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?

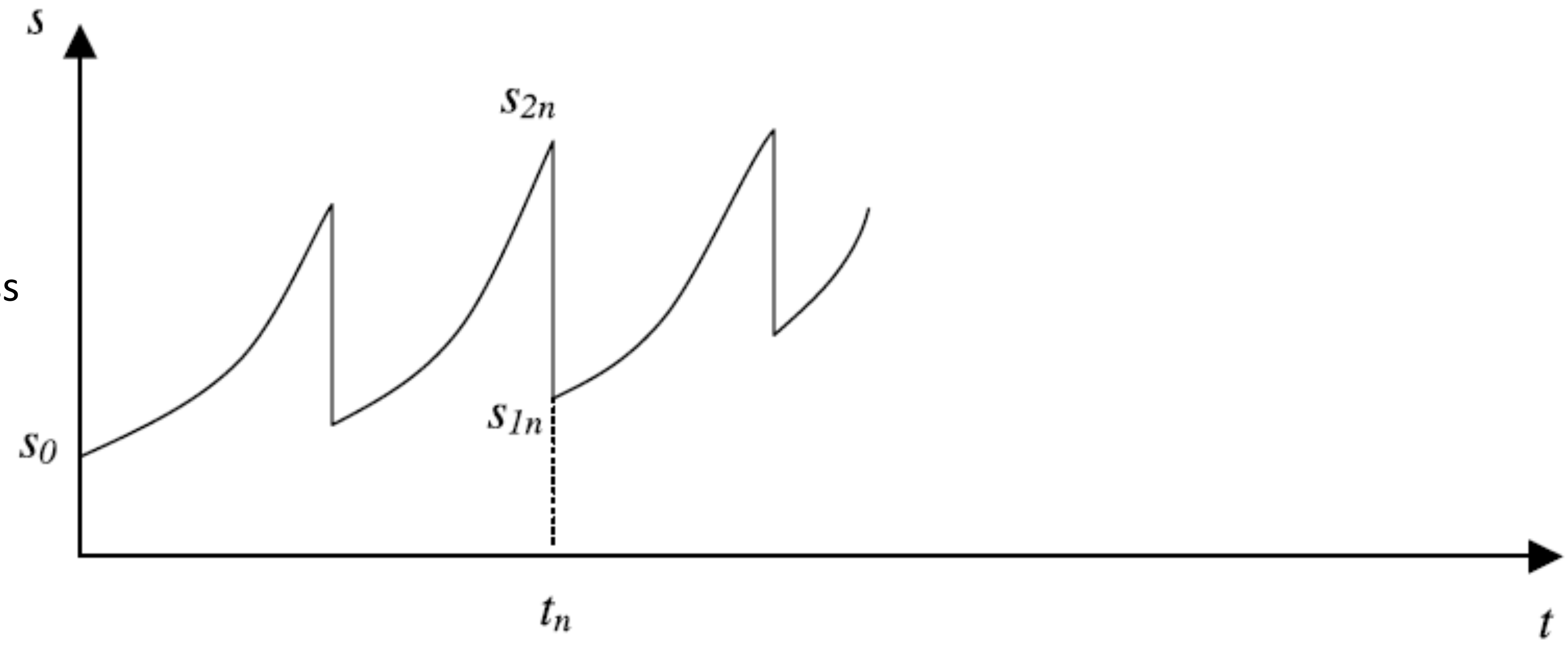
- Trigger roughness examples
  - 2.7m/km: currently used by Caltrans
  - 3.5m/km: Caltrans former policy, used by WSDOT
- Are the trigger roughness values used in practice optimal for LCC minimization?
  - No; based on subjective criteria
- Should all roads be treated the same?
  - Universal trigger 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
- <u>Objective:</u> minimize life cycle costs (LCC) over a finite horizon
  - LCC include all agency and user costs

