Improving the Sustainability of Local Government Pavement: A Process and Practical Results

Presented by
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Information from UCPRC, LBNL/UCPRC/USC team, Tom van Dam (NCE)

Capital Region Climate Readiness Collaborative
UCPRC tour, Davis, CA
27 October, 2016
What is the University of California Pavement Research Center?

• Mission
  – *Dedicated to providing knowledge, the UCPRC uses innovative research and sound engineering principles to improve pavement structures, materials, and technologies.*

• Pavement research begun in 1948 at UCB

• UCPRC begun in 1995
  – UCB 1995 – 2002
  – UCD & UCB – 2002 onwards
Some Recent UCPRC Work

• Caltrans
  – Life Cycle Cost Analysis (LCCA)
  – Mechanistic-Empirical design methods
    • Long life rehabilitation, concrete and asphalt
  – Environmental Life Cycle Assessment (LCA)
  – Construction quality
  – Rapid Rehabilitation construction productivity and work zone traffic management
  – Pavement management
  – Recycling (asphalt, concrete, rubber, etc)
  – Noise, smoothness
  – Freight logistics decisions and pavement condition

• Caltrans and Interlocking Concrete Pave Institute
  – Permeable pavements for storm water infiltration
Some Recent UCPRC Work

- California Air Resources Board
  - Urban heat island life cycle assessment

- CalRecycle
  - Rubber asphalt mix development and specifications

- Federal Highway Administration
  - Sustainability of pavement
  - Full-depth reclamation
  - Wide base single truck tires

- Federal Aviation Administration
  - Asphalt recycling
  - Mechanistic-empirical design methods
  - Airfield environmental life cycle assessment

- This presentation does not reflect policy or recommendations of any of these sponsors
A Sustainable Pavement is an Aspirational Goal

- Might not get there, but we can do a lot better than we are
- Lots of low hanging fruit
FHWA Pavement Sustainability Reference Document

- State of the knowledge on improving pavement sustainability
- Search:
  - “FHWA pavement sustainability”
  - “NCST pavement sustainability”
- Recommendations for improving sustainability across entire pavement life
- Organized around Life Cycle Assessment (LCA) framework
- Other information available at same web site
  - Tech briefs
  - Literature database
Why is Local Government Pavement Sustainability Important?

National $1000 Spent on Transportation in 2008 (US Census Bureau)

<table>
<thead>
<tr>
<th></th>
<th>STATE GOVERNMENT</th>
<th>LOCAL GOVERNMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>97,508,989</td>
<td>61,053,150</td>
</tr>
</tbody>
</table>

![Centerline Miles Pie Chart](chart1)

- Cities: 13,537,8%
- Counties: 15,160,9%
- State: 65,166,39%
- Federal: 75,208,44%

![Lane Miles Pie Chart](chart2)

- Cities: 27,074,7%
- Counties: 50,462,13%
- State: 132,804,35%
- Federal: 170,555,45%

![Vehicle Miles Pie Chart](chart3)

- Cities: 657,0%
- Counties: 657,0%
- State: 180,259,55%
- Federal: 31,414,10%
Measuring Sustainability

• Life Cycle Cost Analysis (LCCA)
  – Economic

• Life Cycle Assessment (LCA)
  – Range of environmental impacts
  – Emerging area

• Sustainability Rating Systems (e.g., INVEST)
  – Environmental and social impacts

Reasons to Measure

Accounting
Decision support
Establish baseline/process improvement
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

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**

Sustainability indices can be used for non-quantitative assessment including social.

*From Saboori  Image sources: Google*
Bang for your buck metric: $/ton CO₂e vs CO₂e reduction

Net costs = initial cost + direct energy saving benefits

  Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-15
Where can environmental impacts be reduced?

- Use Life Cycle Assessment (LCA) to find out
- Use Life Cycle Cost Analysis (LCCA) to prioritize based on improvement per $ spent

From: Kendall et al., 2010
How do Pavements Contribute to California GHG Emissions?

