALT # 1**: 1
- **ALT # 2**: 2
- **ALT # 3**: 3

- **Bituminous 1" Hot Mix Asphalt mill & inlay (HMA)**
Conclusions

• Economic + engineering data can be correlated to produce meaningful, standardized economic and life cycle cost analysis (LCCA) information that would assist pavement managers in selecting an alternative that would yield extended service lives of Oklahoma pavements.

• EUAC is the most efficient, appropriate vehicle for determining PPT (short-term) cost effectiveness

• EUAC: treatment-relevant input, pavement manager-relevant output