Pavement Smoothness and Sustainability

Amlan Mukherjee, PhD
Associate Professor,
Department of Civil & Environmental Engineering
Michigan Technological University

Benjamin Ciavola, PhD
Lead Analyst

Jay Vana
Lead Developer

NAPA Annual Meeting,
February 4th, 2014, Boca Raton, FL

Motivation

Transportation accounts for 28% of the total U.S. GHG Emissions

- Reduce greenhouse gases emissions from:
  - Raw material extraction and/or acquisition
  - Construction material production
  - Equipment usage on site
  - Use phase
- Develop strategies to reduce greenhouse gas emissions at all levels and life cycle stages:
  - Operational: Construction, Maintenance, Rehabilitation
  - Strategic: Alternative design, improved decision processes

What is Life Cycle Assessment

Use/Service Life emissions account for ~90% of pavement life cycle emissions

- Accounting for environmental impacts through *all* the life cycle phases of products and processes
  - Mining and Extraction
  - Manufacturing
  - Transportation
  - Construction
  - Use/Service Life
  - End-of-Life

Life Cycle Assessment (LCA)

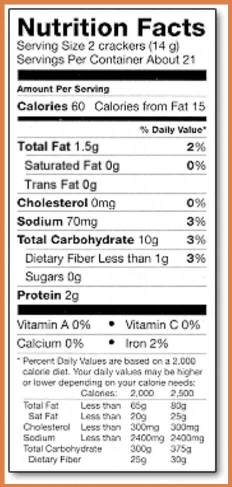
- An LCA as a decision-making tool:
  - To choose between comparable alternatives
- What is the purpose of the LCA:
  - System boundaries may be different:
    - What's in, what's not
  - Units for comparison: "functional units" may vary
    - Lane mile or volume of work done?
- Who is conducting the LCA:
  - Stakeholder perspectives vary

Technical challenges

- Life Cycle Assessment based approaches:
  - Limited standards for highway industry
    - ISO 14040, 14044 – limited guidance
    - Best approach: Univ. of California, PRC guidelines (2010)
  - Purpose not yet clear: comparisons or benchmarks?
  - Alignment of objectives: consideration of services
- Rating Systems:
  - Value laden approach
  - Tend to be prescriptive

Future of LCA Products

Similar to a Nutrition label

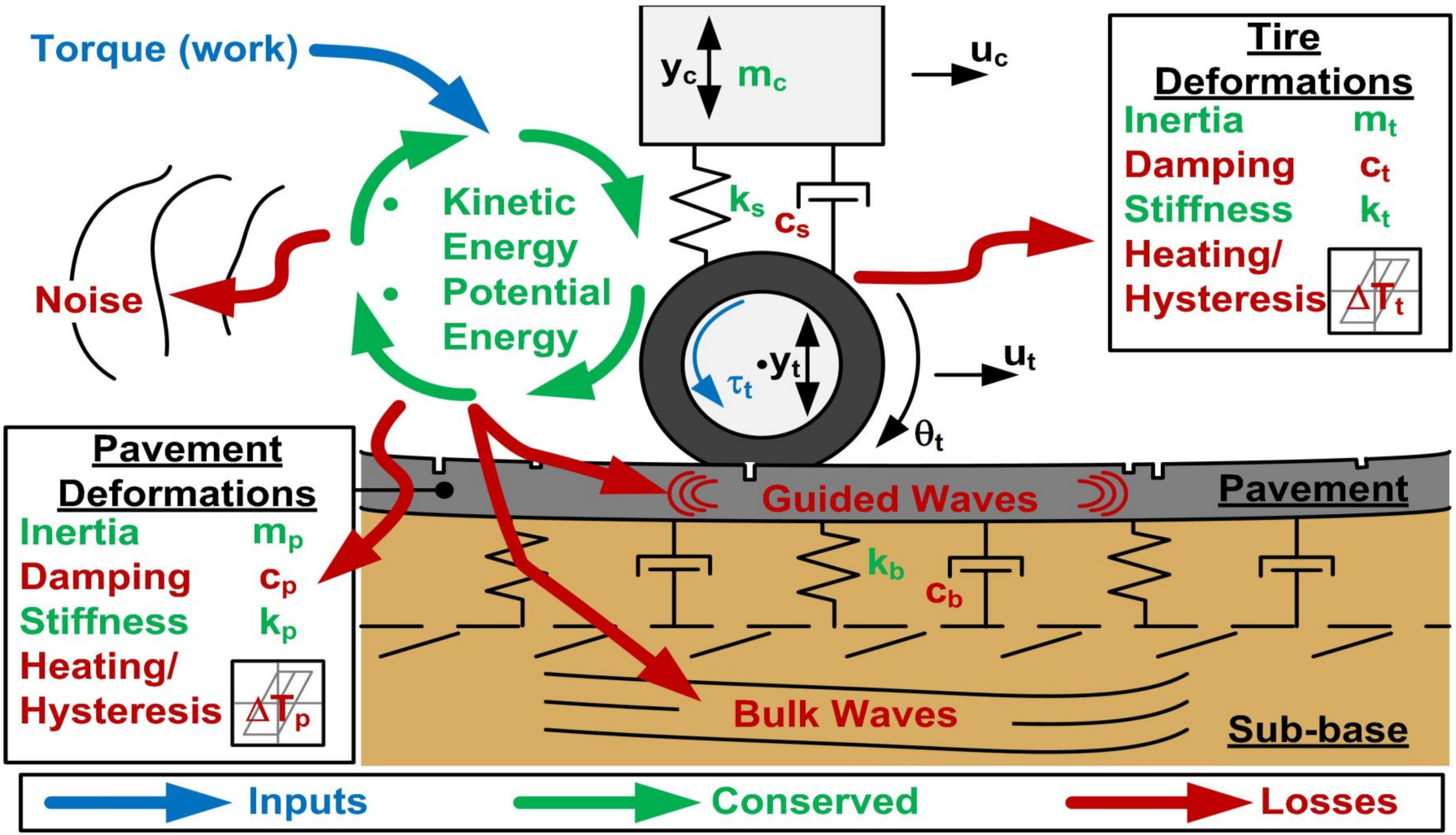


- Environmental Product Declarations (EPD)
  - ISO Type III Environmental Labeling
- Based on Product Category Rules (PCR)
  - Establishes scope and units of LCA
  - Categories such as Global Warming Potential, Eutrophication etc.
- Business-2-Business: Cradle to gate
- Business-2-Consumer: Cradle to grave

Pavement Use Phase

- Use phase – Highest impact
- Rolling Resistance –
  - Deflection, Roughness, Texture
  - Speed, Air Temperature
  - Pavement type
  - Grade, Super Elevation
- Different models –
  - MIRIAM
  - NCHRP 1-45 – Vehicle Operating Costs

Pavement Vehicle Interface



Used with permission from Dr. Andrew Swartz

Objective

- Investigate factors that influence IRI:
  - How does IRI change over time?
  - What conditions influence IRI?
  - What kind of maintenance plans deliver smooth pavements?
- Relate fuel efficiency (as a function of change in IRI) to
  - Maintenance schedules
  - Pavement type
  - Regional factors.
- Take full advantage of existing work

Studies so far

- Measures how IRI influences Factor X
  - Chati et al.: How IRI impacts fuel efficiency
  - Dasari et al: How IRI impacts structural number
- Calibration of predictive systems like ME-PDG, HDM-4
  - Given a starting IRI how is it likely to change/increase as time passes
  - Based on estimation of IRI as a function of other factors (e.g. faults/cracks per unit length, etc.)

The IRI measure

- Units: in/mile or m/km
- A measured quantity – objective and reproducible
- Good replacement for subjective PASER measures
- Models exist
  - ME-PDG: NCHRP 1-37A
  - Chatti et al.: 2 m/km → 1-2% reduction in fuel consumption
- Reliable metric – generally speaking.
- Caution: using calculated values to indicate level of service – best analyzed as a measure.