Out of 459 MMT CO2e

- On road vehicles 155 MMT
  - Pavement roughness and other effects can change vehicle fuel use by about 0 to 4%

- 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

http://www.arb.ca.gov/cc/inventory/data/data.htm
Materials and Construction Stages

- Important for all roads
- More important than use stage for low and medium traffic volume roads
Pavement Management to Improve Sustainability of Network

• To optimize M&R for the network, requires:
  1. Initial funding to reach sustainable maintenance condition
     a. Catch up on rehabilitation and reconstruction
     b. Preserve segments in good condition
  2. Steady funding afterward for preservation, with few needing rehab or reconstruction
  3. Asset management to program treatments based on predicted condition, not after failure occurs

• UCPRC research indicates that annual cost of maintaining network can be reduced by up to 20 % if this path is followed

• Preservation treatments have less environmental impact than rehabilitation
Local Government Check List for Asphalt

• Construction quality
  ✓ 1% decrease air-voids = about 10% more cracking life
  ✓ Maintain and enforce strict compaction requirements
• Does your agency have a compaction requirement (% of maximum density) in your standard specifications?
  ✓ If yes, do you enforce it?
  ✓ If you are relying on the contractor, you are potentially getting **HALF** the possible life out of your asphalt overlays!
• Do you allow use of?
  ✓ Rubberized asphalt
  ✓ Recycled asphalt pavement
  ✓ Warm mix
• Do you all utilities under the pavement?
Local Government Checklist for Concrete

• Reduce cement content in concrete
  ✓ Does your agency allow for high volumes of cement replacing materials?
  ✓ Does your agency allow for the use of cement with lower environmental impact?
  ✓ Do you have a minimum cement content requirement?

• Make it last longer
  ✓ Do you consider shrinkage? Durability?

• Use less
  ✓ Do you allow for design of thinner concrete pavement for local roads?
Environmental Product Declaration (EPD)

- Results of an LCA for a product
  - Produced by industry
  - Most pavement industries working on EPDs now

Environmental Facts

Functional unit: 1 metric ton of asphalt concrete

<table>
<thead>
<tr>
<th>Environmental Impact</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Energy Demand [MJ]</td>
<td>$4.0 \times 10^3$</td>
</tr>
<tr>
<td>Non-renewable [MJ]</td>
<td>$3.9 \times 10^3$</td>
</tr>
<tr>
<td>Renewable [MJ]</td>
<td>$3.5 \times 10^2$</td>
</tr>
<tr>
<td>Global Warming Potential [kg CO$_2$-eq]</td>
<td>79</td>
</tr>
<tr>
<td>Acidification Potential [kg SO$_2$-eq]</td>
<td>0.23</td>
</tr>
<tr>
<td>Eutrophication Potential [kg N-eq]</td>
<td>0.012</td>
</tr>
<tr>
<td>Ozone Depletion Potential [kg CFC-11-eq]</td>
<td>$7.3 \times 10^{-9}$</td>
</tr>
<tr>
<td>Smog Potential [kg O$_3$-eq]</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Boundaries: Cradle-to-Gate
Company: XYZ Asphalt
RAP: 10%

Adapted from N. Santero
EPDs: What’s Happening?

- Cement and concrete industries starting to produce EPDs
- Asphalt and asphalt concrete industries are currently working to produce EPDs
- Customers are starting to ask for EPDs
  - High Speed Rail is requiring EPDs for reporting
  - LEED4 is giving points for EPDs
  - Oregon and Illinois Tollway will soon be requiring them for information purposes
- How will they be used?
  - Caltrans/UCPRC participated in September 2016 TRB/FHWA Workshop to discuss obstacles and possible paths forward for EPDs
  - Procurement? Guidelines? Unintended consequences?
  - Stay tuned!
Published January 2016
Guidance on uses, overall approach, methodology, system boundaries, and current knowledge gaps
Specific to pavements
Includes guidelines for EPDs
Search for information:
- “FHWA pavement LCA”
- “NCST Pavement LCA”

https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=998
Preservation and Bicycle Riders

- **Objective:** Develop guidelines for design of preservation treatments suitable for bicycle routes on state highways and local streets in California

- **Measurements**
  - Pavement textures for chip seals, slurries, HMA
  - Bicycle vibration

- **Surveys of bicycle ride quality**
  - 6 bicycle clubs
  - General public in Davis, Richmond, Chico, Sacramento, Reno

- **Correlations between pavement texture, bicycle vibration and ride quality**
Conclusions from Bicycle Studies

- 80% of riders rate pavements with Mean Profile Depth values 1.8 mm or less as acceptable
  - Limit chip seal stone size
- Most HMA, slurries on city streets have high acceptability
- Surface distresses, particularly transverse cracking, reduce ride quality
- Chip seal specification recommendations in Caltrans report
- Can be considered in PMS
- Consider “Complete Pavement”, restripe to add wider bike lanes and safer turning lanes when paving,
  - Search on “complete streets and preservation ASCE webinar”
Use Stage

