Example case studies: project level, network level, policy level

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UC PRC
UNIVERSITY of CALIFORNIA
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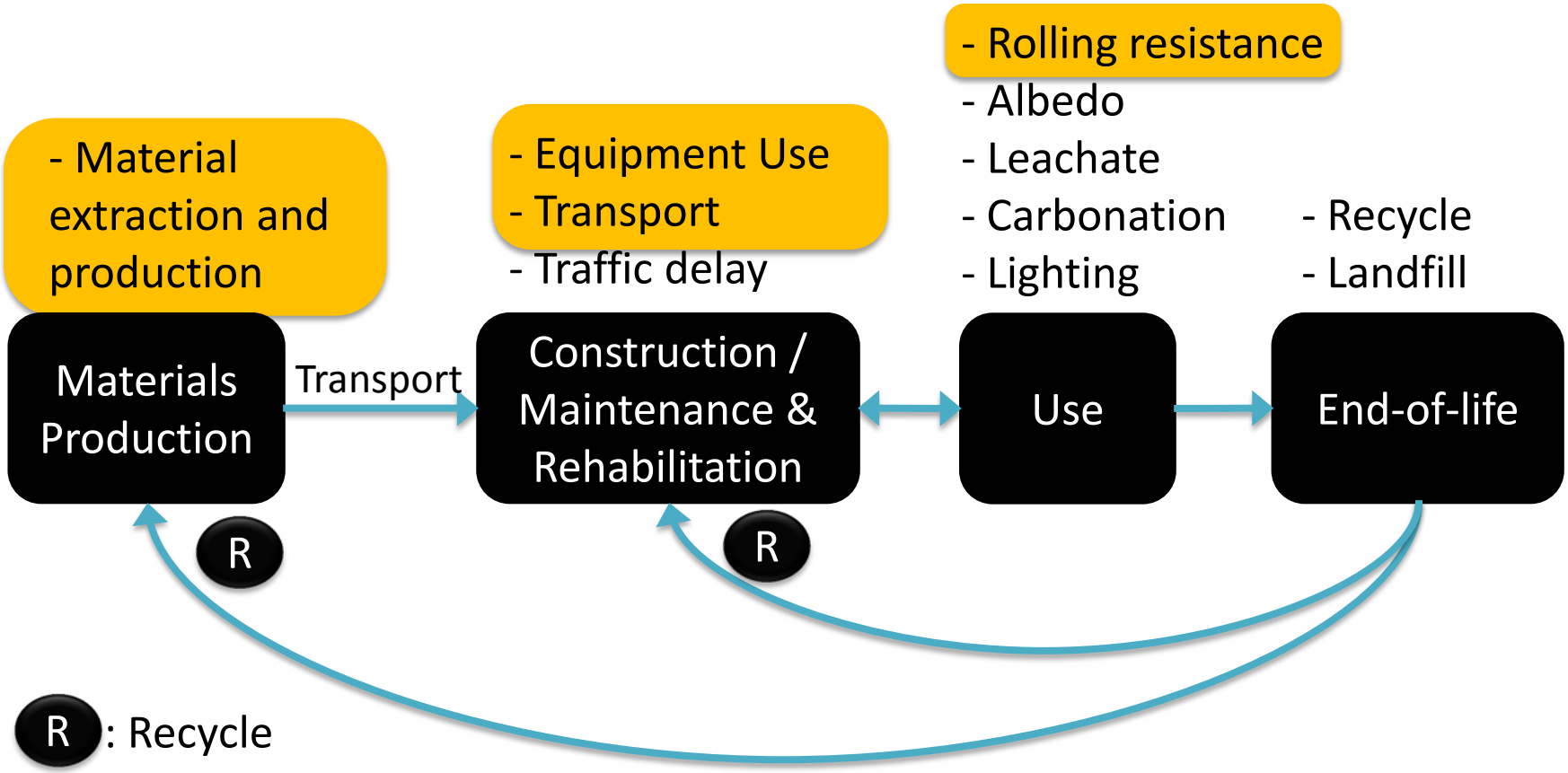
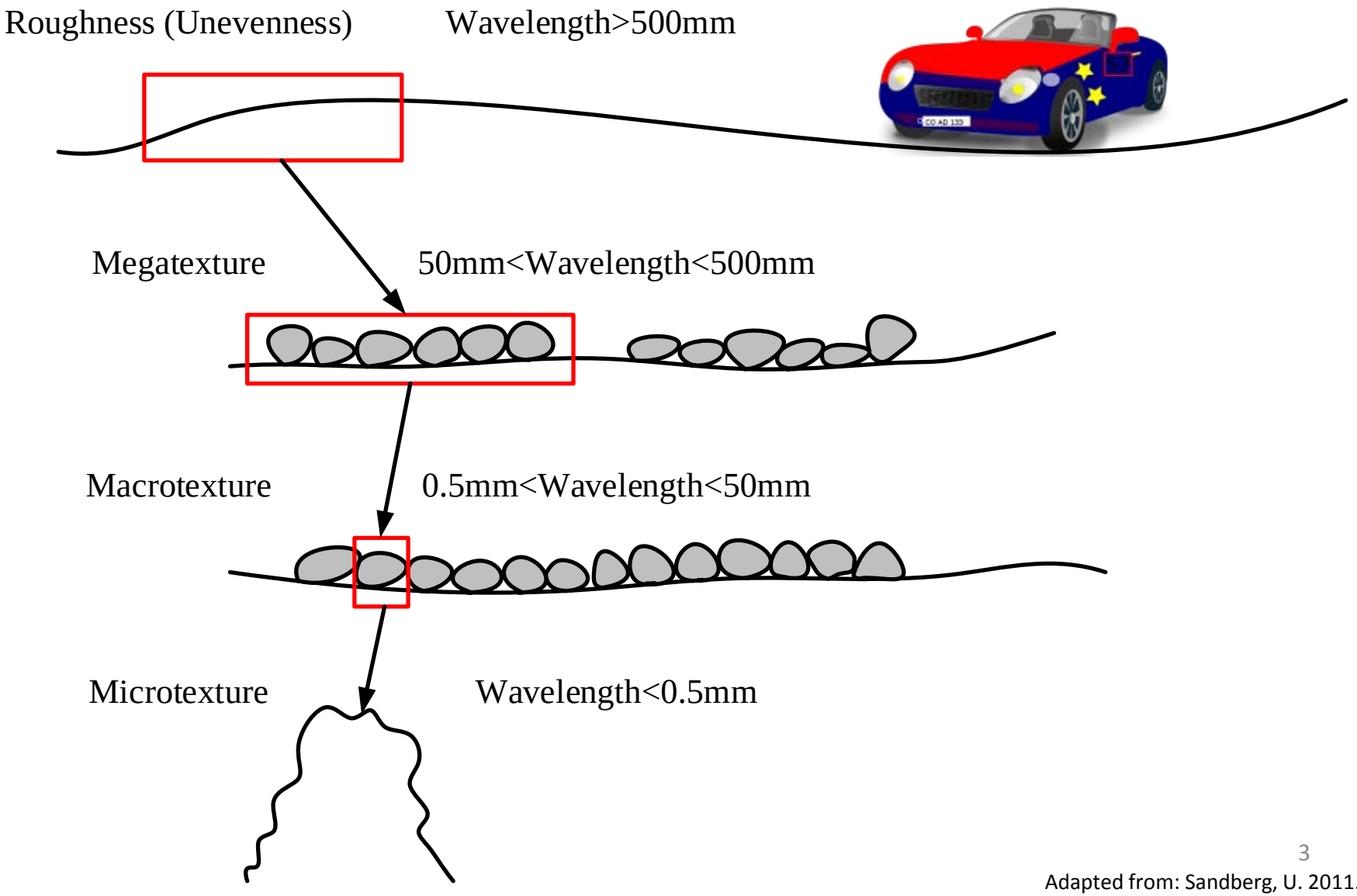
PAVEMENT RESEARCH CENTER

Pavement Life Cycle Assessment



From: Kendall et al, *2010*

Pavement surface characteristics



Adapted from: Sandberg, U. 2011.

Pavement Rolling Resistance

- Roughness
  - Measured with International Roughness Index (IRI)
  - Dissipates energy through suspension
- Macrotexture
  - Measured with Mean Texture Depth or Profile Depth (MPD)
  - Dissipates energy through tire distortion
- Deflection
  - Theory: dissipates energy through deflection of viscoelastic pavement materials (HMA)
  - MIT theory: larger deflection results in vehicle always running uphill

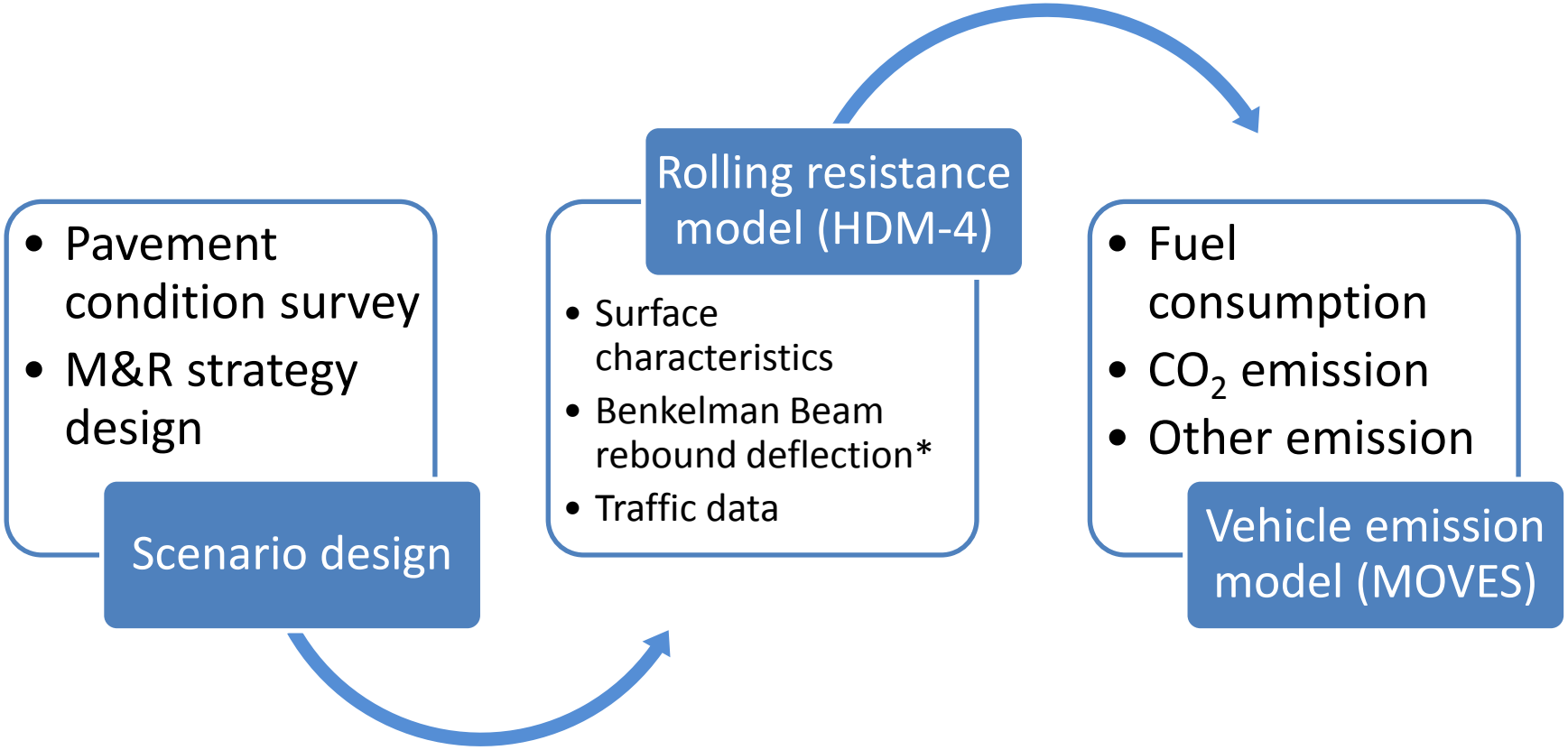
Project Level Goals

- Answer these questions:
  - What is effect of construction smoothness on GWP?
  - What is effect of pavement materials on GWP?
  - What is effect of traffic level on GWP?

Models: Materials and construction

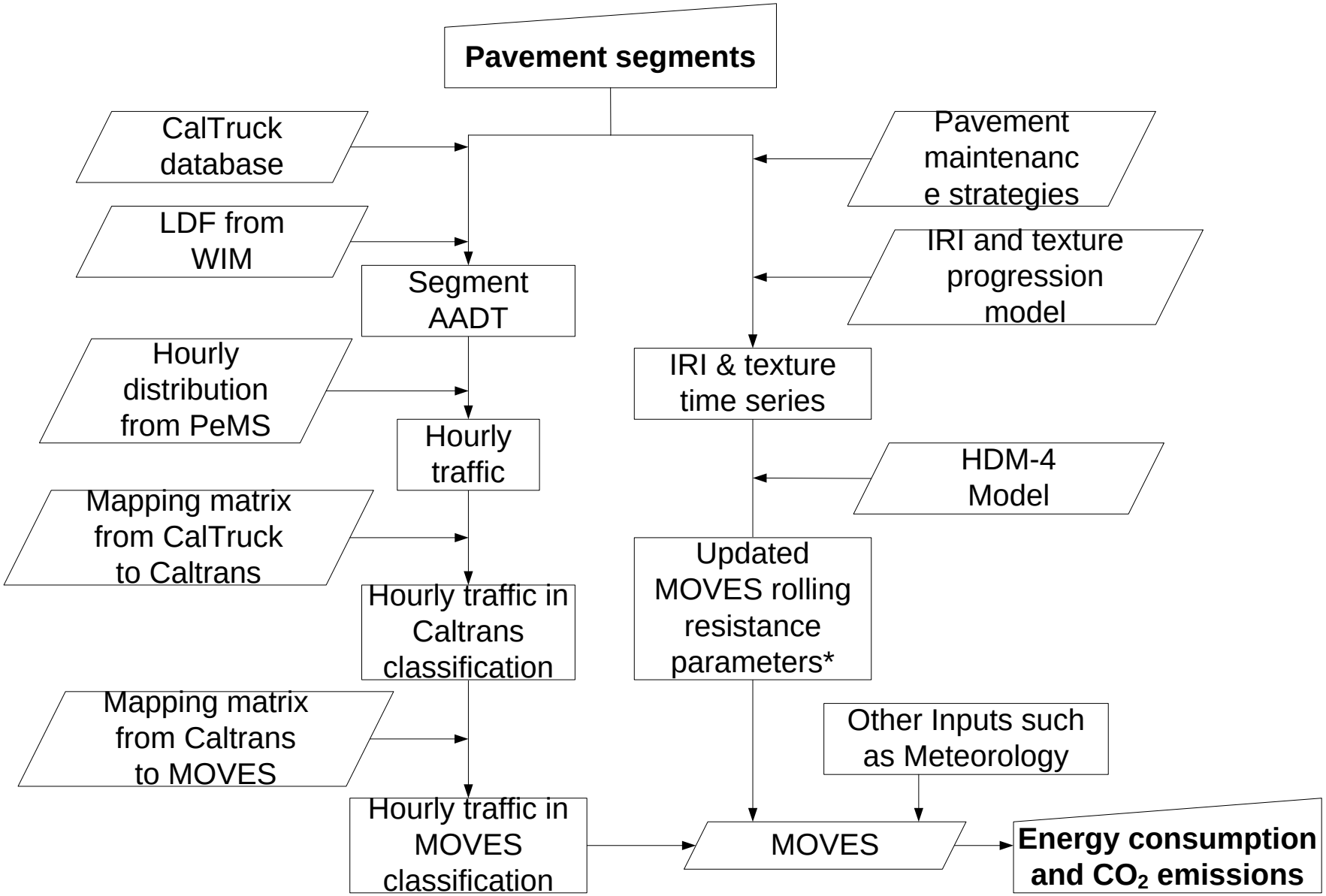
- Materials production and plant emissions:
  - Existing databases and studies
- Off-Road equipment
  - *OFFROAD*: California's off-road equipment emission inventory
- On-Road equipment
  - *EMFAC*: California's on-road vehicles emission inventory
- Equipment and hours
  - *CA4PRS:* Caltrans construction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