The IRI measure

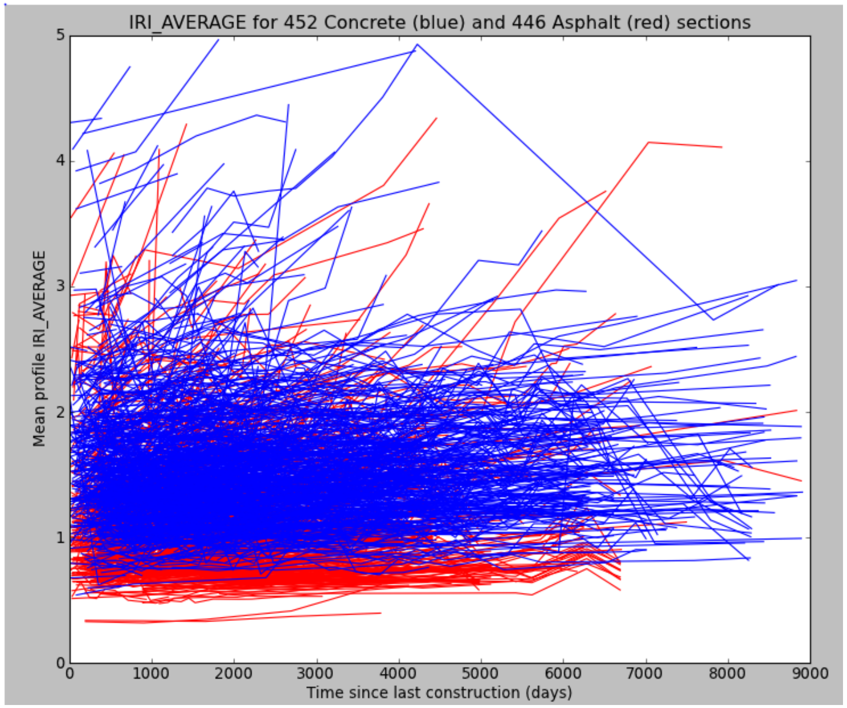
- Units: in/mile or m/km
- A measured quantity – objective and reproducible
- Good replacement for subjective PASER measures
- Models exist
  - ME-PDG: NCHRP 1-37A
  - Chatti et al.: 2 m/km → 1-2% reduction in fuel consumption
- Reliable metric – generally speaking.
- Caution: using calculated values to indicate level of service – best analyzed as a measure.

Method

- Analyze LTPP sections:
  - Clean the datasets …
  - … or identify suitable subset
- Cross classify by:
  - Region,
  - K-ESAL (traffic load)
  - Pavement type: AC, JPCP, CRCP (and flavors)
  - Time of day measurements

Initial plot

- Trends difficult to identify
- Possible corrupted data
- Cleaning difficult
- Required: a pre-validated dataset



Data set

- Subset that was used to calibrate ME-PDG IRI change models
- Data subset is reliable because:
  - The models ensured that calculated IRI (from models) closely co-related with the observed IRI (from LTPP)
  - Data sets are as valid as our understanding of IRI

Complicating Factors

- LTPP Dataset
  - Incomplete
  - Possibly corrupt in places
- Practices that used to be vs. that are
- Different studies for different purposes
- The data is difficult to access
- Nothing "Normal" about anything

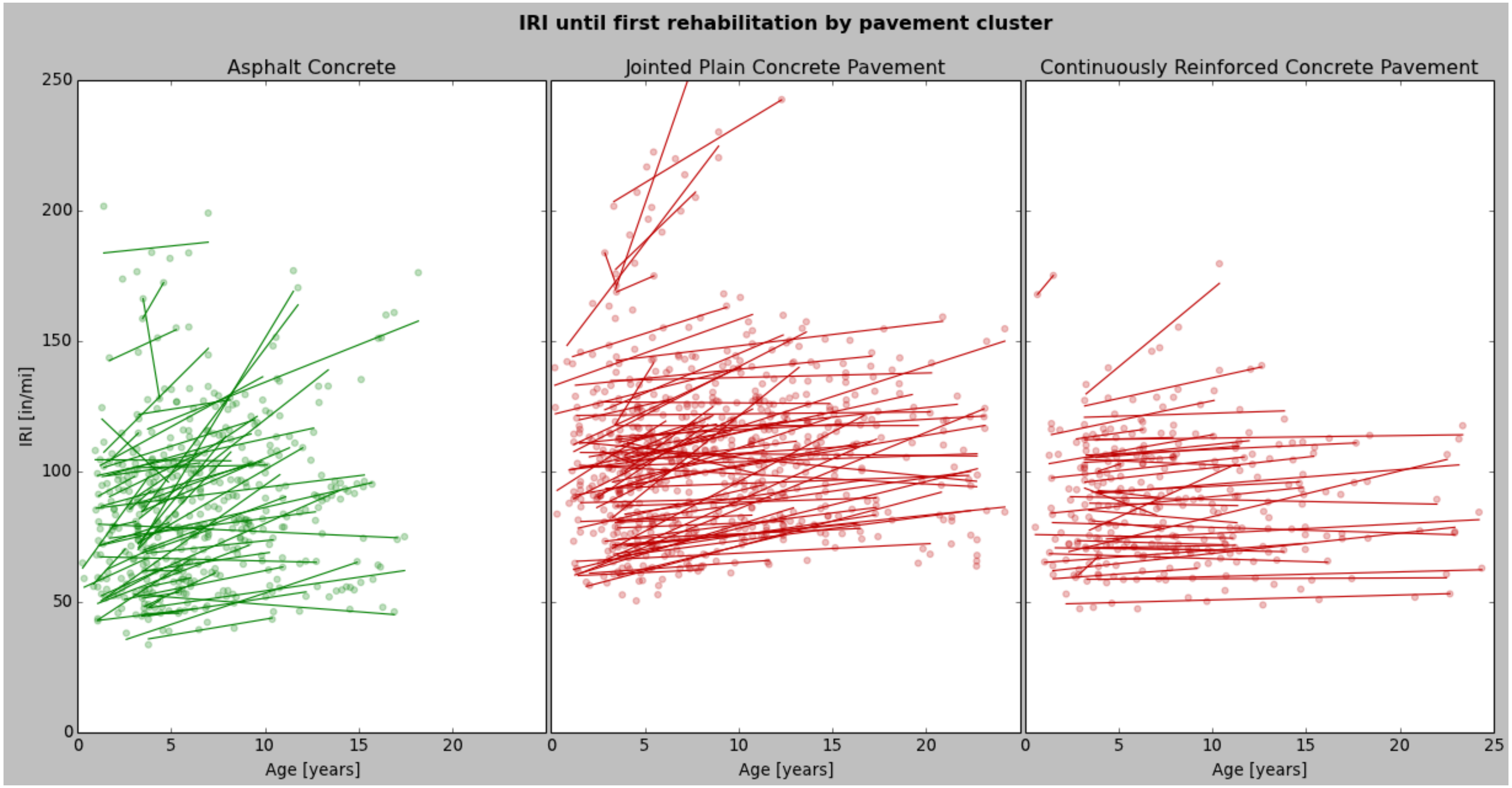
Potentially Useful Factors

- Rate of change of IRI over time
  - Initial IRI
  - Final IRI (at the time of intervention)
  - Time to intervention
- Most effective interventions
- Identify factors that impact change in IRI
  - Climate/region
  - Pavement type
  - Traffic loading
- Effective construction methods

