Vehicular Rolling Resistance vs. Pavement Type – A Practical Viewpoint

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National Center for Asphalt Technology

ACAF Annual Meeting
Outline

• Background
• Pavement life-cycle
• Rolling Resistance
• Pavement properties effect on rolling resistance
• Current studies
• Summary
Background

• Common interests worldwide
  – Environmental stewardship
  – Saving money
Recent Focus

Extraction
Production
Transport

Traffic Delay
On-site Equipment

Rolling Resistance
Carbonation
Lighting
Albedo
Leachate

Traffic Delay
Extraction
Production
Transport

Traffic Delay
Salvage
Transport...

Materials

Construction

Use

End-of-Life

Maintenance,
Preservation
Rehabilitation

National Center
for Asphalt Technology
NCAT
at Auburn University
Factors Effecting Fuel Efficiencies
Total Driving Resistance

Vehicle Driving Resistance
Vehicle Aerodynamics
Vehicle Propulsion

Inertial
Gravitational
Engine
Auxiliary Equipment

Body Air
Tire Air

Tire/Road Rolling

Bearing
Transmission
Suspension

(Courtesy of Tom Harman)
Rolling Resistance

- Force required to keep an object (i.e. wheel or tire) moving
  - Energy losses on pavement surface
  - Internal friction loses
  - Energy losses from tire deformation
(Beauving, 2004)
Objectives

- Literature review
- Critical review of MIT Report *Model-Based Pavement-Vehicle Interaction Simulation for Life Cycle Assessment of Pavements*
Literature Review: Factors Affecting Rolling Resistance
Factors
Only Consider Pavement

- Review of 34 papers/reports on pavement’s effect on rolling resistance
- Findings and limitations of each study addressed
- Properties considered
  - Pavement texture
  - Pavement smoothness
  - Pavement deflection/pavement type
Challenges of RR Research

• Interaction of factors makes it difficult to do single property studies
• Slight changes in tire pressure, air temperature, wind speed, etc... could alter RR of vehicle
Texture

<table>
<thead>
<tr>
<th>Texture Range</th>
<th>Texture Wavelength (mm)</th>
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<tbody>
<tr>
<td>Mega-</td>
<td>50 - 500</td>
</tr>
<tr>
<td>Macro-</td>
<td>0.5 – 50</td>
</tr>
<tr>
<td>Micro-</td>
<td>&lt; 0.5</td>
</tr>
</tbody>
</table>

- **Unevenness**: Amplification ca. 50 times
- **Megatexture**: Amplification ca. 5 times
- **Macrotexture**: Amplification ca. 5 times
- **Microtexture**: Amplification ca. 5 times

Reference length:
- "Short stretch of road"
- "Tyre"
- "Tyre/road contact patch"
PIARC Pavement Surface Characterizes
(Scale: μm, $10^{-6}$ m)

<table>
<thead>
<tr>
<th>Texture</th>
<th>Microtexture</th>
<th>Macro</th>
<th>Mega</th>
<th>Roughness</th>
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<tbody>
<tr>
<td>Ride Quality (IRI)</td>
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<tr>
<td>Rolling Resistance</td>
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<tr>
<td>Vehicle Wear</td>
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<tr>
<td>In-Vehicle Noise</td>
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<tr>
<td>Tire-Pavement Noise</td>
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<tr>
<td>Splash &amp; Spray</td>
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<tr>
<td>Wet Weather Friction</td>
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<tr>
<td>Dry Weather Friction</td>
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<tr>
<td>Tire Wear</td>
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</tbody>
</table>

Key:
- **Bad Impact**
- **Good Impact**
Walter and Conant, 1974

- Energy losses in tires
- Empirical testing
- Most losses were related to tires, but some related to roadway
- Little difference between flexible and rigid pavements
- No structural or material characterization

<table>
<thead>
<tr>
<th>Surface</th>
<th>Rolling Resistance, lb/1000 lb vehicle weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>10 – 20</td>
</tr>
<tr>
<td>Asphalt</td>
<td>12 – 22</td>
</tr>
<tr>
<td>Dirt</td>
<td>25 – 37</td>
</tr>
<tr>
<td>Sand</td>
<td>60 – 150</td>
</tr>
</tbody>
</table>
L.W. Deraad, 1978

- 6 different surfaces
  - Polished and hard concretes (no tining)
  - Asphalt with rounded aggregates, slurry seal, or angular aggregates
- Textural differences accounted for between 8 and 30 percent differences in rolling resistance
- Increased texture, increases RR
- Textural differences between concrete and asphalt, slow speeds
Bester, 1984

- Studied effect of pavement type and roughness on rolling resistance
  - Experimental coast down method
- Pavement type had little effect
- Smoother roads had lower rolling resistance values
- Little characterization of materials or pavements took place.
- Smoothness range: 0.73 – 3.53 m/km
Zaniewski, 1989

- Concrete vs. asphalt
  - Asphalt included asphalt surface treatments and new asphalt
  - Only smooth pavements considered in study
  - Statistically no meaningful data were produced
- Pavement structure was not characterized.
Sandberg, 1990

