Towards Sustainable Pavement Systems: Webinar Series

Webinar #5: Use Phase, Livable Communities, Path Forward

September 9, 2015
Webinar Series

• Sponsored by Federal Highway Administration
• “Towards Sustainable Pavement Systems: A Reference Document”
• Total of 5 webinars from April to September
• Webinars recorded for posting on FHWA website
Housekeeping

- Formal Presentations:
  - 1 hour 40 min
- Questions:
  - 20 minutes
  - Use chat box to submit your questions
- Professional Development Hours (PDHs) Certificates
  - 2 hours per webinar
Today’s Webinar

• Topic: Use Phase, Livable Communities, Path Forward

• Speakers:
  – Gina Ahlstrom, FHWA
  – John Harvey, University of California, Davis
  – Tom Van Dam, NCE
  – Joep Meijer, theRightenvironment

• Moderators:
  – Tom Van Dam, NCE
Background and Overview

Gina Ahlstrom
US DOT is Committed to Advancing Sustainability

• DOT will incorporate sustainability principles into our policies, operations, investments and research through innovative initiatives and actions such as:

  – Infrastructure investments and other grant programs,
  – Innovative financial tools and credit programs,
  – Rule- and policy- making,
  – Research, technology development and application,
  – Public information, and
  – Enforcement and monitoring.

Policy Statement

Signed Secretary Anthony R. Foxx, June 2014
FHWA Sustainable Pavements Program

- Support the US DOT goals for sustainability
- Increase the body of knowledge regarding sustainability of asphalt and concrete materials throughout the pavement life cycle
- Increase the use of sustainable technologies and practices in pavement design, construction, preservation, and maintenance
“Towards Sustainable Pavements: A Reference Document”

- Guidelines for the design, construction, preservation and maintenance of sustainable pavements using asphalt and concrete materials

- Educate practitioners on how sustainability concepts can be incorporated into pavements

- Encourage adoption of sustainable practices
A Collaborative Effort

• Comprehensive review of current literature

• Extensive review by representative from key stakeholders groups:
  – State Departments of Transportation
  – Other Public Agencies
  – Asphalt and Concrete Industries
  – Academia
• Use Phase Considerations
• Vehicle Fuel Consumption and Pavement Characteristics
• Tire/Pavement Noise
• Stormwater Runoff

John Harvey
Use Phase Considerations

• What is the use phase?
  – Processes during operation of the pavement affected by pavement decisions

• Use phase processes considered in FHWA Reference Document
  – Fuel use by vehicles
  – Tire/pavement noise
  – Stormwater runoff
  – Thermal performance, contribution to urban and global climate
  – Lighting
  – Safety related to skid resistance
Pavement Life Cycle

Materials Production
- Material extraction and production

Transport

Construction / Maintenance & Rehabilitation
- Equipment Use
- Transport
- Traffic delay

Use
- Pavement vehicle interaction
- Noise
- Runoff
- Lighting
- Safety
- Lighting

End-of-life
- Recycle
- Landfill

From: Kendall et al, 2010
Use Phase Considerations

**Pavement Characteristics**
- Structural Responsiveness
- Macrotexture
- Roughness
- Permeability
- Albedo, Heat Capacity, and Conductivity

**Impacts on Pavement Use Phase**
- Vehicle Fuel Consumption and Emission
- Noise
- Safety
- Stormwater Runoff and Pollution
- Temperature

**Effects**
- Human Health
- Water Quality
- Air Quality
Processes Generally Not Considered In Pavement Use Phase

- Addition of new lanes to existing roads
- Selection of new road locations and alignments
- Vehicle operation impacts not influenced by pavement decisions
  - Fuel consumption not affected by pavement, poor tire inflation, vertical and horizontal alignment
- Some processes that could be considered
  - Influence of pavement on other vehicle consumption items: tires, maintenance, vehicle replacement time
  - Any emissions to water, air from pavement during use
    - Generally have been found to be negligible or occur at such a slow rate that little effect
Pavement Rolling Resistance
(also called Pavement Vehicle Interaction)

