Pavement Surface Characteristics and Sustainability

Ting Wang, In-Sung Lee, Alissa Kendall,

John Harvey (presenter), Chang-Mo Kim, EB Lee,

2011 Road Profiler User's Group

Reno, NV

UNIVERSITY of CALIFORNIA | PAVEMENT RESEARCH CENTER
Davis • Berkeley

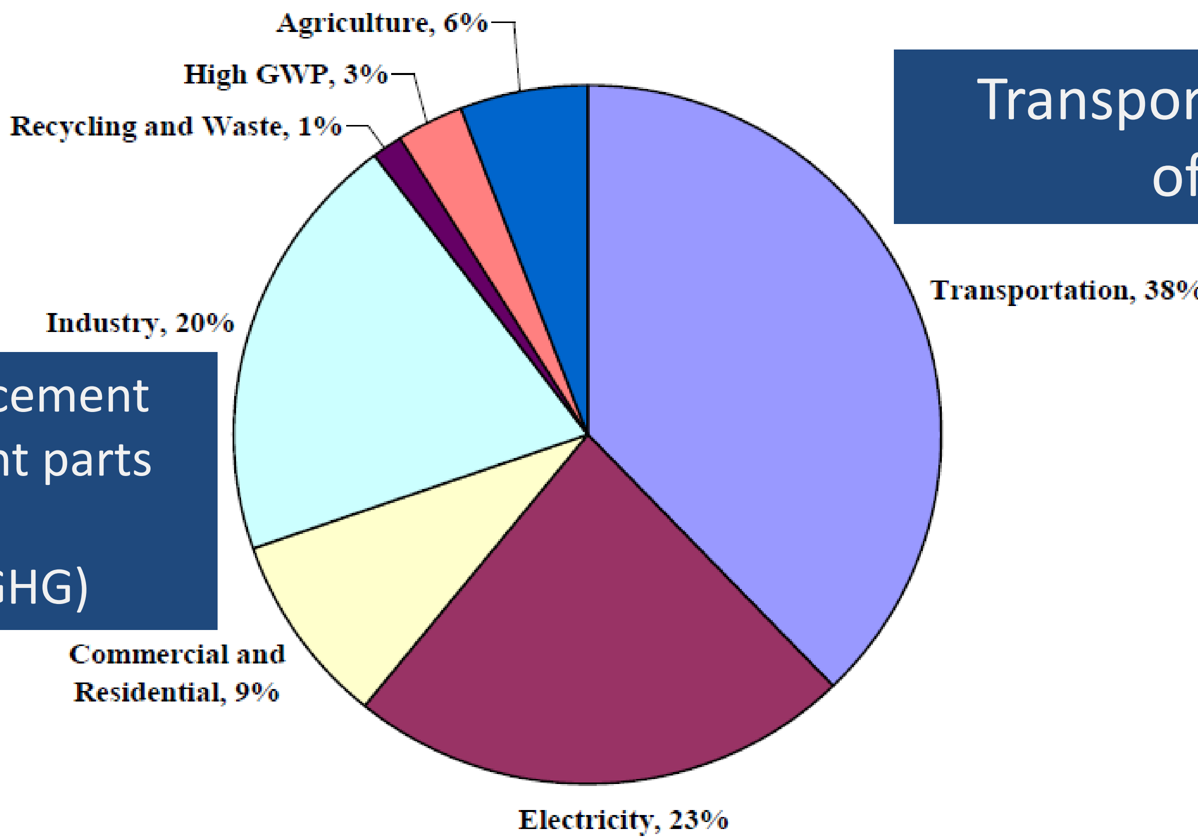
Motivation

- Reduce energy use
  - national policy objective
- Reduce greenhouse gas emissions
  - California state law
- Achieve these goals by the most cost-effective policies possible
  - Prioritize based on $/benefit

California's AB32 framework
(reaffirmed by voters November 2010)

- AB32 requires
  - 2020 GHG emissions at 1990 levels
  - 2050 GHG emissions at 0.2 x 1990 levels

Transportation 38% of 2004 GHG

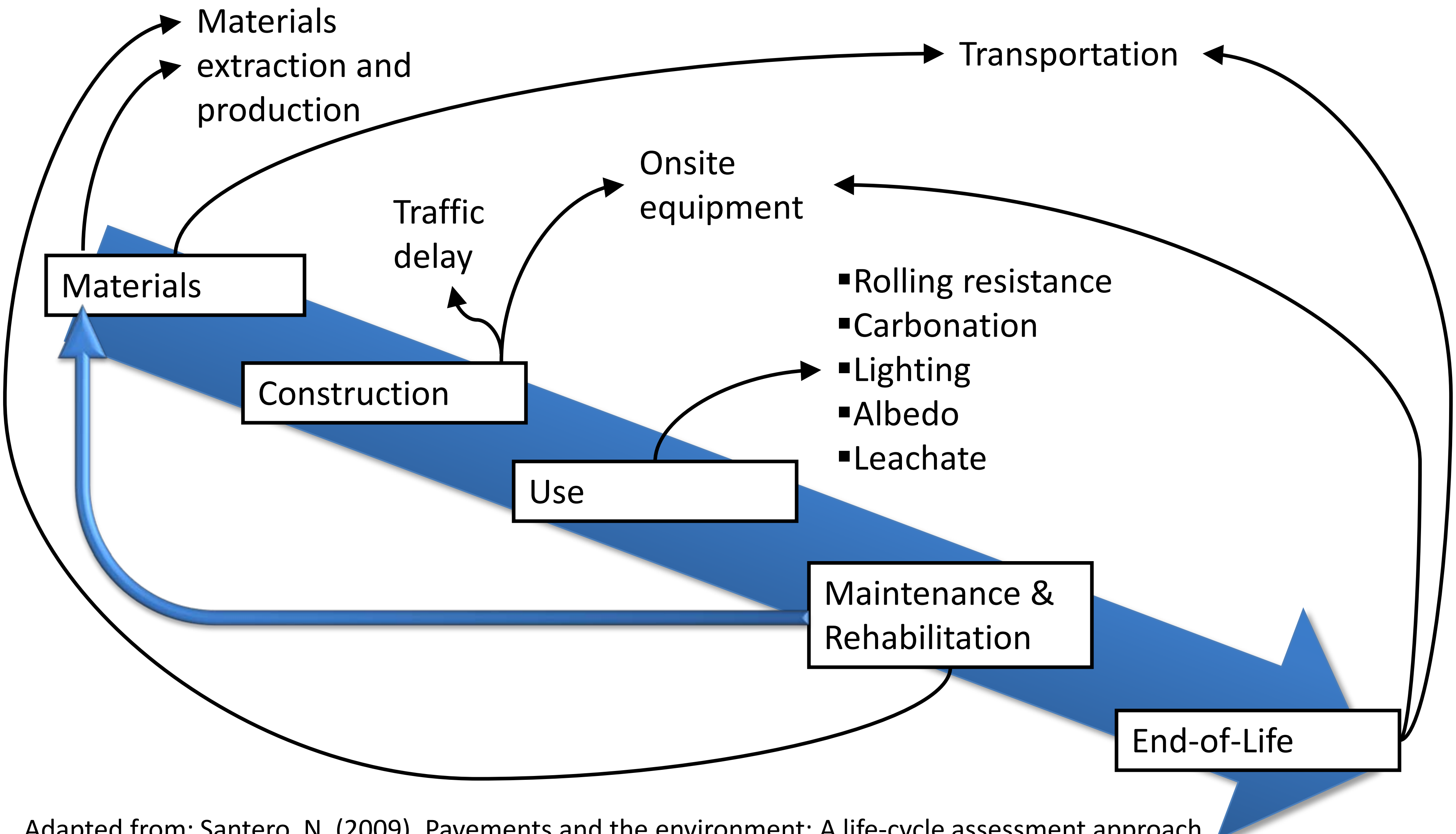


Refineries and cement plants significant parts of Industry (20% of 2004 GHG)

Objectives of Project

- Develop LCA model for state highway and local road networks
  - Initial models using available data sources
  - Update as develop regional databases
- Use model to answer questions regarding GHG ($/ton CO_2e) and fuel use (net reductions):
  - Rolling resistance
  - Design life
  - Recycling vs local materials, transportation costs
  - Alternative rehabilitation strategies

The Pavement Life Cycle (compatible with ISO 14040)



Adapted from: Santero, N. (2009). Pavements and the environment: A life-cycle assessment approach. Ph.D. Thesis, UC Berkeley.

