What are Pavements?

• Engineered structures in contact with the earth's surface built to facilitate movement of people and goods
  – Pedestrians
  – Personal vehicles
  – Freight and freight handling
  – Trains and trams
  – Aircraft and spacecraft
Pavement Types

• Asphalt Concrete Surface
  – Granular bases
  – Subgrade
• Concrete Surface
  – Various bases
  – Subgrade
• Surface Treatment
  – Thin sprayed asphalt on granular bases
• Gravel
• Permeable Pavement
  – Open graded asphalt or concrete layers, open granular layers, on uncompacted subgrade
What are Pavements?
What are pavements?
What are pavements?
Conversion of deteriorating road:

1. **Deteriorating road**

2. **Road conversion**

3. **Newly converted road**

4. **2 years post conversion**
Is access to adequate pavement a necessary for good quality of life?

• Safe, functional, reliable, economical access to:
  – Employment
  – Education
  – Healthcare
  – Markets for your goods and services
  – Purchase goods and services
  – Social interaction
  – Recreation

• Independent of mode of transport

• Do we have too many, just right, not enough roads and other types of pavement?
Why Have Pavements?
Who are the stakeholders and what do they want?

- User
- Owner
- Builder
- Others?
Who owns and manages California public pavement?

State and local government spending on pavement about equal.

How many cities and counties in CA?
The vehicle operating costs of rough pavements

\[ y = 6.613e^{0.0005x} \]
\[ R^2 = 0.9266 \]

\[ y = 5.7421e^{0.0004x} \]
\[ R^2 = 0.9602 \]

\[ y = 4.9391e^{0.0004x} \]
\[ R^2 = 0.9598 \]

\[ y = 4.0169e^{0.0004x} \]
\[ R^2 = 0.9488 \]

\[ y = 1.9384e^{0.0004x} \]
\[ R^2 = 0.9197 \]
Pavement Life Cycle

• Infrastructure Life Cycle
  – Deployment
  – Maintenance
  – Rehabilitation
  – Reconstruction (Abandonment? Reuse?)

• Goal at all stages is greater efficiency
  – how is efficiency defined?
Where Are We Now?

<table>
<thead>
<tr>
<th>Years</th>
<th>Infrastructure</th>
<th>Pavement Research</th>
</tr>
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<tbody>
<tr>
<td>1948-1980</td>
<td>Deployment</td>
<td>Materials, design</td>
</tr>
<tr>
<td>1970-2050</td>
<td>Management</td>
<td>Scheduling of maintenance &amp; rehab</td>
</tr>
<tr>
<td>1995-2025</td>
<td>Reconstruction</td>
<td>Reuse of materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reconstruction, Traffic Considerations,</td>
</tr>
<tr>
<td>2010-2050</td>
<td>Sustainability</td>
<td>Quantification &amp; approaches</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Additional functionality</td>
</tr>
</tbody>
</table>
System Boundaries for Pavement Thinking

- Materials
  - Pavement
  - Pavement Network

- Transportation Facility Network

- Sustainable Transportation Infrastructure System
Natural water, air and thermal cycles here?

What if all this was fully permeable asphalt pavement?

What is most of this pavement being used for?
What Causes Pavement Distress?

• Traffic
  – Heavy vehicles only
  – Load, tire pressure; 4th power law

• Environment
  – Asphalt: heat, temperature = oxidation
  – Concrete: heat, temperature changes = shrinkage, curling
  – All pavement: water in layers beneath surface

• Interaction of traffic/environment, construction quality, materials, design
Loads, axles, tires
Australian for “truck”
Local Government Pavement Design

- **Some agencies**
  - Standard cross sections and materials
  - Little or no construction inspection (particularly compaction)
  - No money for testing and analysis

- **Other agencies**
  - Design for particular traffic, environment, soils
  - Good construction inspection
  - Testing and analysis (is there a net cost savings?)

- **Standard specifications and design methods**
  - Greenbook (mostly in S. California)
  - Use of state specifications (much of N. California, joint powers financing, federally funded projects)
  - Use of consultants
What are Pavements Made Of? and will this change?