Models: Use Phase



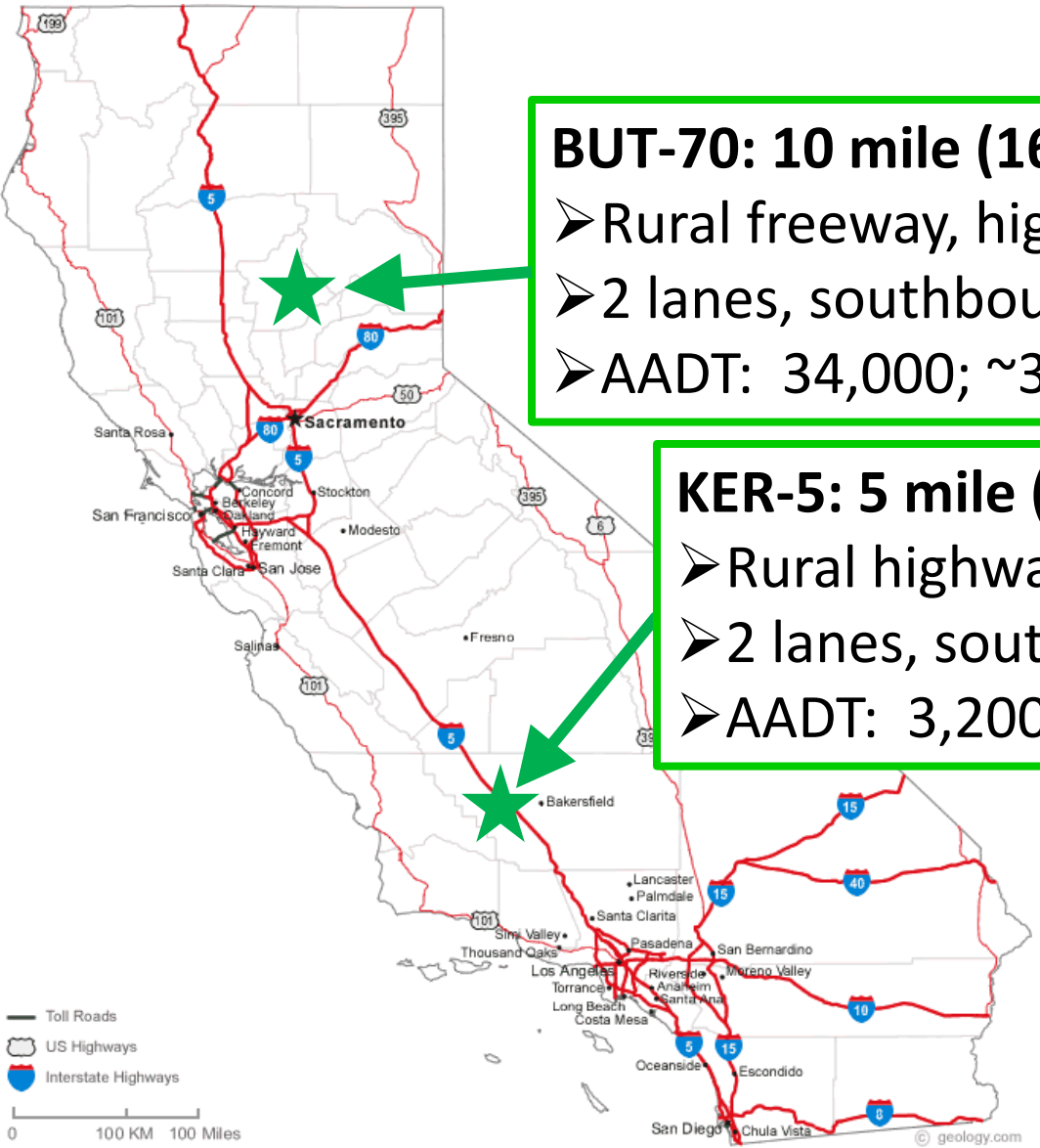
*: Will be addressed after further investigation and when different pavement structures are compared.

Models: Use Phase



*: Currently deflection term is not being addressed, and texture is not compared on different concrete pavements.

Project-level asphalt case studies



BUT-70: 10 mile (16 km) segment (low traffic)

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

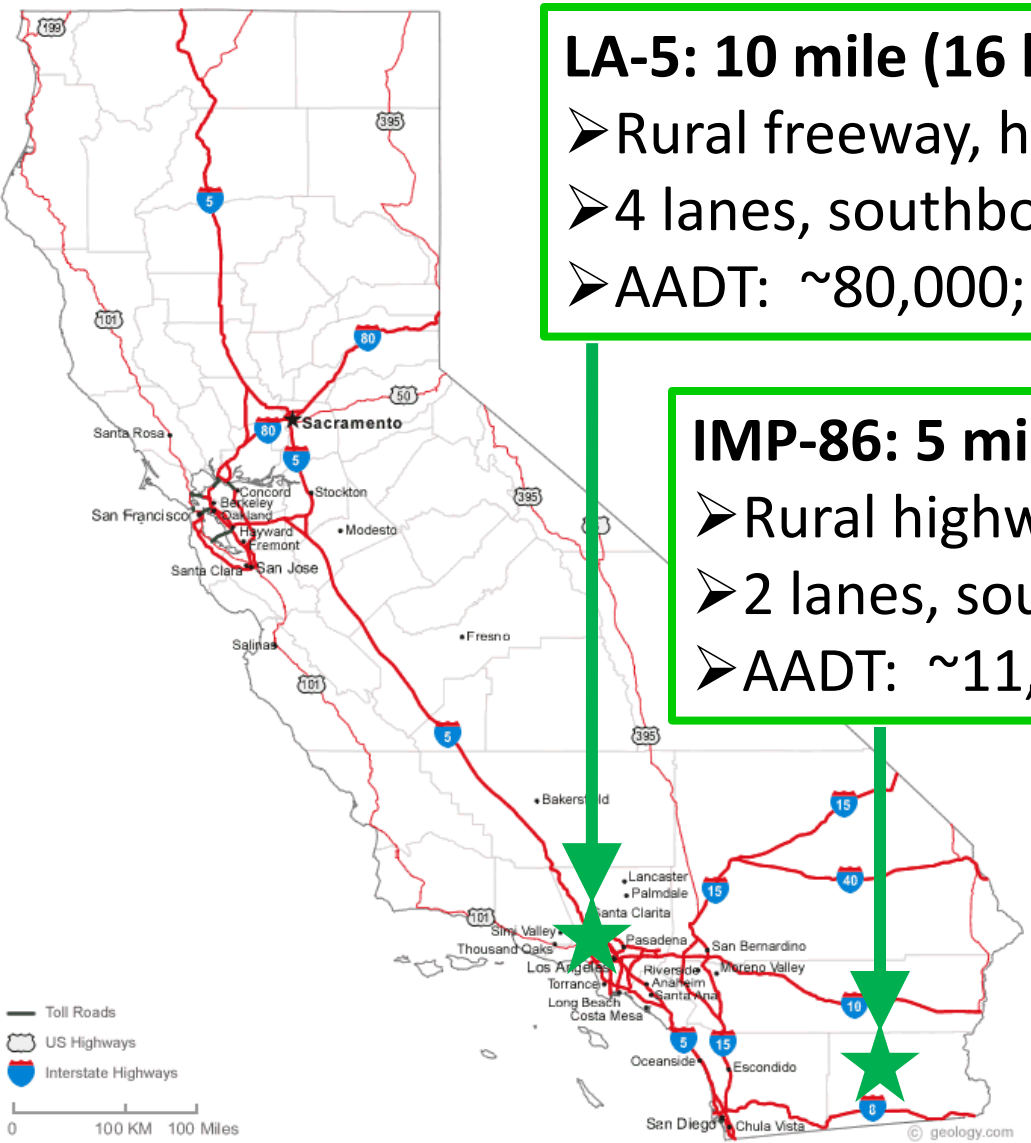
KER-5: 5 mile (8 km) segment (high traffic)

- Rural highway, low traffic volume
- 2 lanes, southbound
- AADT: 3,200; ~15% trucks

Compare:

- *Do Nothing*
- 5 year overlay
  - -HMA, RHMA

Project-level concrete case studies



LA-5: 10 mile (16 km) segment (high traffic)

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

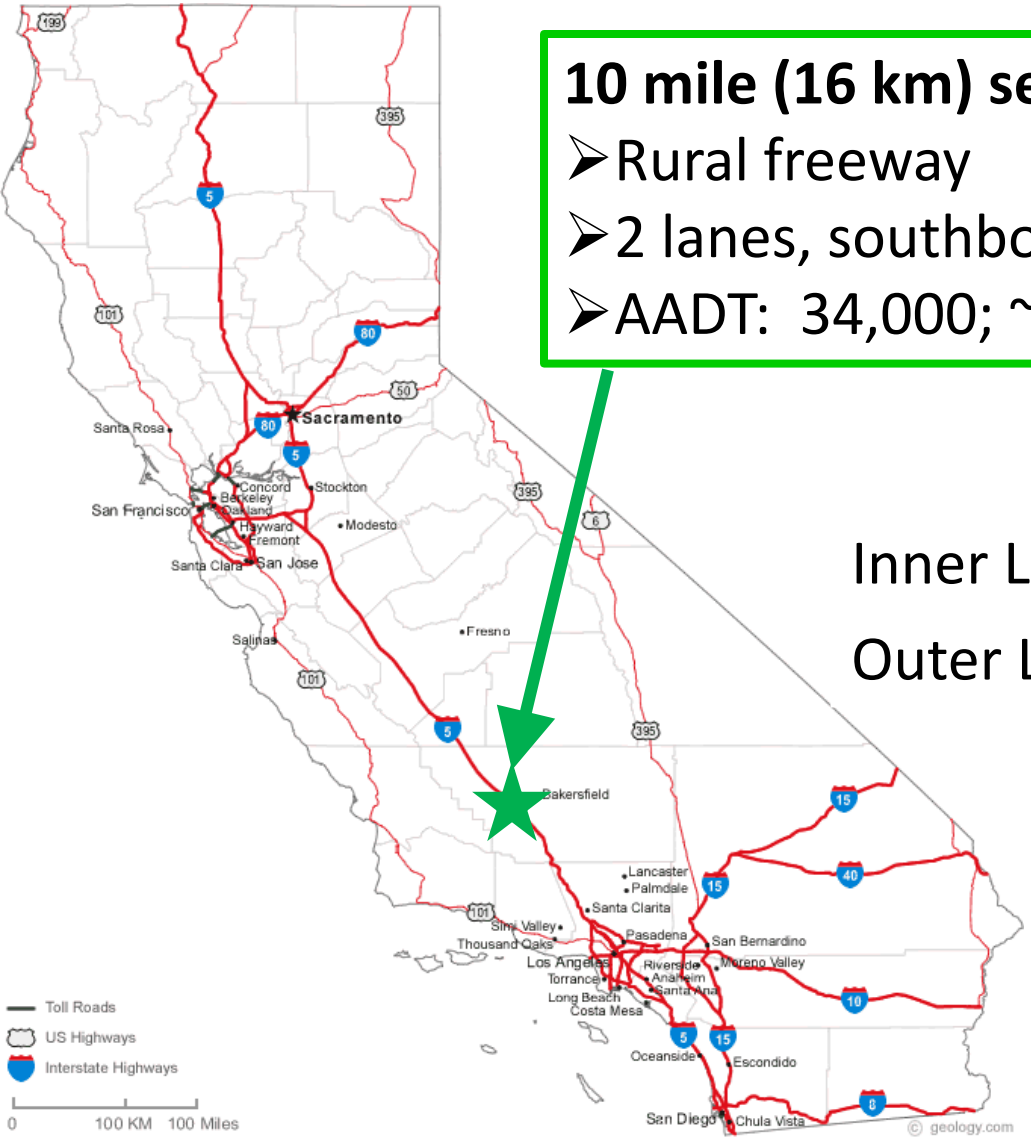
IMP-86: 5 mile (16 km) segment (low traffic)

- Rural highway, low traffic volume
- 2 lanes, southbound
- AADT: ~11,200; ~29% trucks

Compare:

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

Case Study 1 (KER-5): 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 (CAPM)
  - HMA, RHMA