Workshop on LCA for Pavement, Davis, CA, May 2010
Discussions and UCPRC approach downloadable
at www.ucprc.ucdavis.edu/p-lca

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International Society for Asphalt Pavements (ISAP)
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International Society
ISCP
for Concrete Pavements

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Basic Approach by UCPRC for Application to State, Local Networks

- Divide network into categories based on factorial
- Case studies for categories with sensitivity analyses
  - IRI and MPD (for MIRIAM)
  - Materials (type, production method, etc.)
  - Hauling distance
  - Traffic levels and congestion
  - Fleet composition over time (new vehicle technologies)
- Initial assumption: surface type doesn't change
  - Except RHMA vs HMA, PCC vs CSA cement
  - Consider LCA effects of changing surface type after models completed

Factorial for LCA for California State and Local Networks

Factorials	Possible Value
Road type	Rural road; urban road
Road grades	Flat road; mountainous road
Road access type	Restricted access; unrestricted access
Traffic level	Different levels of AADT and AADTT, categorized
Pavement surface type	Asphalt pavement; Cement concrete pavement
Pavement surface characteristics	Different levels of IRI and MPD, categorized
Pavement Treatment	Different treatment options

Models: Materials and construction

- Materials production and plant emissions:
  - Existing databases & studies
  - review by CNCPC, APACA
- Off-Road equipment
  - *OFFROAD*: California's off-road equipment emission inventory
- On-Road equipment
  - *EMFAC*: California's on-road vehicles emission inventory
- Equipment and hours
  - *CA4PRS:* Caltrans construction schedule analysis tool
- Road user delay
  - *CA4PRS* (not yet implemented)

Models: Use Phase

- MOVES
  - MOtor Vehicle Emission Simulator
  - US EPA's current official model for estimating air pollutant emissions from cars and trucks
  - Can consider speed profiles
- HDM-4
  - Highway Development and Management Model
  - Steady speed fuel use
  - Relationship between pavement surface characteristics (MPD, IRI) and rolling resistance
  - Developed by World Bank, recently calibrated with fuel use instrumentation on North American vehicles by Imen & Chatti (Michigan State Univ), through NCHRP 01-45

Pavement – Rolling Resistance – Energy

- HDM-4 model (World Bank; Imen & Chatti)
  - Surface characteristics:

$$CR2 = Kcr2\left[a0 + a1 \times Tdsp + a2 \times IRI + a3 \times DEF\right]$$

  - Rolling Resistance:

$$Fr = CR2 * FCLIM * [b11Nw + CR1(b12M + b13v^2)]$$

- MOVES model (US EPA)

$$P_b = \text{Air resist.} + \text{Inertial and Gradient resist.} + \text{Rolling resist.}$$

$$= \tfrac{1}{2}\rho_a C_D A_{front}(v + v_w)^2 \times v + M\left(a\left(1 + \varepsilon_i\right) + g \times grade\right) \times v + C_R M g \times v$$

Update MOVES parameter

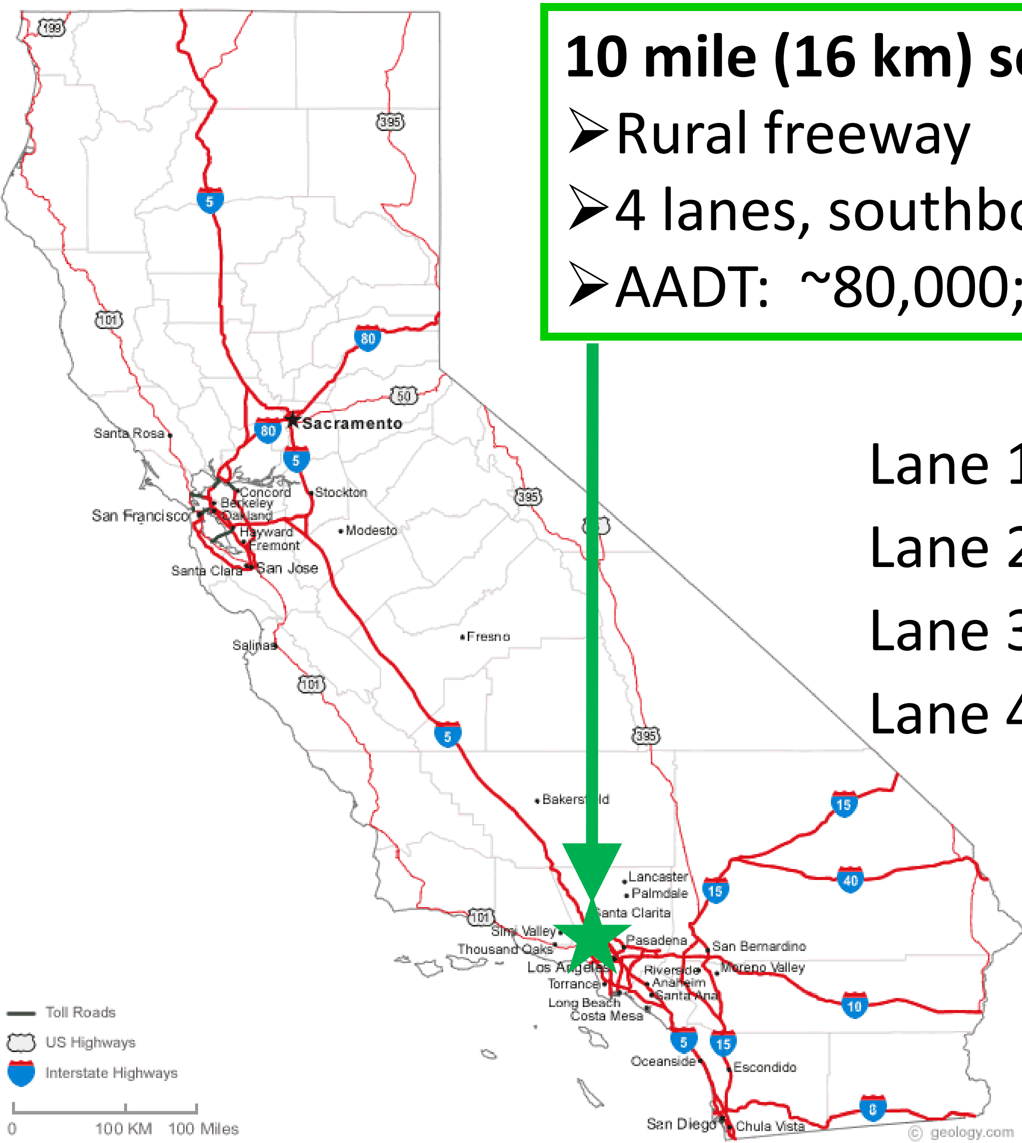
- MOVES parameter from dynamometer test

$$
\begin{aligned}
P_b &= \text{Rolling resist.} + \text{Air resist.} + \text{Inertial and Gradient resist.} \\
&= C_R M g \times v + \frac{1}{2}\rho_a C_D A_{front}(v+v_w)^2 \times v + \left(a\left(1+\varepsilon_i\right) + g \times grade\right) M \times v \\
&= A \times v + B \times v^2 + C \times v^3 + \left(a\left(1+\varepsilon_i\right) + g \times grade\right) M \times v
\end{aligned}
$$