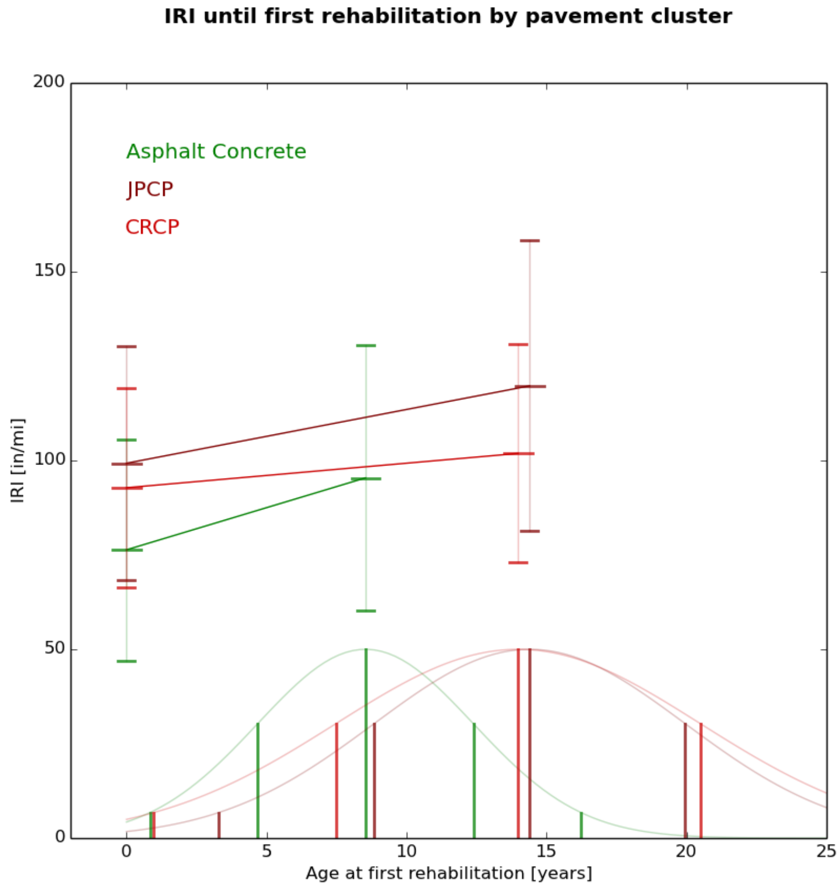
Time to First Intervention

- Metric is relatively free of differing policies
- Three distributions:
  - Initial IRI
  - Final IRI (at the time of intervention)
  - Time to intervention