• Roughness of pavement surface
  – Measured with International Roughness Index (IRI)
  – Dissipates energy through suspension and tire walls

• Macrotexture of pavement surface
  – Measured with Mean Texture Depth or Profile Depth (MPD)
  – Dissipates energy through tire tread distortion

• Structural response of pavement, two approaches
  – 1: dissipates energy through deflection of viscoelastic or damped pavement materials (HMA or subgrade under PCC)
  – 2: wheel moves up side of delayed deflection bowl
Pavement surface characteristics

- **Megatexture**
- **Macrotexture**
- **Microtexture**

**Roughness (unevenness)**

- Short Stretch of Road
  - 0.5 to 50 m
  - (1.6 to 164 ft)
- Tire
  - 50 to 150 mm
  - (0.2 to 2 inch)
- Tire/road Contact Patch
  - 0.5 to 50 mm
  - (0.02 to 0.2 inch)
- Single Aggregate
  - <0.5 mm

Adapted from Sandberg 1997
Approach 1: Energy dissipated in viscoelastic or damped pavement layers

- Calculate material properties and model coefficients using the relaxation modulus master curves developed from FWD
- Calculate viscous energy dissipation using viscoelastic FE modeling (W)

Equation to calculate dissipated energy:

$$ W = \iiint (\pi \sin(\phi_E) \sigma_{0x} \varepsilon_{0z}) dV $$

The dissipated energy per time $w(t)$ is integrated on a $\Delta d$ long slice of the asphalt layer, located in the center of the structure.

$$ W_{truck} = \left( \int w(t) dt \right) \frac{X}{\Delta d} \cdot Z $$
Approach 2: Wheel moving up side of viscoelastic deflection bowl

Model Gen II

\[ \delta E = - \int P \frac{dw}{dX} dX = -P \left( \frac{dw}{dX} \right) \]

Dissipated Energy

Elastic material

Viscoelastic material

Loughalam et al.
Calibration of HDM 4 Models: NCHRP Report 720 (Chatti & Zaabar)
NCHRP 720: Roughness at 96 km/hr (55 mph)

1 m/km = 63 in/mile
3 m/km = 190 in/mile
5 m/km = 317 in/mile
NCHRP 720: Interaction of speed and IRI

(a) Passenger car

(e) Articulated truck

- 40 km/h (25 mph)  - 56 km/h (35 mph)  - 72 km/h (45 mph)
- 88 km/h (55 mph)  - 112 km/h (70 mph)
Do People Go Faster on Smoother Roads, Canceling Benefits?

- Fuel economy goes down for speeds above 45 mi/hr
- Hammarström et al. (2012), using Swedish driver speed behavior measurements (Ihs and Velin 2002): increased driver speeds cancel benefits of improved smoothness
- Wang et al. (2013) in California using large number of measurements before and after pavement maintenance on same asphalt and concrete pavements: reduction of IRI of 63 inches/mi leads to 0.3 to 0.4 mi/hr change in free-flow speed on freeways, negligible effect on vehicle emissions or energy consumption

Drivers on California State Route 1
blogs.wsj.com,
www.hercampus.com
NCHRP 720: Macrotexture

- Only significant for heavy trucks at 35 mph
NCHRP 720 Summary of Field Tests in Michigan

• Field tests confirmed the effect of roughness on fuel consumption
  
  – An increase in IRI of 1 m/km (63.4 in/mi) will increase the fuel consumption of passenger cars by about 2% irrespective of speed. For heavy trucks, this increase is about 1% at normal highway speed (96 km/hr or 60 mph) and about 2% at low speed (56 km/hr or 35 mph).

• Effect of texture depth on fuel consumption could only be seen for heavy truck at low speed (35 mph)
  
  – An increase in MPD of 1 mm (0.039 in) will increase fuel consumption by about 2% at 56 km/hr (35 mi/hr) for heavy slow trucks

• Effect of pavement type could only be seen in summer conditions, only for trucks and only at low speed (35 mph)
  
  – 3.8 to 4.0% for slow heavy and light trucks on summer days
What about Wet Pavement?