Saw-tooth trajectory of pavement roughness

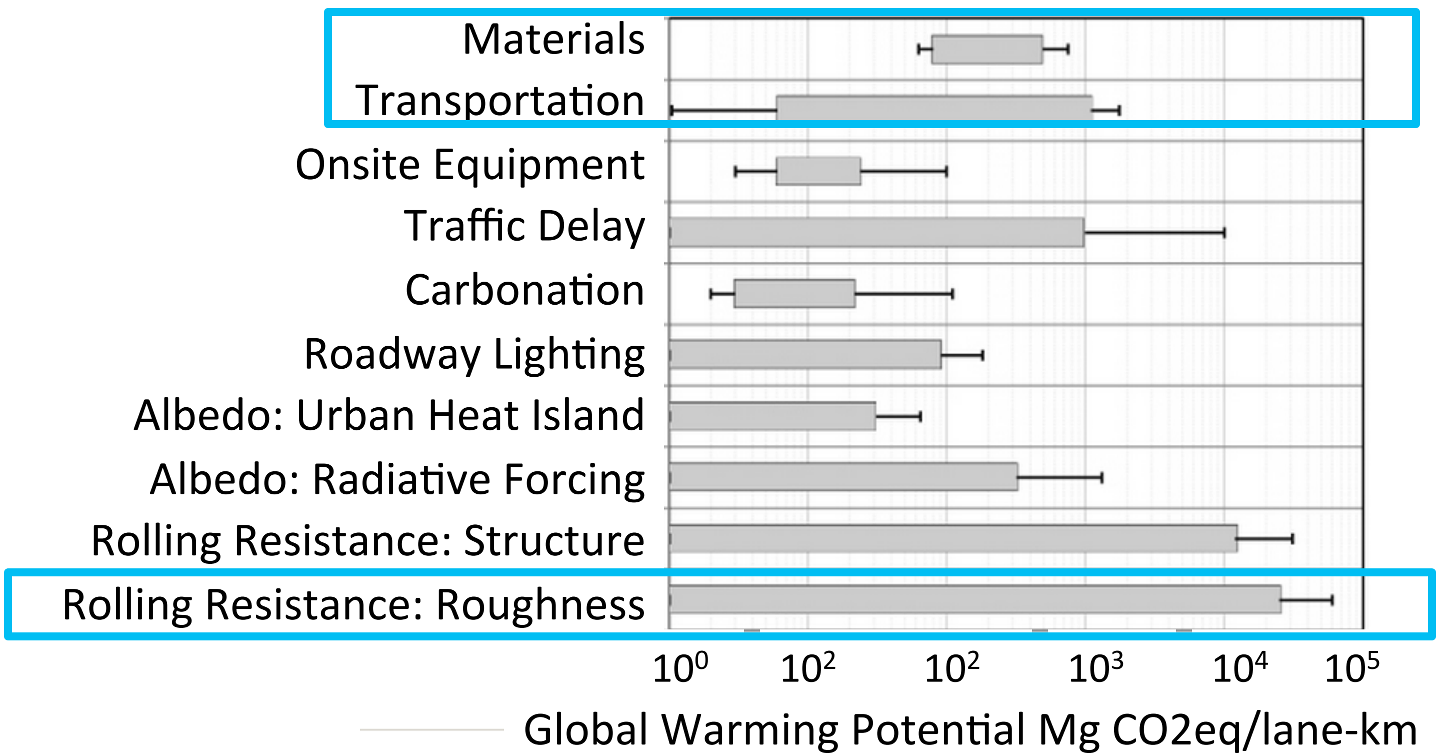
Roughness



Li & Madanat (2002)

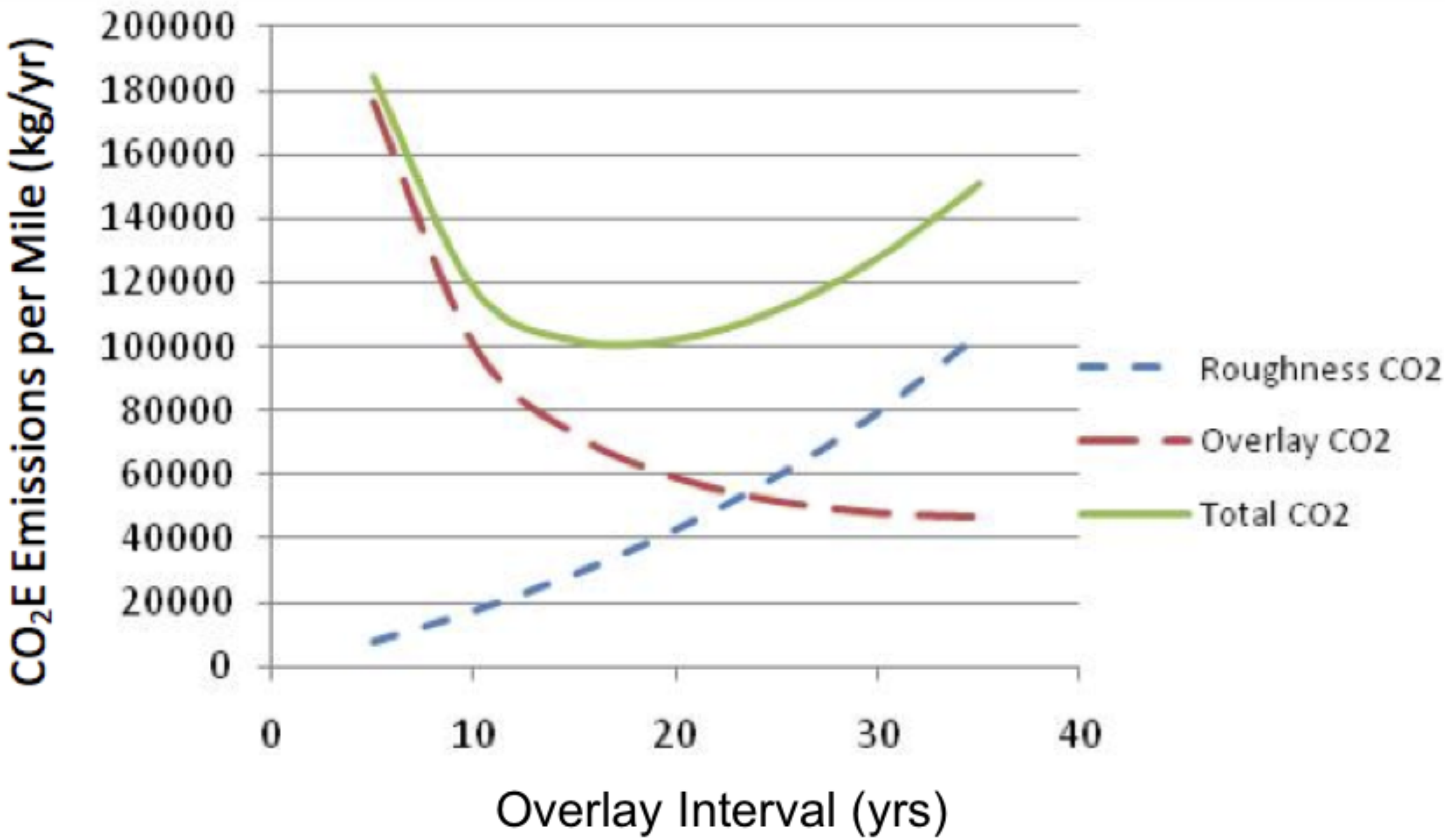
Pavement GHG emissions (LCA)