- Testing parameters
  - Volvo 242
  - Twenty road surfaces
  - Three speeds
- Macrotexture = 7% change in fuel economy
- Smoothest to roughest road = 11% change in fuel economy
Descornet, 1990

- Belgian Road Research Center
- Different textural levels
- 37 different test sections
- Megatexture could influence fuel economy by 9 percent
- No statistical analyses were completed
DeGraaff, 1999

- Passenger cars
- No difference between asphalt and concretes
- No structural characterization completed
National Research Council of Canada, 2000-2006

- Study conducted in 3 phases
- First two studies showed 4-11% and 2% savings on concrete
  - These two phases shown to be erroneous
- Phase 3 showed 0-0.6% savings on concrete
Netherlands Pavement Consultants, 2002

- Used VEROAD software to predict energy dissipation
- Differences between pavements were modeled in different seasons
- Overall, it was expected that 0.05 percent additional fuel savings might come from driving on concrete
Amos, 2006

- Missouri DOT study using dumptrucks before and after rehabilitation
- 130 in/mile to 60 in/mile
- 2.46% improvement in fuel economy
Zaabar and Chatti, 2011 - 2012

• 5 Different vehicles
• Asphalt smoothness values varied more than PCC
  – Resulted in few AC sections which could be incorporated into analysis
• Concrete was more fuel efficient on hot days when large trucks were driving slowly
• Testing only conducted in summer
MIT Work

• Concrete Sustainability Hub

• Focus:
  – Pavement Vehicle Interaction
  – Develop models to show the impact of pavement stiffness on rolling resistance
  – 4+% savings on concrete roads
Methodology

• Chapter by chapter breakdown of report
• Comment on work from the perspective of pavement design
What to Understand about This Work

• There is little transparency in this work
  – It is difficult to ascertain how the model was developed and what data were used to validate and calibrate the model

• The model defies conventional flexible pavement design philosophies
  – Subgrade treatment
    Term definitions and appropriateness, k
  – Infinite beam
Pavements and Tires

- Deformation = energy lost
  - Tire and Pavement Type
- Pavement stiffness >> tire stiffness
  - 2-3 orders of magnitude
- Energy lost from pavement deflection << energy lost from tire deflection
What Data Are Used?

• “For the purpose of this study, all available FWD datasets have been selected from pavements designed to carry highway traffic.” (p. 43)

• Calibration
  – 1,079 rigid pavements
  – 4,565 flexible pavements
Where Do Data Come From?

- Locations (# = sections per state/location)
  - Arizona – 17
  - Ontario, Manitoba, Michigan, Illinois, Iowa – 2
  - Washington, Kansas – 3
  - Utah, Texas, Nevada, Minnesota, – 1
Data Usage

• Functional Classification
  – Rural Principal Arterial – Other: 19 (ADTT: 219 for 10 roadways)
  – Rural Principal Arterial – Interstate: 15
  – Urban Principal Arterial – Other Freeways or Expressways: 2
  – Urban Principal Arterial – Other: 2
    Preventative maintenance

• Type of section:
  – 27 of SPS— not representative of US practice as a whole
Accuracy of Model

• “It is observed that the model predictions match the experimental data to an acceptable accuracy...” (p. 58)
  – Validation Study (Table 4.4)
    Top-layer modulus average error: 7.2%
    Top-layer modulus standard deviation: 13.3%
    Subgrade modulus average error: 12.3%
    Max: 34%
    Subgrade modulus standard deviation: 9.0%
Network Level Analysis

• “Using the distributions of E, k, and h, Monte Carlo simulations are performed to determine an estimate for average and standard deviation of pavement deflection within the network.”
  – Distributions of E, k, and h were developed from LTPP database
    1079 concrete
    4564 asphalt
## Thickness

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Average Thickness, in</th>
<th>Standard Deviation, in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible</td>
<td>5.9</td>
<td>1.96</td>
</tr>
<tr>
<td>Rigid</td>
<td>9.44</td>
<td>1.18</td>
</tr>
</tbody>
</table>
Bienvenu and Jiao, 2013

• Concrete 3.2 to 4.5 percent more fuel efficient than asphalt
  – Asphalt: 9.25 inches (0.75 OGFC on surface), 5 inches of limerock base, and 12 inches of stabilized subgrade
  – Concrete: 13 inches plain jointed portland cement concrete, 1 inch of asphalt concrete, over 4 inches of asphalt treated base.
Bienvenu and Jiao, 2013

- Study has been used to claim field validation of MIT work
- Shows MIT model is overestimates savings

Table 6.2: Calculated advantage/disadvantage of a concrete pavement to an asphalt pavement for a range of top layer modulus and thickness ratios in percent. Values above zero represent cases where concrete pavements perform better than asphalt pavements in regards to PVI.
Summary

• We know that smoothness and texture have an effect of fuel economy
• We are still trying to figure out pavement deflection
  – Difficult to pull one property (stiffness) out when texture and smoothness also affect it
  – Studies have given us conflicting results
Thank you!

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