- Proportionally increase from

$$
\begin{aligned}
\frac{A_{updated}}{A_{default}} &= \frac{CR2_{pavement}}{CR2_{dynamometer}} = \frac{Kcr2\left[a0 + a1 \times Tdsp + a2 \times IRI + a3 \times DEF\right]}{Kcr2\left[a0 + a1 \times \left(1.02 \times 0 + 0.28\right) + a2 \times 0 + a3 \times 0\right]} \\
&= \frac{a0 + a1 \times Tdsp + a2 \times IRI + a3 \times DEF}{a0 + a1 \times 0.28}
\end{aligned}
$$

Case Study 2 (Finished): Concrete CPR B on rural/flat freeway



10 mile (16 km) segment in need of rehab

- Rural freeway
- 4 lanes, southbound
- AADT: ~80,000; ~25% trucks

	Cars	Trucks	IRI
Lane 1 (Inner)	38%	0.2%	3
Lane 2	34%	8%	3
Lane 3	16%	42%	3.5
Lane 4 (Outer)	13%	49%	4

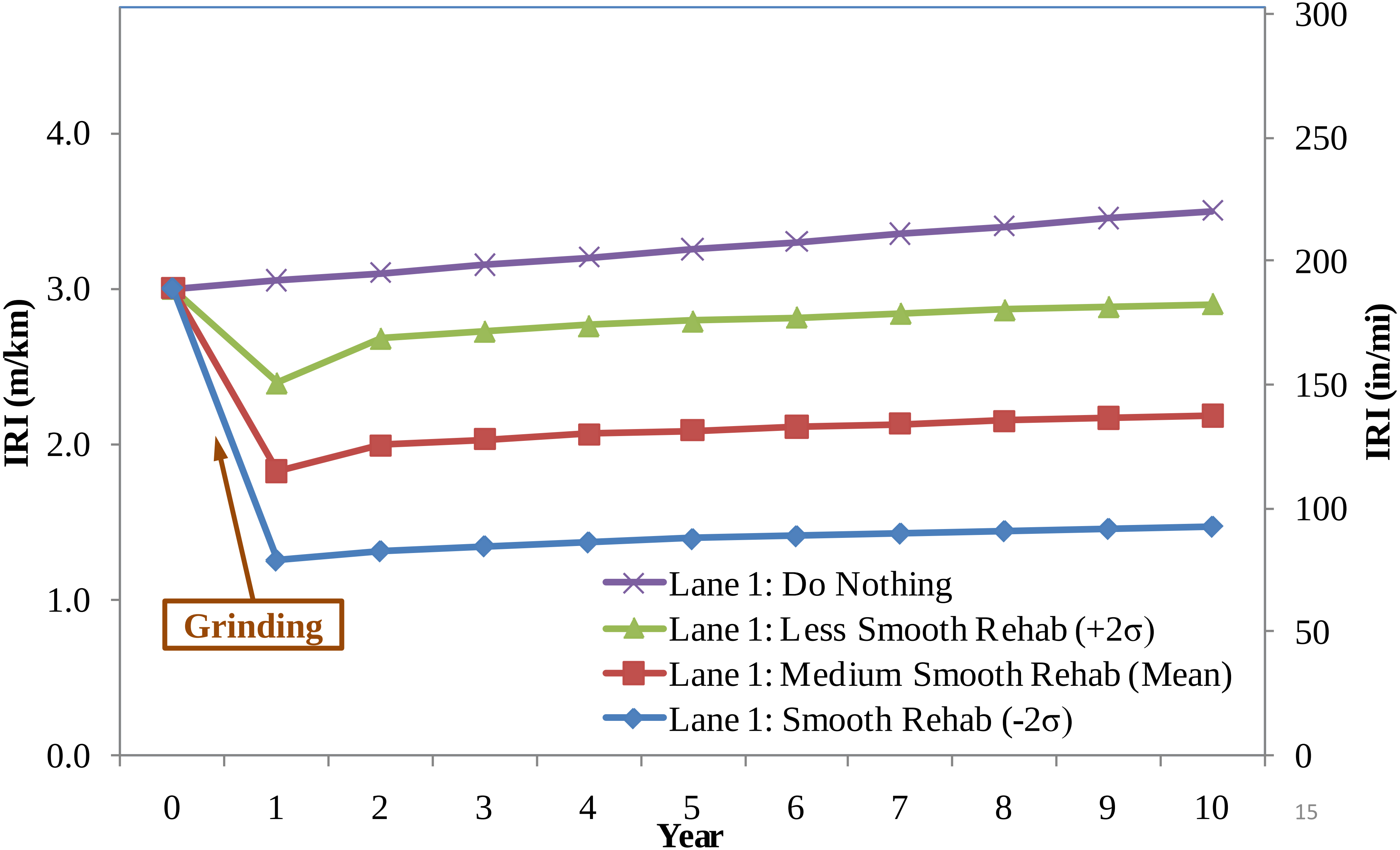
Compare:

- Do Nothing
- 10 year CPR B
  - -Type III, CSA cement

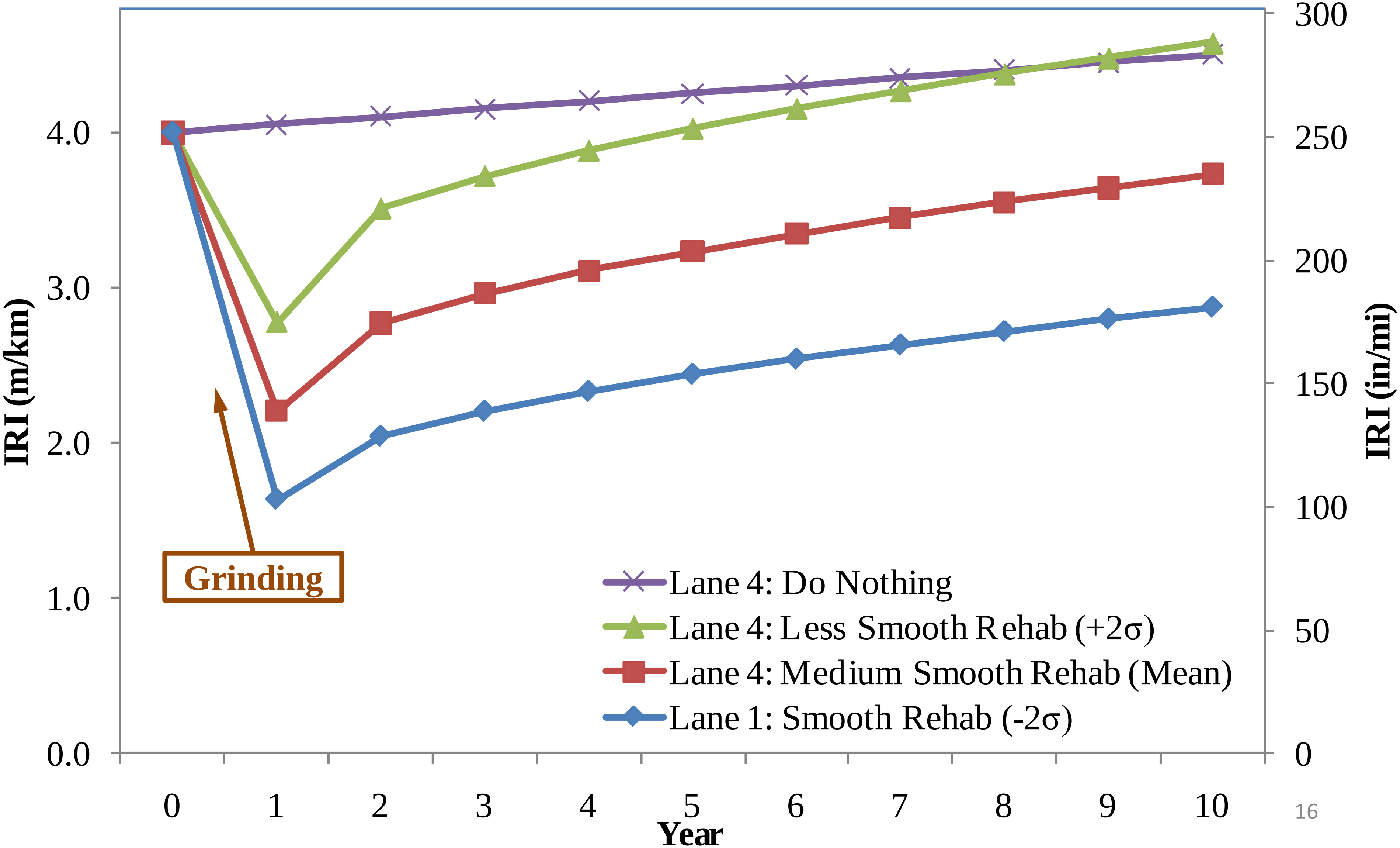
Construction Scenario

Treatment	Design life	Material	Smoothness
CPR B with 3% slab replacement and grinding the entire lane	10 yrs	Type III Rapid Strength Cement (3.2 Mpa in 4 hours)	Smooth Rehab (-2σ)
			Medium Smooth Rehab (mean)
			Less Smooth Rehab (+2σ)
		Calcium Sulpho-Aluminate (CSA) Cement (2.8Mpa in 4 hours)	Smooth Rehab (-2σ)
			Medium Smooth Rehab (mean)
			Less Smooth Rehab (+2σ)

