FHWA Sustainable Pavements Program

Towards Sustainable Pavement Systems: Webinar Series

Webinar #3:
Sustainable Strategies for Concrete Pavements: Materials, Design, and Construction

June 25, 2015
Webinar Series

- Sponsored by Federal Highway Administration
- 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
  – Use dropdown menu to “send questions to staff”

• Professional Development Hours (PDHs) Certificates
  – 2 hours per webinar
Today’s Webinar

- **Topic:** Sustainable Strategies for Concrete Pavements: Materials, Design, Construction
- **Speakers:**
  - Gina Ahlstrom, FHWA
  - Tom Van Dam, NCE
  - John Harvey, University of California-Davis
  - Jeff Roesler, University of Illinois
  - Mark Snyder, Engineering Consultant
- **Moderators:**
  - Kurt Smith, Applied Pavement Technology, Inc.
  - 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
Materials and Consideration of Life Cycle
Aggregate Materials
Hydraulic Cement Materials and Concrete Mixtures

Tom Van Dam
Materials and Consideration of the Life Cycle

• Must consider material choices from a life cycle perspective
  – What are the agency’s sustainability goals?
  – What are the impacts of using a material once versus multiple times?
  – What are the trade-offs in increasing the use of recycled, co-product, or waste materials (RCWMs)?
Recycled, Co-Product, or Waste Materials (RCWMs)

- Recycled materials are obtained from old pavement and are included in new pavement
  - e.g. reclaimed asphalt pavement (RAP) and recycled concrete aggregates (RCA)
- A co-product is from another process (often industrial) that brings value
  - e.g. slag cement
- Waste are materials that would normally be landfilled
  - e.g. fly ash? air-cooled blast furnace slag aggregate?
Considerations When Using RCWMs

• Does the RCWM result in equivalent or better performance?
  – What if it is just slightly worse?
• Does the RCWM have to be transported great distances?
• Does the RCWM make it more difficult to recycle the pavement in the future?
Other Material Considerations

- Does longer life justify increased material transportation or production-related impacts?
- Does the pavement design make best use of lower impact materials?
- Are the impacts of transporting materials considered?
- Are specifications protecting the owner’s interest or a barrier to innovation?
- Are there impacts on construction variability?
Aggregate Materials

• Largest share of mass and volume in a pavement structure
  – Have relatively low environmental footprint per unit mass
  – Consumed in large quantities

• Impact incurred in mining, processing, and transporting aggregates
  – Impact of transportation can be very large
Aggregates

- Used in asphalt and concrete mixtures, bound and unbound base and subbase
- Natural aggregates are classified as crushed stone or sands and gravels
- Manufactured aggregates are often created to possess unique characteristics
  - Lightweight most common
  - Can also include RCWMs such as air-cooled blast furnace slag
Typical Volumes of Aggregate

Percentage of Volume of Typical Concrete

- Cementitious
- Aggregate
- Water
- Air

- 4 to 8%
- 10 to 14%
- 14 to 18%
- 62 to 68%

Tayabji, Smith, and Van Dam 2010

- Produced in all 50 states
- 1,324M tons of crushed stone worth $12B
  - 82% used as construction materials and 10% used in cement manufacturing
- 927M tons of sand & gravel worth $6.4B
  - 93% used in road construction
RCWMs Used as Aggregate

- Reclaimed asphalt pavement (RAP)
- Recycled concrete aggregate (RCA)
- Recycled asphalt shingles (RAS)
- Air-cooled blast furnace slag (ACBFS)
- Steel furnace slag (SFS)
- Foundry sand
Aggregates and Environmental Impacts

- Energy consumption and GHGs – depends on source of electrical power and transport distance
  - Crushed stone has greater impacts
- Other impacts include fugitive dust, water consumption, land-use issues, and community impacts
- Impacts make it difficult to permit new aggregate sources
  - Transport distance increasing
Aggregate Impacts: Energy and GHGs

The chart illustrates the energy consumption (MJ) and global warming potential (CO2-e/kg) for various materials and regions. The bars represent different categories such as 'Crushed, CH, Eco', 'Gravel, CH, Eco', 'Sand, CH, Eco', 'Crushed, SE, Stripple', 'Gravel/Sand, SE, Stripple', 'Crushed, Fl, Hakkinnen', 'Gravel, FI, Hakkinnen', 'Fine, CA, Athena', 'Coarse, CA, Athena', 'Crushed, US, PCA', and 'Sand and Gravel, US, PCA'. The chart compares 'Total Primary Energy' (blue) and 'Total GWP' (red).
# Transportation Mode and Fuel Consumption

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<thead>
<tr>
<th>Mode</th>
<th>Ton-Miles/Gallon</th>
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<tbody>
<tr>
<td>Trucks(^2)</td>
<td>150</td>
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<tr>
<td>Rail</td>
<td>478</td>
</tr>
<tr>
<td>Inland towing</td>
<td>616</td>
</tr>
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**Notes:**

1. This is gross fuel use, not life-cycle fuel use.
2. Truck load assumed to be 25 tons (22.6 mt) on a 40 ton (36.28 mt) gross vehicle weight truck, loaded one way.