• All field studies done under dry conditions
• Modeling results from Sweden indicate that water depths of 0.039, 0.078, and 0.156 inches (1, 2 and 4 mm) can increase vehicle fuel use by 30 percent, 90 percent, and nearly 80 percent, respectively, compared to dry pavement
• Textures that can get water off the surface can improve fuel use under wet conditions
Issues and Tradeoffs of Keeping Pavements Smooth

• Keeping pavements smooth requires more frequent maintenance and rehabilitation
  – Increased environmental impact from M&R

• M&R doesn’t give full benefit if don’t get smoothness from construction
  – Smoothness specifications so not “born rough”
  – Based on IRI not profilograph or bump indicator

• Benefit increases on higher traffic lanes
  – Focus on keeping higher traffic routes smooth
  – Doesn’t mean let low volume roads go bad
Case Study (LA-5): Concrete CPR B on rural/flat freeway

10 mile (16 km) segment in need of rehab
- Rural freeway
- 4 lanes, southbound
- AADT: ~80,000; ~25% trucks

<table>
<thead>
<tr>
<th>Lane</th>
<th>Cars (%)</th>
<th>Trucks (%)</th>
<th>IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1 (Inner)</td>
<td>38%</td>
<td>0.2%</td>
<td>3</td>
</tr>
<tr>
<td>Lane 2</td>
<td>34%</td>
<td>8%</td>
<td>3</td>
</tr>
<tr>
<td>Lane 3</td>
<td>16%</td>
<td>42%</td>
<td>3.5</td>
</tr>
<tr>
<td>Lane 4 (Outer)</td>
<td>13%</td>
<td>49%</td>
<td>4</td>
</tr>
</tbody>
</table>

Compare:
- Reactive Maintenance
- 10 year CPR B
LA-5 (Type III PCC): Cumulative life cycle energy savings grind/slabs vs. reactive maintenance “pay back time”

Materials & Construction
Case Study (KER-5): Asphalt overlay on rural/flat freeway

10 mile (16 km) segment in need of rehab
- Rural freeway
- 2 lanes, southbound
- AADT: 34,000; ~35% trucks

<table>
<thead>
<tr>
<th></th>
<th>Passenger</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Lane</td>
<td>77%</td>
<td>9%</td>
</tr>
<tr>
<td>Outer Lane</td>
<td>23%</td>
<td>91%</td>
</tr>
</tbody>
</table>

Compare:
- Reactive Maintenance
- 5 year HMA overlay
KER-5 (HMA): Cumulative life cycle energy savings asphalt overlay vs. reactive maintenance “pay back time”

- 3% Traffic growth: Smooth Rehab
- 3% Traffic growth: Less Smooth Rehab
- 0% Traffic growth: Smooth Rehab
- 0% Traffic growth: Less Smooth Rehab

Cumulative Energy Saving Compared to Do Nothing (10^6 MJ)

Equivalent Gasoline (10^6 L)
Case Study (IMP-86): Concrete CPR B on rural/flat highway

5 mile (16 km) segment in need of rehab

- Rural highway
- 2 lanes, southbound
- AADT: ~11,200; ~29% trucks

<table>
<thead>
<tr>
<th></th>
<th>Cars</th>
<th>Trucks</th>
<th>IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1 (Inner)</td>
<td>76%</td>
<td>8%</td>
<td>2.5</td>
</tr>
<tr>
<td>Lane 2</td>
<td>24%</td>
<td>92%</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Compare:
- Reactive maintenance
- 10 year grind/minor slab replacement
IMP-86 (Type III PCC): Cumulative life cycle energy savings grind/slabs vs. reactive maintenance “pay back time”

Cumulative Energy Saving Compared to Do Nothing (10^6 MJ)

- 3% Traffic growth: Smooth Rehab
- 3% Traffic growth: Medium Smooth Rehab
- 3% Traffic growth: Less Smooth Rehab
- 0% Traffic growth: Smooth Rehab
- 0% Traffic growth: Medium Smooth Rehab
- 0% Traffic growth: Less Smooth Rehab

Materials/Construction

Equivalent Gasoline (10^6 L)