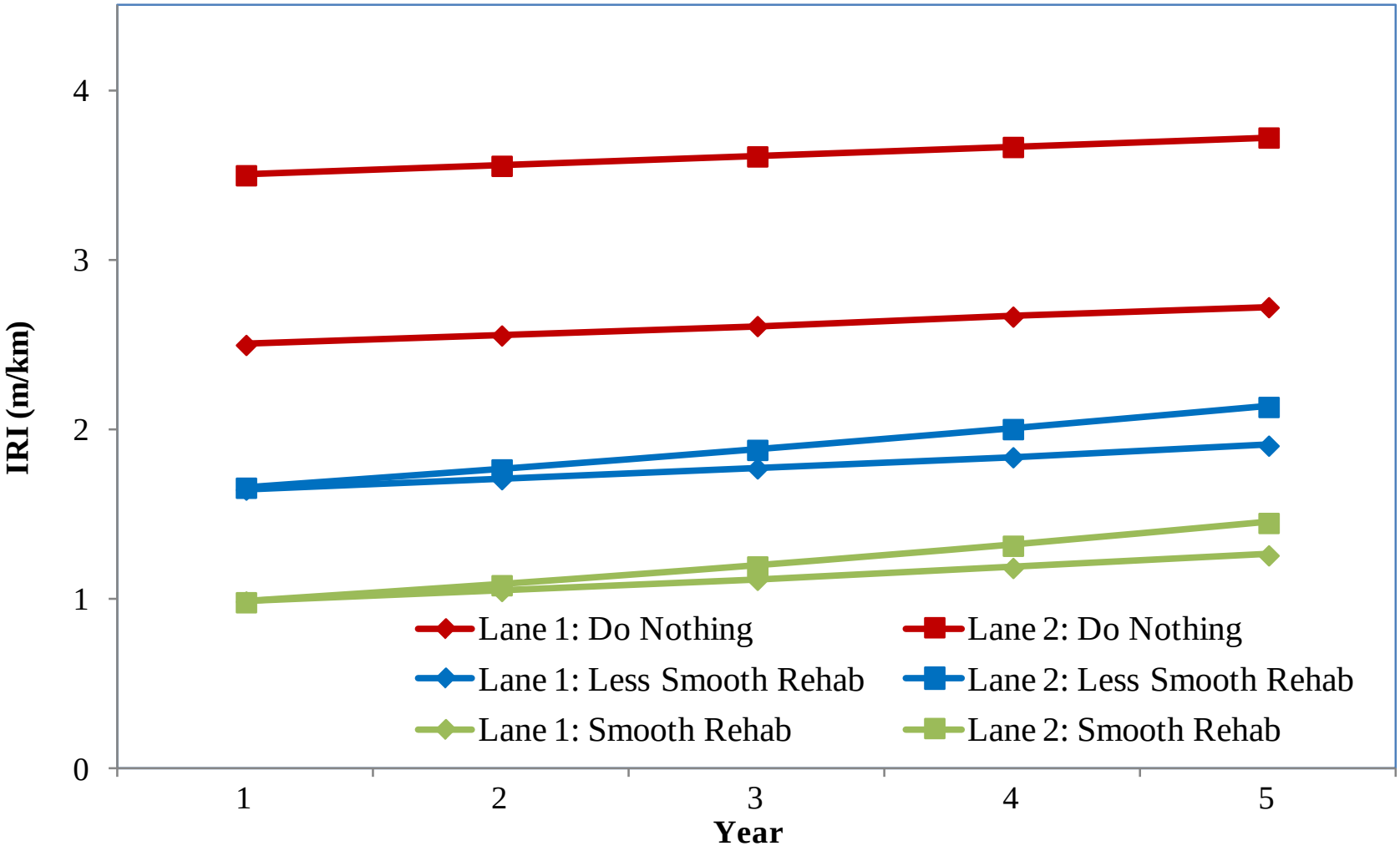
Construction Scenarios: KER-5

HMA Type	Design life	Treatment	Cross Section	Smoothness
CAPM, HMA	5 Years	Mill & Overlay	45 mm (0.15’) Mill + 75 mm (0.25’) HMA with 15% RAP	Smooth Rehab
				Less smooth Rehab
CAPM, RHMA	5 years	Mill & Overlay	30 mm (0.1’) Mill + 60 mm (0.20’) RHMA	Smooth Rehab
				Less smooth Rehab

Equipment Operation (hours): KER-5

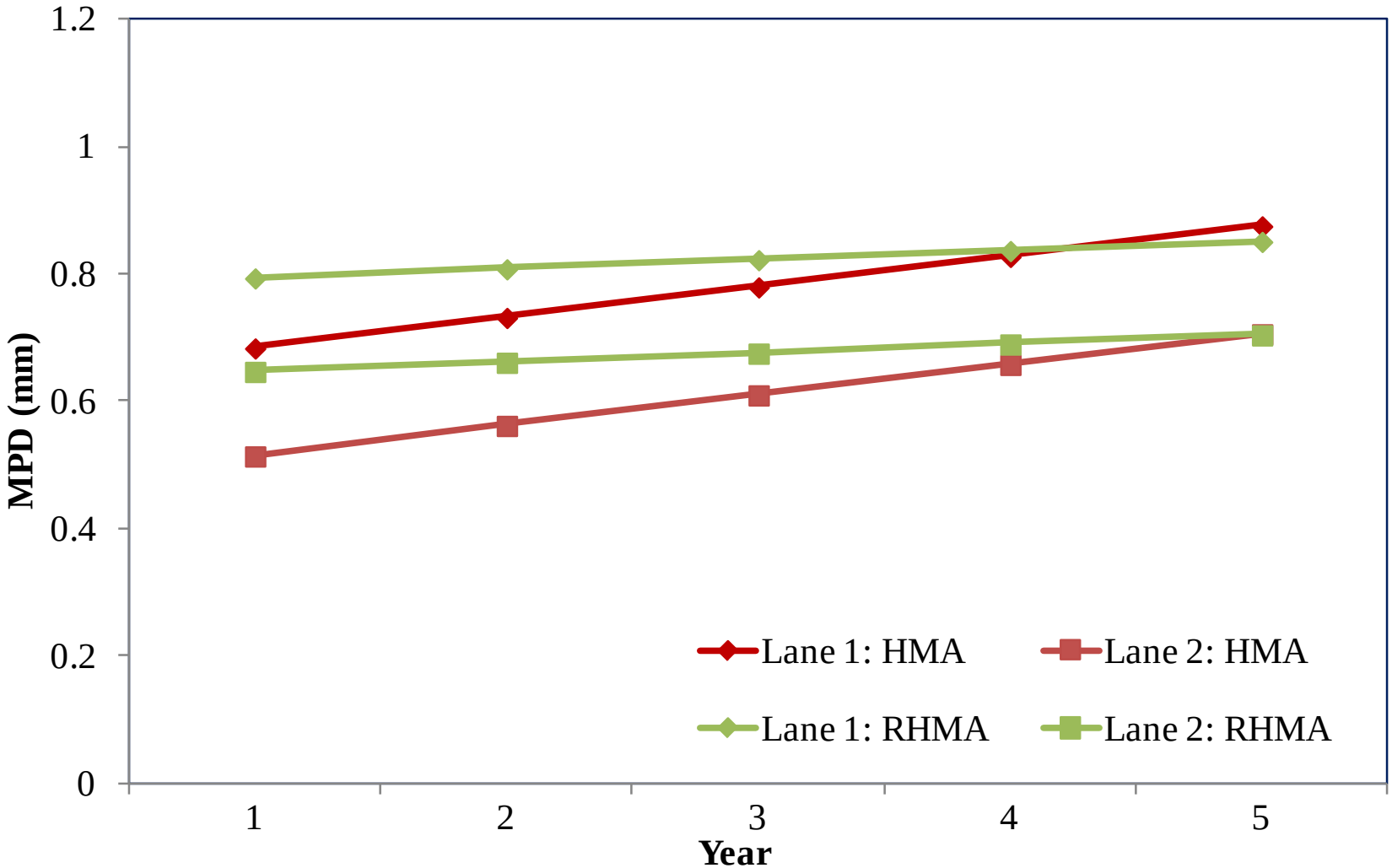
Activity	Equipment	HMA		RHMA	
		Operation	Idle	Operation	Idle
Total Closure for Construction		36 x 9-h Night		27 x 9-h Night	
Milling	Milling Machine	124		86	
	Demo Hauling Truck	1,761		1,244	377
	Pay Loader	216		162	
	Grader	216		162	
	Compactor	216		162	
HMA	AC Paver	216		162	
	R/HMA Delivery Truck	3,098	492	2,456	390
	Roller (vibratory/static)	432		324	
	Roller (pneumatic tire)	216		162	
	Drum Plant (metric ton)	20,628		16,510	
	Drum Plant Operation	108		81	
General	Truck (General + Tack)	870	138	652	104
	Generator	648		486	

KER-5 IRI Scenarios over 10 years*



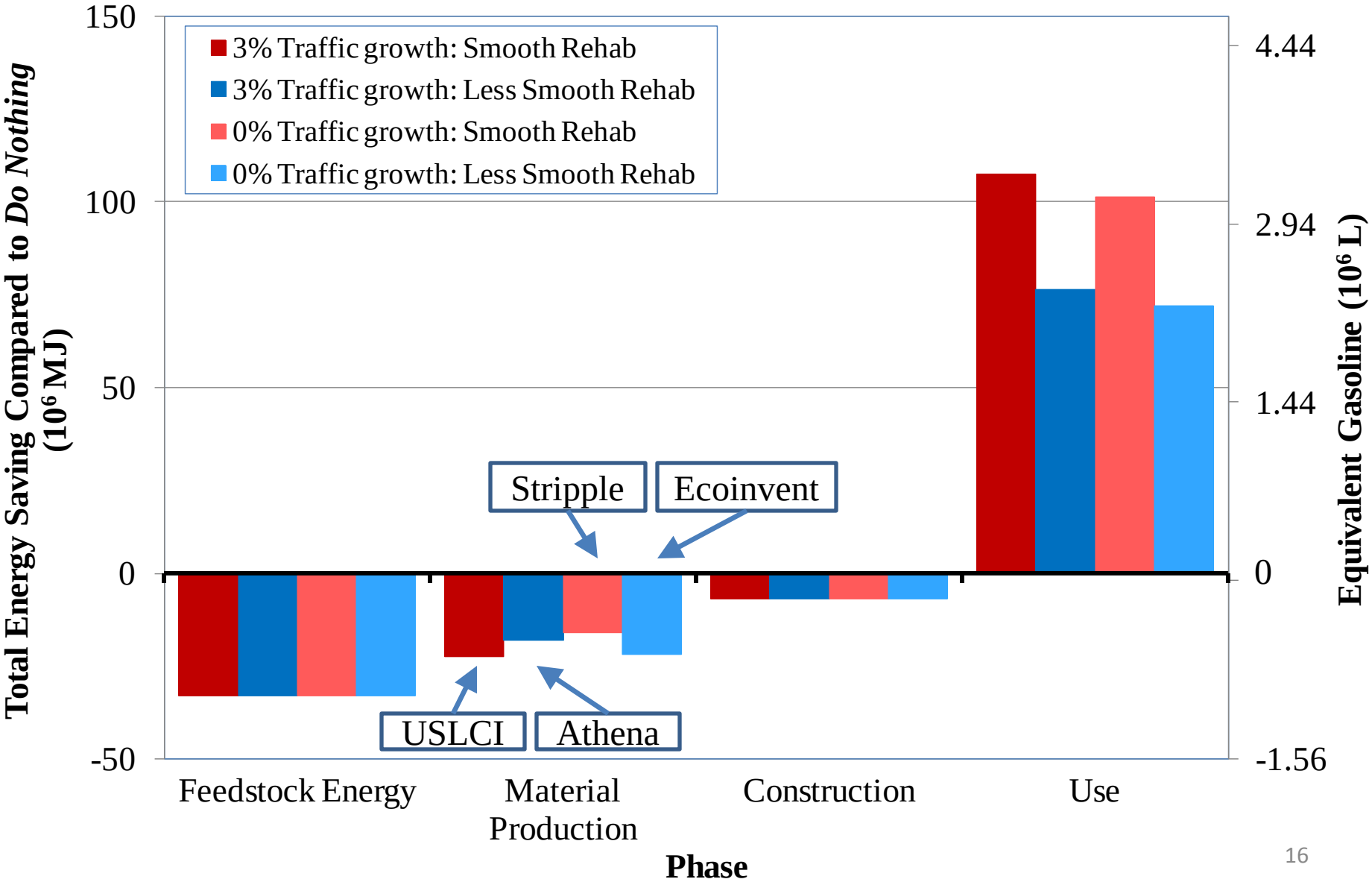
* 1st draft from empirical data, needs review and modeling

KER-5 MPD Progression from CA data*
(For rehabilitated lanes)