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

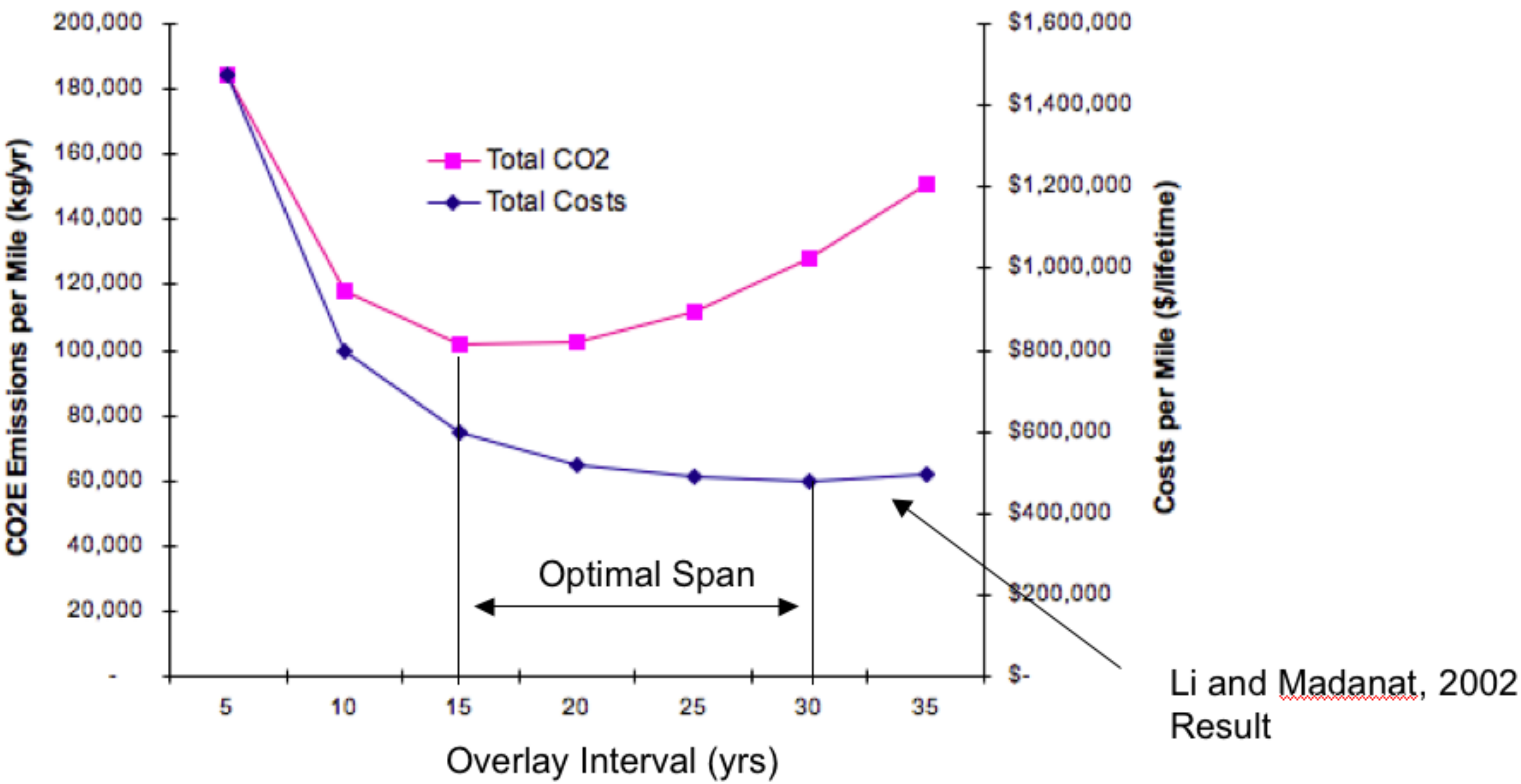


Source: Santero & Horvath (2010)