- Pavement rolling resistance
  - Important for more than 2500 vehicles per day
- Heat Island
- Storm water
- Bicycle ride quality
Use Phase: Fuel Use, Speed, IRI

- Roughness increases vehicle fuel use 0 to 8 percent across range of typical IRI
- Can be some offset from faster driving on smoother pavement

Cars

- Cars more sensitive at faster speeds
- Trucks at slower speeds

Trucks

Increasing Speed from 25 to 70 mph
### Caltrans Network: Optimal trigger by traffic group

<table>
<thead>
<tr>
<th>Traffic group</th>
<th>Daily PCE of lane-segments range</th>
<th>Total lane-miles</th>
<th>Percentile of lane-mile</th>
<th>Optimal IRI triggering value (m/km, inch/mile in parentheses)</th>
<th>Annualized CO₂-e reductions (MMT)</th>
<th>Modified total cost-effectiveness ($/tCO₂-e)</th>
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<tbody>
<tr>
<td>1</td>
<td>&lt;2,517</td>
<td>12,068</td>
<td>&lt;25</td>
<td>-----</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>2,517 to 11,704</td>
<td>12,068</td>
<td>25~50</td>
<td>2.8 (177)</td>
<td>0.141</td>
<td>1,169</td>
</tr>
<tr>
<td>3</td>
<td>11,704 to 19,108</td>
<td>4,827</td>
<td>50~60</td>
<td>2.0 (127)</td>
<td>0.096</td>
<td>857</td>
</tr>
<tr>
<td>4</td>
<td>19,108 to 33,908</td>
<td>4,827</td>
<td>60~70</td>
<td>2.0 (127)</td>
<td>0.128</td>
<td>503</td>
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<tr>
<td>5</td>
<td>33,908 to 64,656</td>
<td>4,827</td>
<td>70~80</td>
<td>1.6 (101)</td>
<td>0.264</td>
<td>516</td>
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<tr>
<td>6</td>
<td>64,656 to 95,184</td>
<td>4,827</td>
<td>80~90</td>
<td>1.6 (101)</td>
<td>0.297</td>
<td>259</td>
</tr>
<tr>
<td>7</td>
<td>&gt;95,184</td>
<td>4,827</td>
<td>90~100</td>
<td>1.6 (101)</td>
<td>0.45</td>
<td>104</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1.38</strong></td>
<td><strong>416</strong></td>
</tr>
</tbody>
</table>
Conclusions Regarding Roughness

• There are reasons for local government pavements to measure and manage roughness on high volume and truck routes

• Currently no commercially available methods to measure under low speeds and stop-start conditions
  – Viable alternative technologies have been used in past
  – Cost per vehicle is about $500 plus certification cost
  – Can use for identifying locations with maintenance needs

• Cannot get IRI from PCI
  – Pavements can have good PCI and be rough and vice/versa
Urban Heat Island Effect

- The formation of urban heat islands is well documented
  - Created, at least in part, by the presence of dark, dry surfaces in heavily urbanized areas
- Exist at many different levels
  - Ground/pavement surface
  - Near-surface (3 – 6 ft)
  - Above street level
  - Atmospheric
- Affects
  - Human thermal comfort
  - Air quality (ground-level ozone, i.e. smog)
  - Cooling energy consumption

EPA 2003
LBNL/USC/UCPRC Study Currently Recently Completed: Life Cycle Assessment and Co-benefits of Cool Pavements

- Sponsored by CARB, Caltrans, response to AB 296
- Albedo is solar radiation reflectivity
  - 0 is completely absorptive
  - 1 is completely reflective
- Modeled 50 year GHG emissions
  - Change of urban pavements to higher reflectivity materials
  - Change of urban temperatures
  - Change in building energy use
- Report to be published in Fall 2016
- Journal paper also submitted
Pavements are an important part of the urban environment.

Urban fabric above tree canopy in Sacramento, California.
The scope of the pLCA tool includes the non-use and use phases of the pavement life cycle.
This study evaluates a subset of results from the pLCA tool.

