The State-of-the-Art of Quiet Highways

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Noise control at the source (focused on pavement) – reduce need for barriers

? Noise generation mechanisms
(using Sandberg’s seminal paper, Acoustical Soc. of Japan, 1999)

? Current implementations of quiet highway technology

? Research for better solutions
Highway texture and tread block induce vibration of the tire carcass. Affected by texture and tire construction. Important at low frequency.
Tread Vibration

- Occurs at contact patch, tread blocks act as little loud speakers
- Affected by pavement texture and tread block materials
- Important at high frequency.
Tread Oscillation

- Due to tangential strain on tread blocks and impact of pavement
- Affected by load, pavement texture and tread compounds
- Important at high frequency

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Tread Adhesion

- Causes tread and carcass vibration
- Depends on the adhesive forces between the tread and the pavement
- Important at low and high frequency

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Stick-Slip

- Causes squeaks and squeals – high frequency
- Local radiation
- Depends on load and tread/pavement adhesion

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Air Pumping

At entrance to contact patch
Dependent on tread passages and pavement porosity
Important at high frequency

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Air Pumping

- Important at contact patch exit
- Dependent on tread pattern and pavement flow resistivity
- High frequency
Acoustical Hologram

From Kim and Bolton

21 mph

183 Hz

Radiation from contact patch

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Carcass Radiation

- Source amplification, low frequency
- Depends on carcass construction
- Important to sideline radiation
Acoustical holography

- Acoustical hologram of a rolling tire (from *Kim and Bolton*)
- Speed 21 mph
- Frequency 128 Hz (low frequency)
Sidewall Radiation

? Source amplification
? Important to sideline radiation
? Depends on tire construction
Horn Effect

Amplification effect by the horn

- Source amplification of air pumping and tread vibration
- Dependent on width of tire and pavement acoustical characteristics
- High frequency, directive effect

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Helmholtz Resonance

- Source amplification near entrance and exit of contact patch
- High frequency effect
Channel Resonance

Pipe resonances in channels formed in the tyre foot-print:

- Source amplification mechanism
- The organ pipe resonance effect
- Mid frequency
Cavity Resonance

- Lightly damped resonance near 250 Hz
- Very evident both internal to the vehicle and externally

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Quiet Pavement Literature

- PCC – porous concrete, exposed aggregate concrete, tining concepts
- Asphaltic concrete – porous asphalt, open-graded asphalt, rubberized asphalt, twin-lay
? Straightforward changes to traditional PCC
  ? Avoid uniform transverse tining
  ? Try longitudinal tining if possible
  ? Brushed concrete with 1 mm depth

? Exposed Aggregate – 5-8 dB quieter but the challenges are construction (8 mm aggregate) and maintenance

? Porous Concrete – acoustically excellent, Purdue is working on construction and durability
Quiet Asphalt Europe

? Porous Asphalt
  ? 20%+ porosity, various aggregate sizes
  ? Durability OK
  ? Lost noise reduction effect due to plugging

? Twin-lay
  ? 2 layers
  ? Durability OK
  ? Self cleaning from tire pumping

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Twin-Lay

- Top layer 6-10 mm aggregate
- Second layer 15-20 mm aggregate
- 20-25% porosity

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Study done in the Netherlands (*Larsen and Bendtsen, Inter-Noise 2001*)

NPV in euros for 3 roads, 3 noise mitigation solutions (twin-lay, barriers, home insulation)