Tradeoffs for Emissions

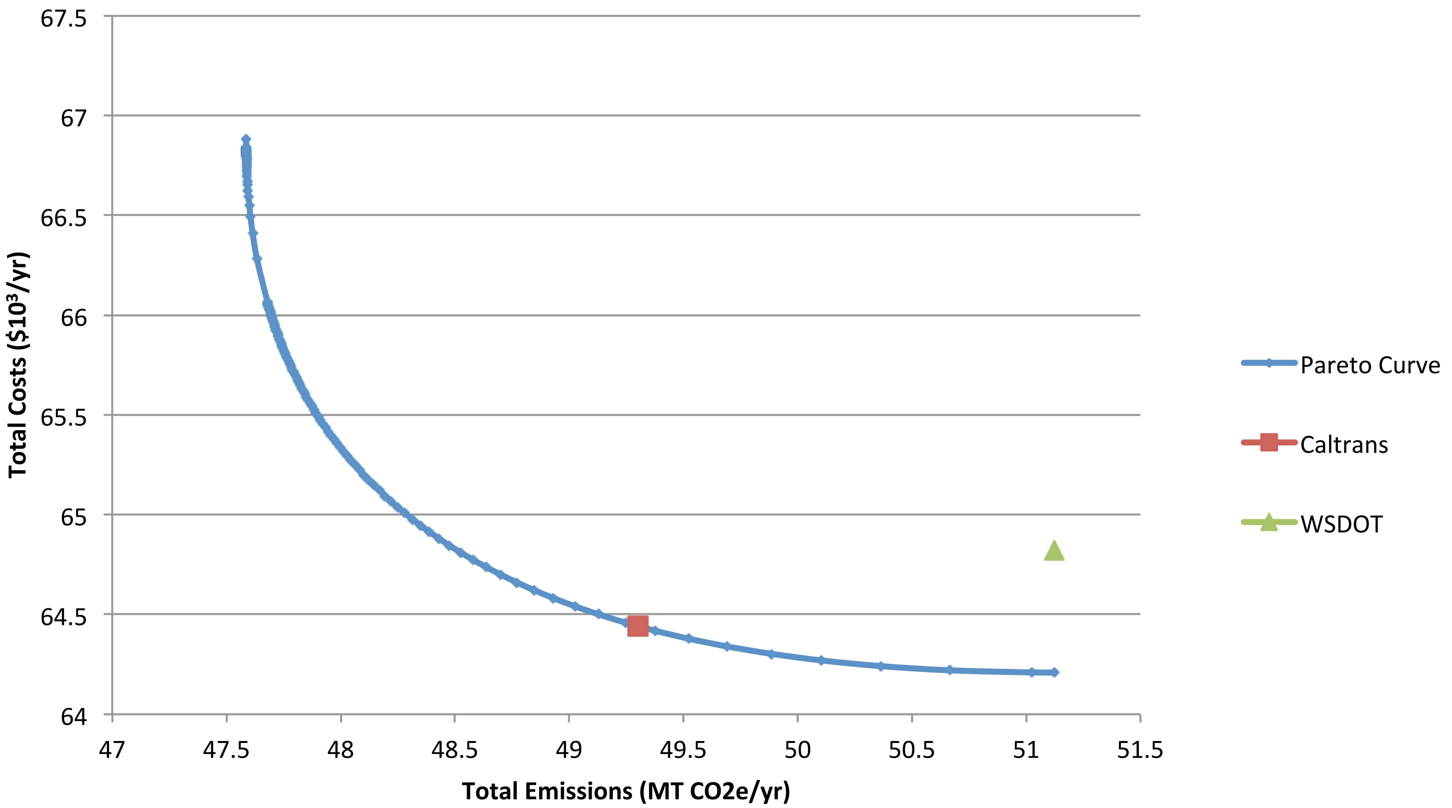


Overlay Intervals: Effects on LC Costs and LC Emissions



Pareto Frontier

Example: Two-Lane Rural Rd



Network-Level Resurfacing Optimization

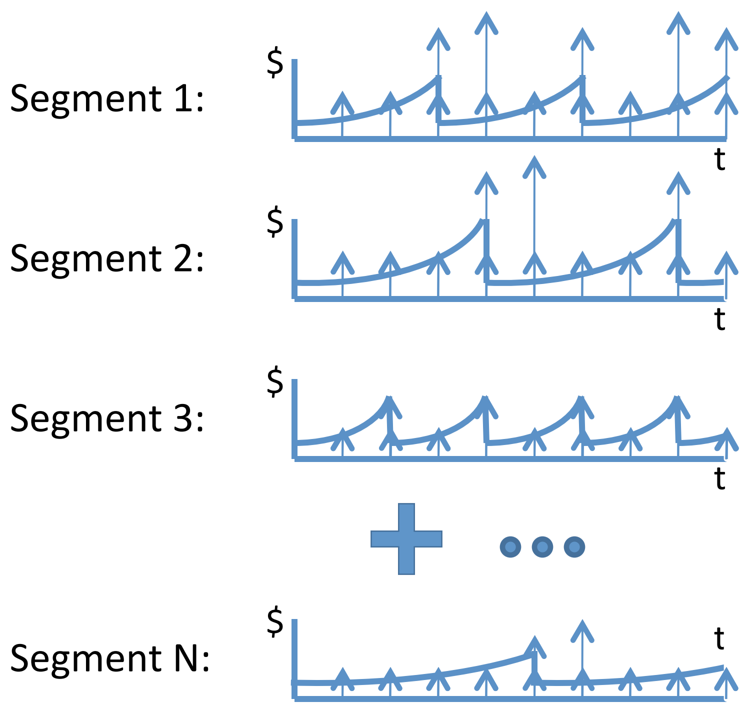
- Managing infrastructure systems to minimize environmental and economic impacts
  - Network-level optimization for LCC
  - Multi-criteria optimization for pavement maintenance

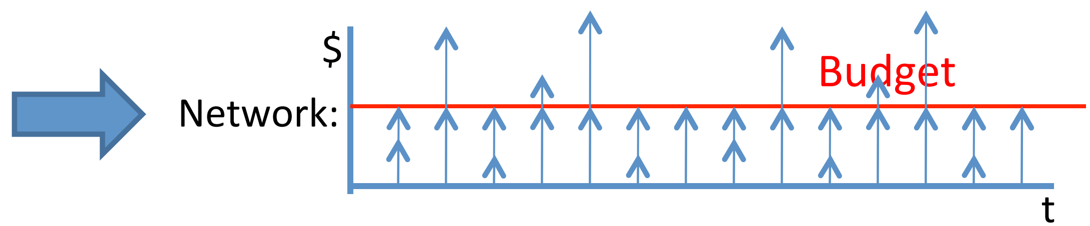
Source: http://commons.wikimedia.org/wiki/File:California_state_highways.svg