Year
Example Application to California Network for Use in PMS

- Optimization for greenhouse gas emissions (GHG) of IRI trigger levels for preventive maintenance
  - Asphalt overlays on asphalt
  - Grinding/slab replacement on jointed concrete
  - Net effect of materials/construction and use

- Dependent on traffic level

- Agency cost or Total cost of reducing energy use and GHG can be calculated for comparison with strategies in other sectors of economy
Method: Divide network based on traffic level

Percentile of lane-mile in the state network

 Daily passenger car equivalent (PCE) per directional segment ($\times 10^3$)

# : Traffic group number
## Result: GHG optimal trigger by traffic group and GHG reduction vs. reactive maintenance

<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 CO$_2$-e reductions (MMT)</th>
<th>Modified total cost-effectiveness ($/tCO$_2$-e)</th>
</tr>
</thead>
<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>
</tr>
<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>
</tr>
<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>
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</table>

Note: The table above provides a summary of the optimal IRI triggering values and associated annualized CO$_2$-e reductions, along with cost-effectiveness metrics for different traffic groups based on daily PCE of lane-segments and percentile of lane-mile. The total CO$_2$-e reductions and modified total cost-effectiveness are also calculated for the entire dataset.
<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>Speed (km/h)</th>
<th>AC</th>
<th>PCC</th>
<th>Mean Difference</th>
<th>Number of Data Points</th>
<th>Sig. (p-value)*</th>
<th>AC</th>
<th>PCC</th>
<th>Mean Difference</th>
<th>Number of Data Points</th>
<th>Sig. (p-value)*</th>
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</thead>
<tbody>
<tr>
<td>Medium car</td>
<td>56</td>
<td>52.9</td>
<td>53.1</td>
<td>-0.2</td>
<td>138</td>
<td>0.71</td>
<td>56.2</td>
<td>56.1</td>
<td>0.2</td>
<td>138</td>
<td>0.8</td>
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<tr>
<td></td>
<td>72</td>
<td>63.9</td>
<td>64.6</td>
<td>-0.7</td>
<td>138</td>
<td>0.22</td>
<td>67.2</td>
<td>68.2</td>
<td>-1.0</td>
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<td>0.1</td>
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<tr>
<td></td>
<td>88</td>
<td>78.9</td>
<td>79.1</td>
<td>-0.2</td>
<td>138</td>
<td>0.9</td>
<td>82.6</td>
<td>82.4</td>
<td>0.2</td>
<td>138</td>
<td>0.8</td>
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<tr>
<td>Van</td>
<td>56</td>
<td>81.8</td>
<td>81.1</td>
<td>0.7</td>
<td>138</td>
<td>0.35</td>
<td>85.7</td>
<td>85.6</td>
<td>0.2</td>
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<td></td>
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<td>96.9</td>
<td>97.6</td>
<td>-0.7</td>
<td>138</td>
<td>0.38</td>
<td>102.0</td>
<td>103.0</td>
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<tr>
<td></td>
<td>88</td>
<td>113.7</td>
<td>115.3</td>
<td>-1.6</td>
<td>138</td>
<td>0.29</td>
<td>119.1</td>
<td>121.4</td>
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<td>138</td>
<td>0.2</td>
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<tr>
<td>SUV</td>
<td>56</td>
<td>101.7</td>
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<td>1.5</td>
<td>138</td>
<td>0.2</td>
<td>106.6</td>
<td>106.1</td>
<td>0.5</td>
<td>138</td>
<td>0.6</td>
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<tr>
<td></td>
<td>72</td>
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<td>119.1</td>
<td>0.8</td>
<td>138</td>
<td>0.4</td>
<td>125.8</td>
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<td>0.3</td>
<td>138</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
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<td>159.6</td>
<td>160.5</td>
<td>-0.9</td>
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<td>0.7</td>
<td>164.8</td>
<td>162.6</td>
<td>0.3</td>
<td>138</td>
<td>0.3</td>
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<td>151.1</td>
<td>5.6</td>
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<td>159.3</td>
<td>0.2</td>
<td>138</td>
<td>0.9</td>
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<tr>
<td></td>
<td>72</td>
<td>188.4</td>
<td>187.8</td>
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<td>198.2</td>
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<td>219.9</td>
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<td>227.2</td>
<td>228.1</td>
<td>-1.0</td>
<td>138</td>
<td>0.7</td>
</tr>
<tr>
<td>Articulated truck</td>
<td>56</td>
<td>209.4</td>
<td>201.4</td>
<td>8</td>
<td>138</td>
<td>0</td>
<td>227.2</td>
<td>228.1</td>
<td>-1.0</td>
<td>138</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>72</td>
<td>225.2</td>
<td>222.9</td>
<td>2.3</td>
<td>138</td>
<td>0.2</td>
<td>227.2</td>
<td>228.1</td>
<td>-1.0</td>
<td>138</td>
<td>0.7</td>
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<tr>
<td></td>
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<td>247.6</td>
<td>248.4</td>
<td>-0.8</td>
<td>138</td>
<td>0.9</td>
<td>227.2</td>
<td>228.1</td>
<td>-1.0</td>
<td>138</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Table 1 Summaries of Mean Fuel Consumption and Test Statistics for All Vehicles
Source: Chatti et al.(2012)
Other Fuel Economy/Pavement Structural Response Field Tests