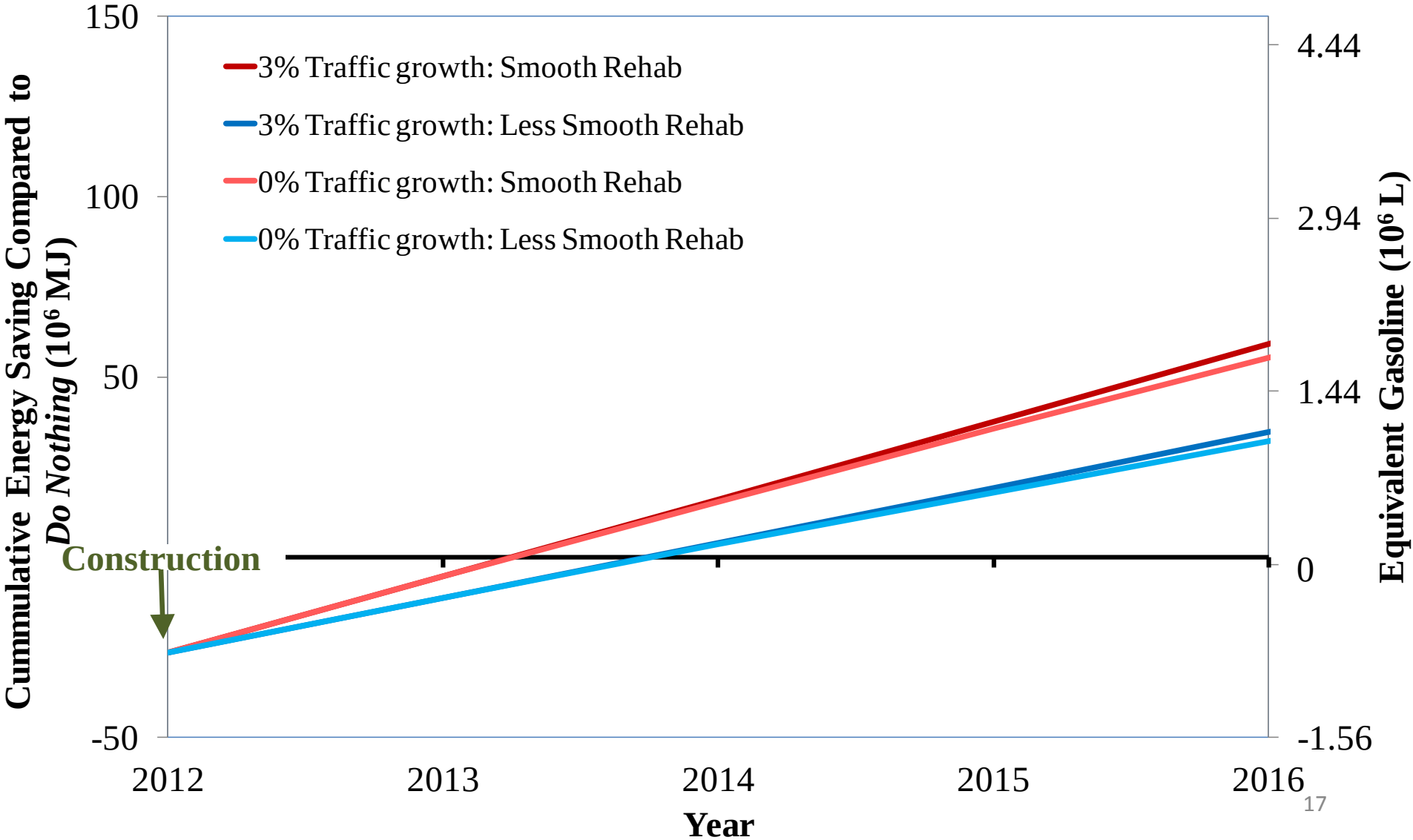


* 1st draft from empirical data, needs review and modeling

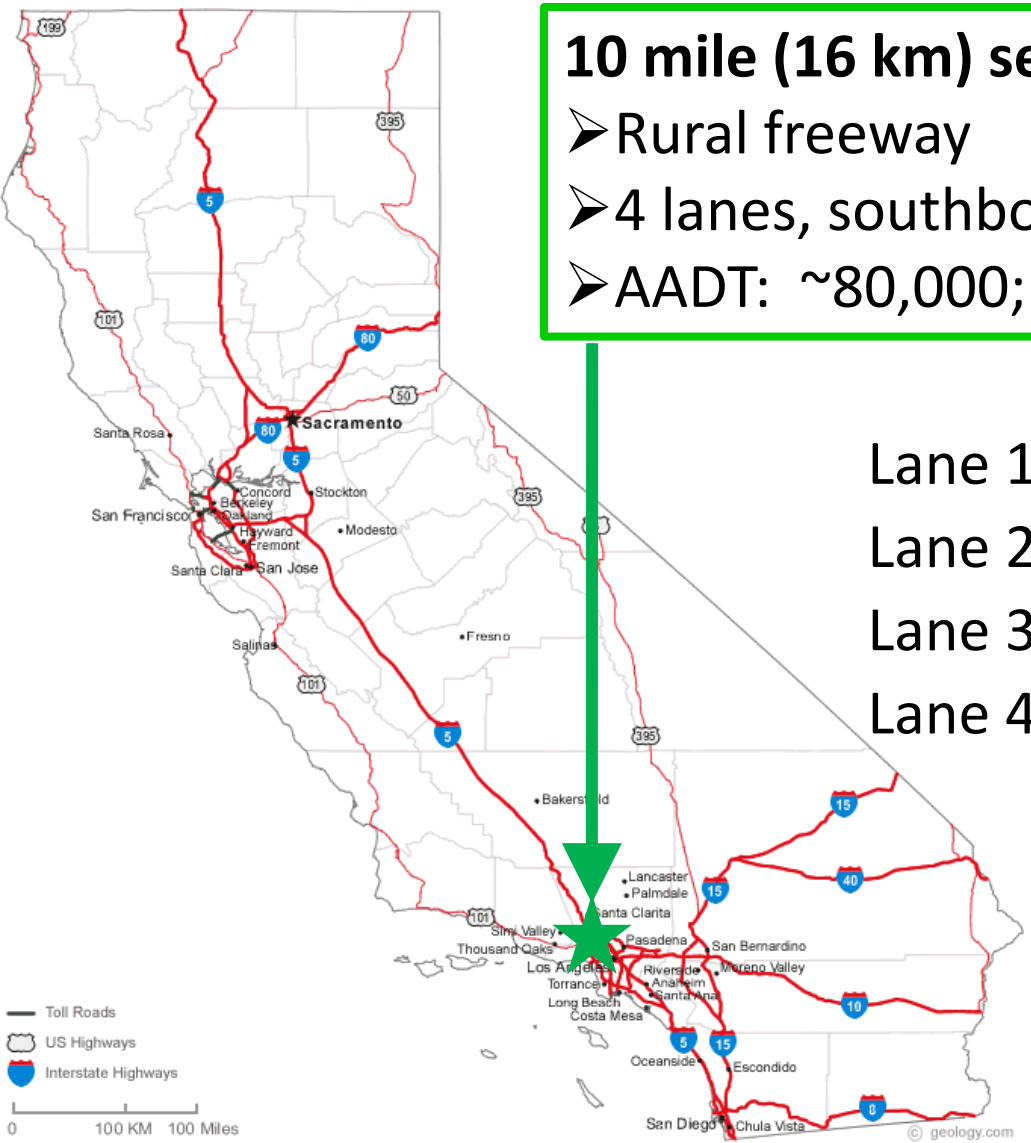
KER-5 (HMA): 5-year life cycle energy savings compared to *Do Nothing*



KER-5 (**HMA**): Cumulative life cycle energy savings compared to *Do Nothing*



Case Study 2 (LA-5): 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

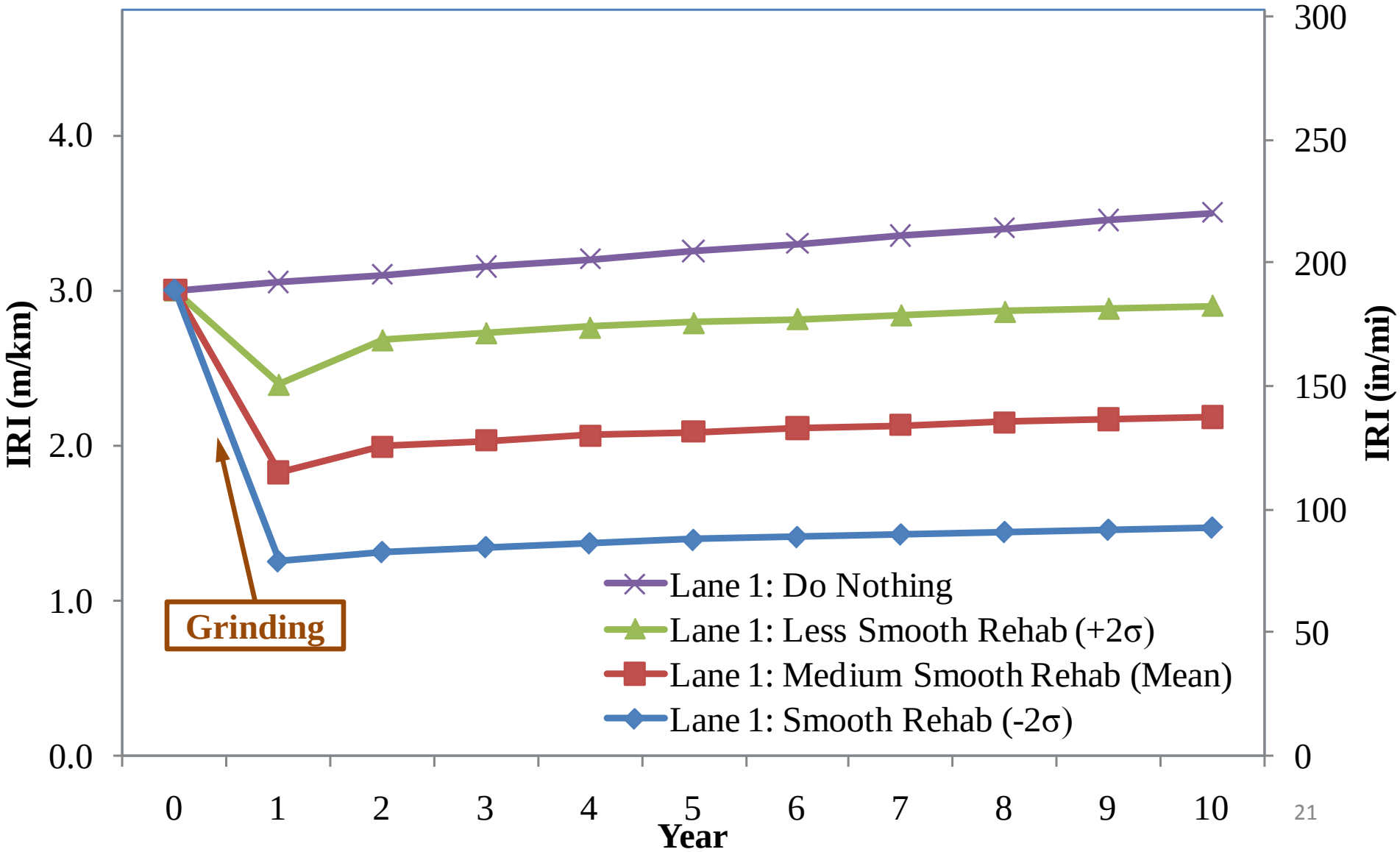
Construction Scenario (LA-5)

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)

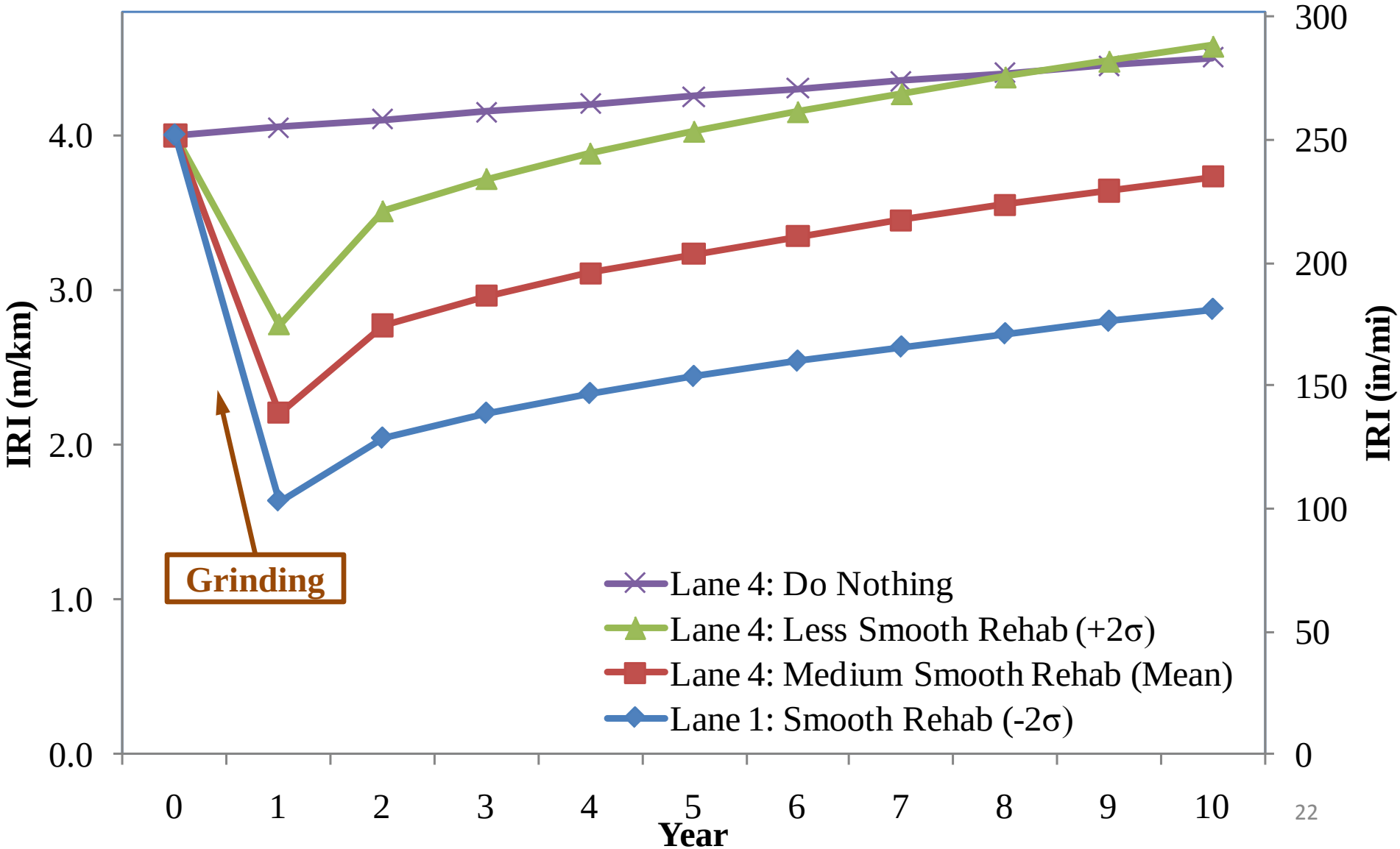
Equipment Operation (hours)

Activity	Equipment	Number per closure	Operation hours	Idling hours
Demolition	Saw cutters (demo & paving)	2	324	
	Excavator	2	180	
	Demo hauling truck	8	495	229
	Payloader	1	92	
	Grader	1	90	
	Compactor	1	90	
PCC	PCC roller screed	1	72	
	Concrete delivery truck	8	436	165
Grinding & Dowels	Diamond grinder	2	563	
	Grinder slurry tanker	4	789	338
	Dowel bar - Gang drill	1	54	
General	General truck	2	216	108
	Generator (180kw, for lighting etc.)	3	486	