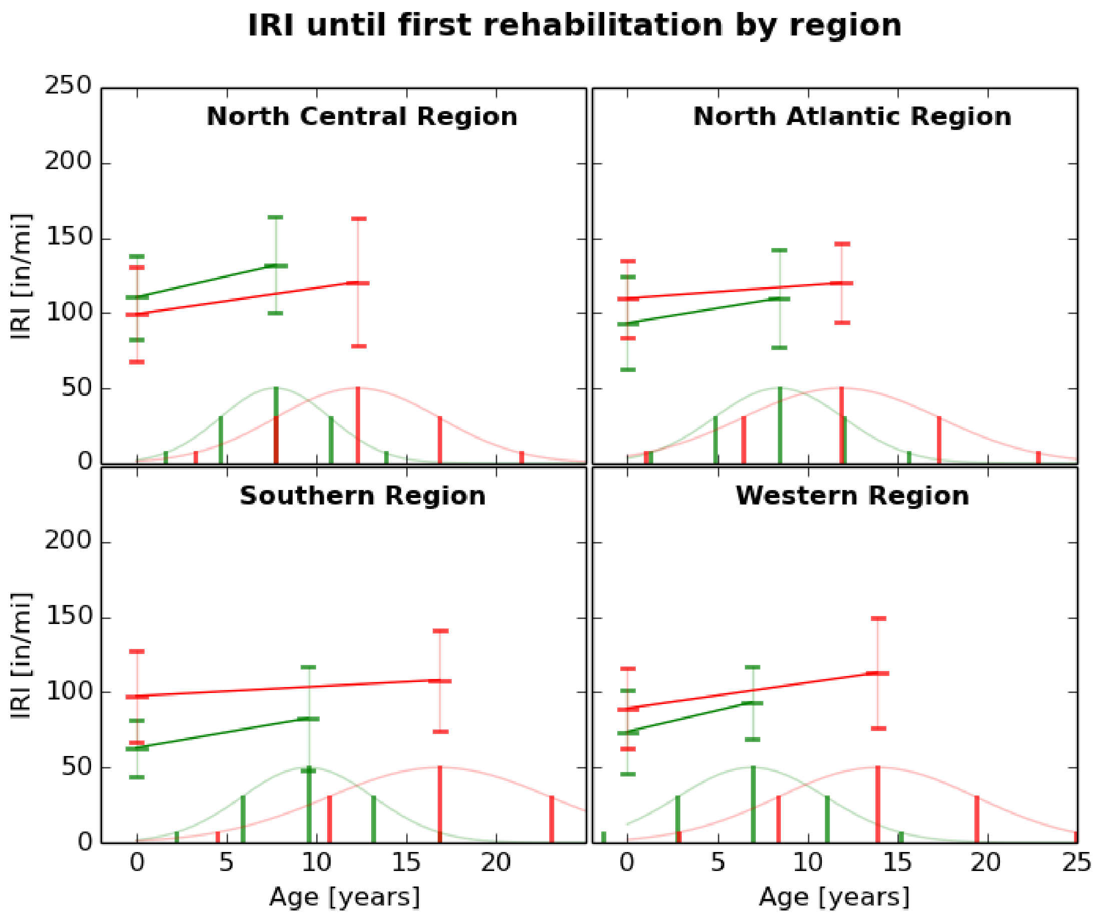
Basic Trends: By Pavement Type



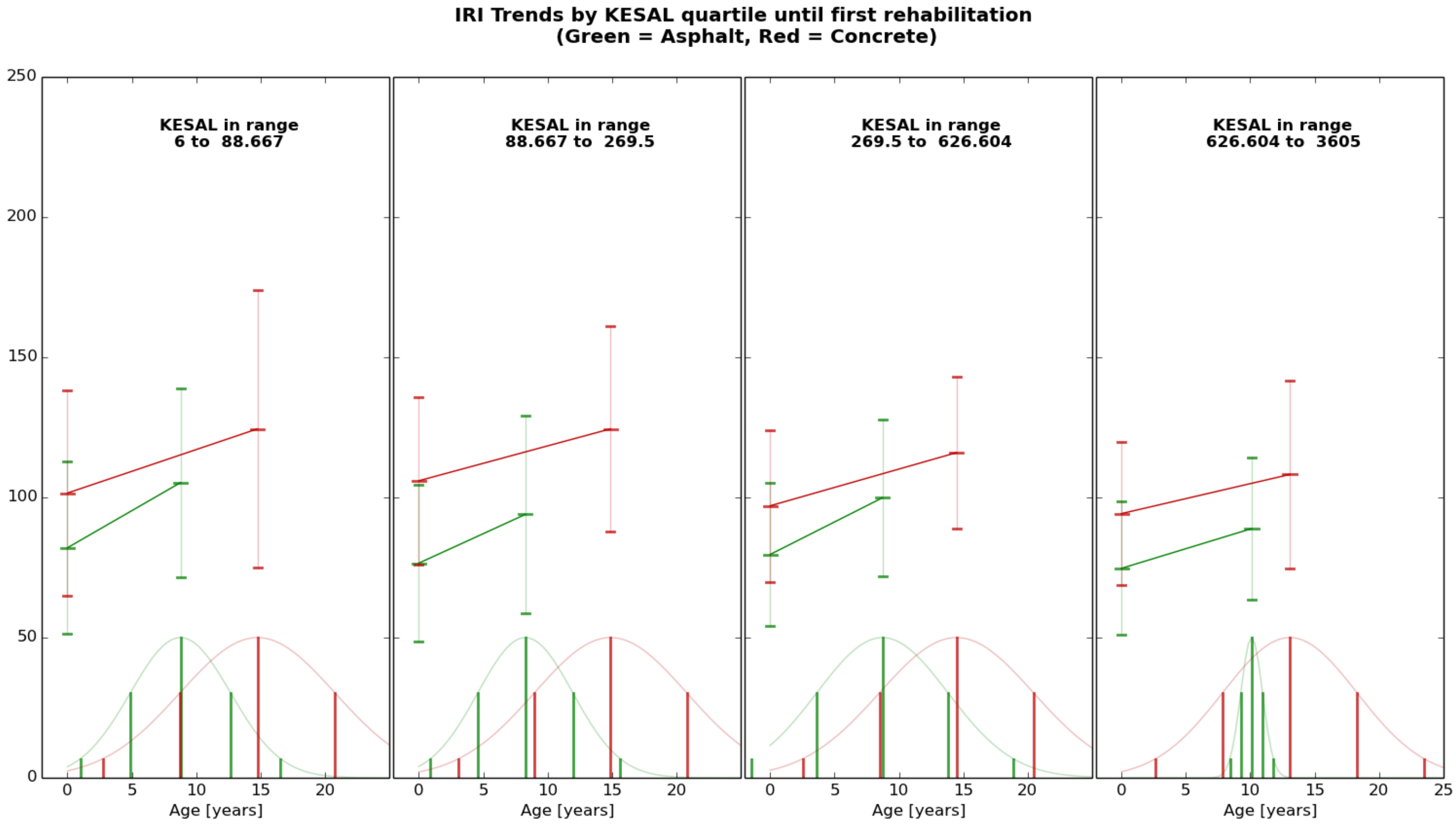
Basic Trends: By Pavement Type



Basic Trends: By Region

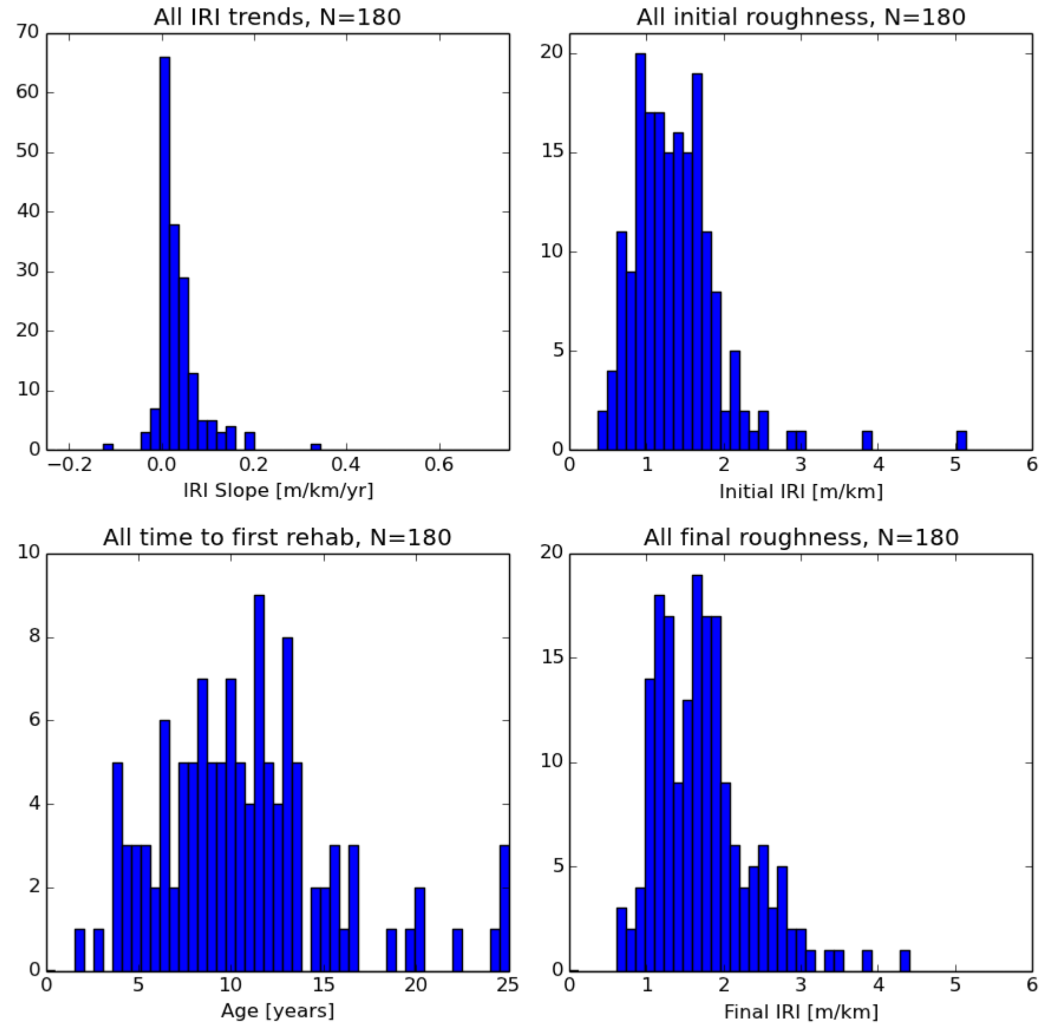


Basic Trends: By ESAL (Traffic Loading)



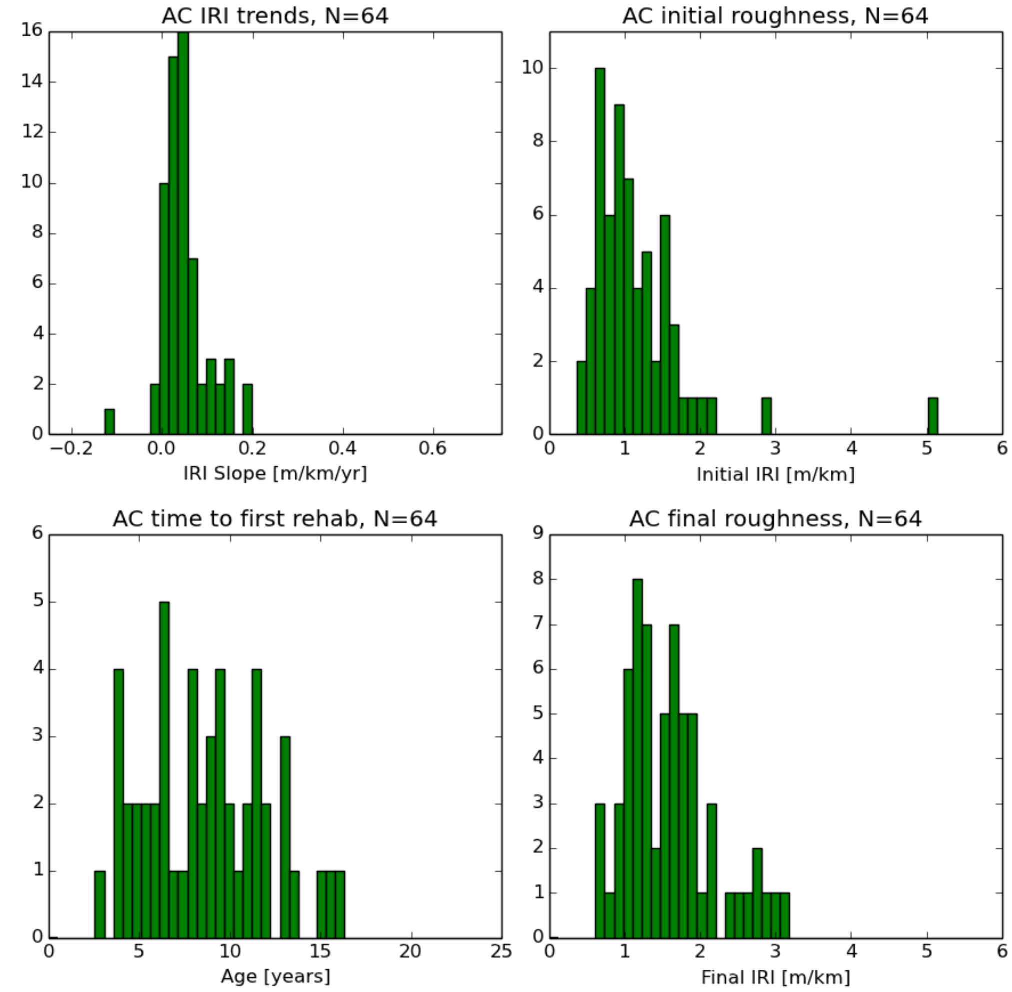
Basic Trends: All Sections

- Initial IRI: 1.35 m/km
- Final IRI: 1.92 m/km
- Time to First Intervention: 15.65 years