About 22 lbs of CO\(_2\) from burning one gallon of diesel fuel
Strategies for Improving Sustainability

- Reduce use of virgin aggregate over the life cycle
- Reduce impact of virgin aggregate acquisition and processing
- Reduce impact of transporting aggregates
  - Use barges or rail if possible
Example: The Illinois Tollway

- Committed to recycling 100% of existing pavements
- Two-lift composite concrete using RCWM in bottom lift
- In-place recycling of existing pavements
- Decisions are first economic, then environmental

Photo compliments of Steve Gillen, Illinois Tollway Authority
Aggregate Issues and Future Directions

- Proximity of aggregate sources to urban centers
  - Trade-off between transportation and local community impacts
- Increasing pressures to increase use of RCWMs
  - Trade-off with regards to performance
- Increased use of marginal aggregates
- Demand for specialty aggregates increasing to meet specific sustainability goals
Hydraulic Cement and Concrete Mixtures

- Hydraulic cement concrete is humankinds most commonly used material after water
  - Approximately 1 yd$^3$/person/year
- Large economic, environmental, and social impacts
  - 80.5 million tons of cement manufactured in the U.S. in 2014
  - In 2013, linked to just under 0.5% of US GHGs
- About 5 percent of cement is used in paved roads
<table>
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<th></th>
<th>On-site Energy 10^6 kJoules</th>
<th>On-site Energy %</th>
<th>CO₂ Emissions 10^6 tonne</th>
<th>CO₂ Emissions %</th>
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<td><strong>Raw Materials – Quarrying and Crushing</strong></td>
<td></td>
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<tr>
<td>Cement Materials</td>
<td>3,817</td>
<td>0.7%</td>
<td>0.36</td>
<td>0.3%</td>
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<tr>
<td>Concrete Materials</td>
<td>14,287</td>
<td>2.6%</td>
<td>1.28</td>
<td>1.2%</td>
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<td><strong>Cement Manufacturing</strong></td>
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<tr>
<td>Raw Grinding</td>
<td>8,346</td>
<td>1.5%</td>
<td>1.50</td>
<td>1.4%</td>
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<td>Kiln: fuels</td>
<td>410,464</td>
<td>74.0%</td>
<td>38.47</td>
<td>36.8%</td>
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<td>Reactions</td>
<td></td>
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<td>48.35</td>
<td>46.3%</td>
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<td>Finish Milling</td>
<td>24,057</td>
<td>4.3%</td>
<td>4.32</td>
<td>4.1%</td>
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<td><strong>Concrete Production</strong></td>
<td></td>
<td></td>
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<tr>
<td>Blending, Mixing</td>
<td>31,444</td>
<td>5.7%</td>
<td>5.65</td>
<td>5.4%</td>
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<td>Transportation</td>
<td>61,933</td>
<td>11.2%</td>
<td>4.53</td>
<td>4.3%</td>
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<tr>
<td><strong>Total</strong></td>
<td>554,409</td>
<td>100%</td>
<td>104.50</td>
<td>100%</td>
</tr>
</tbody>
</table>

Portland Cement in Concrete

Typical concrete at the gate:
0.26 t CO₂ /yd³ concrete
0.24 t CO₂ from portland cement
Sustainability is Enhanced by Using Less Portland Cement

• Reduce clinker in cementitious material
• Reduce cementitious content in concrete
  – From 564+ lbs/yd\(^3\) to 500 lbs/ft\(^3\) or less
  – Context sensitive
• Reduce concrete needed over the life cycle
  – Improved design – thinner structures
  – Improved durability
Reducing Clinker Content in Cement

• Replace clinker with ground limestone and inorganic processing additions
  – AASHTO M 85 portland cement can have up to 5% limestone and 5% inorganic additions
  – AASHTO M 240 Type IL blended cement can have up to 15% limestone

• Replace clinker with supplementary cementitious materials (SCMs)
  – Added at concrete plant
  – Obtained as blended cement (AASHTO M 240)
Supplementary Cementitious Materials (SCMs)