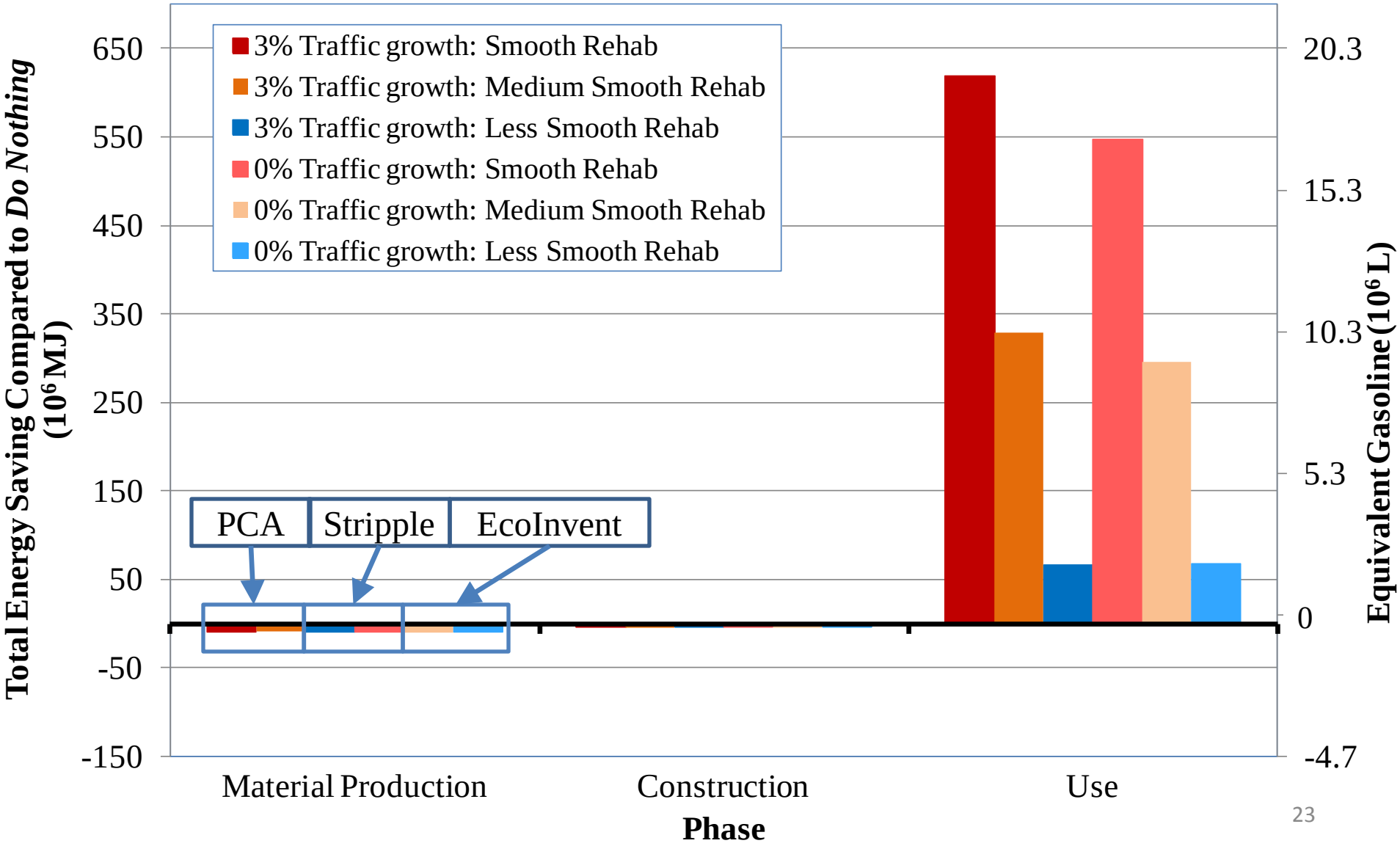
LA-5 Lane 1: IRI over 10 years



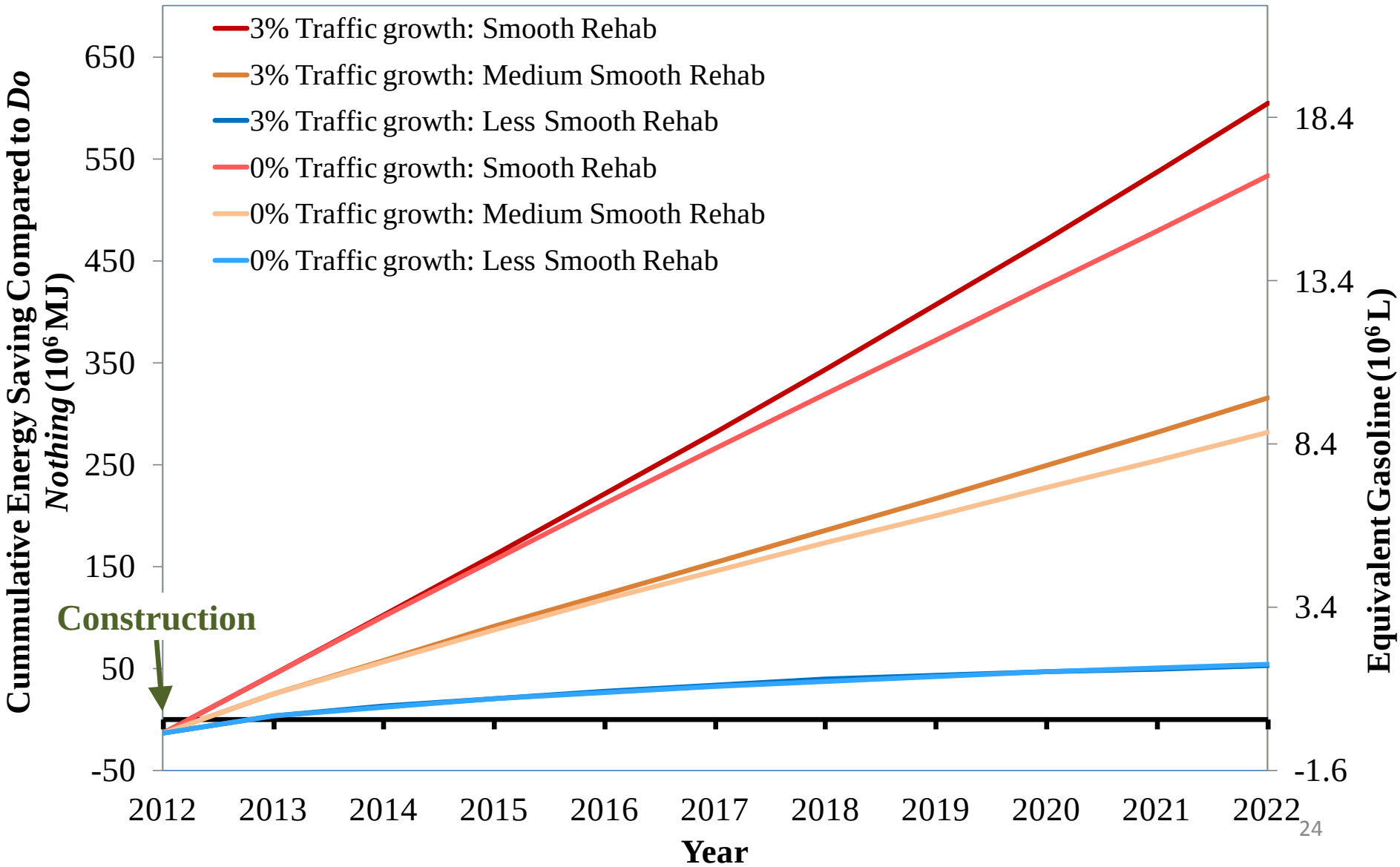
LA-5 Lane 4: IRI over 10 years



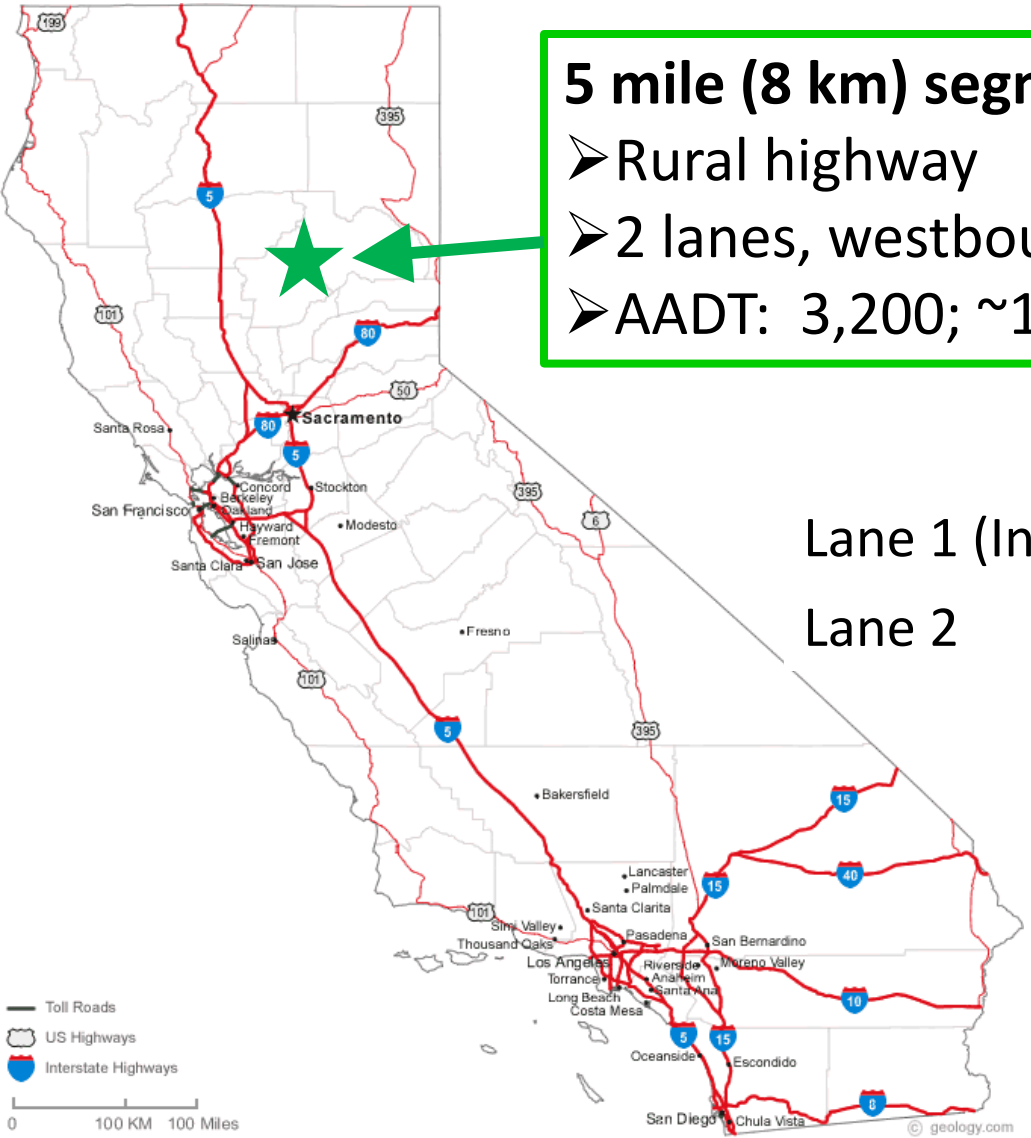
LA-5 (Type III PCC): 10-year life cycle energy savings compared to "*Do Nothing*"



LA-5 (Type III PCC): Cumulative life cycle energy savings compared to *"Do Nothing"*



Case Study 3 (BUT-70): Asphalt overlay on rural/flat highway



5 mile (8 km) segment in need of rehab

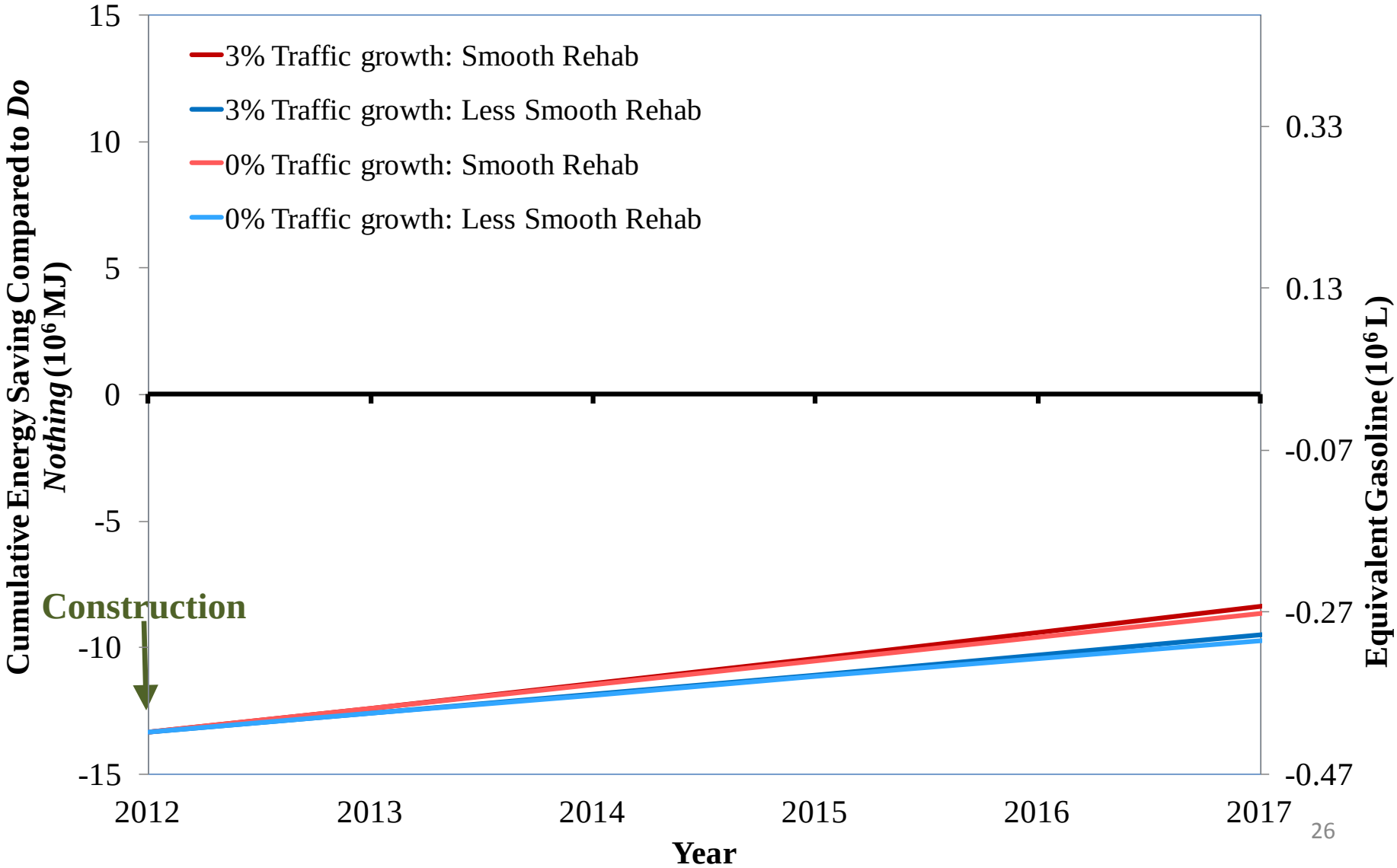
- Rural highway
- 2 lanes, westbound
- AADT: 3,200; ~15% trucks