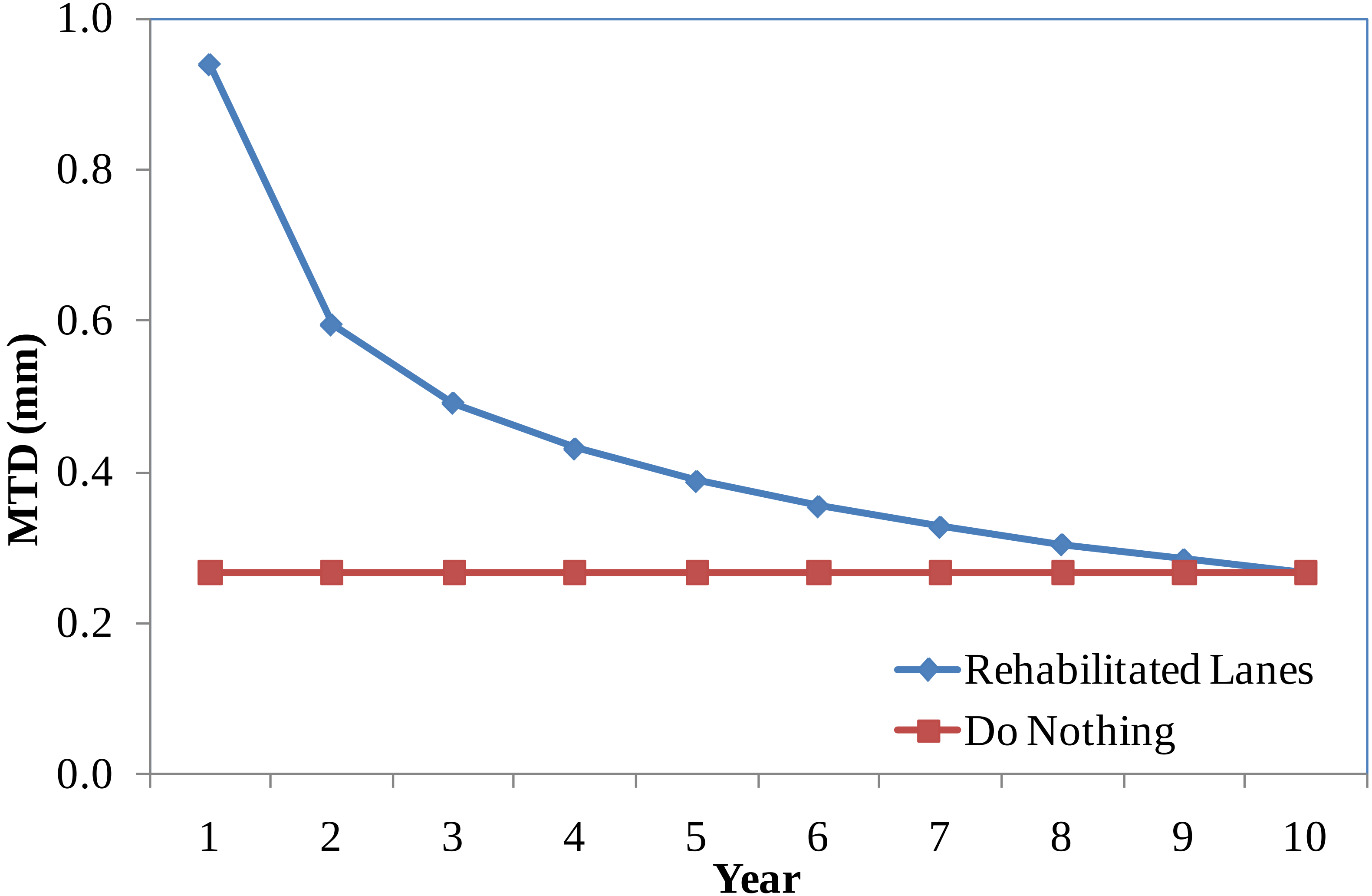
Concrete IRI over 10 years: Lane 1



Concrete IRI over 10 years: Lane 4

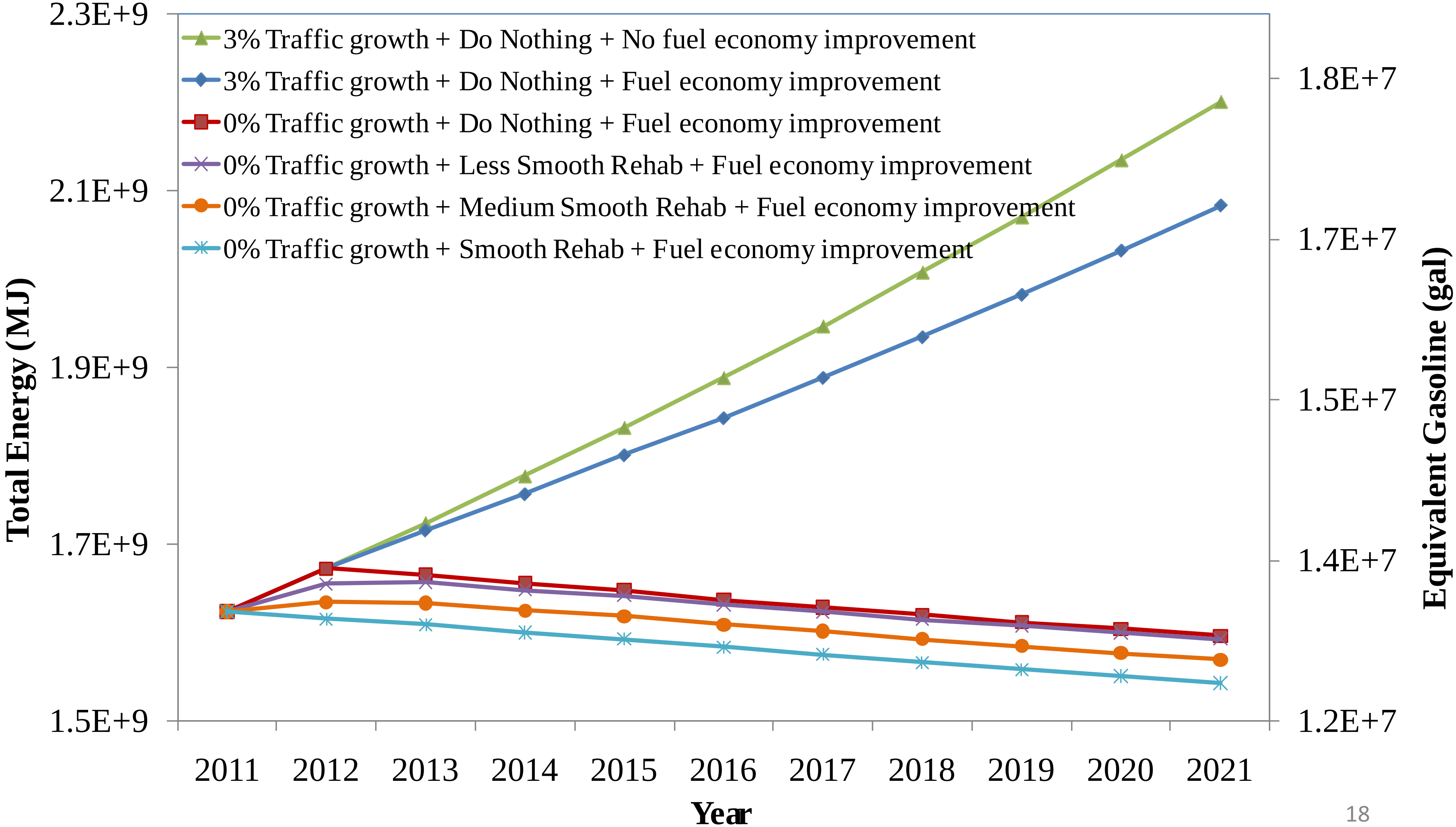


Concrete Mean Texture Depth (MTD) Progression

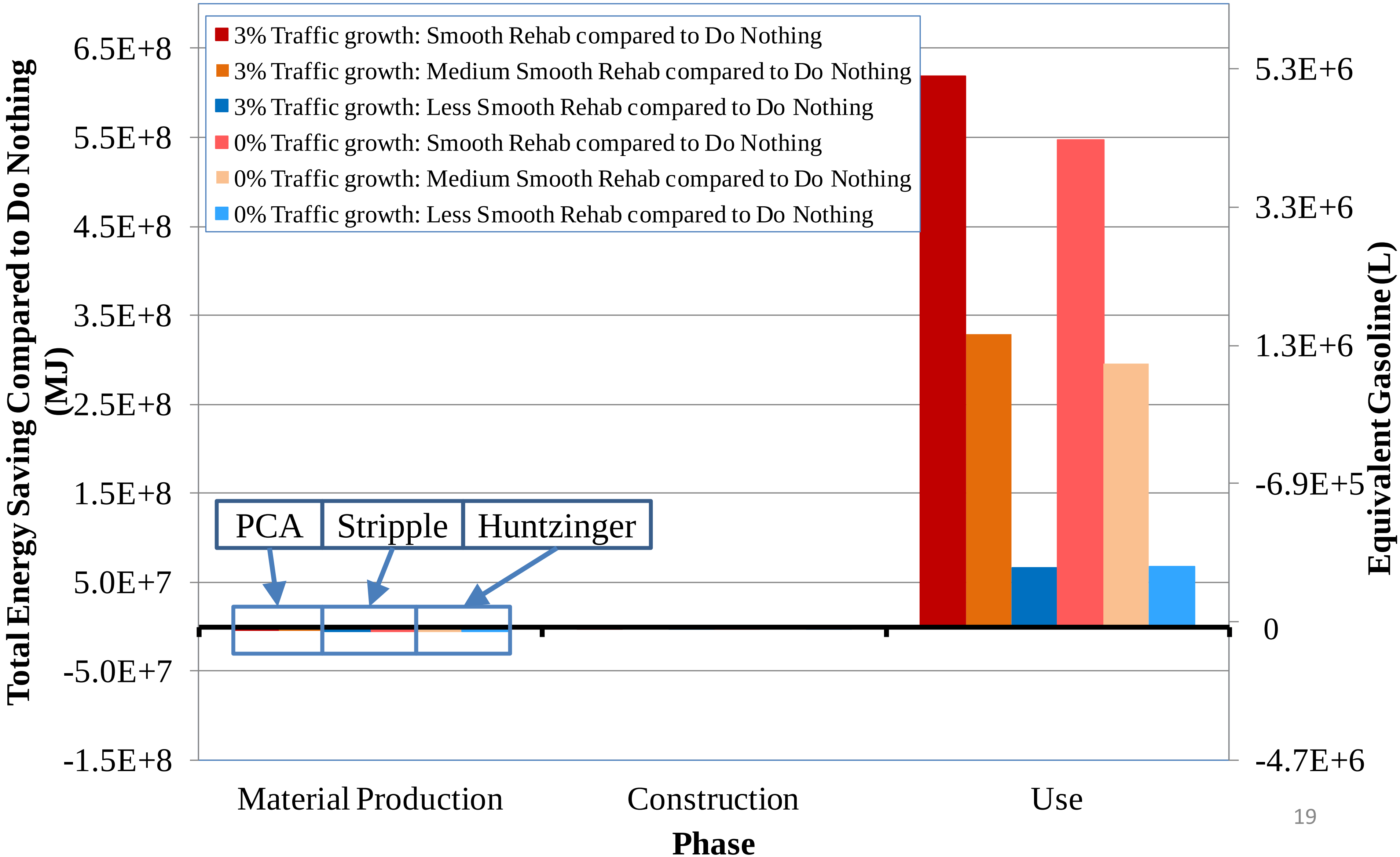


From: Shreenath Rao and James W. Mack, Longevity of Diamond-Ground Concrete Pavements, *Transportation Research Record*, Vol 1684, 1999

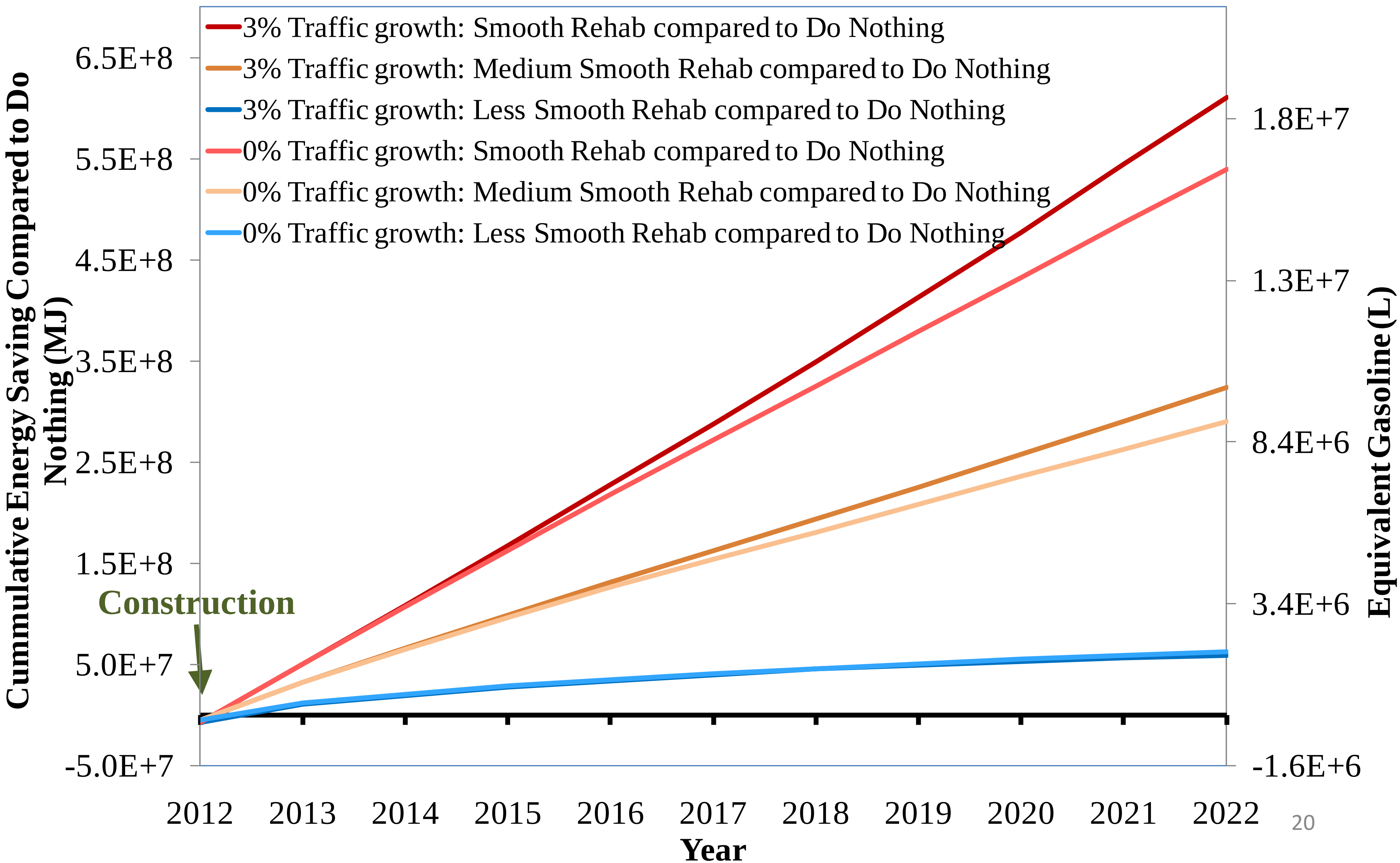
Energy in Use Phase with 0 & 3% Traffic Growth (US unit)