- **Fly ash**
  - Collected from flue gases of coal burning power plant

- **Slag cement**
  - From iron blast furnace

- **Natural pozzolan**
  - Calcined clay, volcanic ash, ground pumice, etc.
Typical Replacement Levels for SCMs in Paving Concrete

- Class F fly ash: 15% - 25%
- Class C fly ash: 15% - 40%
- Slag: 25% - 50%

Note that replacement levels can be much higher in mass concrete placements, as high as 85%
Fly Ash Utilization

ACAA 2014

ACAA Fly Ash Production & Use Comparisons 1966-2013

ACAA 2014

33 of 108
Shipments of Slag Cement

Adapted from Slag Cement Association
AASHTO M 240 Blended Cements

- Produced by cement manufacturers
- Type IP(X), Type IS(X), Type IL(X), and Type IT (X)(Y)
  - Blended with pozzolan, slag cement, limestone or ternary blend
- Also designated as air entrained (A), moderate of high sulfate resistant (MS or HS), or moderate or low heat of hydration (MH or LH)
SCMs and CO₂ Emissions

Reduce Cement By Increasing Aggregate Volume in Concrete

- Maximize aggregate content
  - Use of optimized aggregate grading for paving
- Ensure volume stability of aggregates
  - Porous aggregates require special handling
- Ensure aggregate durability
  - Freeze-thaw
  - Alkali-aggregate reactivity
Cement Content, SCMs, and CO$_2$
Making Concrete Durable

- Good mixture design with relatively low permeability and shrinkage
- Resistance to freezing and thawing
  - In the presence of deicers
- Mitigation of alkali-aggregate reactivity
- Resistance to sulfate attack

Reduced cementitious content and the use of SCMs helps create durable concrete
Strategies to Improve Sustainability of Concrete

- Reduce energy and GHGs during cement production
- Reduce energy and GHGs during concrete production
- Reduce water use
- Increase use of RCWMs and marginal materials as aggregate
- Improve durability of concrete
Water Recycling at Concrete Plant

• Key Issues for Pavement Design
• Example Case Studies

John Harvey
Key Issues for Pavement Design

- **Surface performance**
  - Smoothness affects vehicle fuel use and maintenance
  - Consider life cycle smoothness, not just initial
  - Importance increases with increased traffic

- **Design life selection**
  - Longer life usually means lower life cycle cost and impact
  - Also means higher initial investment (cost, environmental impact)
  - Should include consideration of end-of-life alternatives

Diagram: Simplified model of a vehicle's suspension system showing masses, springs, and forces. The model includes:
- **Body** (sprung mass)
- **Suspension**
- **Axle** (unsprung mass)
- **Tire**
- **Road**

Gillespie and Sayers, EB Lee
Key Issues for Pavement Design

• Pavement type selection
  – Impacts every phase of the pavement life cycle
  – Relative sustainability of different types depends on location, design traffic, and available materials

• Construction and materials selection interaction
  – See discussion of concrete materials
  – Consider ability to get high quality construction
  – Consider work zone traffic delays

• Construction quality requirements

• End-of-Life recycling strategies

Paramics, Lee et al.
Consideration of Payback Time

Example: Design Life

• Return time and uncertainty for high early environmental impact choices
Consideration of Payback Example: Different Grinding Construction Smoothness and Traffic Scenarios

- **Grinding effect on IRI** (-2σ; mean; +2σ):
  \[ IRI_{change}(m/km) = -0.6839 + 0.6197 \times IRI_{beforeGrinding}(m/km) \]

- **IRI progression on rehabilitated lanes**:
  \[ \sqrt{IRI(m/km)} = -1.74 \times 10^{-1} + 9.66 \times 10^{-5} \times \sqrt{CumulativeESAL} + 1.15 \times \sqrt{InitialIRI(m/km)} \]

- **Vs. Do Nothing (Maintenance Only)**

From (1) Caltrans Pavement Condition Survey; and (2) R. Stubstad, M. Darter, et al. The Effectiveness of Diamond Grinding Concrete pavements in California, 2005
Case Study 2 (LA-5):
Effect of construction smoothness

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>186</td>
</tr>
<tr>
<td>Lane 2</td>
<td>34%</td>
<td>8%</td>
<td>186</td>
</tr>
<tr>
<td>Lane 3</td>
<td>16%</td>
<td>42%</td>
<td>217</td>
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<tr>
<td>Lane 4 (Outer)</td>
<td>13%</td>
<td>49%</td>
<td>248</td>
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Compare:
- Do Nothing
- 10 year CPR B
  - Slab replacement, grind
LA-5: Cumulative Life Cycle Energy Savings Compared to “Do Nothing” for Different Grinding Smoothness

- Good quality construction smoothness
- Average construction smoothness
- Poor quality construction smoothness

