Bang for Buck: Best Practices in Pavement Engineering

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City and County Pavement Improvement Center

APWA
Richmond, CA
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City and County Pavement Improvement Center

www.ucprc.ucdavis.edu/ccpic

- Sponsored by League of California Cities and California State Association of Counties
- Chartered 28 September 2018
Mission and Vision for CCPIC

• Mission:
  – CCPIC works with local governments to increase pavement technical capability through timely, relevant, and practical support, training, outreach and research

• Vision:
  – Making Local Government-Managed Pavement Last Longer, Cost Less, and Be More Sustainable
Organization

• UC Partners
  – University of California Pavement Research Center (lead), administered by ITS Davis
  – UC Berkeley ITS Tech Transfer, administered by ITS Berkeley
• CSU partners
  – CSU-Chico, CSU-Long Beach, Cal Poly San Luis Obispo
  – Funding partner: Mineta Transportation Institute, San Jose State University
• Governance:
  – Governance Board consisting of 3 city and 3 county transportation professionals
• Funding
  – Funding to set up CCPIIC and initial activities from the state legislature, SB1 funding through the ITS at UCD and UCB
CCPIC Scope of Work

- Deliver training and technology transfer
- Develop guidance, specifications, and tools
- Establish and deliver a pavement engineering and management certificate program
- Create and operate a resource center
- Provide research and development support
So what can be done to make pavements more sustainable?

- FHWA Sustainable Pavements Task Group
  - Covers everything about pavement and sustainability
  - Tech briefs and webinars
- Google “FHWA sustainable pavement”

Converting performance information to treatment/cost sequence.

End of design period.

Years

Net Present Value

Rehabilitation

Prevention

Performance

End of design period.

Years
LCCA calculations

- Net present value = add up the costs over the analysis period, including discount rate
- Equivalent Uniform Annual Cost, spread NPV over time, with discount

$ (Agency Costs)

$ (User Costs)

Analysis Period

Years

Initial  M  R  R

Salvage Value
Where can LCCA be implemented?

• PMS decision tree optimization
  – Condition trigger levels for treatment (timing)
  – Treatment selection
• Pavement type selection
• Policy evaluation
  – Materials changes
  – Construction quality specifications
  – Design methods
CCPIC LCCA Excel tool

Download at: http://www.ucprc.ucdavis.edu/ccpic/ or Google “CCPIC UCPRC”

• Excel tool to calculate Net Present Value, Salvage Value and Equivalent Uniform Annual Cost
• Can compare 3 scenarios side by side
• Can choose and edit the list and sequence of treatments
CCPIC LCCA Excel tool

- Excel tool to calculate Net Present Value, Salvage Value and Equivalent Uniform Annual Cost
- Can compare 3 scenarios side by side
- Can choose and edit the list and sequence of treatments
## LCCA Excel Tool

### Inputs
1. Treatment type
2. Year of work
3. Discount rate
4. Analysis period

### Outputs
1. Total NPV
2. Total SV
3. EUAC

### Scenario 1

<table>
<thead>
<tr>
<th>Analysis Period</th>
<th>Discount Rate</th>
<th>Total Net Present Value</th>
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<tbody>
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**Clear table for Scenario 1**

<table>
<thead>
<tr>
<th>Sequence of treatments</th>
<th>Treatment</th>
<th>Year of work</th>
<th>Inclusion in Analysis Period</th>
<th>NPV @ Discount Rate</th>
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<th>Remarks</th>
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</table>
LCCA Excel tool

Editable:
- Functional Unit
- Treatment List: Cost, Life of Treatment

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>Treatment No.</th>
<th>Cost/SY</th>
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Performance prediction is key to good pavement management and LCCA

- Pavement Management Systems
  - Performance estimates are typically in terms of pavement condition index (PCI)
Some changes that can be considered to improve life cycle cost

• Pavement management and preservation
  – Treatment timing
  – Treatment selection
  – Treatment sequence

• Asphalt compaction
Life cycle cost analysis results for alternative scenarios for asphalt pavement

**Asphalt Mill and Fill - $38/SY**  
**Microsurfacing - $14/SY**

<table>
<thead>
<tr>
<th>Schedule A</th>
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Life cycle cost analysis results
Results will vary depending on relative costs, discount rate, performance estimates

1 In mile, total costs, 50 years analysis period, 4% discount

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<tr>
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<th>Schedule A</th>
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<th>Schedule C</th>
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Pavement management: Use of PCI vs measured cracking

- PCI is amalgamation of different distresses
- Can have same PCI for very different conditions
- Engineering meaning in the condition survey is lost
- Recommend
  - Use PCI as communication tool for management/public
  - Manage asphalt pavement considering:
    - Cracking: age and traffic caused
    - Other distresses (rutting, raveling)
## Same PCI, different pavement condition