Pavement Resurfacing Optimization at Network-Level

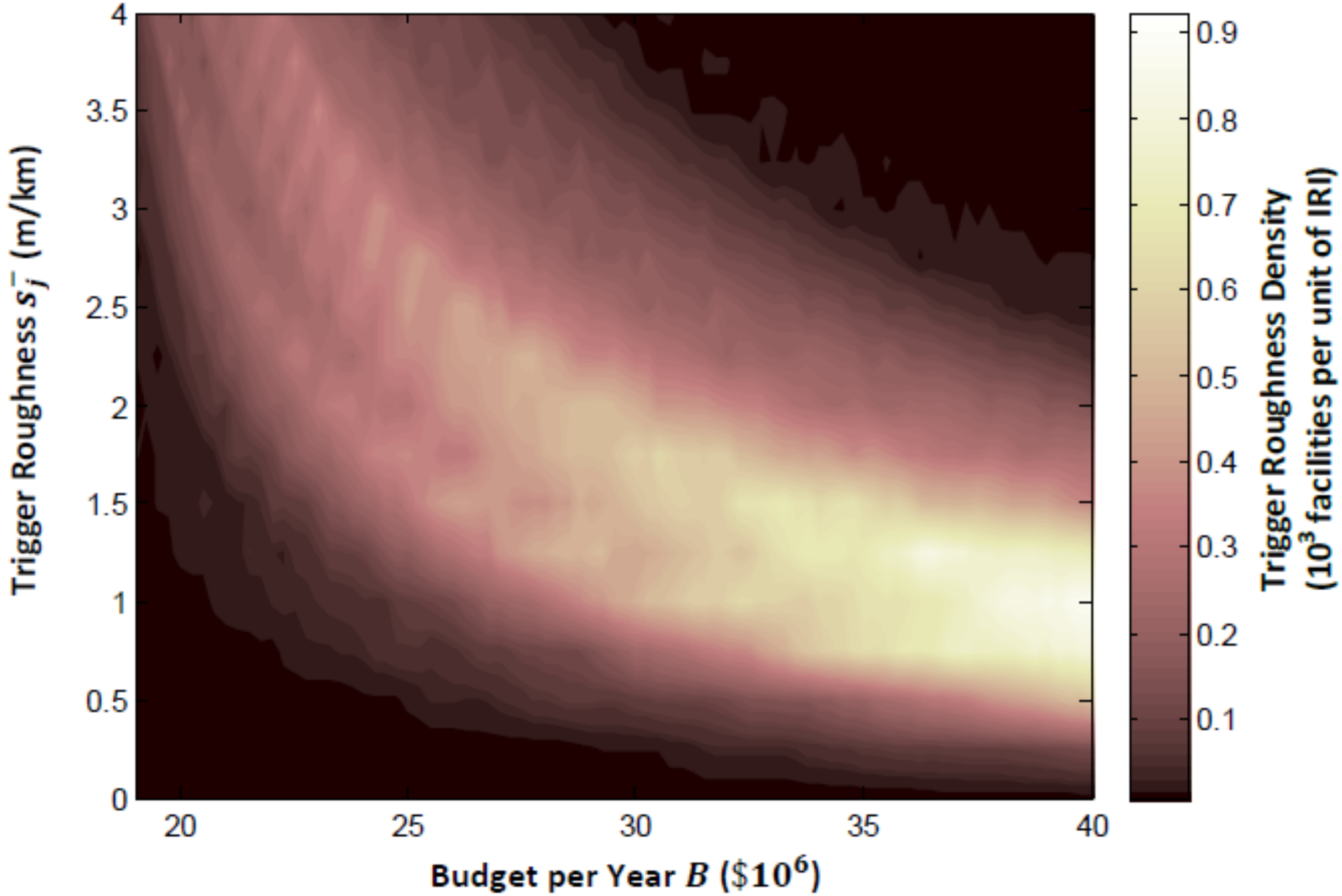
- Bottom-up solution method preserves facility-specific characteristics
- Resource Allocation Problem:

Minimize *Annual Agency Costs + User Costs*
s.t. *Steady State Agency Cost < Budget*





