Integration of LCA into Pavement Management Systems

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Pavement Management Alternatives

Do nothing

- Roughness
- Rolling Resistance (Watanada 1987)
- Fuel Economy (Zaabar and Chatti 2011)
- Wear/ Tear (Barnes and Langworthy 2004)
- Deterioration Rate (Paterson 1987)

Resurfacing

- Roughness
- Material and Construction Costs
When to resurface?

• Trigger roughness examples
  – 2.7m/km: currently used by Caltrans
  – 3.5m/km: Caltrans former policy, used by WSDOT

• Are the trigger roughness values used in practice optimal for LCC minimization?
  – No; based on subjective criteria

• Should all roads be treated the same?
  – Universal trigger vs segment-specific trigger
Pavement Resurfacing Optimization

• Given roughness progression model, maintenance effectiveness, cost of resurfacing, user cost models, determine:
  – Frequency of resurfacing (or trigger roughness), and
  – Overlay thickness

• **Objective**: minimize life cycle costs (LCC) over a finite horizon
  – LCC include all agency and user costs
Saw-tooth trajectory of pavement roughness

Li & Madanat (2002)
Pavement GHG emissions (LCA)

• Sources of GHG emissions: mainly from the use phase and the maintenance (resurfacing) phase

![Bar chart showing sources of GHG emissions.](Source: Santero & Horvath (2010))
Tradeoffs for Emissions
Overlay Intervals: Effects on LC Costs and LC Emissions

Li and Madanat, 2002 Result
Pareto Frontier
Example: Two-Lane Rural Rd
Network-Level Resurfacing Optimization

- Managing infrastructure systems to minimize environmental and economic impacts
  - Network-level optimization for LCC
  - Multi-criteria optimization for pavement maintenance

Source: http://commons.wikimedia.org/wiki/File:California_state_highways.svg
Pavement Resurfacing Optimization at Network-Level

• Bottom-up solution method preserves facility-specific characteristics

• Resource Allocation Problem:

Minimize Annual Agency Costs + User Costs
s.t. Steady State Agency Cost < Budget
Results for network-level case study

Sathaye & Madanat (2012)
Insights from network-level problem

• The uniform trigger roughness policy adopted by many state agencies is not optimal: different pavements have different optimal trigger roughness

• The optimal solution is robust to deterioration model parameter uncertainty
Pareto Frontier for Caltrans D4
Carbon Pricing

![Graph showing costs vs. GHG emissions with different data points and lines indicating Pareto Curve, California Price, and Knittel et al.](image-url)
Percentile of lane-mile in the state network

Optimal IRI trigger for 30% of network with highest traffic = 1.6 m/km (101 in/mile)

Optimal IRI trigger for 25 to 70% of network traffic = 2.0 to 2.8 m/km (127 to 177 in/mile)

Optimal IRI trigger for 25% of network with lowest traffic = do not treat for smoothness
## Comparison of cost-effectiveness

<table>
<thead>
<tr>
<th>Measure</th>
<th>Annual CO₂-e emission reduction</th>
<th>Life cycle cost-effectiveness ($2008/tCO₂-e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDV: Incremental efficiency</td>
<td>20% tailpipe reduction</td>
<td>-75 **</td>
</tr>
<tr>
<td>LDV: Advanced hybrid vehicle</td>
<td>38% tailpipe reduction on new vehicles</td>
<td>42 **</td>
</tr>
<tr>
<td>Commercial trucks: Class 2b efficiency</td>
<td>25% tailpipe reduction</td>
<td>-108 **</td>
</tr>
<tr>
<td>Ethanol fuel substitution</td>
<td>Increase mix of cellulosic ethanol to 13% by volume</td>
<td>31 **</td>
</tr>
<tr>
<td><strong>Current Caltrans trigger</strong> (170 in/mile, or 2.7 m/km)</td>
<td>0.82 MMT</td>
<td>332</td>
</tr>
<tr>
<td><strong>Optimal roughness triggers</strong> (Caltrans cost only)</td>
<td>1.38 MMT</td>
<td>390</td>
</tr>
<tr>
<td><strong>Optimal roughness triggers</strong> (all user benefits included)</td>
<td>1.38 MMT</td>
<td>-665 to -1,509</td>
</tr>
</tbody>
</table>

* Versus Routine Maintenance  **Lutsey, PhD thesis  Wang et al 2014 Environ. Res. Lett. 9 034007
Maintenance Results ($E_M$)

Histogram of Energy Consumption

Center for Sustainable Transportation Infrastructure
Network-Level Evaluation

Evaluated surface of I-81 in Salem (VA) district — 291 lane-miles — Broken into 65 different segments — Condition is CCI, a value ranging from 0 (impassible) to 100 (perfect condition)

5 year analysis — Determined Pareto surface of cost, condition and energy

Center for Sustainable Transportation Infrastructure

![Graph showing the relationship between Total 5 Year Cost (Dollars) and Average 5 Year Condition (CCI). The x-axis represents the average 5-year condition, ranging from 75 to 100, while the y-axis represents the total 5-year cost, ranging from 0 to 6 x 10^6 dollars. The graph is color-coded to represent energy consumption, with darker shades indicating higher energy consumption.](image-url)