### CASE 1: TRAFFIC LOADING RELATED, PCI = 34

<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>SEVERITY</th>
<th>QUANTITY</th>
<th>DV</th>
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</thead>
<tbody>
<tr>
<td>Alligator Cracks</td>
<td>High</td>
<td>1x6</td>
<td>18</td>
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<tr>
<td>Alligator Cracks</td>
<td>Medium</td>
<td>1x4 1x5 1x7</td>
<td>17</td>
</tr>
<tr>
<td>Potholes</td>
<td>Medium</td>
<td>3</td>
<td>48</td>
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<tr>
<td>Potholes</td>
<td>Low</td>
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<td>30</td>
</tr>
<tr>
<td>Rutting</td>
<td>Low</td>
<td>2x5 2x8</td>
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</table>

### CASE 2: AGE, CONSTRUCTION, UTILITIES, OTHER FACTORS, PCI = 32

<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>SEVERITY</th>
<th>QUANTITY</th>
<th>DV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long/Trans Crack</td>
<td>High</td>
<td>15 20 8 6 12 18 6x7</td>
<td>43</td>
</tr>
<tr>
<td>Long/Trans Crack</td>
<td>Medium</td>
<td>25x2 18 13 9 10</td>
<td>20</td>
</tr>
<tr>
<td>Patching/Utility</td>
<td>High</td>
<td>25x4 25x2</td>
<td>40</td>
</tr>
<tr>
<td>Patching/Utility</td>
<td>Medium</td>
<td>12x6 4x7</td>
<td>20</td>
</tr>
<tr>
<td>Block Cracks</td>
<td>High</td>
<td>4x6 6x5</td>
<td>13</td>
</tr>
</tbody>
</table>
Variables in the PCI for asphalt pavement

- **Fatigue cracking and potholes caused by heavy loads:**
  - Alligator cracking
  - Potholes
- **Cracking caused by aging:**
  - Block cracking
  - Joint reflections
  - Longitudinal and transverse cracking

- **Other distresses**
  - Low ride quality
  - Bleeding
  - Bumps and sags
  - Corrugations
  - Depressions
  - Edge cracking
  - Lane/shoulder drop-off
  - Patching and utility cut patching
  - Polished aggregate
  - Rutting
  - Shoving
  - Slippage cracking
  - Swelling
  - Weathering and raveling
Bottom Up Fatigue Cracking

- Interaction of asphalt concrete layer, support of underlying structure, materials selection, construction compaction
- Traffic loading
  - Only the truck loads count, cars are too light
  - slower speeds = longer durations = bigger strains
- Environment
  - temperature
  - water sensitivity
  - aging
Fatigue Cracking

Bottom up cracking

Asphalt
Concrete
Base
Sub-Base
Subgrade

Tensile Strain $\varepsilon_t$
Initial Wheelpath Cracking
(transverse or longitudinal)
Cracks connect: Alligator Cracking
(Caltrans calls “Type B”)

![Alligator Cracking](image.png)
Fatigue Cracking in Wheelpaths
Reflective Cracking

Bottom up cracking

Asphalt
Concrete

Cracked AC, PCC or CTB

Base
Sub-Base
Subgrade
Reflection Crack over PCC Joint
Effect of asphalt construction compaction on axle loads to cracking

Simulation based on FHWA Westrack project field results

3 inch asphalt pavement

Axles to Cracking

<table>
<thead>
<tr>
<th>Axles to Cracking</th>
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<tbody>
<tr>
<td>3,500,000</td>
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<td>3,000,000</td>
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<tr>
<td>1,000,000</td>
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<tr>
<td>500,000</td>
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</table>

- 6.1 percent air-voids
- 12.0 percent air-voids

General rule: 1% increase in constructed air-voids = 10% reduction in fatigue life
Treatment for load related fatigue cracking

• Asphalt will fatigue
• Surface treatments will slow some
• Will need to do periodic mill and fill
• Do not let wheelpath cracking become extensive or must reconstruct
Aging of the Asphalt

- Aging of the asphalt
  - Caused by oxidation, volatilization
  - Faster if high permeability and temperature
  - Permeability greatly reduced with better asphalt compaction

- Effects
  - Stiffening of mix with time
  - Won’t relax stresses from thermal contraction as well
Block Cracking

- Typically caused by long-term aging of asphalt concrete and daily temperature cycling (expansion/contraction)
- May also be reflection cracking from shrinkage cracks in cement treated base
- Poor asphalt construction compaction allows air to enter and age the asphalt faster, accelerates aging
Block Cracking

Top down cracking
Aging mostly done by 5 years after placement

Stiffness increase from Aging

Mix and place

Years

0          5          10         15        20
Treatment for age-related cracking

• Keep the surface protected from aging
• Can potentially due perpetual slurries or microsurfacings
• What frequency?
  – Do not let cracking get extensive
  – But doing more frequently than needed can be a waste
Example fatigue vs age-related treatment sequences

Aging related distresses (no diminishing prevention treatment lives)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year</th>
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</thead>
<tbody>
<tr>
<td>Asphalt Mill and Fill</td>
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Load related distresses (diminishing prevention treatment lives)

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<tbody>
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Asphalt Mill and Fill - $38/SY
Microsurfacing - $14/SY
<table>
<thead>
<tr>
<th>Cost Comparison for Different Loading Patterns</th>
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<tr>
<td>Aging Related Distresses</td>
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<tr>
<td>Loading Related Distresses (Diminishing Prevention Treatment Life)</td>
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<td>$545,067</td>
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Recommendation for use of LCCA