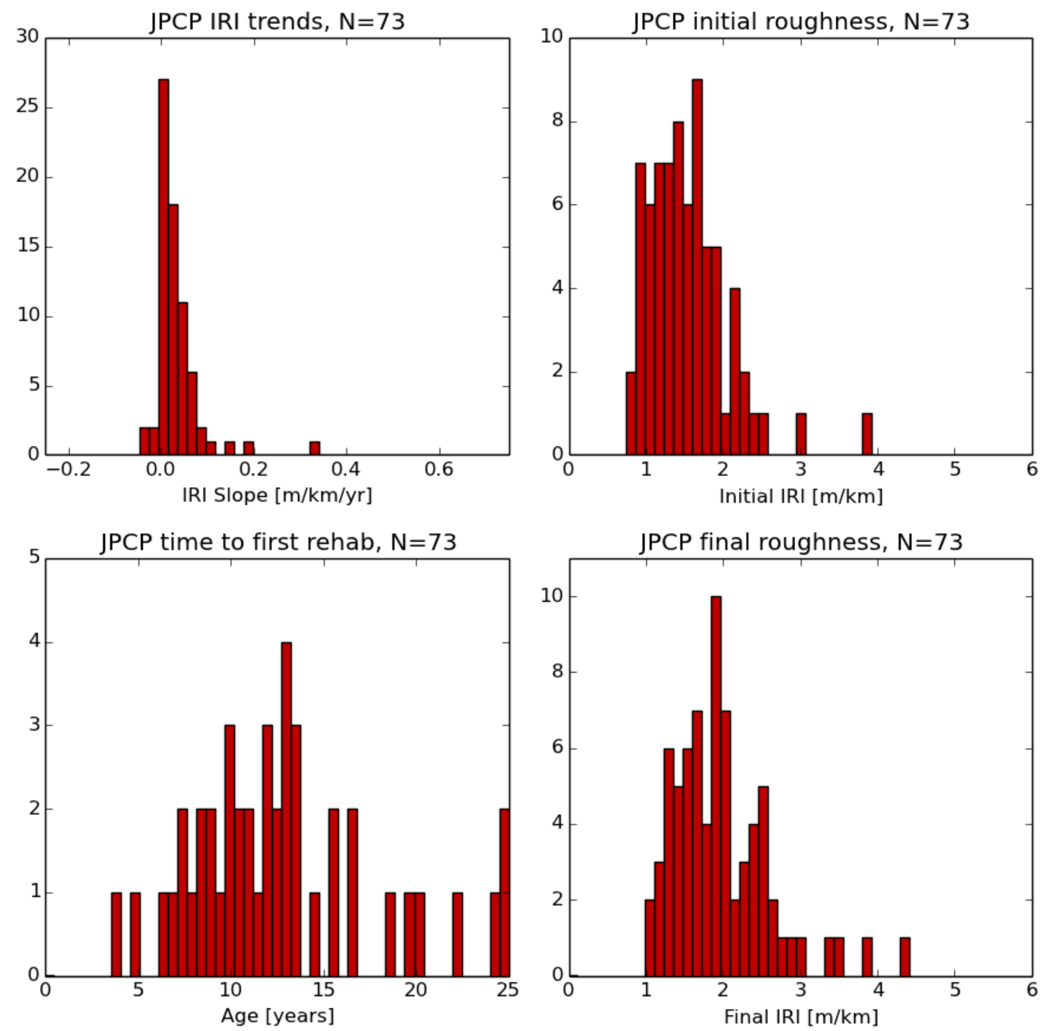
Basic Trends: Asphalt

- Initial IRI: 1.12 m/km
- Final IRI: 1.81 m/km
- Time to First Intervention: 11.97 years



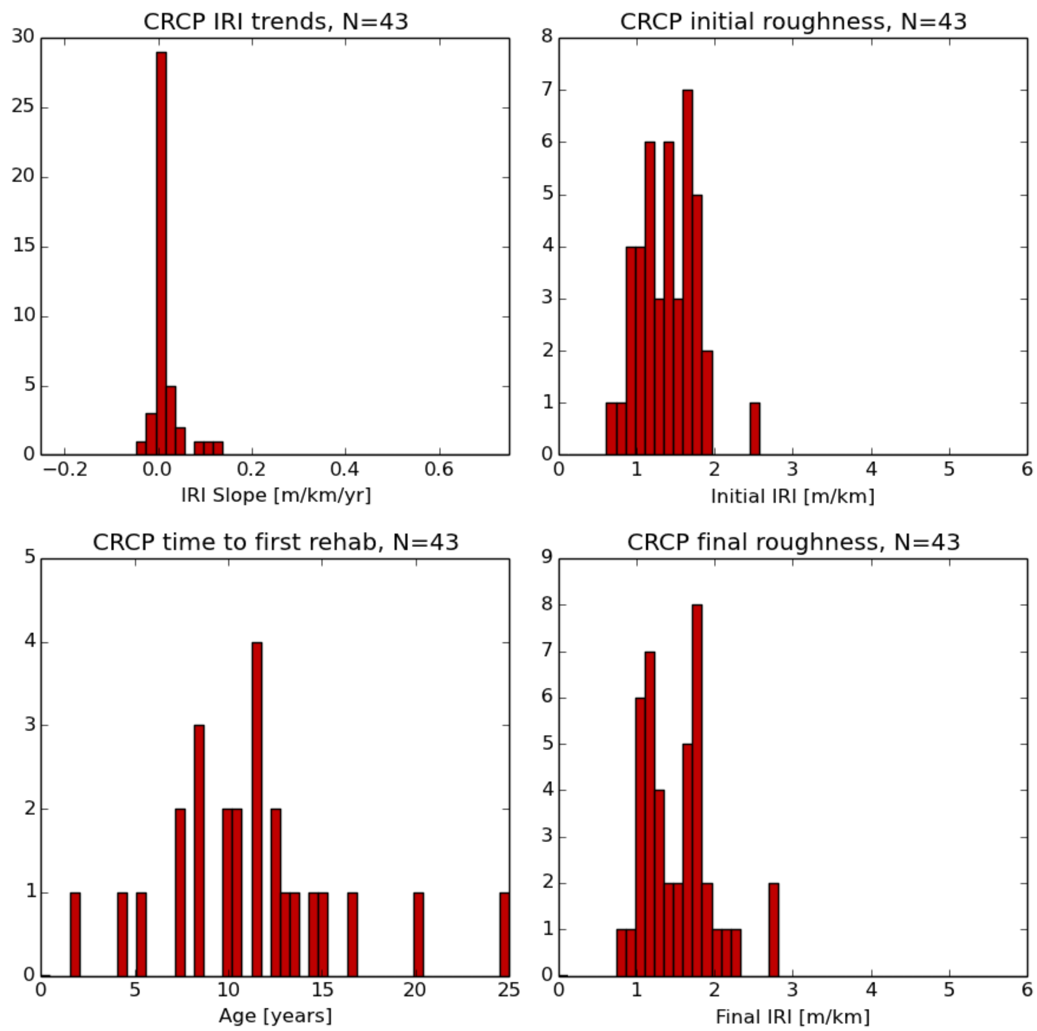
Basic Trends: JPCP

- Initial IRI: 1.47 m/km
- Final IRI: 2.16 m/km
- Time to First Intervention: 17.82 years