Materials and Construction

Cumulative Energy Saving Compared to Do Nothing (MJ)

Equivalent Gasoline (L)
Case Study 4 (IMP-86): Effect of Construction Smoothness

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>
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<tr>
<td>Lane 1 (Inner)</td>
<td>76%</td>
<td>8%</td>
<td>155</td>
</tr>
<tr>
<td>Lane 2</td>
<td>24%</td>
<td>92%</td>
<td>170</td>
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</table>

Compare:
- Do Nothing
- 10 year CPR B
- Slab replacement, grind

Wang et al.
IMP-86: Cumulative Life Cycle Energy Savings Compared to “Do Nothing” for Different Grinding Smoothness

- Good quality construction smoothness
- Average construction smoothness
- Poor quality construction smoothness

Materials and Construction

Cumulative Energy Saving Compared to Do Nothing (MJ)

Equivalent Gasoline (L)

Year

Mechanistic-Empirical Design Methods

• Permit rapid evaluation of:
  - Materials
    ➢ Increased recycled content
    ➢ Materials with lower environmental impact
    ➢ Changes in mix design
    ➢ Locally available, lower quality specifications
  - Construction
    ➢ Improved quality (smoothness and durability in particular)
    ➢ Less variability
  - Pavement structures
    ➢ Climate, traffic and subgrade specific designs
    ➢ With materials and construction noted above
Process for Considering Sustainability in Pavement Design

Inputs:
- Project performance, cost, and sustainability objectives
- Project traffic, climate, available materials, and construction processes
- Agency design, LCCA, sustainability practices and policies

Step 1: Develop generalized pavement type or rehabilitation approach alternatives

Step 2: Develop pavement designs using ME or agency design procedures

Step 3: Consider future maintenance and rehabilitation (chapters 4 & 7)
Step 4: Calculate and Evaluate:
- Performance
- Cost
- Environmental Impact
- Societal Impact

Step 5: Modify initial design using LCCA, LCA, and rating systems (to reduce cost and minimize environmental and societal impact while still meeting performance and agency objectives and policies)

Modified Alternative 1
Modified Alternative 2
Modified Alternative 3
Modified Alternative n

Step 6: Select preferred design alternative based on agency goals and policies.
Concrete Pavement/Rehabilitation Types
Sample Sustainable Design Strategies
Future Directions/Emerging Technologies

Jeff Roesler
Selection of Concrete Pavement Types for Sustainable Design

- Select candidate pavement types based on material, construction, M&R, use, and end of life phases
  - New or rehabilitated concrete pavement
- Define pavement layers/materials and inputs
- Perform pavement structural designs
Sustainable Pavement Design
Initial Evaluation

• Define goals / policies of agency or owner
  – Sustainability objectives & metrics
    ➢ LCA, LCCA, rating system, etc.
  – Performance objectives
    ➢ Structural (cracking, faulting)
    ➢ Functional (smoothness, safety, noise)
  – Drainage
  – Design life / end-of-life

• Project constraints – traffic management
• Construction process
Concrete Pavement Types: New or Reconstructed

- Tradeoffs
  - Design life, smoothness, maintenance/repair, rehabilitation options
  - Initial vs. life cycle costs
  - Life cycle assessment (LCA) impact factors (e.g. GWP)
Composite Pavement Type: Two-Lift Concrete

Considerations
- Single lift paving vs. two lift
- Recycled or marginal materials in bottom lift
- Premium concrete surface, e.g., noise and friction
Longer Life Concrete Pavement

- Principal arterial
  - 30 to 60 year design life
- Durable concrete materials & reinforcement
- Non-erodible base layer & drainage
- Edge support – widen lane or tied shoulder

Long Life Example: CRCP
Concrete Pavement Types: Overlays of Concrete

**Structural Asphalt Concrete Overlay**
- Intact Distressed Concrete Pavement or Rubblized Concrete Pavement
- Asphalt, Cement Treated or Granular Base Layer
- Granular Subbase Layer
- Compacted Subgrade

**Structural (Bonded/Unbonded) Concrete Overlay**
- Bonded or Unbonded Concrete Overlay
- Existing Concrete Pavement
- Asphalt, Cement Treated or Granular Base Layer
- Granular Subbase Layer
- Compacted Subgrade

**Considerations**
- Design life, existing pavement condition, end of life, elevation restrictions, reflective cracking, traffic constraints, funding resources
Concrete Pavement Types: Stormwater Management

- Considerations
  - Management of stormwater discharge and peak flow
  - Lower speed roadways
Modular Pavement: Precast Concrete Slabs