• A number of field studies have been performed measuring vehicle fuel economy on different pavement structures under different conditions
  – Differences between pavement types varied
  – Mostly characterized as “asphalt” and “concrete” without characterization of responses under different loads and temperatures for specific pavements
  – See discussion in Reference Document

• Structural response vs. fuel economy and models not yet comprehensively validated with well characterized pavement structures

• Validated models will permit evaluation of under ranges of traffic, climatic conditions that occur daily, seasonally, and different pavements

• Caltrans sponsored model comparison recently completed
  – Oregon State University/Massachusetts Institute of Technology/Michigan State University models
  – Report being prepared for review
  – Field validation study being prepared
Conclusions and Recommendations for Rolling Resistance

• Roughness (IRI)
  – Generally has the greatest effect on fuel economy for typical ranges of IRI on U.S. highway networks, compared with structural responsiveness, macrotexture
  – Important for all vehicles, speeds and temperatures
  – Consider smoothness performance over life cycle in design and management
  – Implement IRI based smoothness specifications
  – Timely M&R considering traffic levels

• Texture (MPD)
  – Generally only significant for slow heavy trucks
  – Need sufficient texture for safety
Conclusions and Recommendations for Rolling Resistance

• Structural response, knowledge to date
  – Under certain conditions structural responsiveness can have a significant measurable effect
  – Lighter and faster vehicles, colder conditions, cause smallest differences between different pavements
  – Highly variable, depending on temperature, underlying support conditions, which change daily and seasonally
  – Range from approximately no difference to same order of magnitude as high roughness
  – Need to simulate interaction of vehicle types, speeds, temperatures for specific cases to find net impact

• Models currently being calibrated
Why Worry About Tire/Pavement Noise?

- Noise pollution increasing concern in U.S. and worldwide
- Highway noise affects people in adjacent residences and businesses and people in vehicles
- Health, quality of life effects on humans from noise pollution identified by World Health Organization
- Public awareness of road noise increased over the past 40 years
  - FHWA and other agencies are dealing with highway noise
Estimated light vehicle noise due to tire-pavement noise, powertrain noise, and aerodynamic noise at cruise speed (Rasmussen et al. 2008)
On Board Sound Intensity (OBSI) measurement for tire/pavement noise
Vehicle pass-by levels at 25 ft (7.6 m) versus OBSI level for the SRTT at all test sites and speeds—normalized data (Donavan and Lodico 2009)
Mechanisms of Asphalt Tire/Pavement Noise (Ongel et al.)

![Graph showing sound intensity levels in dB(A) against 1/3 octave band analysis frequencies. The graph compares different types of asphalt materials and their noise levels, highlighting the impact of texture and air-void content.](image-url)
Concrete Textures and Tire/Pavement Noise (Rasmussen et al.)