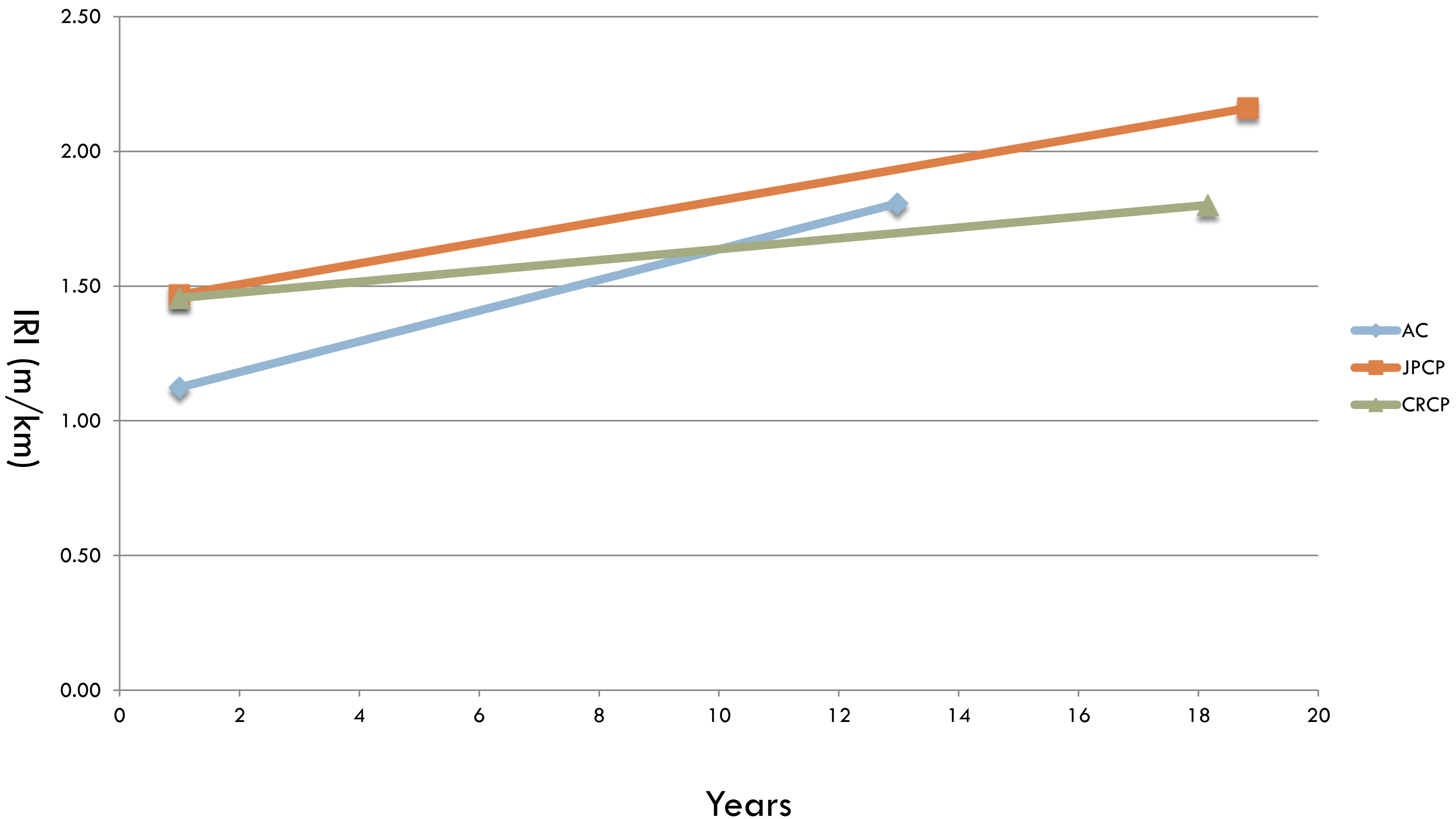


Basic Trends: CRCP

- Initial IRI: 1.46 m/km
- Final IRI: 1.8 m/km
- Time to First Intervention: 17.15 years



Basic Trends: Summarized



Significance: Statistical

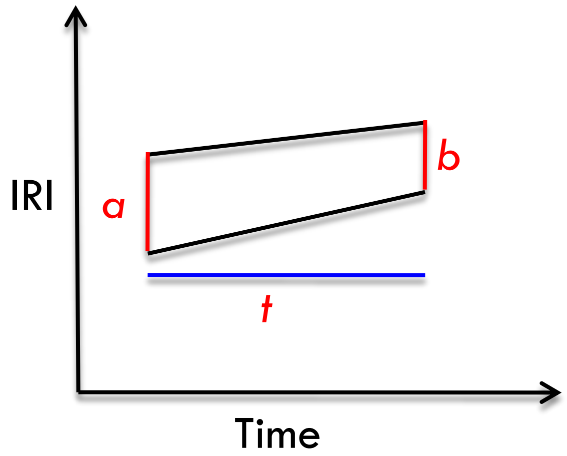
- Hypothesis: No difference between rate of change of IRI between AC and XXCP
  - Consider time rate change (m/km/year)
- *p-value* of difference between time rates = 0.006
- Statistically significant difference.

Concerns

- Specify goal of study:
  - Limited overloading of models
  - Caution: sometimes benchmark, not compare
- When comparing two alternatives:
  - Defining a metric – appropriate caveats
  - Statistical significance vs. Actual significance
- Who is this study meant for?
  - The decision-making interface
- Transparency and easy repeatability

Significance: Actual

- Rate of change of IRI
  - AC: 0.06m/km/year
  - JPCP: 0.04m/km/year
- Over time period of 12 years:
  - *a = Initial Diff*
  - *b = Final Diff*
  - *t = Time Period*



$$\gamma = \tfrac{1}{2}\,[a + b].t$$
$$= 4.19 \text{ m/km.year}$$

Difference of ~ 3-4% fuel consumption up to time to first intervention

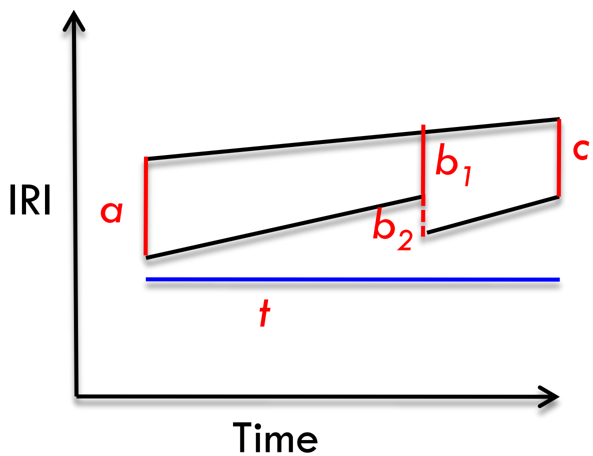
Significance: Actual

- Average fuel consumption[1]:
  - Passenger vehicles: 498 gallons/year
  - Light duty trucks: 694 gallons/year
- 254,212,610 passenger vehicles and distribution[2]:
  - Light duty vehicle, short + long wheel base: 92.5%
  - 2 axles and 6 tires + Truck, combination: 4.3%
  - Motorcycles, etc.
- Savings per year: **433 Million gallons of gasoline**
  - 0.3% of Annual US Gasoline Consumption (2011)

[1]Office of Transportation and Air Quality - EPA420-F-08-024 - October 2008
[2]RITA BTS Table 1-11. US Bureau of Transportation Statistics.

Critique of metric

- Penalizes Asphalt:
  - After 12 years: IRI reduces due to intervention
- Penalizes Concrete:
  - Provides a longer span to first intervention
- An appropriate metric would:



$$y = \tfrac{1}{2}\,[a + b_1].t_1 + \tfrac{1}{2}[b_1 + b_2 + c].t_2$$

$$t = t_1 + t_2$$

Introduces Complications

- How do the following balance out?
  - Cost of intervention
  - Change in long-term fuel consumption
  - Life cycle impacts of materials and construction
  - Traffic loading
  - Context of network

Effective Interventions

- Full depth joint repairs (20-30% reduction in IRI)
- Slab replacement (~20% reduction in IRI)
- Surface grinding (>30% reduction in IRI)
- Surface treatments (20-40% reduction in IRI)
  - Tag coats
  - Fog seal coats
- What are the sequences?