Results for network-level case study



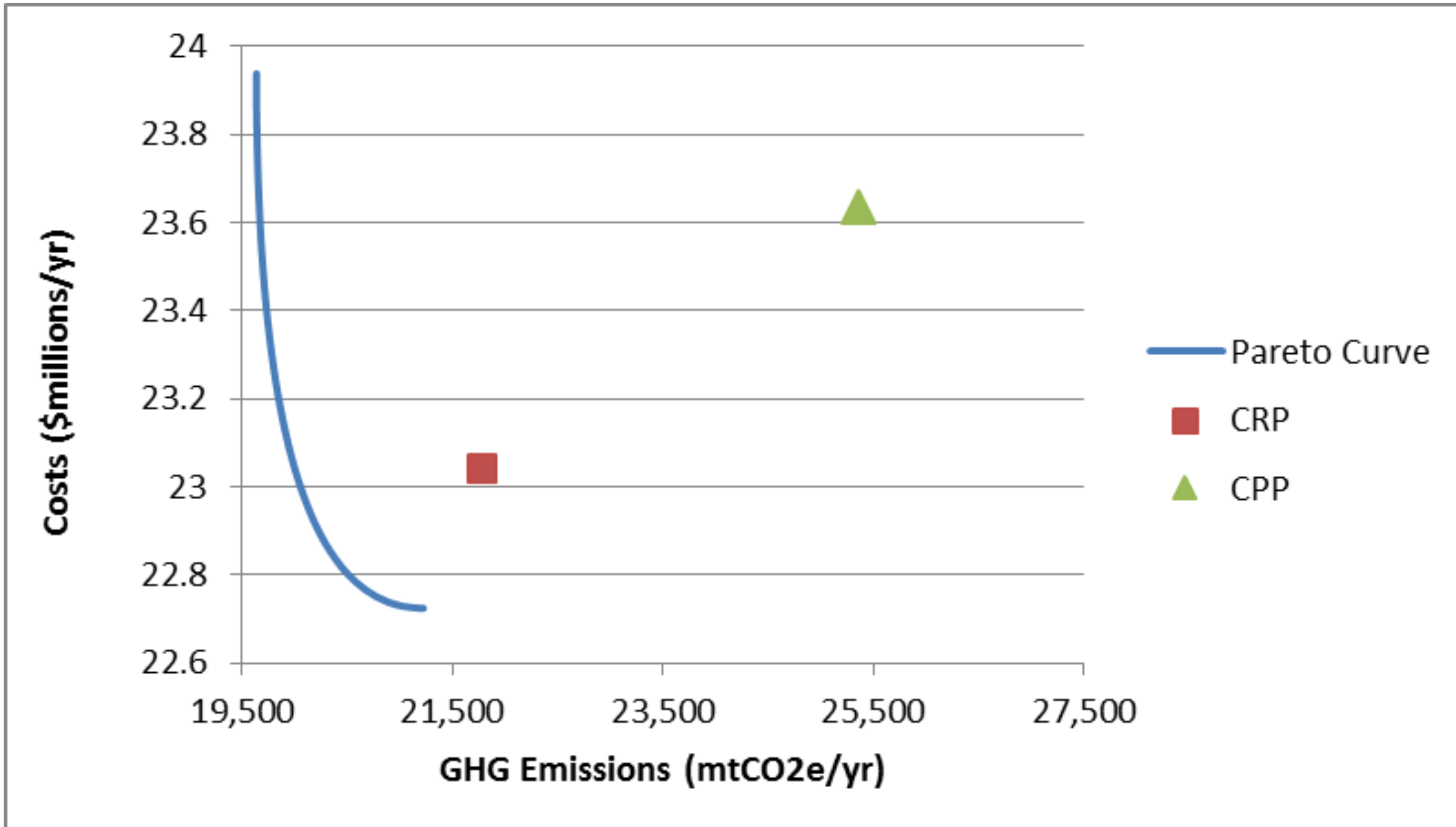
Sathaye & Madanat (2012)

Insights from network-level problem

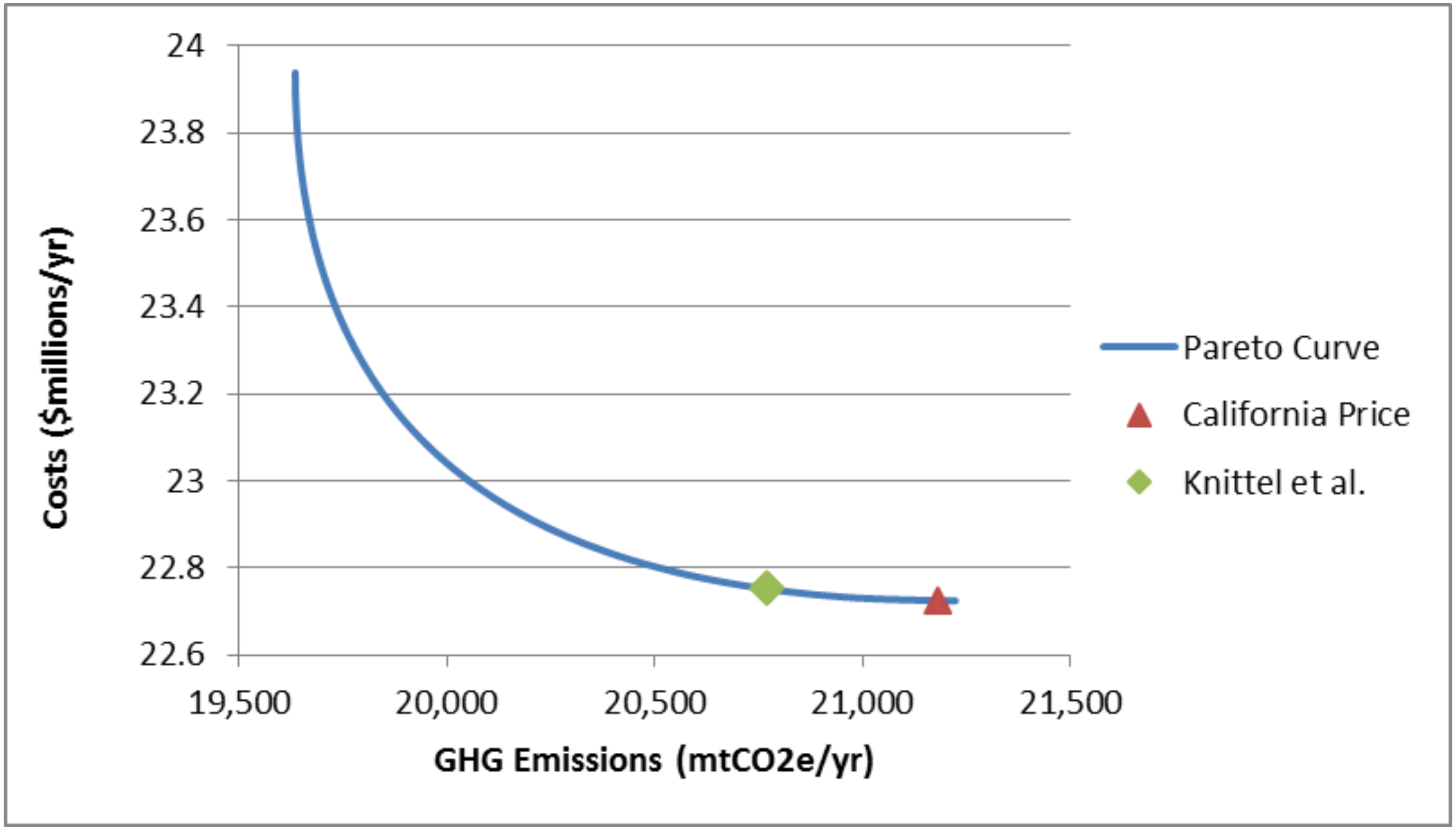
- The uniform trigger roughness policy adopted by many state agencies is not optimal: different pavements have different optimal trigger roughness