Fort Miller Group
Super-Slab™
Concrete Pavement Surface Options

- Friction, noise, surface runoff
  - Tining
  - Diamond grinding and grooving
  - Turf drag

- Future considerations:
  - Urban Heat Island (Albedo)
  - Photocatalytic cement

Beeldens & Boonen (2011)
Layer and Material Type Selection

- Existing or new pavement structure
  - Proposed roadway cross-section
- Options for using recycled materials
  - subbase, base, shoulders, concrete layer

- Construction & Traffic Management Process
- Limit handling & hauling for more sustainable design

Fig. 1. Roadway reconstruction material processing and flow.
Local Materials/ Low-Impact Transportation

- Transporting materials has major environmental and social impacts
  - Consider materials specifications and whether designs can be developed to maximize use of local materials

- Consider adoption of a zero-waste approach that includes recycling of all pavement materials on-site or nearby

- Avoid compromising pavement longevity

- Reduce environmental impact of materials over the life cycle
  - Cannot just consider initial construction
Sustainable Pavement Design: Reconstruction Example

Original Pavement Structure

Potential Recycling Plan

Proposed Pavement Structure

4" HMA
10" JRCP
12" Granular Base

3" PCC Virgin
9" PCC FRAP
3" WMA
6" Crushed PCC
6" Granular Base

6" HMA

2" WMA
7" WMA
6" Crushed PCC
6" Granular Base
Accelerated Construction

- Can reduce cost and environmental impact
  - Less mobilization and demobilization
  - Less worker travel
  - Short intense pain vs. prolonged delays

- Techniques:
  - Designs and specifications to minimize thickness, speed construction
  - Continuous and full direction closures
  - Extensive traffic management planning, traffic monitoring and adjustments
  - Extensive public outreach
  - Provision of alternative transportation
Do you support I-15 Devore “Rapid Rehab” approach?

Before-construction:
- No, 56%
- Yes, 44%

Do you support future “Rapid-Rehab” projects?

After-construction:
- No, 30%
- Yes, 70%
I-88 Tollway Example (September 2012)

- Illinois Tollway’s first two-lift pavement
- Bottom lift was a ternary blend (cement, slag, fly ash) with 21% coarse FRAP
- Bottom lift was 8 inches with 3.5-inch top lift
- Bottom lift had lower compressive and flexural strengths but similar fracture properties to the top lift
I-90 Existing Pavement Structure

- **Existing Roadway:**
  - 4” HMA
  - 10” PCC (JPCP)
  - 12” Granular Subbase

- **Shoulders (HMA):**
  - 5 – 11 ft wide
  - 6 – 7” thick

ADT = 317,000 veh.
Trucks = 11%

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<th>MP 17 to MP 45.6</th>
<th>MP 45.6 to MP 78</th>
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<tr>
<td>12.5' Lane</td>
<td>12.5' Lane</td>
</tr>
<tr>
<td></td>
<td>12.5' Lane</td>
</tr>
<tr>
<td></td>
<td>12.5' Lane</td>
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<tr>
<td>5' Shoulder</td>
<td>5' Shoulder</td>
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<td>5' Shoulder</td>
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<td>12.5' Lane</td>
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<td>11' Shoulder</td>
<td>12.5' Lane</td>
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<tr>
<td></td>
<td>12.5' Lane</td>
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</tbody>
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• Agency Goals/Constraints:
  – Recycle 100% of existing roadway
  – Maintain traffic revenue!!
  – Provide land for construction staging areas
  – Use:
    ➢ Two-lift concrete
    ➢ WMA
    ➢ Recycled materials – FRAP, RAS, RCA, existing granular subbase

12” PCC (2 Lifts)
  Top Lift: 3” (Virgin Concrete)
  Bottom Lift: 9” (20% FRAP)

3” WMA

3” Capping Stone

6” Crushed Concrete Subbase

6” Granular Subbase
Use Phase Considerations

- Depends on roadway functional class (arterial, collector, etc.; rural vs. urban)

- Principal arterials
  - Smoothness - maintained
    - reduces environmental impact
  - Longevity
    - low level distress means less maintenance/repair

- Lower volume roads
  - Material and construction dominate environmental impact
Other Use Phase Factors

- **Traffic**
  - Fuel efficiency is correlated to smoothness
  - Also affected by texture, structural response
  - Noise, skid, pollution, and particulates

- **Stormwater**
  - Urban issues include flooding and stormwater treatment
  - Safety – splash/spray

- **Aesthetics**, *urban heat island* effect, artificial lighting, utility cuts, manholes
Summary of Design Considerations

• Achieve longer life, thinner pavement, or more efficient design for same life by integrating
  – Structural design
  – Materials selection and layers
  – Construction (& traffic) process