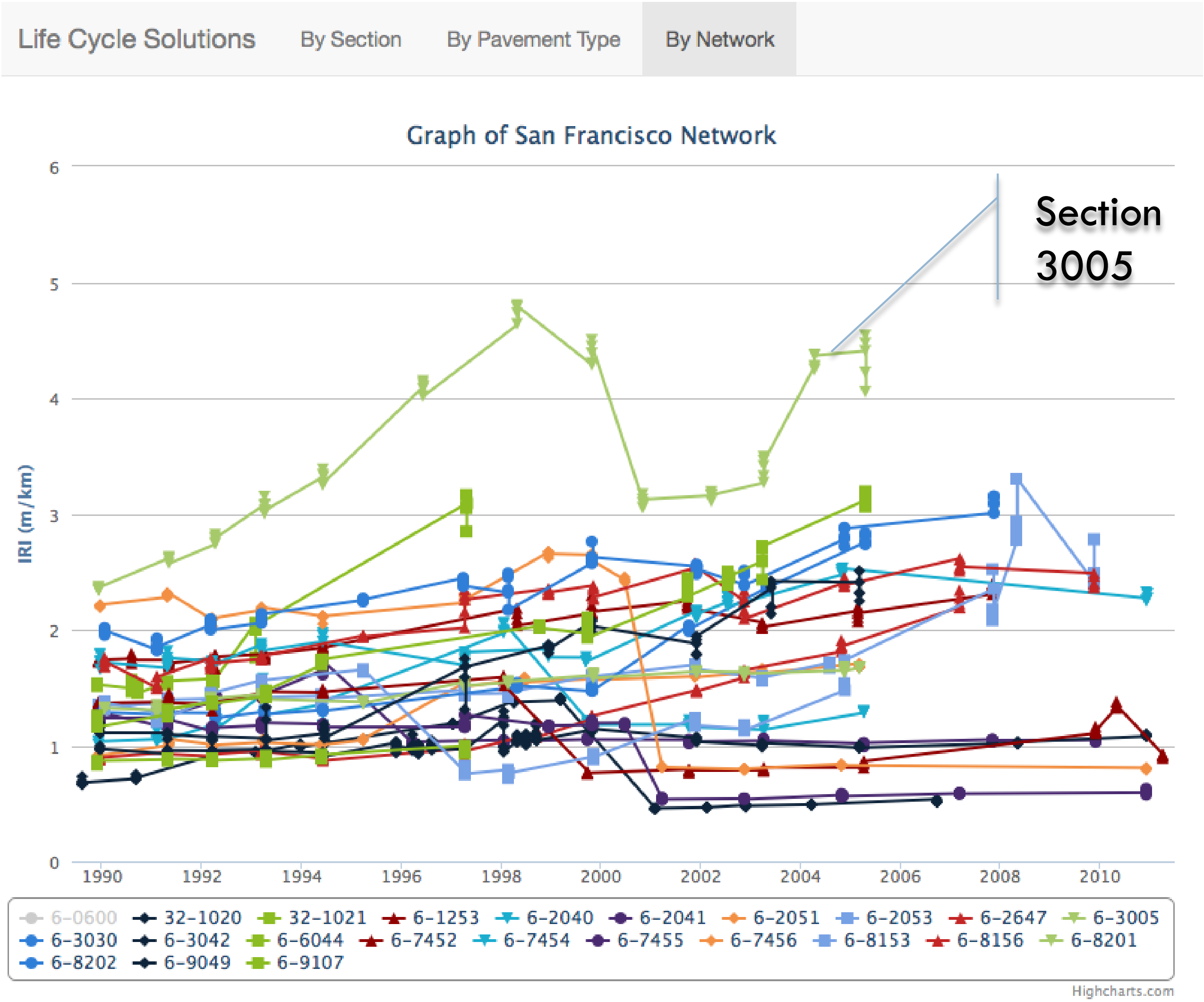
Towards Context Sensitive Solutions

- Try not to generalize
  - Solutions must be sensitive to context
  - Transparency is critical
- Statistical significance: handle with caution
  - Nothing is “Normal”
  - Failure statistics may prove to be better suited
- Consider network based approach
  - Use actual data
  - Empower decision-makers

The Website

- Easy Access to LTPP IRI data
  - Transparency
- Allow for customized assessment by stakeholders
- Allow for network wide assessment by agencies
  - Integration with PE-2 – Project Level Perspective

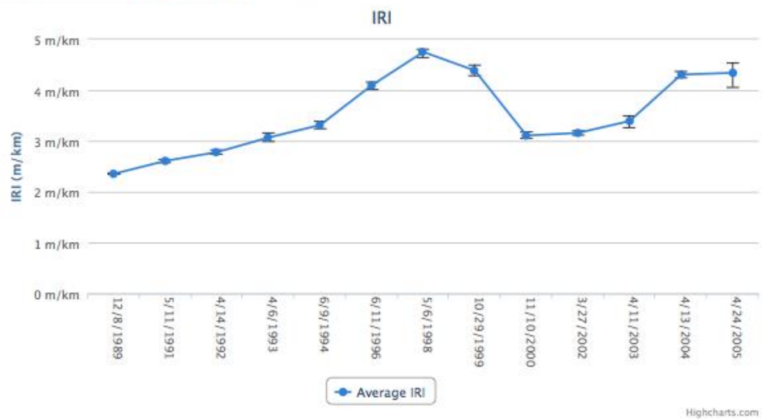
Network View



Section View

Life Cycle Solutions | By Section | By Pavement Type | By Network

California | 3005 | Select



More

US-5

JPCP Over Non-Bituminous Treated Base

ESAL: 1612,000, Experiment 3 (GPS)

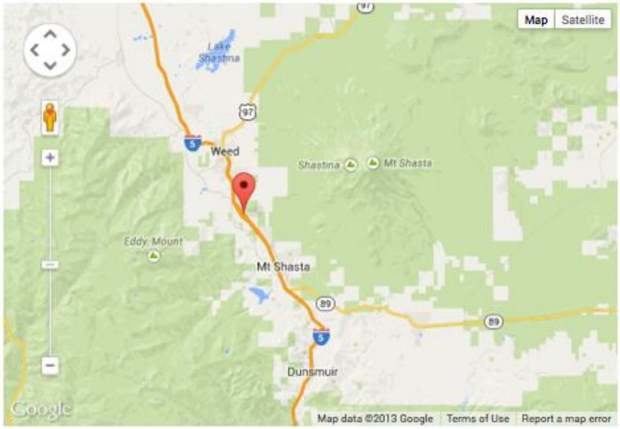
1 May 1996: Skin Patching, Full-Depth Patching of PCC Pavement Other Than at Joint