	Cars	Trucks	IRI
Lane 1 (Inner)	61%	8%	3.8
Lane 2	39%	92%	3

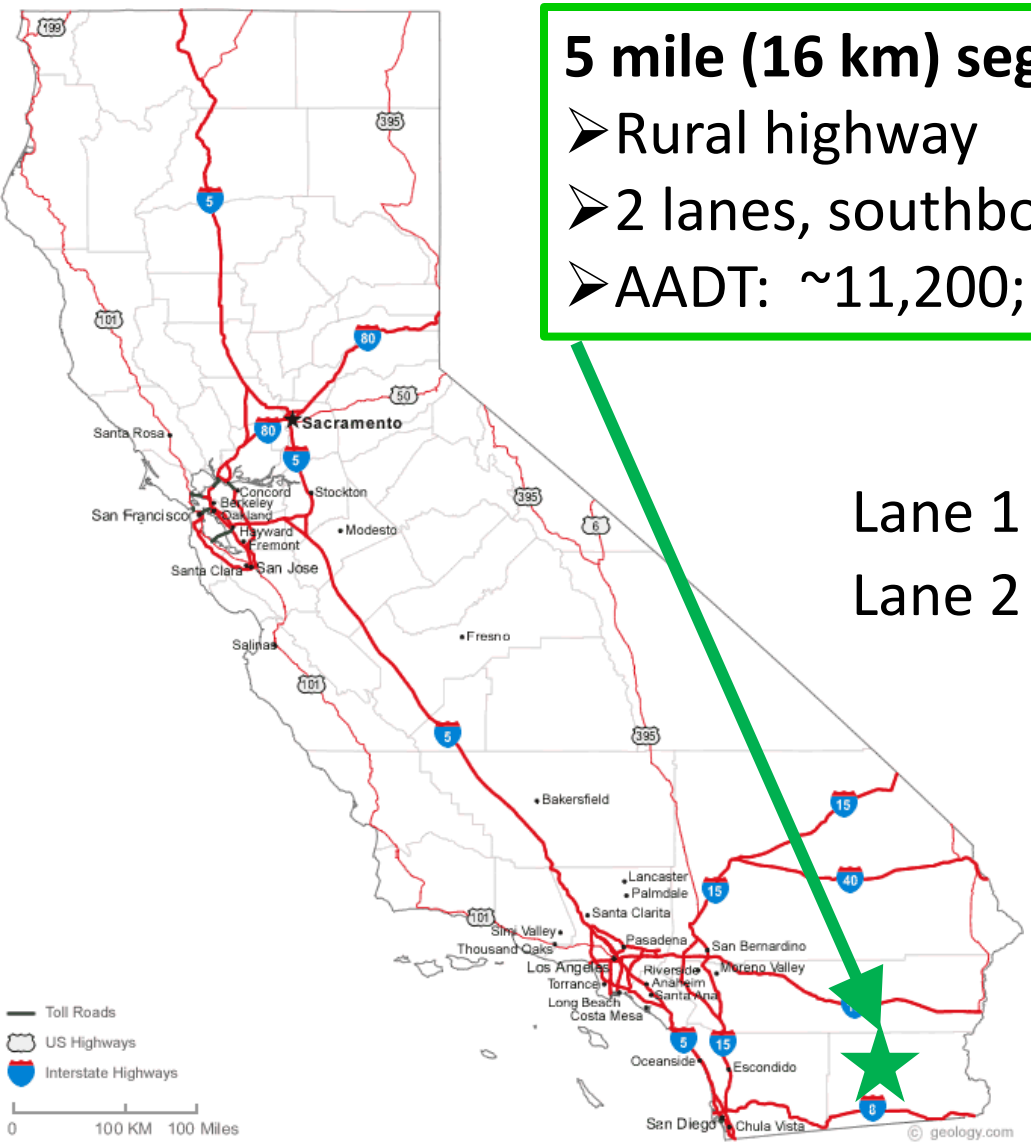
Compare:

- Do Nothing
- 5 year rehab (CAPM)
  - HMA, RHMA

BUT-70 (HMA): Cumulative life cycle energy savings compared to "*Do Nothing*"



Case Study 4 (IMP-86): Concrete CPR B on rural/flat highway



5 mile (16 km) segment in need of rehab

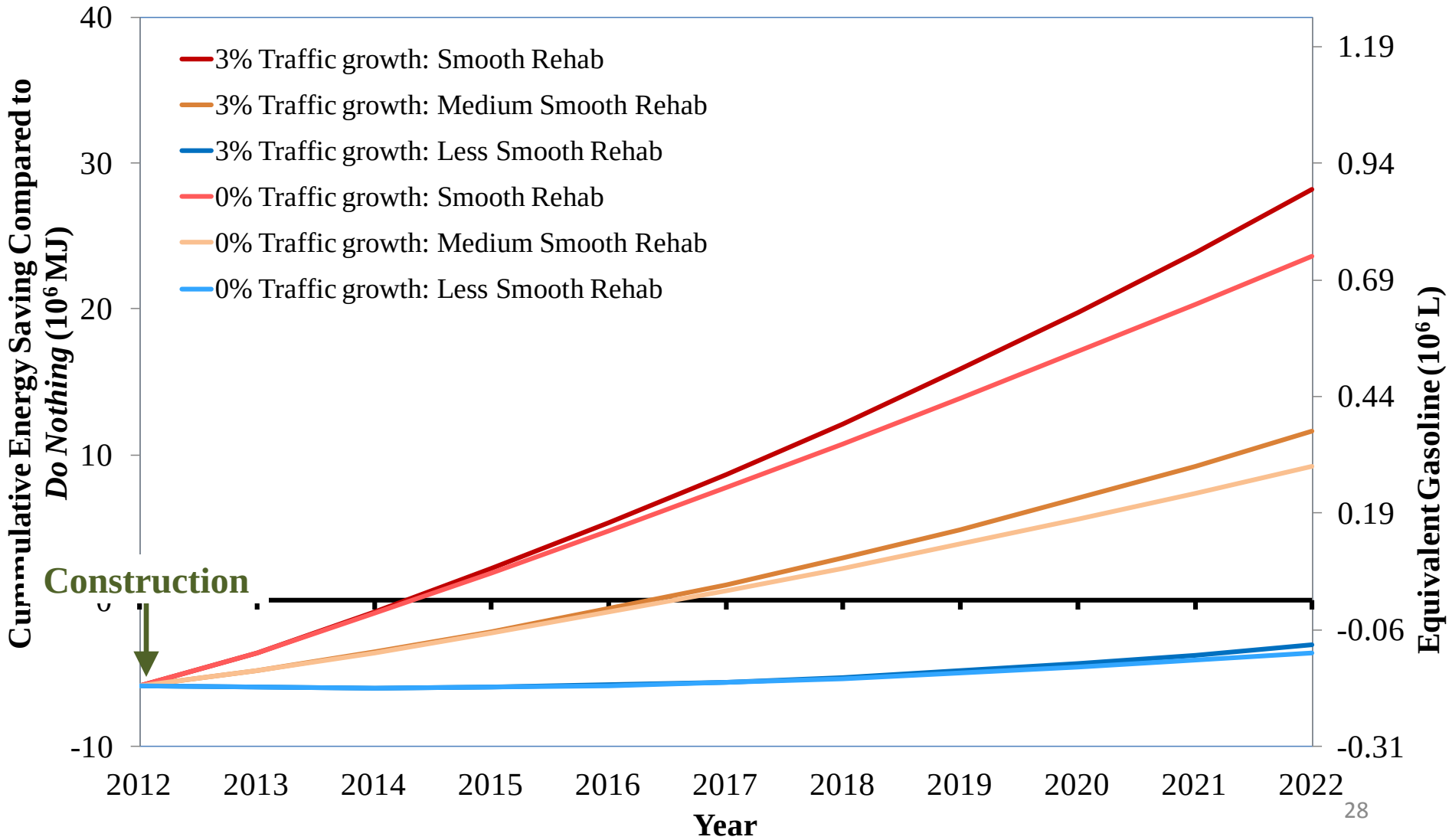
- Rural highway
- 2 lanes, southbound
- AADT: ~11,200; ~29% trucks

	Cars	Trucks	IRI
Lane 1 (Inner)	76%	8%	2.5
Lane 2	24%	92%	2.7

Compare:

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

IMP-86 (**CSA cement**): Cumulative life cycle energy savings compared to "Do Nothing"



Summary table: Payback time (years)

Asphalt cases			
Case	**Material**	**Smooth**	**Less Smooth**
High traffic	HMA	1.3	1.7
	RHMA	1.1	1.5
Low traffic	HMA	>5	>5
	RHMA	>5	>5

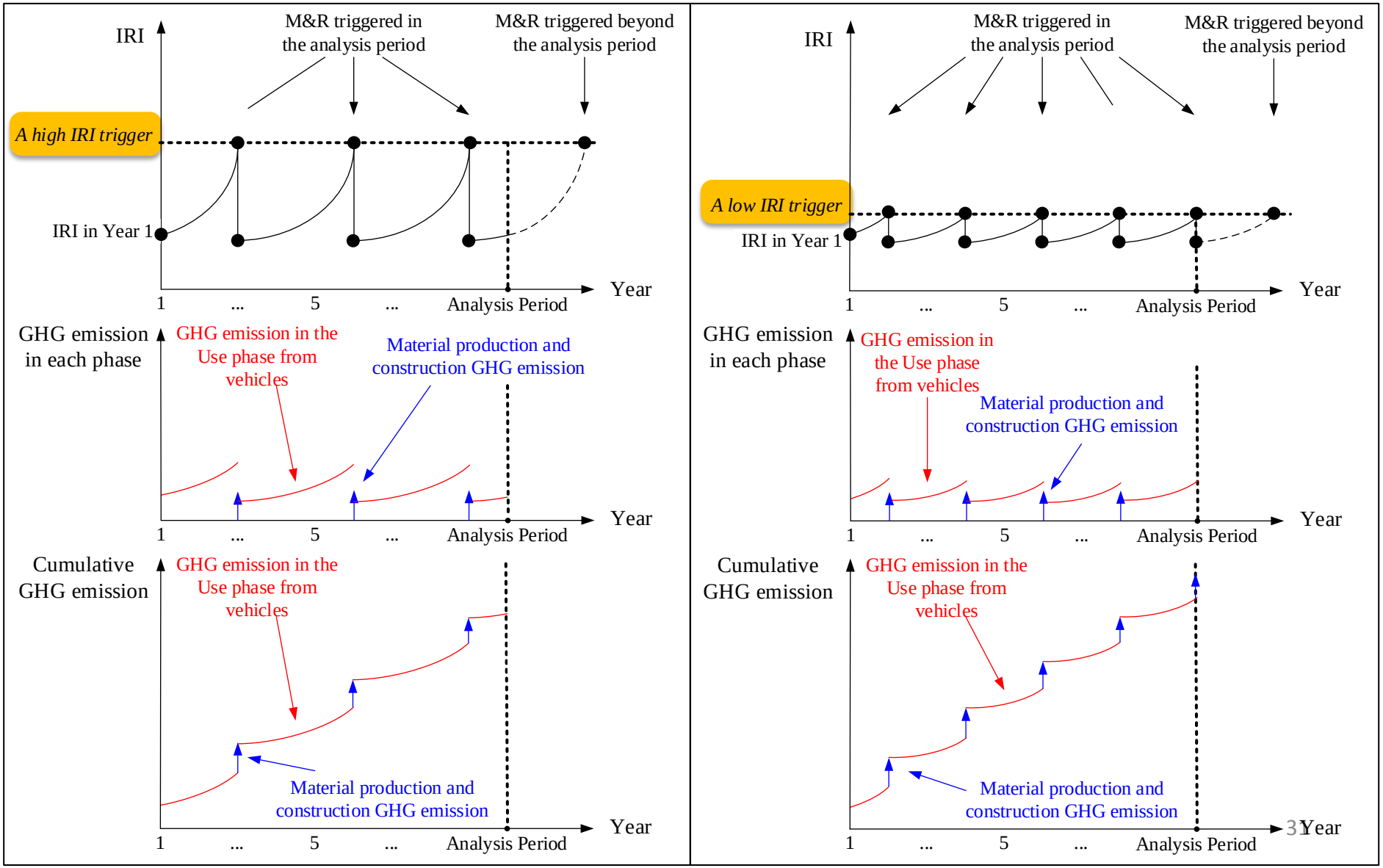
Concrete cases				
Case	**Material**	**Smooth**	**Medium Smooth**	**Less Smooth**
High traffic	Type III	<1	<1	<1
	CSA	<1	<1	<1
Low traffic	Type III	2.7	5~5.1	>10
	CSA	2.3	4.4~4.5	>10

Conclusion: Traffic level matters!

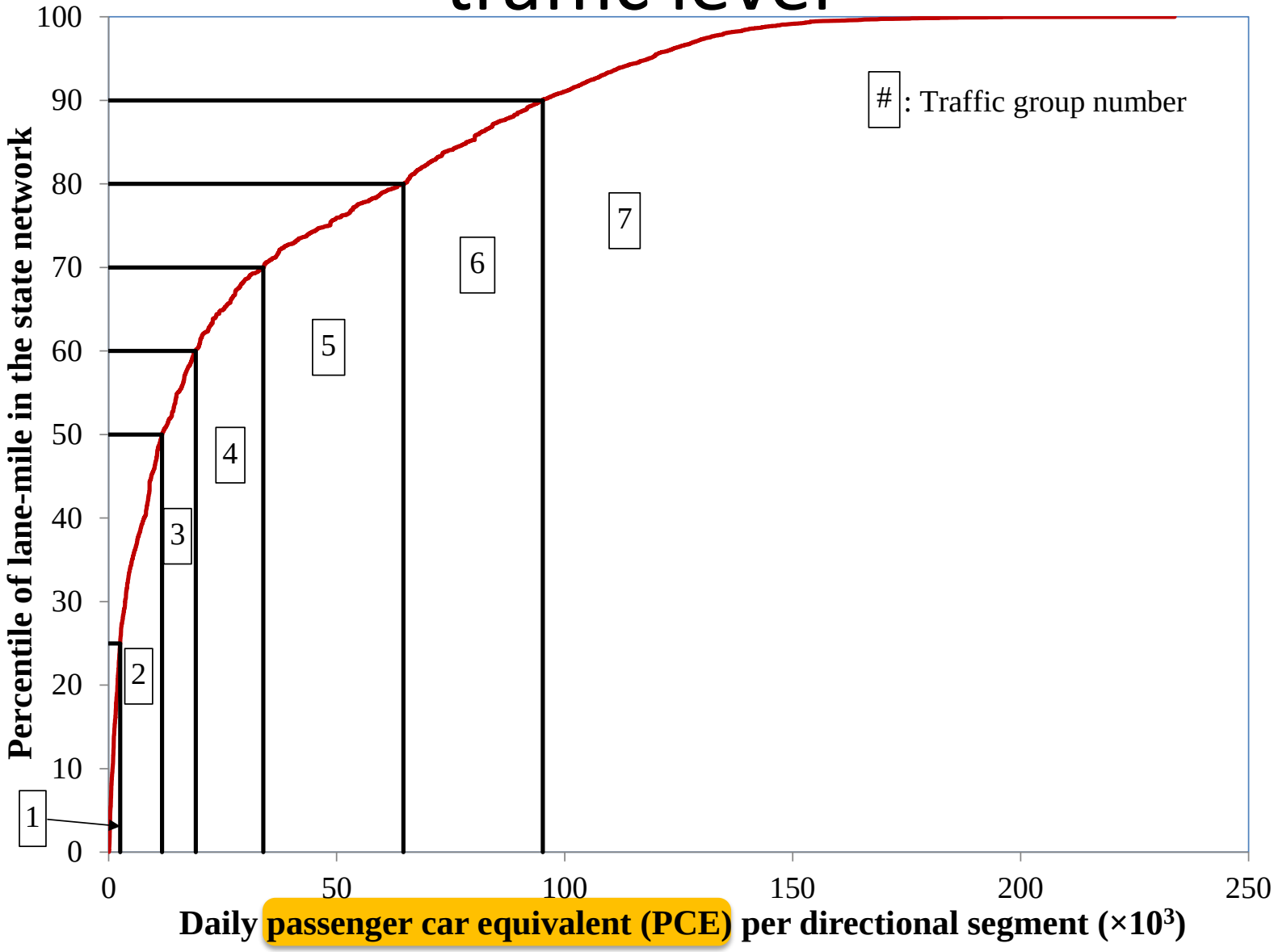
Application of Case Studies to Pavement Management System