- **Probability Density**
  - Diamond Grinding
  - Drag
  - Longitudinal Tinning
  - Transverse Tinning

- **A-weighted Overall OBSI Level, 60 mph, SRTT (dB ref 1 pW/m²)**

Range: 98 to 110 dB
Conclusions for Tire/Pavement Noise

• Noise can be important
  – Passengers
  – Surrounding people and wildlife

• Asphalt pavement
  – Open-graded and SMA overlays
  – Improved durability from rubberized and smaller stone mixes

• Concrete pavement
  – No transverse tining; longitudinal for new, grinding or grooving for M&R
  – Grind and groove (new generation concrete surface) can further reduce noise
Stormwater runoff issues for pavement

- Conventional paved pavement surfaces relatively impermeable
- Water runs off much faster than from vegetated or undeveloped surfaces, often straight into stormwater collection systems
  - Can overwhelm collection systems, and if combined system, can overflow sewage
- Stormwater is unfiltered
- Stormwater can raise stream temperatures where there is summertime rain
Pavement Solutions

- Permeable asphalt surfaces can slow flows, provide some filtering
- Fully permeable pavement
  - Capture water and drain to subgrade or store for slow release (where subgrade impermeable)
  - Can potentially help with local urban cooling
  - Concrete, asphalt, interlocking concrete (paver) solutions
  - Primarily used for light vehicle, slow speed applications
  - Designs for heavier vehicles developed for all types
    - Calibrated for pavers, not yet for concrete and asphalt
  - Vegetated pavements also available
- Must consider durability, clogging for all solutions
Fully Permeable and Vegetated Pavements

John Kevern, NAPA, Soil Retention Products, UCPRC
• Pavement Thermal Performance and Contribution to Urban and Global Climate
• Artificial Lighting and Safety

Tom Van Dam
Pavement Thermal Performance

- Thermal performance is defined as the change in pavement temperature over time as influenced by:
  - Properties of the paving materials
  - Ambient environmental conditions
- Properties of interest include albedo, thermal emittance, thermal conductivity, specific heat, and surface convection
- Environmental factors include sunlight, wind, air temperature, and evaporative cooling
Thermal Performance

- It is complicated and not always intuitive
- Models continue to be developed and validated that are improving our understanding
- Major considerations include pavement surface temperature and reflectivity
- Impacts can be local, regional, and possibly global
Basic Thermal Model - Day

Solar Energy
Reflectance
Radiation
Convection

PAVEMENT
AGGREGATE BASE

SUBGRADE - 1

CONDUCTION

SUBGRADE - 2

SUBGRADE - 3

From NCPTC/NCAT 2013
Basic Thermal Model - Night

From NCPTC/NCAT 2013
Albedo

• Albedo (or solar reflectance) – Measure of the ability of a surface to reflect solar radiation
  – Ranges from 0 (no sunlight reflected) to 1 (all sunlight reflected)

• Generally light-colored materials have a higher reflectance than dark-colored materials
  – Color is not the only factor
Other Properties

• Emittance – efficiency with which a surface emits radiant energy
• Thermal conductivity – the ability of a material to conduct or transmit heat
• Specific heat – energy needed to raise a unit mass of a substance by one unit of temperature

The values for each property are similar for dense-graded asphalt and concrete, thus albedo is the one property where significant differences may exist.
Urban Heat Island Effect (UHIE)

Urban Heat Island Profile

°F

92
91
90
89
88
87
86
85

°C

33
32
31
30

Temperature

Rural
Commercial
Suburban Residential
Downtown
Urban Residential
Park
Suburban Residential
Cities Can Be Hot

From Amy Dickie – Global Cool Cities Alliance
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
Heat Islands

• Surface and near-surface heat islands can affect human comfort, air quality (ground-level ozone formation), and energy use of buildings and automobiles

• Atmospheric heat islands can impact summertime peak energy demand, electrical grid reliability, and GHG emissions
  - Highly dependent on increased temperatures resulting in increased air conditioner use
  - Heat-related illness and death, pollution, and water quality also increases
Contribution of Pavements

- Paved surfaces account for roughly one-third of the land surface in urban areas
- Multiple computer simulations suggest that paving materials can contribute to the UHIE
  - Related to albedo
  - Field data lacking
- Recent studies incorporate urban canopy models that consider urban complex urban morphology
  - Three-dimensional modeling include the impacts of vertical surfaces and shadowing
Direct Solar Radiation is Critical