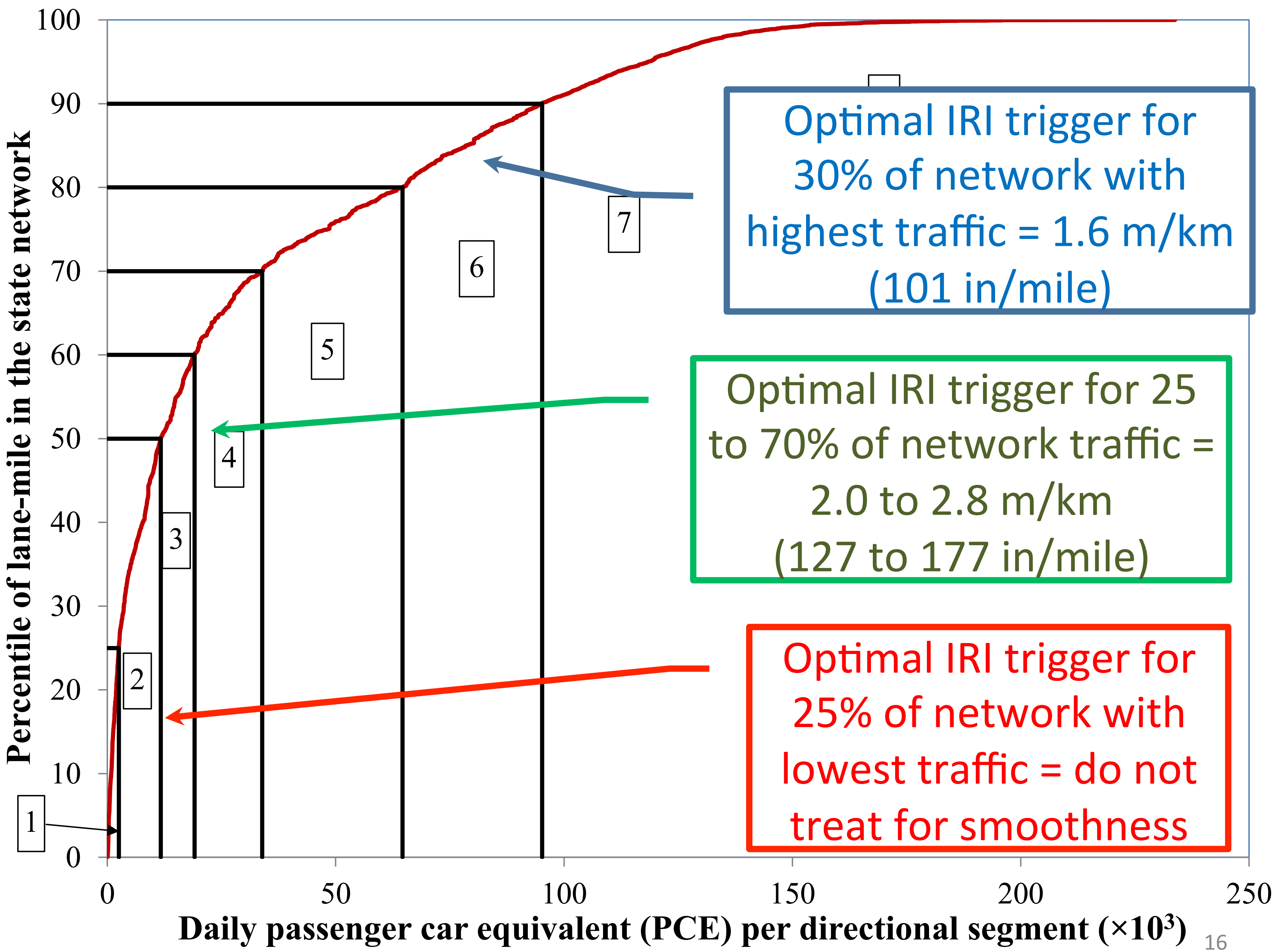
- The optimal solution is robust to deterioration model parameter uncertainty

