How to Get More Bang for Your Bucks, Best Practices in Pavement for Local Government

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4 April 2018
• League of California Cities and County Engineers Association of California will be setting up governing board in next months
Why is Local Government Pavement Important to Sustainability?

Pavement Spending
Local $/State $ usually about 0.8 to 1

SB 1
$ 2.5 billion for state highways
$ 2.0 billion for local government
How do Pavements Contribute to California GHG Emissions?

- 459 MMT CO2e in 2013
  - On road vehicles 155 MMT
    • Optimizing smoothness, texture, deflection energy on state network reduces by 1% of this
  - Refineries 29 MMT
    • Paving asphalt about 1% of refinery production
  - Cement plants 7 MMT
    • Paving cement about 5% of cement plant production
  - Commercial gas use 13 MMT
    • Very small amounts for asphalt mixing plants
  - Mining 0.2 MMT
    • Large portion for aggregate mining

![2013 Total CA Emissions: 459.3 MMTCO2e](http://www.arb.ca.gov/cc/inventory/data/data.htm)

**Possible Pavement Reductions**

<table>
<thead>
<tr>
<th>Reduction</th>
<th>MMT/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling resist to optimum</td>
<td>1.5</td>
</tr>
<tr>
<td>Reduce cement use 50%</td>
<td>0.2</td>
</tr>
<tr>
<td>Reduce asphalt use 50%</td>
<td>0.7</td>
</tr>
<tr>
<td>Reduce hauling 10%</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>2.9</strong></td>
</tr>
</tbody>
</table>
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

Life Cycle Cost Analysis (LCCA) Basics

Ride Quality
Structural Capacity

Years

Field Maintenance Pavement Preservation

Needs attention
Unacceptable

Rehab

Years
LCCA calculations

- Net present value = add up the costs over the analysis period, including discount rate

$\text{(Agency Costs)}$

$\text{(User Costs)}$

Initial          M    R                       R

Years

Analysis Period

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
Four Key Stages of Life Cycle Assessment

1. **Goal Definition and Scope**
   - Define questions to be answered (sustainability goals) and system to be analyzed.

2. **Life Cycle Inventory Assessment**
   - The "accounting" stage where track inputs and outputs from the system.

3. **Impact Assessment**
   - Where results are translated into meaningful environmental and health indicators.

4. **Interpretation**
   - Where the results of the impact assessment are related back the questions asked in the Goal.

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Figure based on ISO 14040, adopted from Kendall.
US EPA Impact Assessment Categories
(TRACI – Tool for the Reduction and Assessment of Chemical and other environmental Impacts)

- Global warming
- Stratospheric ozone depletion
- Acidification
- Eutrophication
- Photochemical smog
- Terrestrial toxicity
- Aquatic toxicity
- Human health
- Abiotic resource depletion
- Land use
- Water use

Impacts to people

Impacts to ecosystems

Depletion of resources

From Saboori   Image sources: Google
Generic Life Cycle Assessment

Raw Material Acquisition → Material Processing → Manufacturing or construction → Use → End-of-Life

- M = Materials
- E = Energy
- W = Waste
- P = Pollution
- T = Transport

Kendall, A., Keoleian, G. A., 2009
Pavement Life Cycle Assessment

- Material extraction and production
- Equipment Use
- Transport
- Traffic delay
- Rolling resistance
- Albedo: heat island & lighting
- Leachate
- Recycle
- Landfill

From: Kendall et al., 2010
Why use LCA for evaluating environmental performance?

• Quantifies outcomes:
  – GHG, energy, pollutants, finite resources
• Uses project-specific inputs:
  – materials, transport, construction, traffic levels, re-use
• Requires explicit prioritization of outcomes for decision-making
• Can account for regional and time variability, and other uncertainties in data sets and analysis
ISO Standards and FHWA Pavement LCA Framework Document; LCA tools

- International Standards Organization (ISO) standards for LCA are generic for all materials
- FHWA guidance specific to pavements published in 2016
- New web-based pavement LCA tool being developed for Caltrans now: eLCAP
- New spreadsheet tool being developed for FHWA now
What Should be Done for Sustainability?

Bang for your buck metric: \$/ton CO$_2$e vs CO$_2$e reduction

- Many alternatives to improve sustainability
- How to prioritize?
- Cost from Life Cycle Cost Analysis (LCCA)
- Environment from Life Cycle Assessment (LCA)

Adapted from Lutsey, N (2008) Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-15
Some Applications and Results
Changes to improve sustainability

- Asphalt compaction
- Concrete mix specifications
- Unpaving
- Pavement management and preservation
- Measuring impacts of material you buy
- Heat island
- Preservation and bicycles
LCA evaluation of Materials and Construction

• For most local roads the impacts of materials impacts greater than construction equipment, transport impacts and smoothness
  – And most of the impacts in the materials are in the asphalt or cement binder
  – Recycling that minimizes use of new asphalt and cement has benefit
  – Must consider full life cycle not initial impact

• Construction quality is very important
  – Getting longer life per ton or cy of material is usually the most effective way to reduce environmental impacts
  – Better compaction has no downsides
Asphalt compaction specifications

• Is your asphalt living only half as long as it could?
  – Increase in air-voids of 1% = 10% shorter life
  – Typical air-voids achieved
    • If no measurement/penalties = 10 – 14%
    • If measurement/penalties if > 8% = 6 to 8%
    • Difference in life = -40% = -8 years
  – Why?
    • More air permeability = aging = raveling + cracking
    • More holes in it = cracking
    • More water permeability = moisture damage + aging
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”
Effect of compaction on axle loads to cracking

