What’s Your Pavements’ Mileage?

LCA-PLUS for Sustainable Development of Our Nation’s Pavement Network

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Why Pavement-Vehicle Interactions Matter?

Accounts for 82% of emissions:
- Pavement Vehicle Interaction: 72%
- Others: 10%

US consumes 174 billion gallons of fuel per year on highways / 10% consumed in California (2010):
  - 1% CA saving ≈ 9.1 million barrels of crude oil per year
  - ≈ $520 million per year
  - ≈ 2 million tons of CO_2 per year

An Estimate

• Rough Estimate of Extra-Fuel Consumption:
  – Consider your State
  – 6,750–8,500 gal/lane-mile/year (!)
  – Equivalent: 40–50 Tons CO2/mile/year (!)

• Example California: For the 49,000 CALTRANS lane-miles ALONE:
  ~ 2 Million Tons CO2/year

• An opportunity for substantial CO2 reductions, in EVERY State.
• This is **not** about **Concrete vs. Asphalt**, this is about unleashing opportunities for Greenhouse Gas Savings.

• Method in place: Pavement-Vehicle Interaction: Roughness + Deflection

• Life Cycle Assessment of…
  — STATUS QUO: Network analysis for the US
  — FUTURE POTENTIAL: Possibilities for Improvement

• Moving forward together…
Method in Place

The Good Practice

http://web.mit.edu/cshub
Model-Based Assessment of Pavement Vehicle Interaction (PVI)

Pavement Deflection

MIT-Model

Pavement Roughness

MEPDG+HDM4

Structure and Material
PVI-Roughness Model / (similar to J. Harvey/UCPRC)

- Inputs:

- HDM-IV Model:

(*) Zabaar and Chatti (2010)

(*) MEPDG Output- 90% reliability level
Roughness is only Half of the PVI Picture

PVI-DEFLECTION MODEL

- Simplest pavement deflection model:
  - Approach:
    - Calibrate/FHWA
    - Validate/FHWA
    - Scale Fuel Consumption from Gradient Force
  - Input:
    - Pavement stiffness $E$
    - Pavement Thickness $h$
    - Substrate stiffness $k$

\[ \eta = x - Vt \]

The current state of the US Road Network: “mileage”

STATUS QUO: WHAT IF BUSINESS AS USUAL

Moving beyond “BaU”
FHWA/LTPP Monitored Sections

Total of 5643 sections: 1079 rigid, 4564 flexible

Data used:
- Top layer modulus $E$
- Subgrade modulus $k$
- Top layer thickness $h$
- Loading condition $q$
- Roughness
- Traffic Volume (AADT, AADTT)
Roughness-Induced Extra-Fuel Consumption

The difference is statistically insignificant

t-test: 4.8% difference
Current State (statistical evaluation) of Extra-Fuel Consumption due to PVI

50 yr PVI GHG Emissions of Two Pavement Scenarios Relative to a “Flat” Pavement

40 – 50 tons CO2 per lane-mile/Year

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Fuel Consumption (Million liters/km)</th>
<th>GHG Emissions (Mg CO₂e/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>6,750 gal/lane-mi/yr</td>
<td>12,000</td>
</tr>
<tr>
<td>Asphalt</td>
<td>8,500 gal/lane-mi/yr</td>
<td>18,000</td>
</tr>
</tbody>
</table>

(Two-lane kilometer section design from Athena (2006); AADT=15,000; AADTT 1,500; AC maintenance at years: 17, 28, 38, 47; PCC maintenance at years 20, 40; 95% confidence)
The US uses 174 billion gallons of fuel per year on highways. Excess fuel consumption of 740 million gallons per year.
Opportunities for Improvement

Moving beyond Business as Usual

Designing for the Future
Can we do better? – Yes, we can!

- Pavement Deflection
- Pavement Roughness

2011 MIT-Model

Structure and Material

SYNERGY

Pavement Design
HOW TO MOVE BEYOND BUSINESS AS USUAL?

INPUT:
- Structure
- Materials
- Traffic
- Climate
- Design Criteria

Pavement Design

OUTPUT:
- E(t)
- IRI(t)
- Maintenance
- Traffic-evolution

Structurally Sound Design

MEPDG, CAL-ME,…

Sustainable Design

OUTPUT:
- Comparative Design
- Design Alternatives

OUTPUT:
- CO2eq(t)
- Costs

Life Cycle Embodied + Use
Proof of Concept
State-of-the-Art Pavmt Design

• Input: MEPDG*

<table>
<thead>
<tr>
<th>Concrete and Asphalt Pavements</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design life (years)</td>
<td>50</td>
</tr>
<tr>
<td>Location</td>
<td>Columbus, Ohio</td>
</tr>
<tr>
<td>AADT (vehicles/day)</td>
<td>15,000</td>
</tr>
<tr>
<td>AADTT (trucks/day)</td>
<td>1,500</td>
</tr>
<tr>
<td>Traffic growth</td>
<td>4%</td>
</tr>
<tr>
<td>Total Lanes</td>
<td>2</td>
</tr>
<tr>
<td>Lane width (m)</td>
<td>3.7</td>
</tr>
<tr>
<td>Terminal IRI (in/mile)</td>
<td>172</td>
</tr>
</tbody>
</table>

• Output: MEPDG*

| Concrete Section (JPCP)**     |
|-------------------------------|--|
| PCC                           | 10” |
| Non-stabilized                | 6”  |
| Subgrade                      | Semi-infinite |

| Asphalt Section***            |
|-------------------------------|--|
| Flexible                      | 10” |
| Non-stabilized                | 10” |
| Subgrade                      | Semi-infinite |

+ E(t,T), IRI(t), k, h, Traffic,…

* MEPDG = Mechanistic Empirical Pavement Design Guide
** JPCP transverse cracking dominates 50yr design
*** IRI, Permanent deformation (AC only) dominates
Roughness & Deflection Induced Emissions are EQUALLY important

- **Concrete**
  ![Graph of GWP / Mg CO2e/km vs Pavement Age / months for Concrete]

- **Asphalt**
  ![Graph of GWP / Mg CO2e/km vs Pavement Age / months for Asphalt]

- Both are of similar order of magnitude and need to be taken into account
REDUCTION OF CO2 BY DESIGN

- Design Options For 10” Pavement Structures

LCA Shows:

- STATUS QUO:
  5,000/tons CO2/50yr.

- Reduce to:
  1,000/tons/CO2/50yr
  (for new/reconstruction)
Looking Forward

- This is **not** a matter of concrete vs. asphalt; this is about science-based engineering solutions for sustainable pavement systems.

- **We are inviting you to join our efforts in the CSHub@MIT**
  - Carry the information into your States, to your local DOTs
  - Become a Champion for your State/County to (1) evaluate the mileage of your pavement system.
  - …and (2) to help identify possible improvement scenarios that substantially reduce the environmental footprint: GET MORE MILEAGE OUT OF YOUR PAVEMENT SYSTEM

  - And Costs… !

Come and join us for Industry Day at MIT
September 27, 2012 [http://web.mit.edu/cshub](http://web.mit.edu/cshub)