• Maximize use of recycled and locally available materials
  – Consider specifications changes

• Consider
  – Use phase impacts
  – End-of-life scenarios
Future Directions/Emerging Technologies

- Improved ME design capabilities
- Performance related construction specifications
- New materials including more recycled materials and multi-functional cements
- Integration of cost and environment impact in design criteria
- More consideration of future preservation, rehabilitation and recycling in design
• Construction Considerations
• Strategies to Improve Sustainability of Concrete Pavement Construction Practices

Mark B. Snyder
Key Construction Issues Impacting Sustainability

• Energy consumption
  – Transport of materials and construction operations

• Impacts on surrounding areas
  – Exhaust and particulate emissions (local and global), impact on wetlands and streams
  – Traffic delays, congestion and noise

• Impact of construction quality on pavement performance and overall service life
  – Surface texture (friction [safety], noise)
  – Roughness (impact on use phase fuel consumption)

• Economics of construction practices
  – Agency costs, user costs (construction-related, use phase)
Energy Consumption

• Construction: an energy-intensive process
  – Activities may include: excavation, earthwork, material processing and placement compaction/consolidation of paving layers, texturing, jointing
  – Equipment may include: excavators, haul equipment, crushers, mixers, graders, rollers, placers and pavers, and more.

• Energy consumption factors:
  – Internal: Operational efficiencies
  – External: Site operations and site conditions
Construction: Total Emissions and Emission Intensity

Highway/Road/Bridge Construction EI = 0.49 MT/$1000 (2002)
Quantifying Sustainability Impact of Traffic Delays

• Energy and emissions contribution of traffic delays due to construction activities are often ignored in pavement LCAs

• Impact on environment, associated with traffic delays, may be quantified using appropriate tools:
  – Traffic simulator to estimate driving schedule under changing roadway capacity
  – EPA’s MOVES software to calculate additional emissions and energy consumption with changing driving schedules
Vehicle Emissions Simulations

- EPA’s NONROAD
  - Emission modeling system for non-road equipment
  - Energy consumption
  - Emissions to air
    - HC, CO, NOx, PM, SO2, and CO2

- EPA’s MOVES
  - Emission modeling system for mobile sources
  - Energy consumption
  - Emissions to air
    - 120+ emissions

Also available: PE-2, GreenDOT
Case Study: Work Zone Scenarios and Impacts Using MOVES

- Traffic scenarios considered a 7.6 mi work zone (Kang et al., 2014):
  - Partition the project into 4 work zones and use night time closure to complete each
  - Partition the project into 2 work zones and use 16-hr closure between 10 pm and 2 pm
  - No partition with 32-hr closure starting from 9 pm and finishing 5 am

GWP due to traffic delay was 1.3 % (best case scenario) to 2.7 % (worst case scenario) of the total GWP including material and construction phases. However, if no queue develops, there can be energy savings (Wang et al., 2014)
Impacts of Construction on Surrounding Areas

- Emissions from Equipment Exhaust
- Airborne Particulates from Construction Operations
- Noise Generated from Construction Operations
- Construction Impacts on Local Traffic, Residences, and Business Operations
- Construction in Streams, Wetlands, and Environmentally Sensitive Areas
Impacts of Construction: Traffic Delays and Congestion

- Work zones can cause user delay, increased fuel consumption, and compromised roadway safety
- Indirect economic and environmental impact result from construction activities due to reduction in roadway capacity and delays
  - Highway construction zones account for 24% of nonrecurring congestion equivalent to 482 million vehicle-hours per year (USDOT 2006)
  - Loss of highway capacity (60 million vehicles per day - Wunderlich and Hardesty, 2003)
Impacts of Construction Quality

Performance expectations from durable materials and effective designs will be unrealized with poor construction quality.

- Quality must be reflected in both structural and functional (e.g., friction, noise, IRI) characteristics.
  - Example: strong, durable pavements with poor ride may have high costs of fuel, vehicle maintenance, and damage to transported goods.

