Integrating Pavement Life-Cycle Cost Analysis and Life-Cycle Assessment for Multi-criteria Decision Making

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Outline

• The climate policy perspective

• LCCA and LCA

• Integrating LCCA and LCA

• Policy levers
The importance of transportation in climate policy making

• International: ~25% of GHG emissions
• California: ~40% of GHG emissions

• Transport policy typically focuses on:
  Vehicle efficiency, Alternative fuels, Travel Reduction

• Most work has focused on fuel consumption, for which short-term fuel demand elasticity has been low, and technologies have been relatively slow to make an impact

• The infrastructure supply-chain has also been shown to contribute significantly to emissions
Outline

• The climate policy perspective
  • Some completed transportation LCA work
  • Climate policy prioritization

• LCCA and LCA

• Integrating LCCA and LCA

• Policy levers
LCA for US passenger transportation

Source: Chester & Horvath (2009)
LCA for US freight transportation

Source: Facanha & Horvath (2006)
Within-Vehicle Class Consolidation on SR-13

Years between overlays

<table>
<thead>
<tr>
<th>Years</th>
<th>Status Quo</th>
<th>After Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
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<tr>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
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</tr>
</tbody>
</table>

GHG ($10^3$ kg CO$_2$ eq./yr)

<table>
<thead>
<tr>
<th>Status Quo</th>
<th>After Shift</th>
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</thead>
<tbody>
<tr>
<td>Overlay</td>
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</tr>
<tr>
<td>Tailpipe</td>
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</tr>
<tr>
<td>30</td>
<td>140</td>
</tr>
<tr>
<td>51</td>
<td>96</td>
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</table>

$SO_2$ (kg/yr)

<table>
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<tbody>
<tr>
<td>Overlay</td>
<td>Tailpipe</td>
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<tr>
<td>55</td>
<td>93</td>
</tr>
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</table>

$PM_{2.5}$ (kg/yr)

<table>
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<td>8</td>
<td>29</td>
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<tr>
<td>13</td>
<td>21</td>
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</table>

Source: Sathaye, Horvath & Madanat (2010)
Outline

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• Policy levers
Climate policy prioritization in California

• Total achievable GHG reductions

• Cost-effectiveness:
  – $ costs per GHG reductions
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Life-Cycle Cost Analysis

• Agency costs
  – reconstruction
  – maintenance (e.g. overlays)

• Social costs
  – traffic delays
  – vehicle wear
  – accident costs
  – environmental costs
    • e.g. price per ton of carbon emissions
Optimization of costs

• objectives:
  agency costs
  user costs
  user benefit

• constraints:
  agency budget
  minimum pavement condition
Life-Cycle Assessment

- Maintenance Supply Chain
- Fuel consumption resulting from roughness
- Delay

Emissions → Concentration → Exposure → Intake → Dose → Health Effects

Quantifying environmental impacts

**Table 2. Air Pollution Damages Costs by Impacted Region**

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<tr>
<th>Pollutant name</th>
<th>Average cost (2003 US$/t)</th>
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<tr>
<td></td>
<td>Urban</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>6,144</td>
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<tr>
<td>Nitrogen oxides</td>
<td>156</td>
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<tr>
<td>Sulfur dioxides</td>
<td>170</td>
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<tr>
<td>Carbon monoxide</td>
<td>2</td>
</tr>
<tr>
<td>Lead</td>
<td>3,955</td>
</tr>
<tr>
<td>VOC</td>
<td>1,960</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>—</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>—</td>
</tr>
<tr>
<td>Methane</td>
<td>—</td>
</tr>
</tbody>
</table>

Source: Kendall, Keoleian & Helfand (2008)
Indexes

- Can provide a communicable framework (e.g. LEED)

- Life-cycle emissions vary by time and location
  - Deterioration is an uncertain process
  - Variability in fuel consumption across fleet
  - Traffic networks differ

- Equity Concerns

- Point systems oversimplify impacts
  - Higher ratings can result in higher impacts
Outline

• The climate policy perspective

• LCCA and LCA

• Integrating LCCA and LCA
  – Multi-objective optimization
  – Question marks

• Policy levers
Multi-objective Optimization of costs and GHGs

- objectives:
  - agency costs
  - user costs
  - user benefit

- constraints:
  - agency budget
  - GHG emissions
Using a Pareto optimal frontier

Example policies
Outline

• The climate policy perspective

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  – Multi-objective optimization
  – Question marks

• Policy levers
Approach to pavement management systems

• Single-facility level vs. Network-level
  • Heterogeneity of LCA results suggest importance of budget allocation issues
Time horizon

• Discount rates
  – Investment, Opportunity Costs
  – Social discount rate (IPCC)

• Period
  – Pavement functional design life
  – Environmental regulatory objectives
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• Policy levels
What level of government for multi-criteria decision making?

• Pavement management is conducted at multiple levels

• Implementation of pollution policy was developed at the city, regional and state levels in the US

• Environmental policy is mandated at the state or federal level in many countries

• GHG policy is entering the international level

• Highlights the need for communication across government levels
Important Concepts

• Cost effectiveness and total GHG reductions
• No-regrets options

• Potential problems with blanket indexes
• Pareto optimal frontier for multi-criteria decision making

• Communication is necessary across multiple levels of government