<table>
<thead>
<tr>
<th></th>
<th>City street</th>
<th>Ring road</th>
<th>Freeway</th>
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<tbody>
<tr>
<td><strong>Asphalt</strong></td>
<td>30 year cost</td>
<td>296,000</td>
<td>360,000</td>
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<td></td>
<td>dB reduction</td>
<td>5</td>
<td>6</td>
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<tr>
<td></td>
<td>NEF reduction</td>
<td>103.2</td>
<td>153.2</td>
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<td></td>
<td>Cost/db/dwelling</td>
<td>89</td>
<td>150</td>
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<td></td>
<td>Cost/NEF</td>
<td>2,870</td>
<td>2,350</td>
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<td><strong>Barrier</strong></td>
<td>30 year cost</td>
<td>–</td>
<td>1,335,000</td>
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<td></td>
<td>dB reduction</td>
<td>–</td>
<td>0–12 (average: 3.9)</td>
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<td>NEF reduction</td>
<td>–</td>
<td>75.5</td>
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<td>Cost/db/dwelling</td>
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<td>Cost/NEF</td>
<td>–</td>
<td>17,680</td>
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<td><strong>Insulation</strong></td>
<td>30 year cost</td>
<td>2,685,000</td>
<td>1,607,000</td>
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<td>dB reduction</td>
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<td>NEF reduction</td>
<td>99.0</td>
<td>170.0</td>
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<td>Cost/db/dwelling</td>
<td>449</td>
<td>448</td>
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<tr>
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<td>Cost/NEF</td>
<td>27,120</td>
<td>9,450</td>
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</table>
“Rubberized” highway

- Rubber as part of the binder
- Seems to affect tread vibration mechanisms
- Durability OK

“Poro-elastic” Concepts

- Small proof of concepts tests only
- Affects tread vibration and air pumping and horn effect mechanisms
Georgia and Florida
  ? Utilize open-graded asphalt for noise and splash control
  ? 1-3 dB better than dense graded asphalt

Arizona
  ? Conducting studies of rubberized asphalt pavement

California
  ? Sacramento – rubberized highway (3-4 dB)
  ? Open-graded asphalt
  ? Advanced PCC

Wisconsin
  ? PCC tining – reduced annoyance
1. Measurement and Evaluation of Roadside Noise Generated by Transit Buses, E. Mockensturm, B. Kulakowski; The Pennsylvania State University

2. Study of the Performance of Acoustic Barriers for Indiana Toll Roads, L. Mongeau, J.S. Bolton; Purdue University

3. Development of Porous, Modified Asphalt Mixes for Noise Control Applications, R. McDaniel, J. Olek; Purdue University

4. Fundamentals of Tire/Road Interaction Noise, J. S. Bolton, J. Olek, R. Bernhard; Purdue University
5. Development of Quiet and Durable Porous Portland Cement Concrete Paving Materials, J. Olek, W. J. Weiss; Purdue University

6. Concrete Mixtures that Incorporate Inclusions to Reduce the Sound Generated on Portland Cement Pavements, J. Olek, W. J. Weiss; Purdue University / B. Magee; University of New Hampshire

7. Tire/Pavement Interaction Noise Generation and Radiation Mechanisms, C. Burroughs; The Pennsylvania State University
8. Investigation of Novel Acoustic Barrier Concepts, Phase I: Concept Development and Preliminary Evaluation, L. Mongeau, J.S. Bolton; Purdue University

9. A Guide for the Construction of Reduced Noise Pavement, R. Bernhard; Purdue Univ. & R. Wayson; Univ. of Central Florida

10. Identification of Laboratory Techniques to Optimize Superpave HMA Surface Friction Characteristics, R. McDaniel, NCSC, & B. Coree, Iowa State Univ.
To understand fundamental generation mechanisms of tire/road interaction noise

? Construct a test apparatus to measure tire and pavement responses due to a rolling tire on a realistic pavement

? Examine tire and pavement behavior to determine the impact of tire and pavement design combinations on noise generation

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? Two rolling tires

? Realistic pavement on the exterior of the drum

? Motor rated for 60 hp for braking capability

? Speeds up to 30 mph

? Loading capacity up to 1000 lbs

? Drum diameter of 12 feet

? Pavement depths of either 8” or 16”
TPTA - Status

Tire/Pavement Test Apparatus (TPTA) was delivered in July.

Commissioning is almost complete.
TPTA Pavement

- Smooth surface almost complete
- Porous concrete samples ready
- Tined concrete being cast

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Conclusions

Solutions (1-4 dB) with traditional pavement:
- longitudinal tining on PCC
- open-graded asphalt

5-10 dB should be possible when we resolve the challenges of
- construction
- safety (friction)
- durability

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