Simulation based on FHWA Westrack project field results
What you need to do

- Use a quantitative (QC/QA) specification to measure compaction, do not mix method requirements (how to do the compaction) in the specification
- Write spec in terms of *in-place bulk density* and *theoretical maximum density* (TMD) and not *laboratory theoretical maximum density* (LTMD)
- Use cores or nuclear gauges calibrated for the specific mix/project to provide daily feedback to contractor and agency
- Collect and keep cores in case of a dispute
- Apply payment reductions if they don’t meet your specification, and enforce those payment reductions
LCCA and LCA example: 8% vs 12% air-voids

• Assumptions:
  – Rural pulverize HMA, compact, 4 in. HMA
  – $26/sy
  – 12% air-voids = 12 year life
  – 8% air-voids = 18 year life

• Net present cost* over 50 year period:
  – 12% air-voids = $4.36 million
  – 8% air-voids = $3.09 million = 29 % less cost

• Greenhouse gas emissions are 34% less

*2% discount rate
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?
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
  – Decrease cost
  – Decrease environmental impact
  – Increase durability of the concrete

• 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

### Global Warming Potential (GWP) [kg CO2e] per 1 kg of PCC

- **Urban Street - no SCM**: 0.159
- **Playground - no SCM**: 0.122
- **State Highway - 15% SCM**: 0.107
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?
Other options that can have both cost and environmental benefits

- Reclamation/recycling of asphalt pavements
- Use of concrete demolition as aggregate base
- Use of RAP in asphalt mixes
- Bonded concrete overlays on asphalt with high supplementary cementitious material content
- Rubberized asphalt
- Rubberized cape seals
- In all cases, need to have good pavement engineering and especially good construction quality control
- Guidance regarding many of these items will be coming to CCPIC this year based on Caltrans and federally funded work
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
Pavement management
Use of PCI vs measured cracking, rutting

- 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 type (traffic related wheelpath cracks, aging/shrinkage related out of wheelpath cracks)
    - Other distresses (rutting, raveling)
### CASE 1: TRAFFIC LOADING RELATED, PCI = 34

<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>SEVERITY</th>
<th>QUANTITY</th>
<th>DV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alligator Cracks</td>
<td>High</td>
<td>1x6</td>
<td>18</td>
</tr>
<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>
</tr>
<tr>
<td>Potholes</td>
<td>Low</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Rutting</td>
<td>Low</td>
<td>2x5 2x8</td>
<td>10</td>
</tr>
</tbody>
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### CASE 2: AGE, CONSTRUCTION, UTILITIES, OTHER FACTORS, PCI = 32

<table>
<thead>
<tr>
<th>DISTRESS</th>
<th>SEVERITY</th>
<th>QUANTITY</th>
<th>DV</th>
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</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>
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Pavement management
Rehab with no preservation

- Net present value = sum of costs to year 0, discounted in future years
Pavement management
Rehab with preservation

- Net present value = sum of costs to year 0, discounted in future years
### LCCA results

#### Urban alternatives

<table>
<thead>
<tr>
<th>Activity</th>
<th>$/sy</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA 2 inch mill and fill</td>
<td>38</td>
<td>0</td>
</tr>
<tr>
<td>HMA 2 inch mill and fill</td>
<td>38</td>
<td>20</td>
</tr>
<tr>
<td>HMA 2 inch mill and fill</td>
<td>38</td>
<td>40</td>
</tr>
<tr>
<td>Remove, replace 6 inches HMA</td>
<td>52</td>
<td>0</td>
</tr>
<tr>
<td>Remove, replace 6 inches HMA</td>
<td>52</td>
<td>25</td>
</tr>
</tbody>
</table>

- 50 year analysis, 2% discount rate
- Remove and replace scenario 14% more cost
- Preservation scenario 12% less cost; 8% less GHG
What you need to do

• Pavement management
  – Do engineering work based on truck traffic level, cracking and surface defects data, not PCI
  – Use your costs and LCCA to develop best treatment practice and preservation timing
    • Need performance models
    • Requires condition survey, traffic and as-built data
  – Learn to use LCCA to discuss preservation spending with council/board
  – CCPIC has created simple LCCA spreadsheet tool, currently being piloted
Building pavement knowledge and getting it into practice

• CCPIC is developing a Pavement Engineering professional development certificate
  – Aimed for local government staff and their consultants
  – Through ITS Berkeley Tech Transfer

• Are you selecting pavement consultants based on pavement knowledge?
  – What questions are you asking in the interview?
Pavements are no longer just about carrying cars and trucks
Pavements are an important part of the urban environment

Sacramento

- Pavements: 39%
- Vegetation: 29%
- Roofs: 19%
- Other: 14%

Pavements = urban hardscape not just roads and streets

- Stormwater management, groundwater infiltration
- Tire pavement noise
- Human thermal comfort
- Pedestrian and bicycle functionality
- Better interaction with urban forestry
Final Thoughts: Communicating with the Public about Pavement

• What is our message about what is being done that is positive and better

• Livability and Quality of Life, relate to people’s lives and wallets/purses
  – Access by different modes, shared prosperity, environmental impact, public participation, safe and healthy communities, wise use of resources

• Set goals and measure and report progress

• Have the right messengers
  – Trusted messengers who are informed about pavement progress, not necessarily pavement engineers!

Catherine Hurley, Argonne Nat Lab, ISIE conference 2017
Thank you, Questions?

- Tech briefs and other information at: 
  - www.ucprc.ucdavis.edu/ccpic

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