- Most pavements are made of engineered soils and processed rock
- Asphalt concrete is 85% aggregate by volume; 10% asphalt; some plastic, rubber modifiers
- Portland cement concrete is 70% aggregate by volume; 11% portland cement; up to 25% of cement replaced by fly ash; some steel

- Nearly all of these materials can be perpetually recyclable into the same infrastructure
Fifty-Year Aggregate Demand Compared to Permitted Aggregate Resources

The pie diagrams show the projected 50-year demand for aggregate as of January 2009 compared to currently permitted aggregate resources (in short tons). The 50-year demand for a particular study area is graphically represented by one of four pie diagram sizes. Study area boundaries are shown on the index map of aggregate studies (lower left).

* Permitted aggregate resources (also called aggregate reserves) are those portions of the resources for which local/county agencies (counties and cities) have issued mining permits. Non-permitted aggregate reserves information is given in each aggregate study report. See accompanying text for references to these reports.
Pavements: will the demand for them increase or decrease?

- Streets, roads, highways, freeways, parking
- Railroads, switching yards, intermodal yards
- Runways, taxiways, aprons
- Land-side port facilities, container yards
- Bike paths, sidewalks, other hardscape
- Permeable pavement for stormwater management
FHWA Pavement Sustainability Reference Document

- State of the knowledge on improving pavement sustainability
- Search on “FHWA 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
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
How do Pavements Contribute to California GHG Emissions?

- Out of 459 MMT CO2e in 2013
  - On road vehicles 155 MMT
    - Optimizing smoothness, texture, deflection energy on state network reduces by 1% of this
    - Hauling of pavement materials?
  - 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

Possible Pavement Reductions MMT/year
- Rolling resist to optimum 1.5
- Cement use 50% 0.2
- Asphalt use 50% 0.7
- Demo, oil, stone haul 10% 0.6
- TOTAL 2.9

http://www.arb.ca.gov/cc/inventory/data/data.htm
Pavement Rolling Resistance

• Roughness (models available)
  – Measured with International Roughness Index (IRI)
  – Dissipates energy through suspension

• Macrotexture (models available)
  – Dissipates energy through tire distortion

• Deflection (models under development)
  – Theory: dissipates energy through deflection of viscoelastic pavement materials (HMA)
  – Theory: larger deflection and viscoelasticity results in vehicle always running uphill
What is most important in terms of improving pavement environmental impact?

• For highest traffic segments:
  – On road vehicles and pavement/vehicle interaction most important

• On lower traffic segments:
  – Materials (mostly) and construction most important

• For all:
  – Make same materials last longer through better construction, maintenance and design
Three Easiest Strategies to Improve Sustainability of Pavement Materials & Construction

• **Improve durability with construction compaction specifications**
  – 1% change in air-voids = about 10% change in cracking life
  – Warm mix to improve compaction or reduce mixing temperature
  – Strict compaction requirements
  – Caltrans has reduced typical air-voids from about 11% to 7% since mid-90s

• **Reduce cement and cementitious content in concrete**
  – Change specifications to allow:
    • Reduced cement content
    • Cement replacement with supplementary cementitious materials (SCM)
    • Inter-ground limestone

• **Timely preservation and maintenance before gets too bad**

• **Some other things to do:**
  – Use reclaimed asphalt pavement (RAP) and tire rubber in asphalt mixes, use reclaimed building demolition for bases
Environmental Product Declaration (EPD)

Environmental Facts

Functional unit: 1 metric ton of asphalt concrete

<table>
<thead>
<tr>
<th>Parameter</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%

Example LCA results

Adapted from N. Santero; photo S. Muench
What’s happening in Davis (both city and campus) right now

• Several years of almost no road and bike path repair
• Many years of underfunding, badly damaged roads that should have had preservation
• Bus routes and trucks
• Pavement management system used to identify roads, maximize ben/cost for constrained budget
Treatments being used

• Rubberized asphalt mill and fill
  – Put on cracked asphalt
• Cold in-place recycling
  – Recycle and stabilized top 75 mm, then overlay
• Full-depth recycling
  – Similar to CIR but all the asphalt, because all cracked
• Rubberized cape seals
  – Where cracking has just started on collectors
• Slurry seals
  – Where cracking has just started on residential routes