- Apply results from the case studies to the pavement network
- Questions to answer:
  - Optimal IRI triggers to minimize the life cycle GHG emission on California highway network.
  - Cost-effectiveness of treatments and IRI trigger for each traffic level.
- Explore the integration with PMS

Different IRI triggers (high vs. low)



Method: Divide network based on traffic level



Input data: M&R treatments

- Asphalt: 45mm milling and 75mm overlay
- Concrete: slabs replacement for 3rd stage cracking and grinding all lanes
- Impacts from work zone traffic ignored

Treatment	GHG emission (tCO_2-e /m^3 material)	Cost ($/lane-mile)
Asphalt overlay using HMA	0.236	200,000
Slab replacement using Type III cement	0.561	1,700,000
Grinding	0.116	50,000

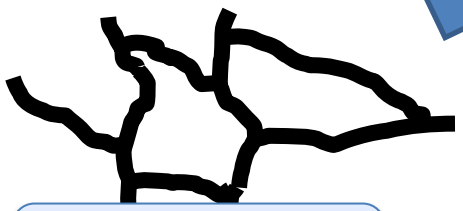
Use phase emission factors

- Vehicle emission factors
  - Based on previous project-level study
  - Variable: Pavement type; road type; road access type; vehicle type; IRI and MPD
  - Highly linear: R^2>0.99

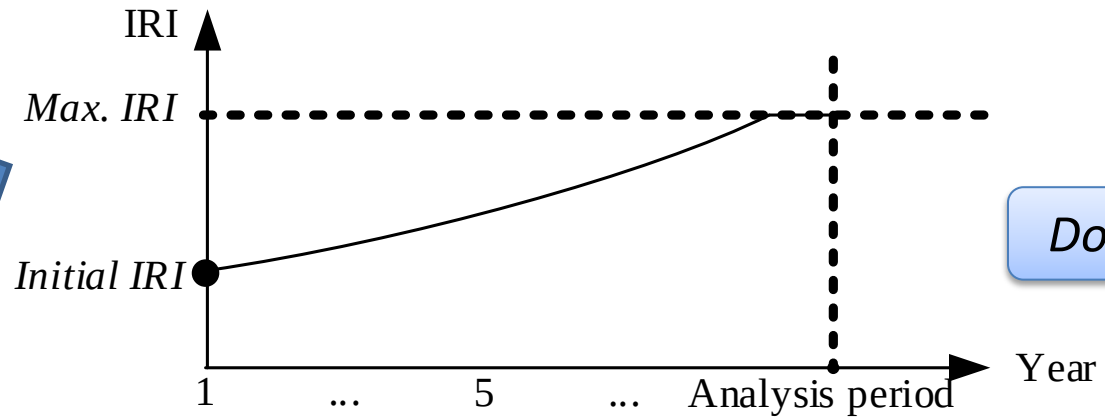
$$CO_2\ emission\ \ factor\left(t/1000\ miles\right) = a1 \times MPD + a2 \times IRI + Intercept$$

Surface type	Road type and access type	Year	Vehicle type	*a1*	*a2*	*Intercept*
Concrete	Urban restricted	2012	Passenger car	0.00186234	0.01090168	0.36515695
……						

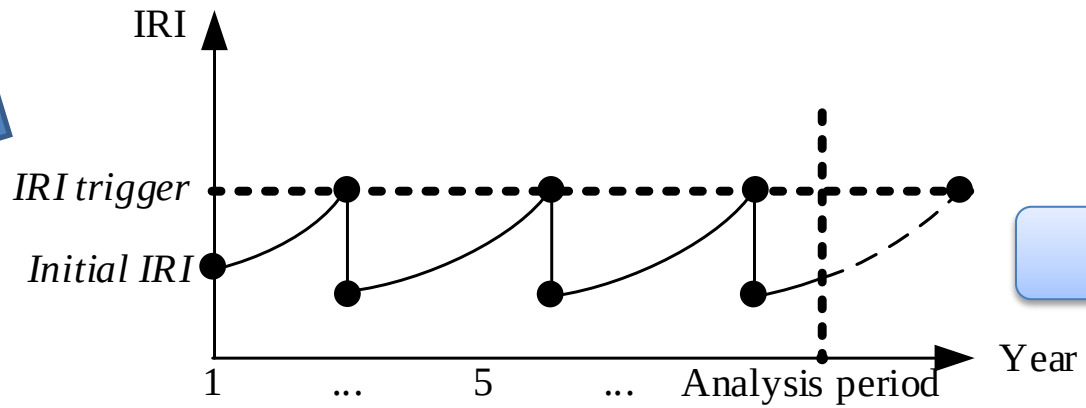
Modeling: *M&R* and *Do Nothing* scenarios



Management segment



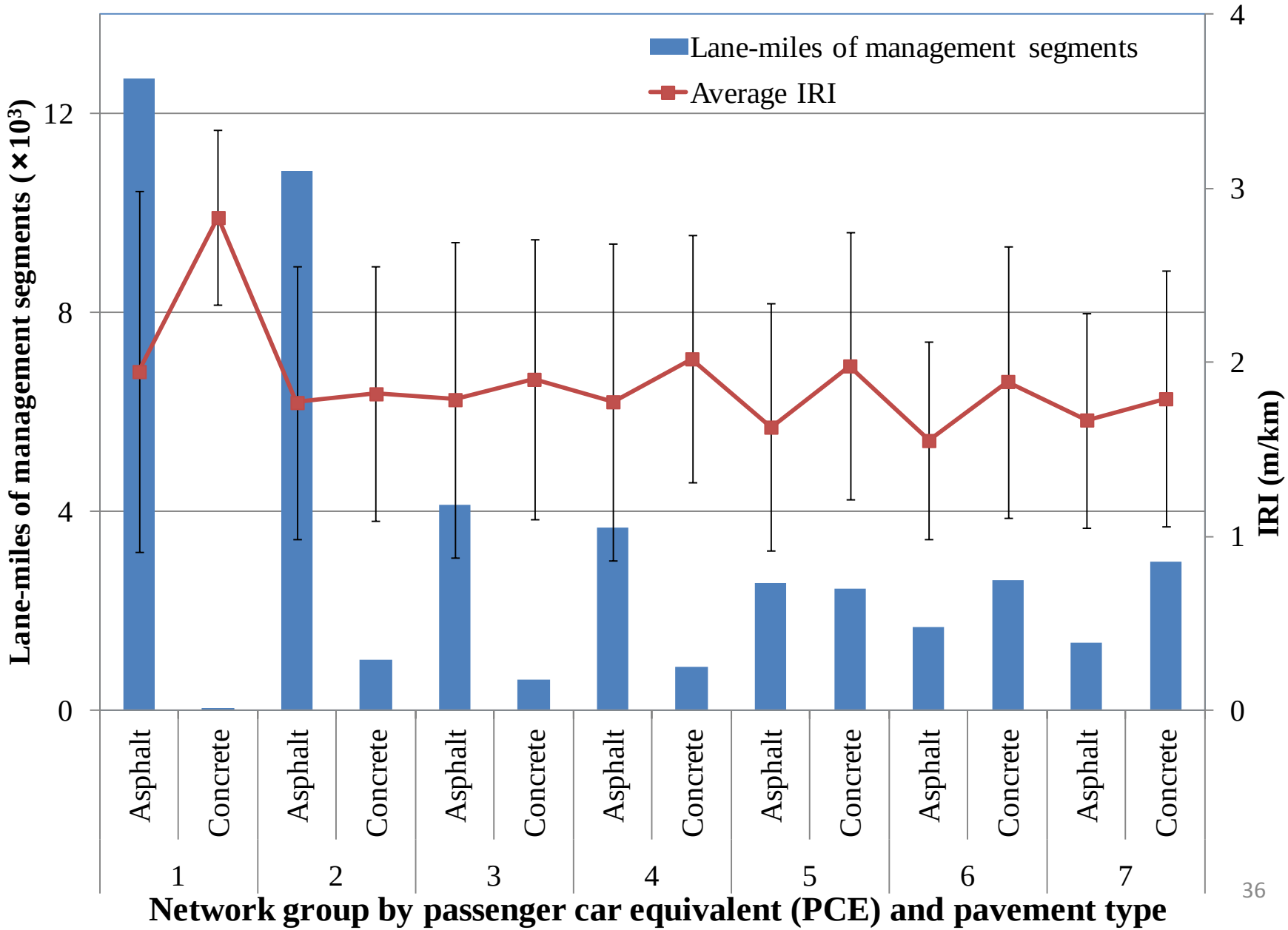
Do Nothing



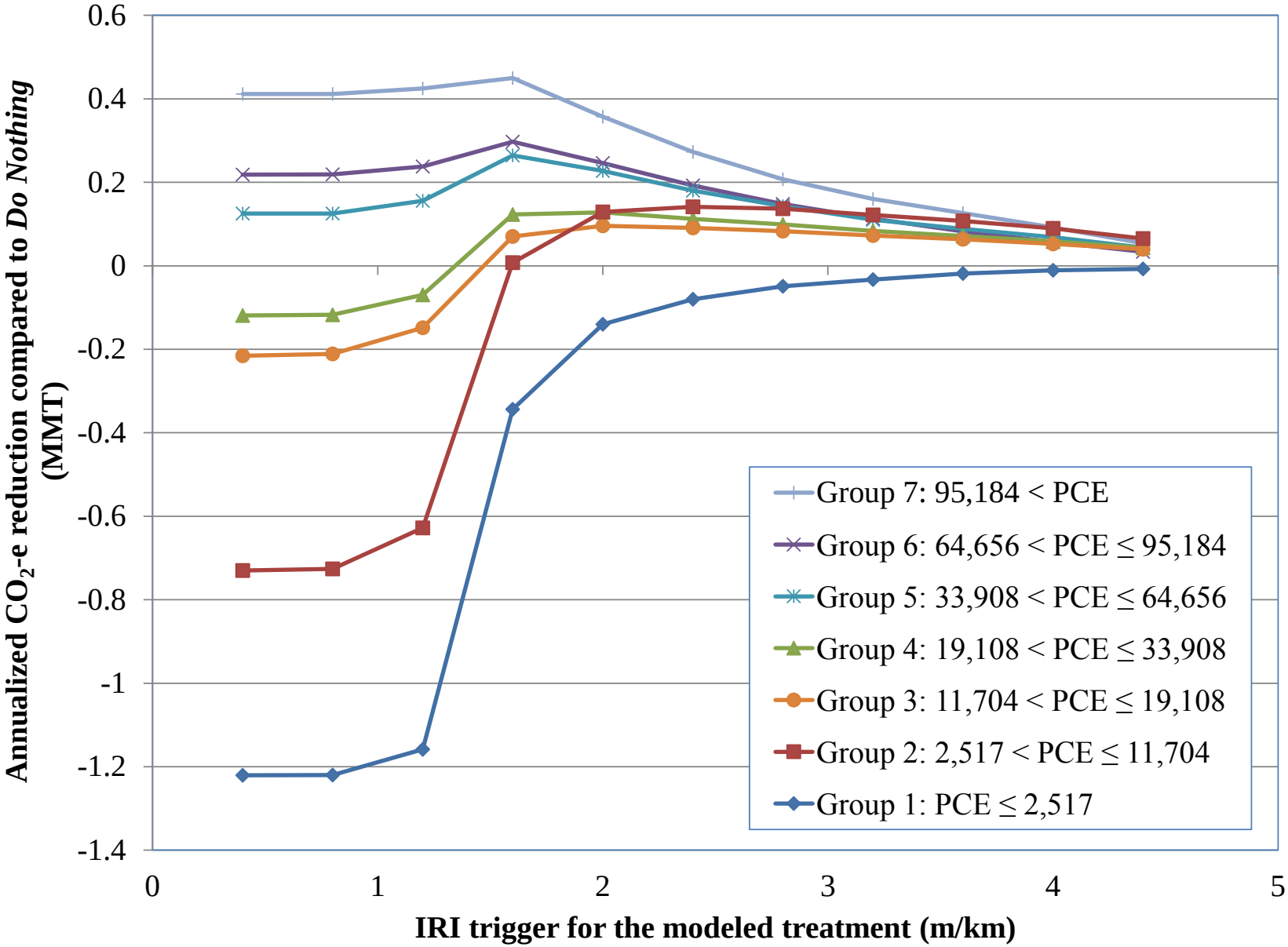
M&R

Analysis period: 10 Years (2012 to 2021)

Network overview



Result: Different IRI triggers



Result: Optimal trigger by traffic group

Traffic group	Daily PCE of lane-segments range	Total lane-miles	Percentile of lane-mile	Optimal IRI triggering value (m/km, inch/mile in parentheses)	Annualized CO_2-e reductions (MMT)	Modified total cost-effectiveness ($/t$CO_2$-e)
1	<2,517	12,068	<25	-----	0	N/A
2	2,517 to 11,704	12,068	25~50	2.8 (177)	0.141	1,169
3	11,704 to 19,108	4,827	50~60	2.0 (127)	0.096	857
4	19,108 to 33,908	4,827	60~70	2.0 (127)	0.128	503
5	33,908 to 64,656	4,827	70~80	1.6 (101)	0.264	516
6	64,656 to 95,184	4,827	80~90	1.6 (101)	0.297	259
7	>95,184	4,827	90~100	1.6 (101)	0.45	104
Total					**1.38**	**416**