- Durability/longevity is a primary factor impacting pavement sustainability.
Economics of Construction Practices: Initial and Long-term, Agency and User

• Work zones cause 24% of nonrecurring U.S. congestion: 482 million annual vehicle-hours of delay (USDOT 2006) and $700M annual fuel loss (Antonucci et al, 2005)

• Construction changes to enhance sustainability often increase costs.
  – Examples: noise and pollution reduction, erosion control, improving local access during construction

• Costs must be weighed against expected benefits. High-cost changes may not be adopted, even with potential environmental and societal benefits.
Improving General Construction Sustainability: Fuel Use and Emissions

- Minimize haul distances
- Select appropriate equipment type and size
- Reduce idling times
- Retrofit/upgrade equipment and/or use hybrid equipment
  - Dual-fuel generators, grid electricity
- Use alternative fuels
Improving General Construction Sustainability: Alternative Fuels

- Diesel (non-road): 3000-5000 ppm sulfur
  - Ultra-low Sulfur Diesel (ULSD): <15 ppm
    - Lower energy content, higher price
- Biodiesel (B5 and B20)
  - Reduced PM, CO and HC emissions, reduced engine wear
  - Higher price, increased NO\textsubscript{x}, lower power and fuel economy, hose/gasket degradation

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Emissions (lb CO\textsubscript{2})</th>
<th>GHG Reduction – 3% Fuel</th>
<th>GHG Reduction, 10% Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>22.37/gallon</td>
<td>600 M lbs CO\textsubscript{2}</td>
<td>2000 M lbs CO\textsubscript{2}</td>
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<tr>
<td>Gasoline</td>
<td>19.54/gallon</td>
<td>186 M lbs CO\textsubscript{2}</td>
<td>621 M lbs CO\textsubscript{2}</td>
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<tr>
<td>Nat. Gas</td>
<td>11.7/1000ft\textsuperscript{3}</td>
<td>106 M lbs CO\textsubscript{2}</td>
<td>353 M lbs CO\textsubscript{2}</td>
</tr>
</tbody>
</table>
Improving General Construction Sustainability: Erosion and Runoff

- Minimize extent and duration of disturbed areas
  - Construction phasing
- Use perimeter control barriers
  - Fences, straw bales, etc.
- Apply erosion control matting or blankets
- Re-vegetate ASAP
- Store/stockpile materials away (e.g., > 40 ft) from water courses.
- Cover stockpiles or provide barriers for rain events
Improving General Construction Sustainability: Noise Reductions

• Construction time restrictions
  – Reduced productivity? Increased emissions due to prolonged construction?

• Equipment maintenance/modifications
  – Requires capital investment
Improving General Construction Sustainability: Accelerated Construction

- Establish performance goals and measures for work zones
  - e.g., target work zone delay to be less than 6% of all traffic delays (The Netherlands); U.S. value estimated at 10%.

- Incorporate lane/road closure analysis strategies during project planning
  - Use project management programs such as FHWA’s QuickZone, CalTrans’ CA4PRS, and Dynasmart

- Implement effective road and lane closure strategies during construction

- Implement intelligent transportation systems (ITS) to provide alternative routes or modes to drivers
Case Study: QuickZone

- Quickzone is a *software tool for traffic analysis* that compares traffic impacts for work zone mitigation strategies and estimates traffic delays and cost.
- Quickzone was used during the planning stage for *Woodrow Wilson Bridge replacement project* with an objective to minimize impact on road users.
  - Duration of project was reduced from an estimated 6 months to 2 months.
  - Efficient communication was created between the contractor and bridge management team.
## Case Study: I-15 Devore Selection of Closure Type Using CA4PRS

<table>
<thead>
<tr>
<th>Construction Scenario</th>
<th>Schedule Comparison</th>
<th>Cost Comparison ($M)</th>
<th>Max. Peak Delay (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Closures</td>
<td>Closure Hours</td>
<td>User Delay</td>
</tr>
<tr>
<td>1 Roadbed Continuous</td>
<td>2</td>
<td>400</td>
<td>5.0</td>
</tr>
<tr>
<td>72-Hour Weekday Continuous</td>
<td>8</td>
<td>512</td>
<td>5.0</td>
</tr>
<tr>
<td>55-Hour Weekend Continuous</td>
<td>10</td>
<td>550</td>
<td>10.0</td>
</tr>
<tr>
<td>10-Hour Night-time Closures</td>
<td>220</td>
<td>2,200</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Lee et al. from I-15 Devore project
Improving General Construction Sustainability: Contracting Alternatives

- Emissions control through contract-required EPA certification of equipment or emissions-reducing retrofit pollution controls.
  - Examples: MassDOT Central Artery, IDOT Dan Ryan, various NY Metro Transportation Agency projects

- Alternative bidding and contracting to encourage reduced GHG and other pollutant emissions
  - A + B (cost plus time) bidding to reduce project duration
  - A + B + C (C = environmental costs) bidding has been proposed (Ahn 2012)
    - Use LCA to estimate emission and energy consumption values for C
Concrete Pavement Construction: Overview