**USER INPUTS**
- City
- Pavement area to be modified
- Business-as-usual pavement design
- Alternative pavement design

**LIFE CYCLE ASSESSMENT TOOL**

**CITYWIDE ENVIRONMENTAL IMPACTS**
- Global warming
- Energy use
- Criteria air pollutants
- Local air temperature
- Local air quality

**UNITS REPORTED IN STUDY**
- Global Warming Potential (GWP), kg of CO₂e
- Primary Energy Demand (PED), MJ
- Outdoor Air Temperature, °C
The pLCA tool has an easy-to-use interface.
The case studies evaluate cool pavement campaigns in two California cities.
Second case study evaluates rehabilitation pavement treatment options

**BUSINESS-AS-USUAL**
- Aged albedo: 0.10
- Thickness: 6 cm
- Lifespan: 10 years

**ALTERNATIVE**
- Aged albedo: 0.25
- Thickness: 10 cm
- Lifespan: 20 years

Mill-and-fill conventional asphalt concrete

Bonded cement concrete overlay
Raising pavement albedo by 0.15 lowers outside air temperature by ~0.08 °C

Rehabilitation: Substituting cement concrete overlay (aged albedo 0.25) for asphalt concrete mill-and-fill (aged albedo 0.10)
What are the life cycle environmental changes from the pavement change?

**Primary Energy Demand**

Fresno, Rehabilitation: Substituting cement concrete overlay (aged albedo 0.25) for asphalt concrete mill-and-fill (aged albedo 0.10)
50-year life-cycle increase in GWP

Los Angeles, Rehabilitation: Substituting cement concrete overlay (aged albedo 0.25) for asphalt concrete mill-and-fill (aged albedo 0.10)

Global Warming

-7 kg CO$_2$ per 0.01 increase in albedo (IPCC AR5)
Los Angeles, GWP, materials component

![Graph showing GWP over 50 y (kg CO2e/m²) for different materials: Slurry seal (7 y) with 3 kg CO2e/m², Chip seal (7 y) with 7 kg CO2e/m², Styrene Acrylate Coating (5 y) with 16 kg CO2e/m², Conventional Asphalt Concrete (6 cm, 10 y) with 34 kg CO2e/m², Bonded Concrete Overlay (10 cm, 20 y) with 167 kg CO2e/m².]}
Permeable Pavement for Stormwater Management

• Impervious pavement in urban areas contributes to
  – Water pollution (*oil*, *metal*, *etc.*)
  – Reduced groundwater recharge
  – Increased risk of flooding
  – Local heat island effect (*less evaporation*)

• Permeable pavement could help address the issues related to stormwater runoff volume and quality

• Initial analysis indicates that can have lower life cycle cost than other BMPs
Getting the Permeable Pavement Results

• Pervious Concrete and Porous Asphalt for Heavy Traffic
  – Preliminary permeable pavement designs that can be tested in pilot studies under typical California traffic and environmental conditions

• Permeable Interlocking Concrete Pavement for Heavy Traffic
  – Design method and validation results
  – Being incorporated into ICPI and ASCE designs
Pavement and Bicycle Riders

- Develop guidelines for design of preservation treatments suitable for bicycle routes on state highways (Phase I) and local streets (Phase II) in California

- Tasks
  - Pavement texture measurements
  - Bicycle vibration measurements
  - Surveys of bicycle ride quality
    - 6 bicycle clubs
    - General public in Davis, Richmond, Chico, Sacramento, Reno
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Conclusions

• “State of the Knowledge” recommendations for improving pavement sustainability are available
  – Cost
  – Environment
• Improving environmental sustainability often also brings lower life cycle cost
  – Agency cost and user cost
• Improvements become permanent from reviewing and changing standard practices
• Everyone focused on getting sufficient funding
  – Sustainability discussion can help get funding
  – Sustainability can also often decrease life cycle cost
Upcoming studies

• Life Cycle Assessment of Complete Streets
  – NCST
  – Includes development of “pavement justice” social and economic indicators

• Urban Metabolism
  – NCST

• Sustainable Freight Movement
  – NCST

• Surveys
  – Local government pavement needs survey (NCST)
  – Permeable pavement obstacles to implementation (Caltrans)
• How do we get the Caltrans and FHWA content to local government in an implementable form?
• Working on securing funding ($500k/year), working with LOCC, CSAC
• Organization
   – Local government board of directors
   – Research, pilot project support, model specs and procedures, training
   – Leverage existing resources: ITS Tech Transfer, LAP, APWA, CSUs (LB, SLO, Chico, Sac) for regional support
• If you think this is worthwhile, please let your organizations know
Questions?
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