10-year energy savings from materials (Type III), construction, use phase compared to "Do Nothing"



Cumulative energy savings from materials (Type III), construction, use phase compared to "Do Nothing"



Case Study 1 (Finished): Asphalt overlay on rural/flat freeway

10 mile (16 km) segment in need of rehab

- Rural freeway
- 2 lanes, southbound
- AADT: 34,000; ~35% trucks

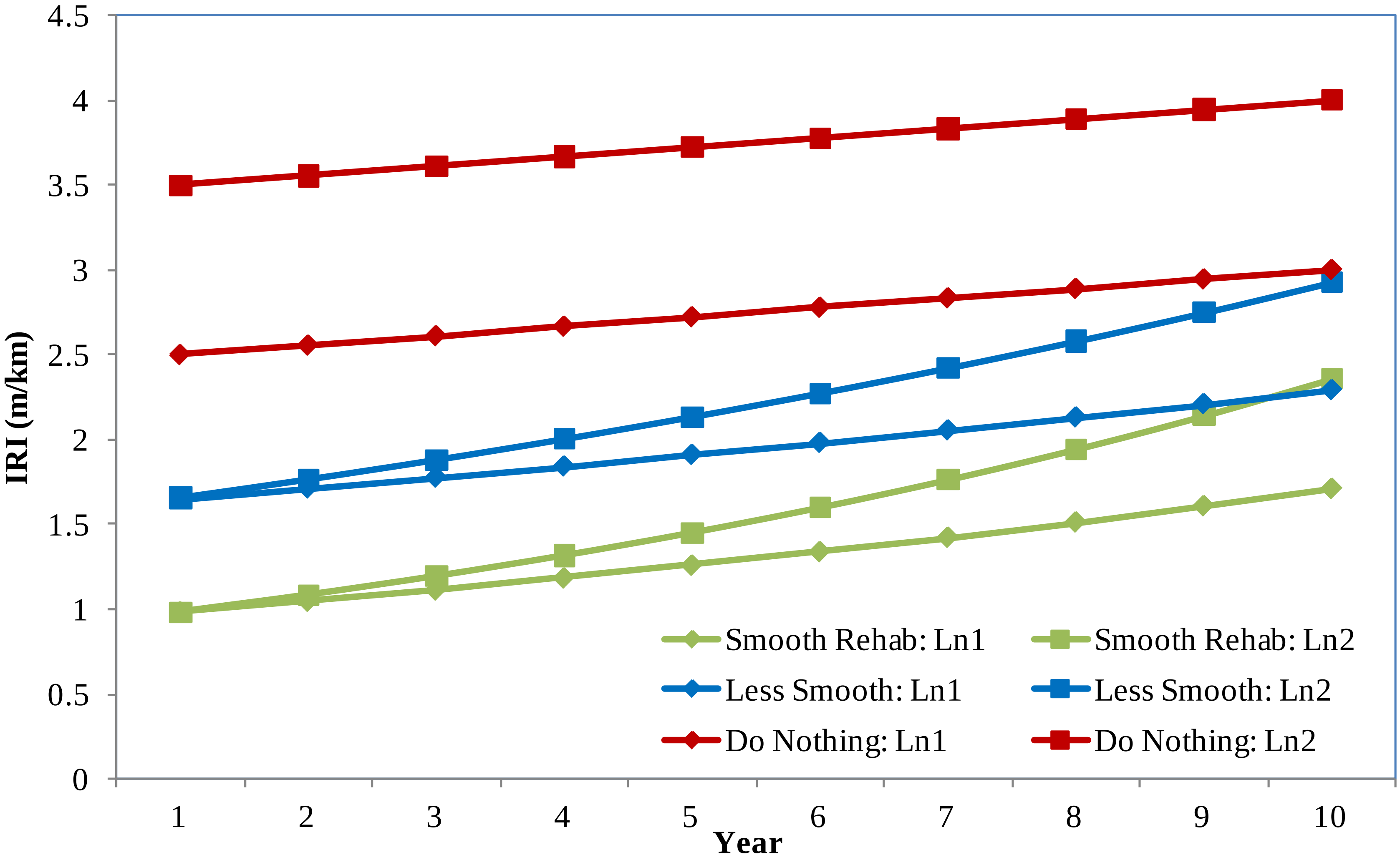
	Passenger	Trucks
Inner Lane	77%	9%
Outer Lane	23%	91%