<table>
<thead>
<tr>
<th>Construction Activity</th>
<th>Fuel Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgrade Preparation (grading and finishing)</td>
<td>0.300-0.700 gals/cubic yard</td>
</tr>
<tr>
<td>Base Layer Preparation (hauling, placement, and compaction)</td>
<td>0.400-0.600 gals/ton</td>
</tr>
<tr>
<td>Concrete Mix Production</td>
<td>0.09 gals/c.y.</td>
</tr>
<tr>
<td>Concrete Hauling (short)</td>
<td>0.60 gals/c.y.</td>
</tr>
<tr>
<td>Concrete Placement</td>
<td>0.267 gals/c.y.</td>
</tr>
</tbody>
</table>

(fuel factor source: Skolnik, Brooks, and Oman 2013)
Improving the Sustainability of Concrete Pavement Construction Practices

• Reduce use of virgin materials
  – On-site recycling
  – Two-lift paving

• Minimize construction fuel use and emissions
  – On-site recycling (foundation layers)
  – Match construction equipment and production capacities
  – Single-lift construction
  – Use of roller-compacted concrete (RCC)
  – Use of early-entry saws

• Conserve and protect water resources
  – Collect and re-use concrete wash water
Improving the Sustainability of Concrete Pavement Construction Practices

• Improve initial ride quality (reduce use phase fuel consumption and emissions)
  – Two-lift paving
  – Real-time profile (RTP) measurement and control

• Increase pavement service life
  – Improved construction QA (including dowel alignment)
  – Improved curing materials and practices

• Balance surface friction requirements with tire-pavement noise impacts
On-site Recycling

- Reduced project (material) costs
- Reduced haul costs
- Reduced fuel consumption
- Reduced GHG emissions
- Reduced consumption of resources
- Reduced use of landfills
Considerations for Concrete Recycling

- Many potential applications
  - Base/subbase materials (most common), new concrete and asphalt paving layers, riprap, fill and embankment, many others
- Suitability may be limited by quality of source concrete
  - Pavements vs building demolition debris
  - Materials-related distress (AAR, freeze-thaw)
- Production processes impact product quality
- Stockpile runoff and drainage effluent
Two-lift Paving

• Pros:
  – Potential improvement in initial ride quality, with resulting reduction in use-phase user costs, fuel consumption and emissions
  – Potential for improved use of local and recycled materials

• Cons:
  – Possible increased construction cost (slight)
  – More energy consumed in construction
Use of Roller-Compacted Concrete

• Pros:
  – Significant construction cost savings (primarily materials)
  – Lower fuel consumption and GHGs in construction
  – Adequate ride quality for low-speed pavements

• Cons:
  – Overlay or diamond grinding for higher-speed pavements (added cost, fuel and possibly material
Collect and Re-Use Concrete Wash Water

- Increased costs for collection and removal
- Reduced costs for remediation and clearing drains
- Eliminate localized vegetation kills
- Eliminate pH impact on local surface waters
Real-Time Profile (RTP) Measurement

• What is it?
  – An integrated system of profile data collection sensors and processing software that provides real-time profile feedback to the contractor.

Photo credits: Gary Fick, SHRP2 R06E Contractor
Real-Time Profile (RTP) Measurement

• **Pros:**
  – Better ride quality, lower vehicle operating costs
  – Reduced need for construction corrections
  – Potential reductions in use-phase fuel consumption and GHGs

• **Cons:**
  – Capital cost of equipment

Photo credit: Gary Fick, SHRP2 R06E Contractor
Improved Construction QA

• Examples: Dowel alignment measurement, Super Air Meter (SAM)

• Pros:
  – Potential for increased service life, more time between M&R activities, lower user costs

• Cons:
  – Additional testing costs
  – Equipment costs
Texture to Balance Surface Friction and Noise Concerns

- Surface friction (sustainability through safety, reduced crash rates)
- Minimize generation of tire-pavement noise
- Texture type selection and proper construction prevent premature surface corrections ($) and safety problems

Photos courtesy of ACPA.
Remarks

• Construction has an impact on energy consumed and resulting local and global environmental impacts
• Pavement construction activities offer many opportunities to adopt practices that improve pavement sustainability
• The construction phase is a phase over which engineers and contractors have a great deal of influence
• Achieving specification targets and maintaining good construction quality are keys to reducing life-cycle impact
• Tools are available for sustainable management of pavement construction
Thank You!

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- Please join us at these upcoming webinars!

<table>
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<tr>
<th>Schedule</th>
<th>Webinar Event</th>
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<tbody>
<tr>
<td>Aug 20</td>
<td>#4: Maintenance, Rehabilitation, and End-of-Life</td>
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<tr>
<td>1-3 pm EDT</td>
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<tr>
<td>Sep 9</td>
<td>#5: Use Phase, Livable Communities, and Path Forward</td>
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<tr>
<td>1-3 pm EDT</td>
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