Photovoltaic Solar Resource: Flat Plate Tilted South at Latitude

June

Legend
kWh/m²/Day
10
9
8
7
6
5
4
3
2
1
0

Annual average solar resource data is shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states is a 10 km, satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005. The data for Alaska is a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003). This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy December 2008.
Other Factors

• Light reflected from a pavement can have negative impacts
  – Human comfort (warming, glare)
  – Adsorbed onto the building envelop
    ➢ Can increase need for air conditioning but may reduce artificial lighting needs

• The problem is complicated

• The source of electricity and heating fuel makes a difference
Also Consider Radiative Forcing

Cubasch et al. 2013)
Pavement Type and Albedo

Albedo Changes With Age

EPA 2008
Preservation/Rehabilitation Can Alter Albedo

- Treatments that darken the surface decrease albedo
  - e.g. fog seals, slurry seals, microsurfacing, dark overlays
- Treatments that lighten the surface will increase albedo
  - Chip seals with light-colored aggregates
  - Light-colored overlays
  - Light-colored coatings?
- Diamond grinding can go either way
Diamond Grinding
Albedo, Pavement Temperature, and the UHIE

• All things equal, pavements with lower albedo get hotter when directly exposed to solar radiation
  – Results in higher air temperature within inches of the surface

• Most studies suggest that this can lead to a slight increase in atmospheric heat island
  – Regional impacts less certain (some studies suggest localized heating “downstream”)
Impact of Albedo on Surface Temperatures
Pavement Reflectivity and Artificial Lighting

• Advances in adaptive LED lighting are resulting in large energy savings
• The color and texture of a pavement influences the required level of illumination
  – Light-colored surfaces require less lighting (lower lumens per luminary or less luminary
  – Adaptive lighting can take full advantage of this
• No clear consensus regarding impacts on nighttime safety
  – Contrast very important
Contribution of Pavement Surface Conditions to Safety

- Roadway condition is a leading cause of crashes – Keep roads smooth
- Crashes increase in work zones – minimize the number and duration of work zones
- Adequate surface friction is required to provide safe stopping distances
  - Macrotexture is essential
- Uniform cross slopes provide drainage
  - Drains water off the surface
Concluding Remarks

• Concrete pavements are typically more reflective than asphalt pavements
  - Reflectivity changes with age
  - Preservation and rehabilitation activities can profoundly alter reflectivity

• In locations where solar reflectance is deemed important, it should be maintained

• Proprietary treatments to establish high reflectivity may have a high environmental impact over the life cycle
Concluding Remarks

• If lower pavement temperatures are desired, a systems approach should be used
  – Not just pavement albedo
  – Consider shading and pervious pavements

• Research is on-going to determine to what extent pavement albedo influences the UHIE or global climate change
Concluding Remarks

• Adaptive lighting techniques with LEDs offers the opportunity for large energy savings

• Trade-offs exist with regards to pavement reflectivity and nighttime and daytime safety
  – Improved luminance versus improved visibility due to contrast

• Good friction is required to enhance braking
  – Other important pavement characteristics include maintaining ride quality
  – Surface drainage is also important
Pavement Sustainability within Larger Systems

Joep Meijer
Pavement Sustainability within Larger Systems

- Overview of how pavements can interact with larger system sustainability goals
  - Social context systems
  - Ecosystem context systems
  - Innovation and potential market expansion
Pavement Sustainability within Larger Systems

- Sustainable communities
- Ecosystems
- Strategies for improving sustainability
  - Enhance Aesthetics
  - Historical and cultural identity
  - Minimize impact of utility cuts
  - Improve worker and community health
  - Balanced approach to allowable hours of construction
- Future directions and emerging trends
Sustainable Communities

- Partnership for Sustainable Communities
  - Provide more transportation choices
  - Promote equitable, affordable housing
  - Increase economic competitiveness
  - Support existing communities
  - Leverage federal investment
  - Value communities and neighborhoods
Sustainable Communities