Compare:
- Do Nothing
-10 year rehab
-HMA, RHMA

Construction Scenarios: Case Study 1

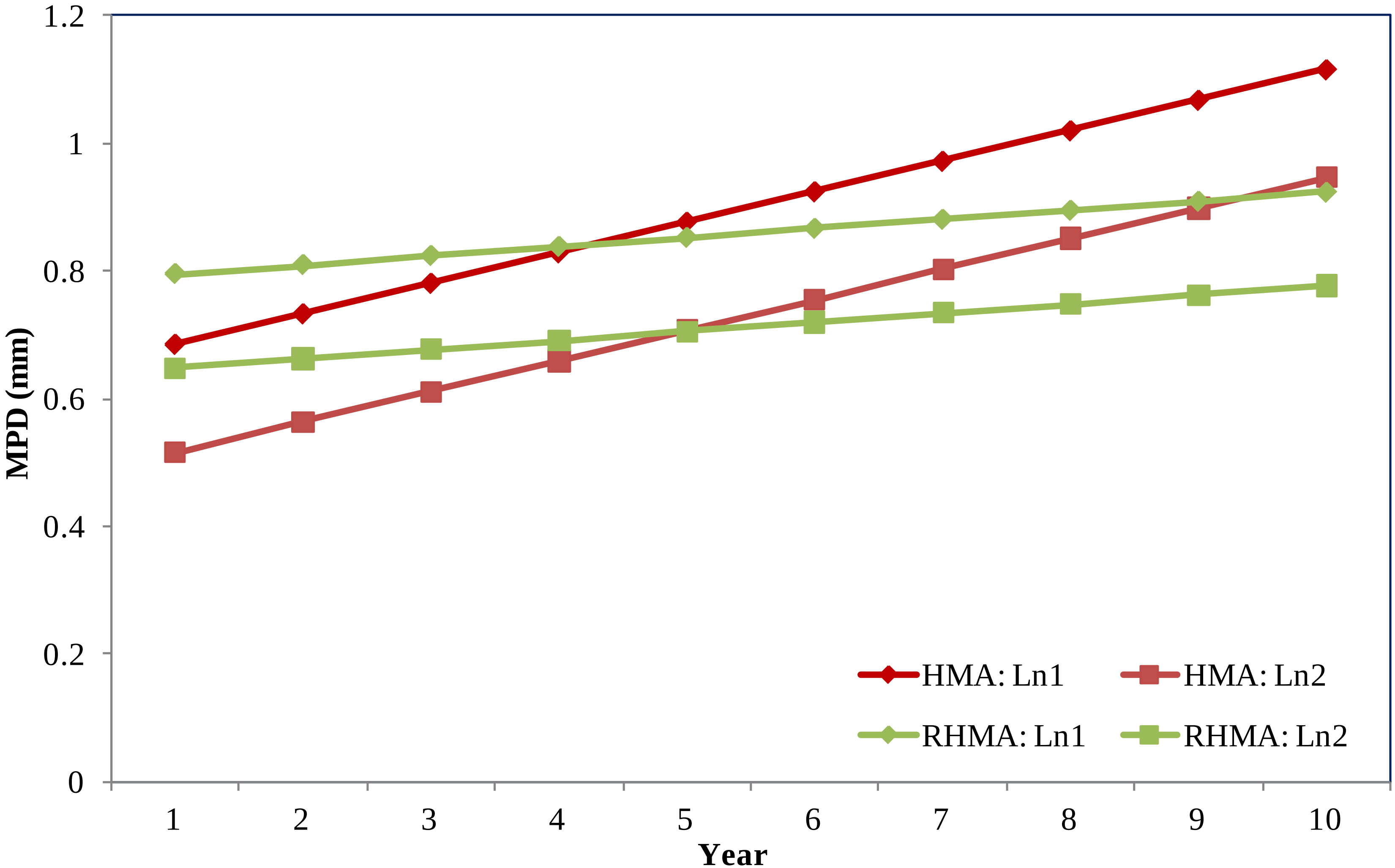
HMA Type	Design life	Treatment	Cross Section	Smoothness
HMA	10 Years	Mill & Overlay	45 mm (0.15’) Mill + 75 mm (0.25’) HMA with 15% RAP	Smooth Rehab
				Less smooth Rehab
RHMA	10 years	Mill & Overlay	30 mm (0.1’) Mill + 45 mm (0.15’) RHMA	Smooth Rehab
				Less smooth Rehab

Asphalt IRI Scenarios over 10 years*



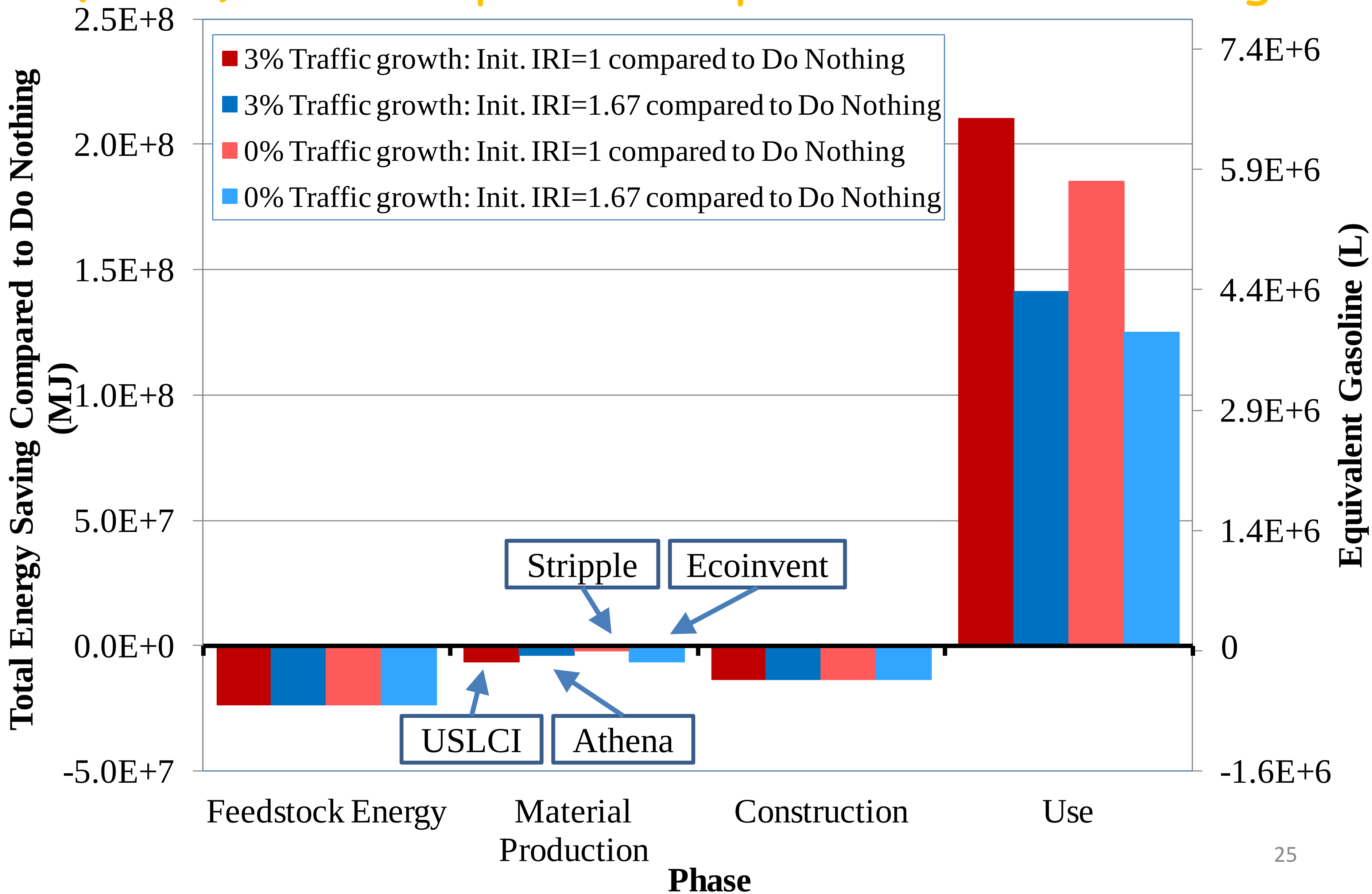
* 1st draft from empirical data, needs review and modeling

Asphalt MPD Progression from CA data* (For rehabilitated lanes)