1 July 1999: Full-Depth Patching of PCC Pavement Other Than at Joint

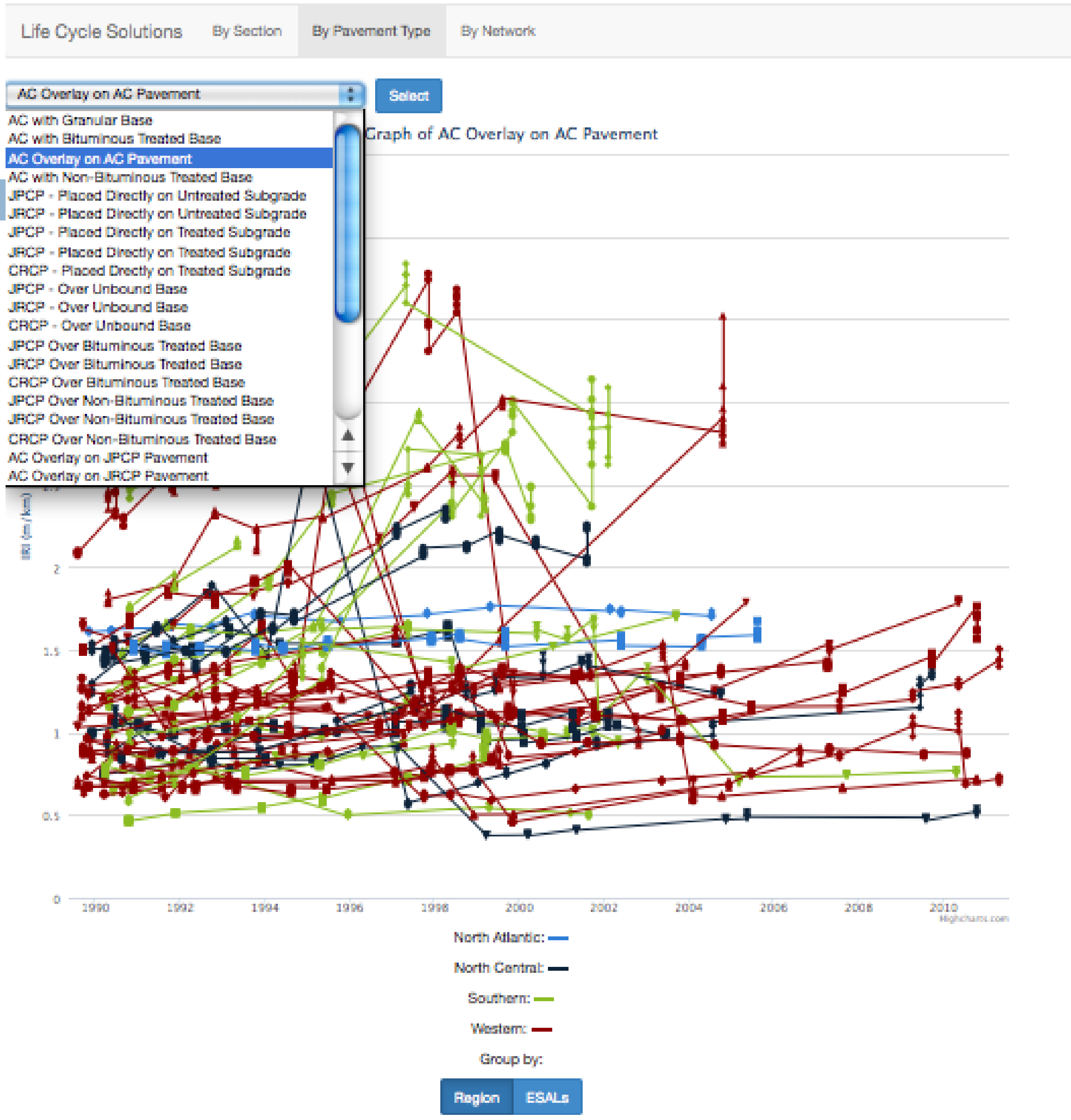
1 July 2000: Lane-Shoulder Longitudinal Joint Sealing, Crack Sealing, Full-Depth Patching of PCC Pavement Other Than at Joint, Transverse Joint Sealing

1 July 2002: Full-Depth Patching of PCC Pavement Other Than at Joint

1 April 2004: Lane-Shoulder Longitudinal Joint Sealing, Crack Sealing, Transverse Joint Sealing

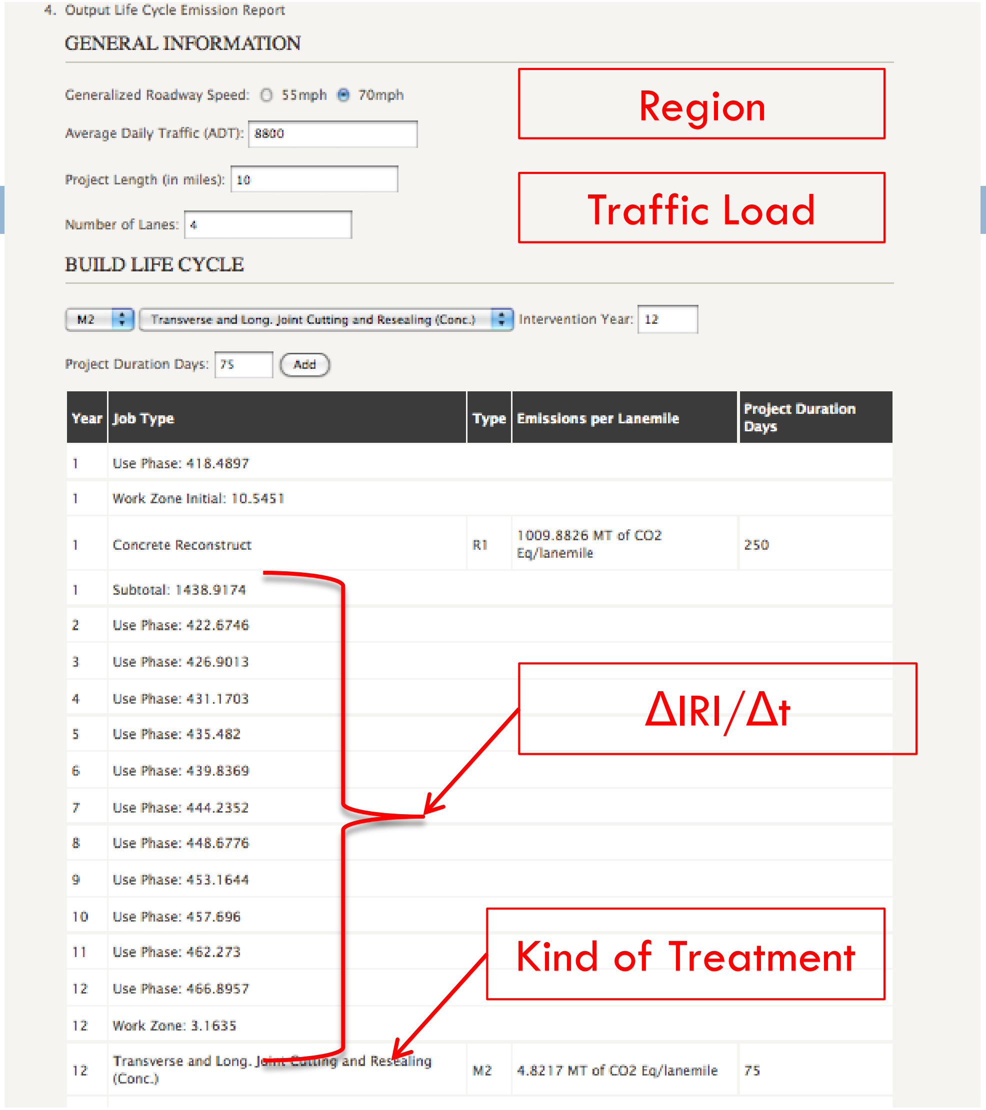


Pavement Type View



PVI in LCA

- PE-2 currently:
  - Only accounts for vehicle emissions using MOVES
- In future:
  - Account for network level IRI change
  - Based on ESALS, Pavement Type
  - Type of Intervention



4. Output Life Cycle Emission Report

GENERAL INFORMATION

Generalized Roadway Speed: 55mph 70mph

Average Daily Traffic (ADT): 8800

Project Length (in miles): 10

Number of Lanes: 4

BUILD LIFE CYCLE

M2 | Transverse and Long. Joint Cutting and Resealing (Conc.) | Intervention Year: 12

Project Duration Days: 75 Add

Year	Job Type	Type	Emissions per Lanemile	Project Duration Days
1	Use Phase: 418.4897			
1	Work Zone Initial: 10.5451			
1	Concrete Reconstruct	R1	1009.8826 MT of CO2 Eq/lanemile	250
1	Subtotal: 1438.9174			
2	Use Phase: 422.6746			
3	Use Phase: 426.9013			
4	Use Phase: 431.1703			
5	Use Phase: 435.482			
6	Use Phase: 439.8369			
7	Use Phase: 444.2352			
8	Use Phase: 448.6776			
9	Use Phase: 453.1644			
10	Use Phase: 457.696			
11	Use Phase: 462.273			
12	Use Phase: 466.8957			
12	Work Zone: 3.1635			
12	Transverse and Long. Joint Cutting and Resealing (Conc.)	M2	4.8217 MT of CO2 Eq/lanemile	75

Thank You

Acknowledgments: National Asphalt Pavement Association

- Dr. Howard Marks, Dr. Heather Dylla.

Region 1			
Maintenance Operations			
	Cycle 1	*Cycle 2*	*Cycle 3*
Age (yrs)	6.04	10.13	15.3
Distress Index (Before/After)			
Value	10.01/2.55	11.4/2.2	35/0
Region 2			
Maintenance Operations			
	Cycle 1	*Cycle 2*	*Cycle 3*
Age (yrs)	7.44	12.75	15
Distress Index (Before/After)			
Value	27.3/11.4	24.7/17.5	35/0