- Sustainable communities
  - Partnership for Sustainable Communities
    - Combined DOT, HUD, EPA effort
  - National Complete Streets Coalition
    - Advocacy for multimodal/connected streets
  - National Scenic Byways Program
    - FHWA program recognizing roads for cultural, historic, natural, recreational, scenic qualities
  - U.S. National Register of Historic Places
    - 6,800 transportation-related listings
  - Walk Score
    - Private company that provides walkability, transit service, and bike friendliness scores
Sustainable Communities

- More transportation choices (roads, trails, bike paths, sidewalks)
- Investing in walkable neighborhoods (sidewalks, paths, aesthetics)
- Increase mobility (roads, paths, trails)
- Reduce GHG emissions (materials, construction, use)
- Community revitalization (aesthetics, cultural identity)
- Efficiency of public investments (LCCA, long-life)
- Expanded markets (integrated design)
Ecosystems

- Eco-Logical (2006)
  - Provides guidance to mitigate effects of infrastructure with ecosystem.

- Federal Lands Highway Program (FLHP)
  - Key partners: NPS, USFS, USFWS, Bureau of Indian Affairs
  - Partner agency goals: stewardship of the larger ecosystem
Ecosystems

- **Des Plaines River Valley Bridge**
  - The total height of the bridge ranges from 80 to 100 feet (24 to 30 m).
  - The height allows the endangered Hine's Emerald Dragonfly to fly safely beneath the bridge, away from the flow of traffic.
Ecosystems

• Wildlife Crossings – Dutch example
  – Interstate cutting wildlife habitat in two parts
  – Crossing build to accommodate migration
  – Part of ecological infrastructure map
  – 25+ in place
Strategies for Improving Sustainability

- Enhance Aesthetics
- Historical and cultural identity
- Minimize impact of utility cuts
- Improve worker and community health
- Balanced approach to allowable hours of construction
Westbound on the Zion-Mount Caramel Highway (Utah SR 9) within Zion National Park

- Historical identity
- Aesthetics
- Safety trade-offs in favor of ecosystem preservation
Utility Work

- **Pavers**
  - Utility cut repairs
  - Machines for paving
  - Pervious
Improve Worker and Community Health

- Emission reductions using warm mix
Future directions and emerging trends

- Photocatalytic pavement
- Energy production
Photocatalytic Pavement

- Catalytic conversion of emissions to reduce ozone
- Titanium dioxide
Solar Noise Barriers

- Safety
- Noise
- Integrated solar PV
- Aesthetics
Energy Harvesting Road

- Safety
- Heating
- Cost and durability
Pavement Sustainability within Larger Systems

- Overview of how pavements can interact with larger system sustainability goals
  - Social context systems
  - Ecosystem context systems
  - Innovation and potential market expansion
Where do we go from here?
The Path Forward

Tom Van Dam
Review of Technologies, Innovations, and Trends

• Sustainability inspires innovation
  – It is a journey, not a destination
  – Considering economic, environmental, and societal factors over the life cycle is a game changer

• There is considerable “low hanging fruit” that can make an immediate difference

• Emerging trends offer even greater advancements
Low Hanging Fruit

• Increased use of recycled materials (e.g. RAP, RAS, RCA, in-place recycling)
  – Illinois Tollway
• Full adoption of WMA technologies
  – Use effectively to reduce temperatures and extend life
• Increased use of SCMs to reduce GHGs
  – Challenges exist but innovations abound
Low Hanging Fruit

• Improved pavement design
  – Mechanistic-empirically based
• Use materials wisely
• Permeable pavement systems
• Precast pavements and interlocking pavers
• Innovative construction technologies
  – Improved smoothness, quality, and MOT
• Intelligent preservation
  – Keep good pavements in good condition
Emerging Trends

• Recognition of the importance of the use phase
  - We are all in this together

• Recognition of pavements as being part of larger systems

• Development/adoption of sustainability assessment tools
And Finally….

- The reference manual represents a single step in the journey
- Stay informed
- Challenge convention
- And as Garrison Keillor says, “Be Well, do good work, and stay in touch”
Thank You!

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