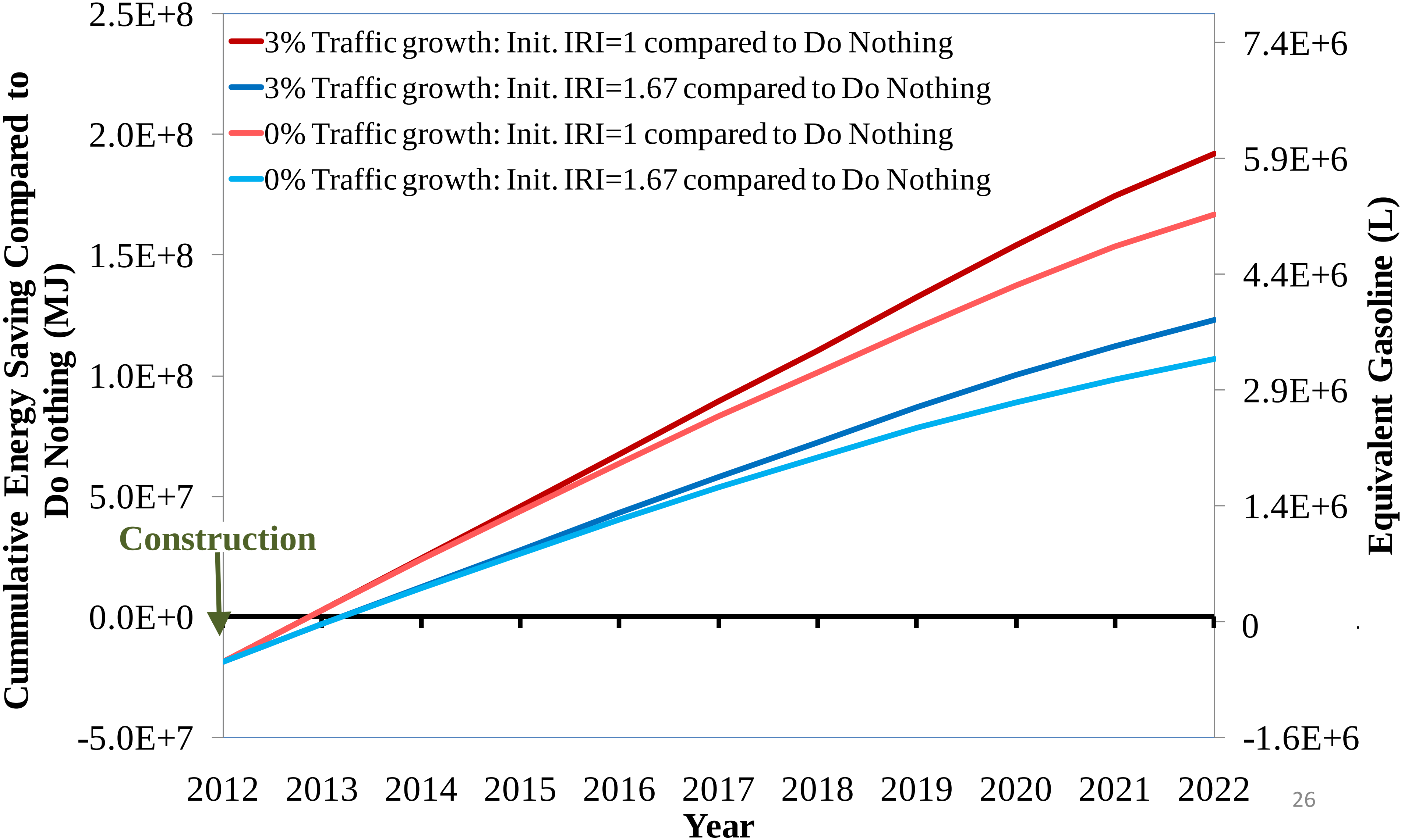


* 1st draft from empirical data, needs review and modeling

10-year energy savings from materials, construction (HMA), and use phase compared to "Do Nothing"



Cumulative energy savings from materials, construction (HMA), and use phase compared to "Do Nothing"



Acknowledgement

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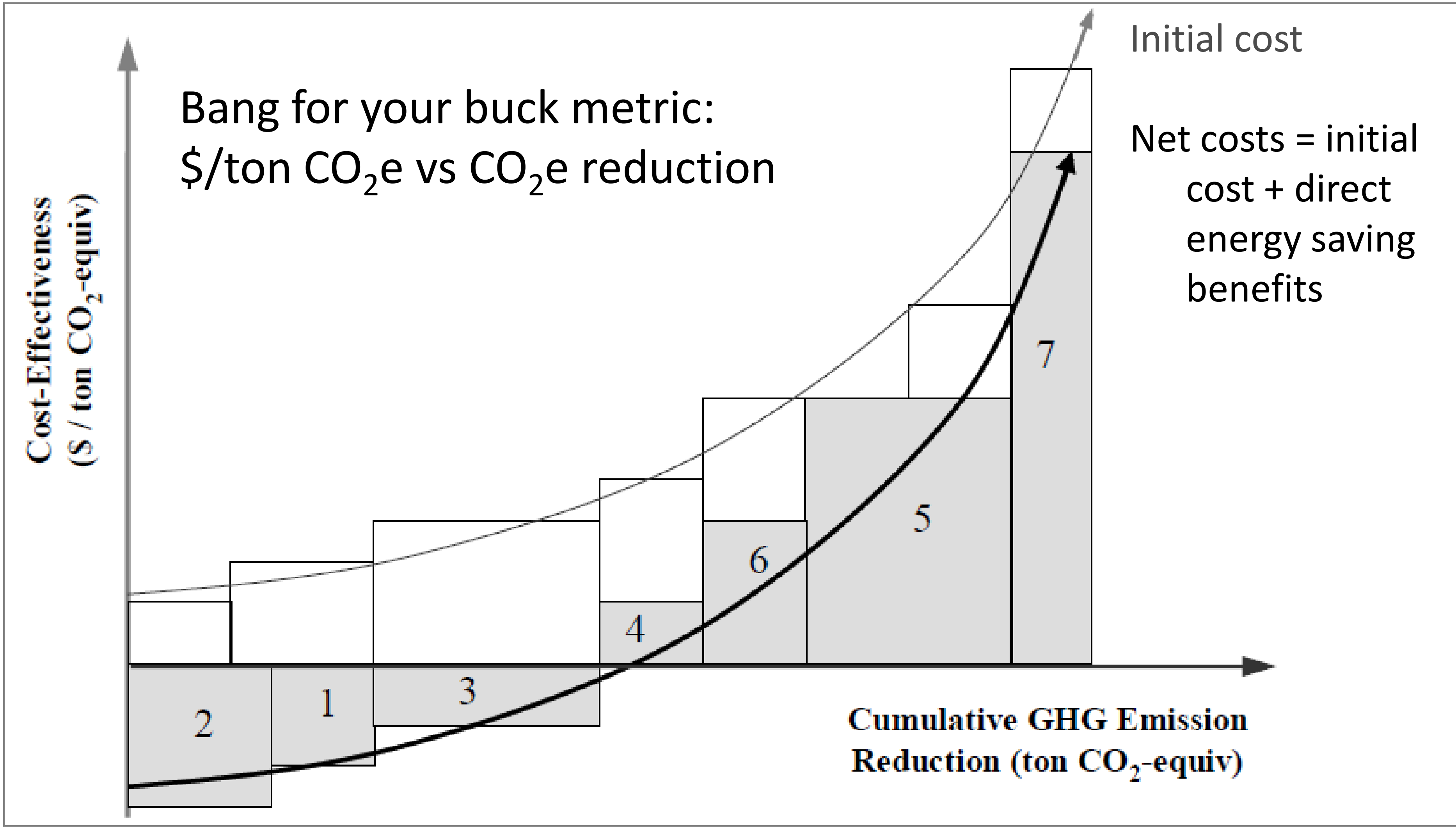
- This project is part of a larger pooled-effort program called "Miriam", partnering with 8 European National Highway Research Laboratories
  - Studying pavement rolling resistance

Disclaimer

The contents of this presentation reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California, the Federal Highway Administration, the University of California, the MIRIAM project or its sponsors, the International Society for Concrete Pavements, or the International Society for Asphalt Pavements. This presentation does not constitute a standard, specification, or regulation.

Questions?



- First-order quantitative "what-if" analysis
- Prioritizing Climate Change Mitigation Alternatives: Comparing Transportation Technologies to Options in Other Sectors, Lutsey, N. (2008)

Details: Future Work

- Finish the rest of the case studies
- Finish the application to California's network
- Include the effect of construction work zone traffic and traffic congestion (urban cases)
- Perform sensitivity analysis on parameters such as RR range, materials, traffic closure, etc.
- Apply the result to the Cost-Effectiveness curve

Future Work (Cont'd)

- Investigate the dissipated energy on asphalt, composite, semi-rigid pavement
- Investigate the macro-texture progression of concrete pavement
- Investigate the effect of congestion on rolling resistance impact
- Investigate the overall rolling resistance on composite and semi-rigid pavement