Pareto Frontier for Caltrans D4



Carbon Pricing



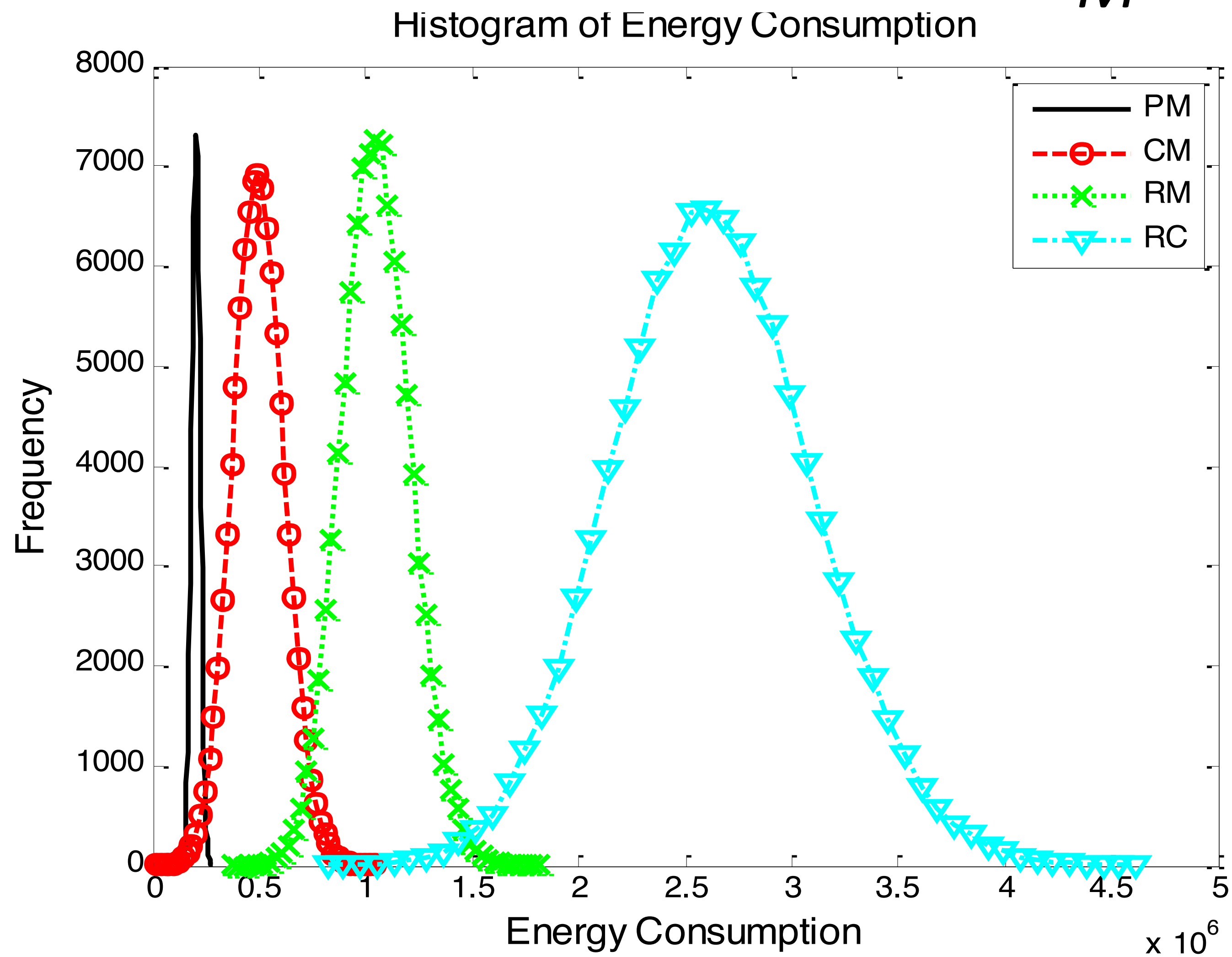

Percentile of lane-mile in the state network
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
Daily passenger car equivalent (PCE) per directional segment (×10³)
1
2
3
4
5
6
7
Optimal IRI trigger for 30% of network with highest traffic = 1.6 m/km (101 in/mile)
Optimal IRI trigger for 25 to 70% of 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

Measure	Annual CO_2-e emission reduction	Life cycle cost-effectiveness ($2008/t$CO_2$-e)
LDV: Incremental efficiency	20% tailpipe reduction	-75 **
LDV: Advanced hybrid vehicle	38% tailpipe reduction on new vehicles	42 **
Commercial trucks: Class 2b efficiency	25% tailpipe reduction	-108 **
Ethanol fuel substitution	Increase mix of cellulosic ethanol to 13% by volume	31 **
Current Caltrans trigger* (170 in/mile, or 2.7 m/km)	**0.82 MMT**	**332**
Optimal roughness triggers* (Caltrans cost only)	**1.38 MMT**	**390**
Optimal roughness triggers* (all user benefits included)	**1.38 MMT**	**-665 to -1,509**

* Versus Routine Maintenance   **Lutsey, PhD thesis   Wang *et al* 2014 *Environ. Res. Lett.* **9** 034007

Maintenance Results (E_M)



Network-Level Evaluation