• Pavement management
  – Use PCI in network-level analysis to set overall budget, measure network condition
  – Do treatment selection engineering work based on truck/bus traffic level, cracking and surface defects data, not PCI
  – Use your costs, cracking predictions and LCCA to develop best sequences of treatments
    • Look at your fatigue and aging-related cracking data
    • Estimate treatment lives
  – Learn to use LCCA to discuss with council/board
Recommendation for how to get good asphalt compaction

- Use a quantitative (QC/QA) specification to measure compaction
- Write spec in terms of \textit{in-place bulk density} and \textit{theoretical maximum density} (TMD) and not \textit{laboratory theoretical maximum density} (LTMD)
- Use cores or nuclear gauges calibrated for the specific mix/project to provide daily feedback to contractor and agency
- Apply payment reductions if they don’t meet your specification, and enforce those payment reductions
Caltrans experience with method spec vs using in-place measurement and penalties (QC/QA)

- Spec changed in 1996-98
- Very large culture change in Caltrans

“Trust but verify”
But what about?

• Won’t this increase the bid cost for my asphalt?

• Isn’t the cost of managing this specification high?

• Won’t coring damage my new pavement?

• What can I do to help my contractors meet and exceed the specification and further increase the life of my overlays?
## Compaction effects repeated mill and fill

- 3% change in air-voids is about 30% change in cracking life

\[ \text{Asphalt Mill and Fill - $38/SY} \]

<table>
<thead>
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<th>Treatment</th>
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<td>46</td>
<td>Asphalt Mill and Fill</td>
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Life cycle cost analysis results
effects of asphalt compaction

Compaction effect, continuous rehab strategy
(1 ln mile)

$426,086

$468,291

$584,559

$300,000

$350,000

$400,000

$450,000

$500,000

$550,000

$600,000

$650,000

$700,000

6% AV Good compaction

9% AV Usual practice

12% AV Bad compaction
Some other changes that can be considered to improve life cycle cost

- Update street and minor concrete mix specifications
  - Reduce cement content and use supplementary cementitious materials
- Full-depth reclamation
- Cold in-place recycling
- Bonded concrete overlays
Questions?

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Concrete mix specifications

• Older concrete specifications
  – Written to ensure enough cement to meet strength and durability requirements
  – Often included minimum cement content

• Modern concrete mix designs
  – Minimize need for portland cement
  – Replace with supplementary cementitious materials (SCM)
  – Minimize amount of cement paste in the mix: dense aggregate gradations
Concrete mix specifications

• What are SCMs?
  – Fly ash, natural pozzolans, slag cement
  – These can come pre-blended (new ASTM specs)
  – Caltrans also allows 5% replacement with ground limestone
    • Agencies are evaluating up to 15%

• These changes to mix design specs
  – Increase durability of the concrete
  – Decrease environmental impact

• When was the last time you reviewed your concrete specifications?
Effects on greenhouse gas emissions

- Mix designs from a city that hasn’t reviewed specs are:

```
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Global Warming Potential (GWP)[kg CO2e] per 1 kg of PCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Street - no SCM</td>
<td>0.159</td>
</tr>
<tr>
<td>Playground - no SCM</td>
<td>0.122</td>
</tr>
<tr>
<td>State Highway - 15% SCM</td>
<td>0.107</td>
</tr>
</tbody>
</table>
```
What you need to do

• *Use dense aggregate gradations*: Reduces cost, shrinkage

• *Specify limits on shrinkage and strength*: Reduces water contents

• *Require quality control and quality assurance testing for strength, shrinkage, other properties of interest*. Small cost for sampling and testing

• *Require use of supplementary cementitious materials*. Tend to reduce shrinkage, improve durability, reduce greenhouse gas emissions, may reduce cost

• *Allow the use of blended cements (ASTM C595)*

• *Work with a concrete mix design expert to review your specifications and change them*
But what about?

• How do I know that these mixes will give me good performance?
• Will these changes in specifications cost me more?
• Are there any other issues such as constructability with these mixes?
Full-depth Reclamation (FDR)

• For badly cracked asphalt or to correct cross-slope
• Pulverize and stabilize (one pass), compact, overlay
• Stabilization options
  – Foamed asphalt (about 2.5 %) with cement (about 1%)
    • Need some granular material below the asphalt
  – Cement
    • If no granular material below asphalt
    • Enough cement to reach minimum strength and no more!
  – No stabilizer
    • Acts like granular base
  – Engineered emulsions
    • More work needed to develop recommendations
Cold Central Plant Recycling (CCPR)

- Like FDR but set up a mobile plant on site
- Mill out asphalt, process on site, put back
- Can do any required subgrade stabilization
Cold In-place Recycling (CIR)

- Partial depth (top 2 to 5 inches)
- Mill and stabilize, compact, overlay
- Stabilized with emulsion and a small amount of cement
- Must achieve correct gradation