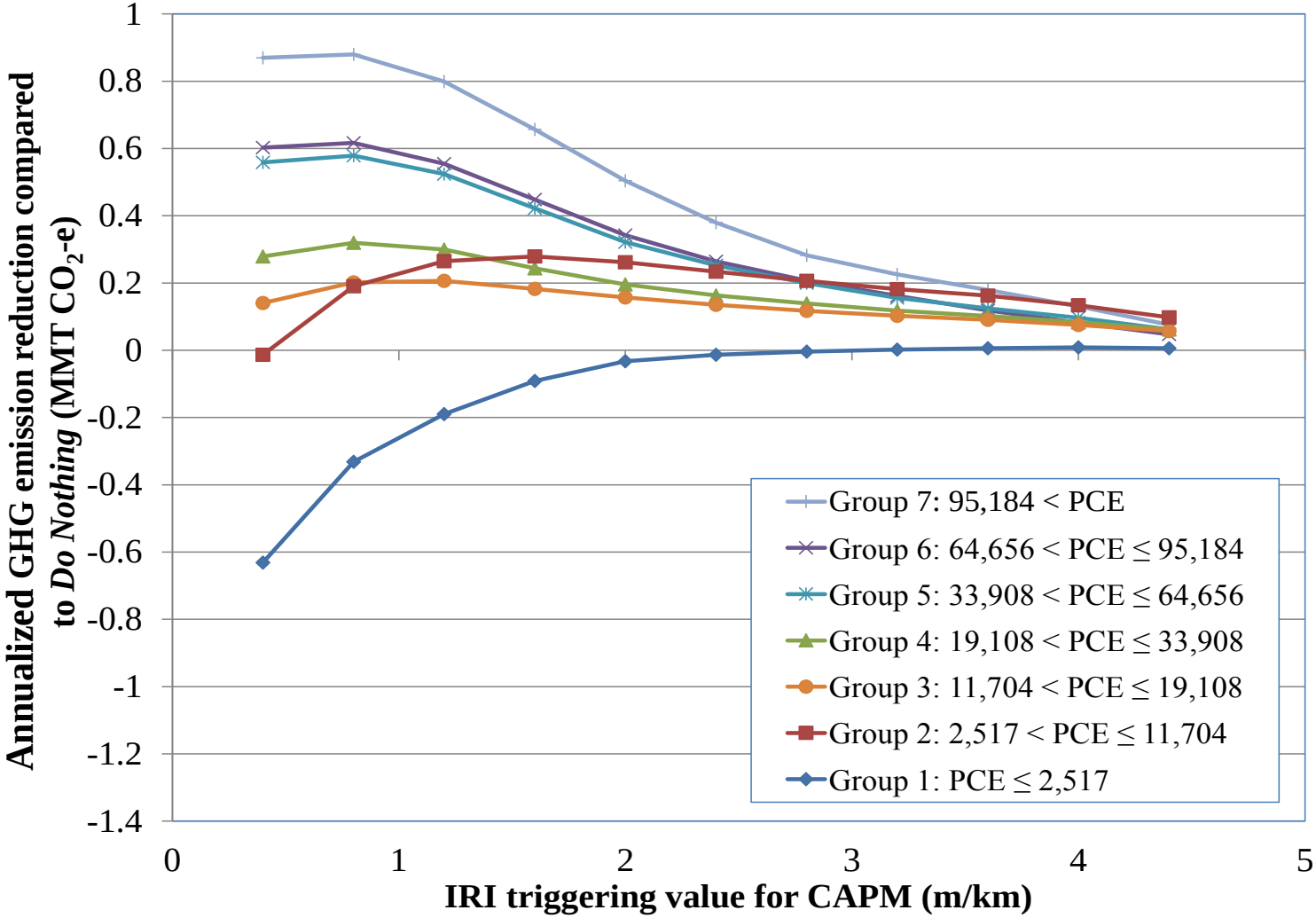
Comparison with other strategies

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 2.68 m/km)	**0.82 MMT**	**332**
Optimal roughness triggers*	**1.38 MMT**	**390**
Optimal roughness triggers* (all user benefits included)	**1.38 MMT**	**-665 to -1,509**

* Versus Do Nothing

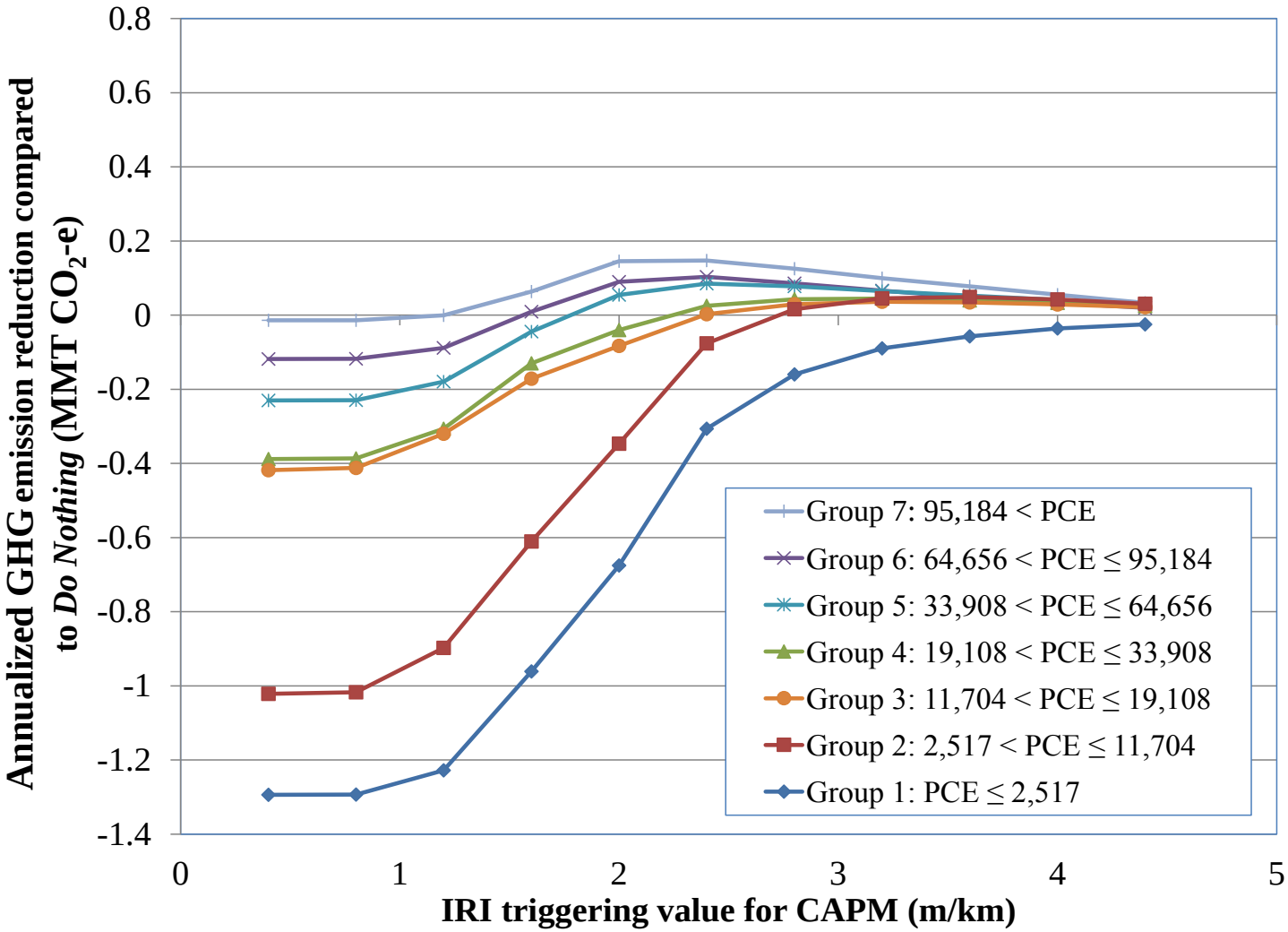
What if construction has poor quality?

- Good quality (*Average IRI* - **σ**)

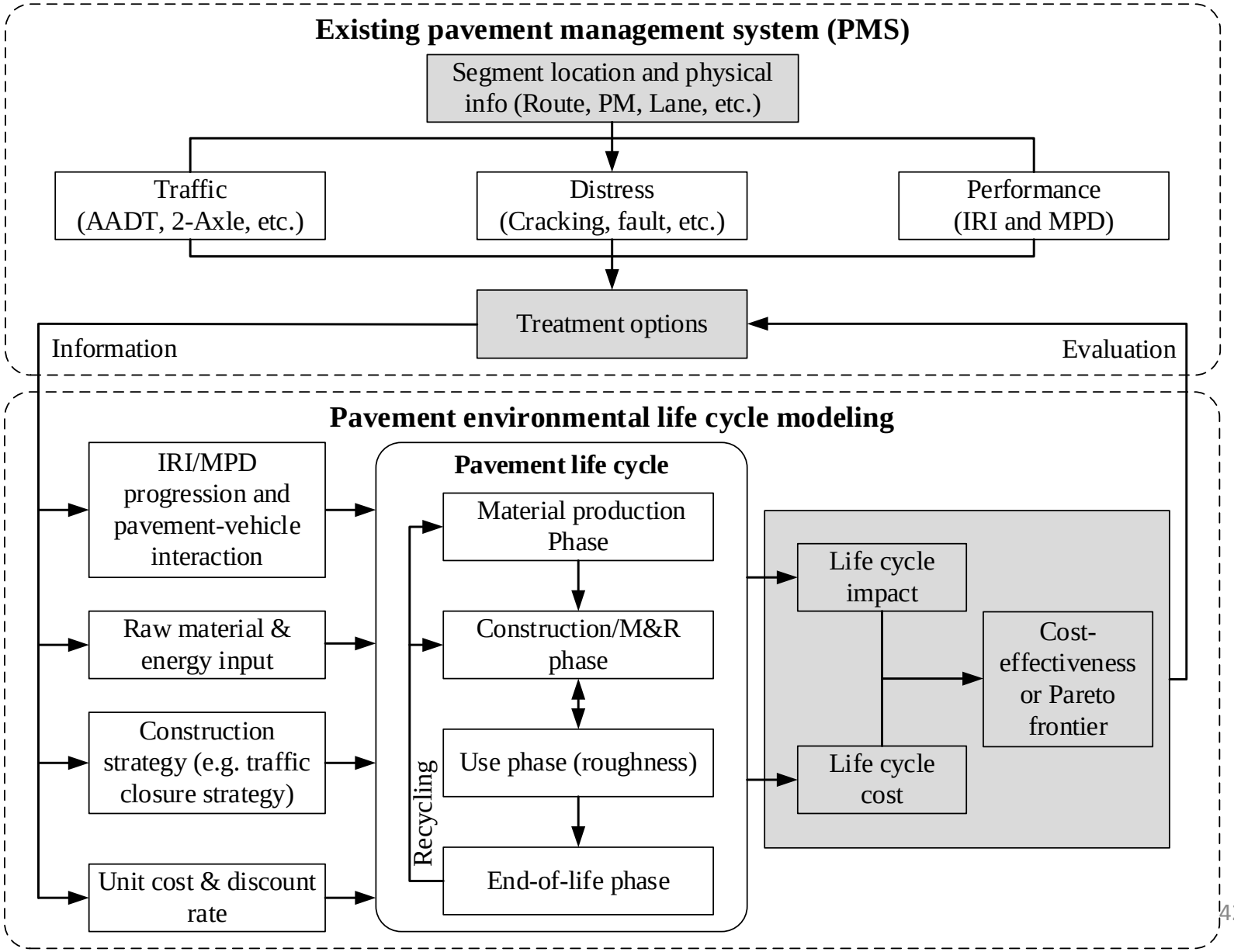


What if construction has poor quality?

- Bad quality (*Average IRI* + **σ**)



PMS and LCA integration



HEAT ISLAND GROUP

Life Cycle Assessment and Co-benefits of Cool Pavements

Lawrence Berkeley National Laboratory

University of California – Davis

PE International

University of Southern California

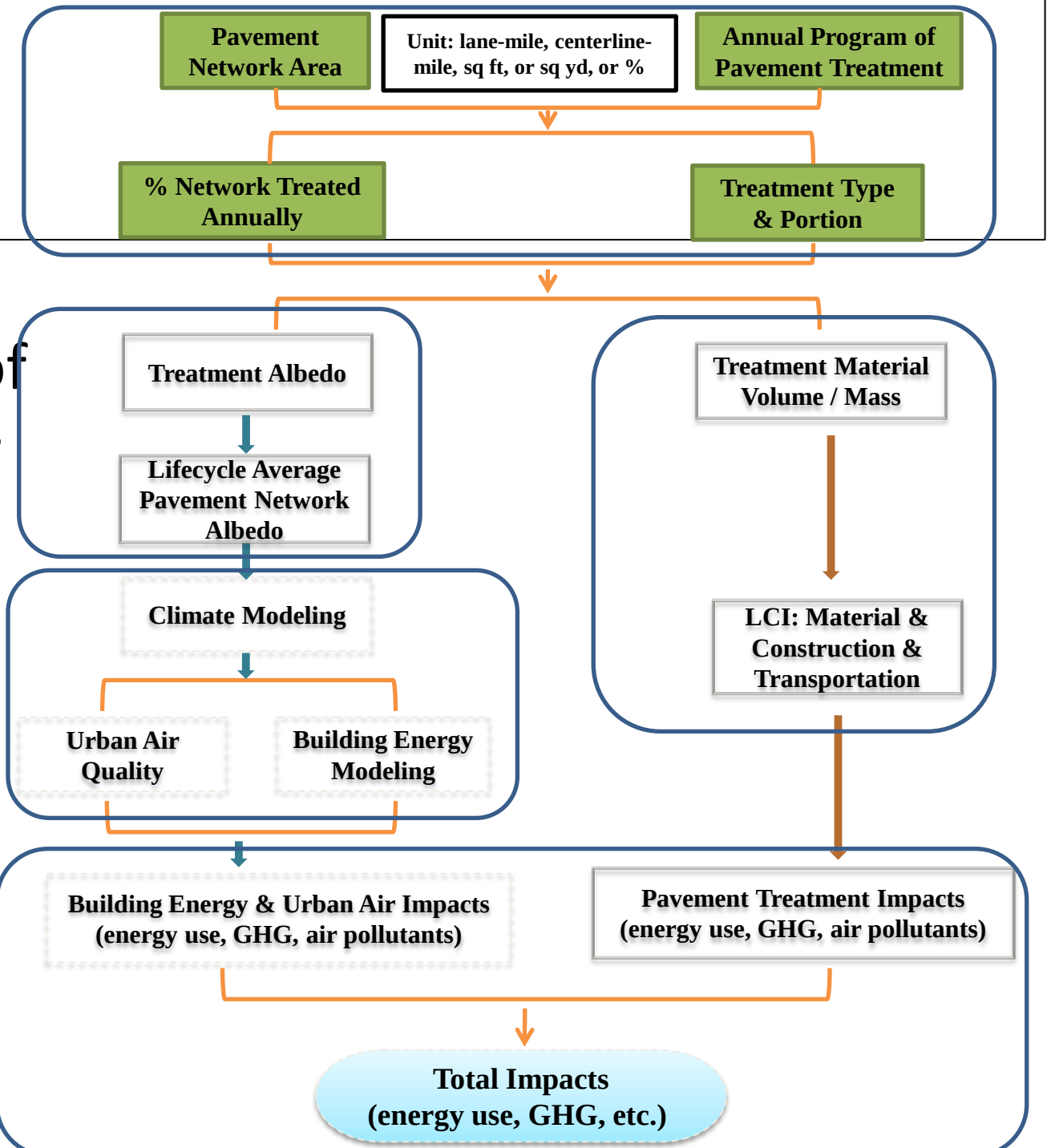
Quarterly Review

May 2, 2014

Elements of LCA

- Goal: evaluate environmental impact of reflective pavement:
  - Reduced temperatures reduces air conditioning use, reducing GWP from electricity
  - Reflective pavement (concrete) emits more GWP than less reflective thin asphalt surface treatments
  - Are reflective pavements in urban areas good or bad?

Proposed flow of calculations for user tool to support LBNL proposed user interface



Questions?