MIT CONCRETE SUSTAINABILITY HUB

Doing more with less: economically-efficient management of pavement networks

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and CSHub Team

Michigan Concrete Association Workshop
February 25, 2021

The US is not sufficiently investing in its ailing road system

21% of the US highways are in poor condition

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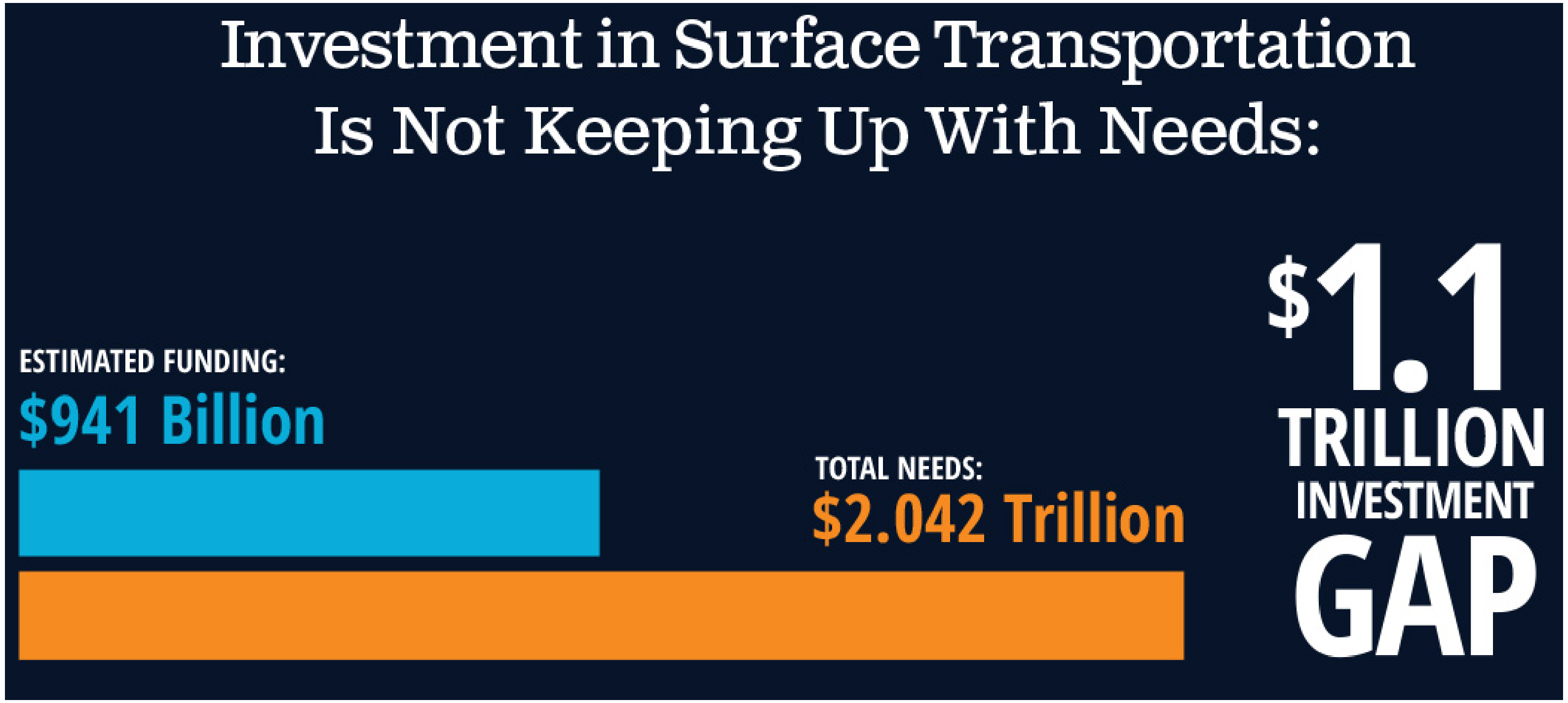
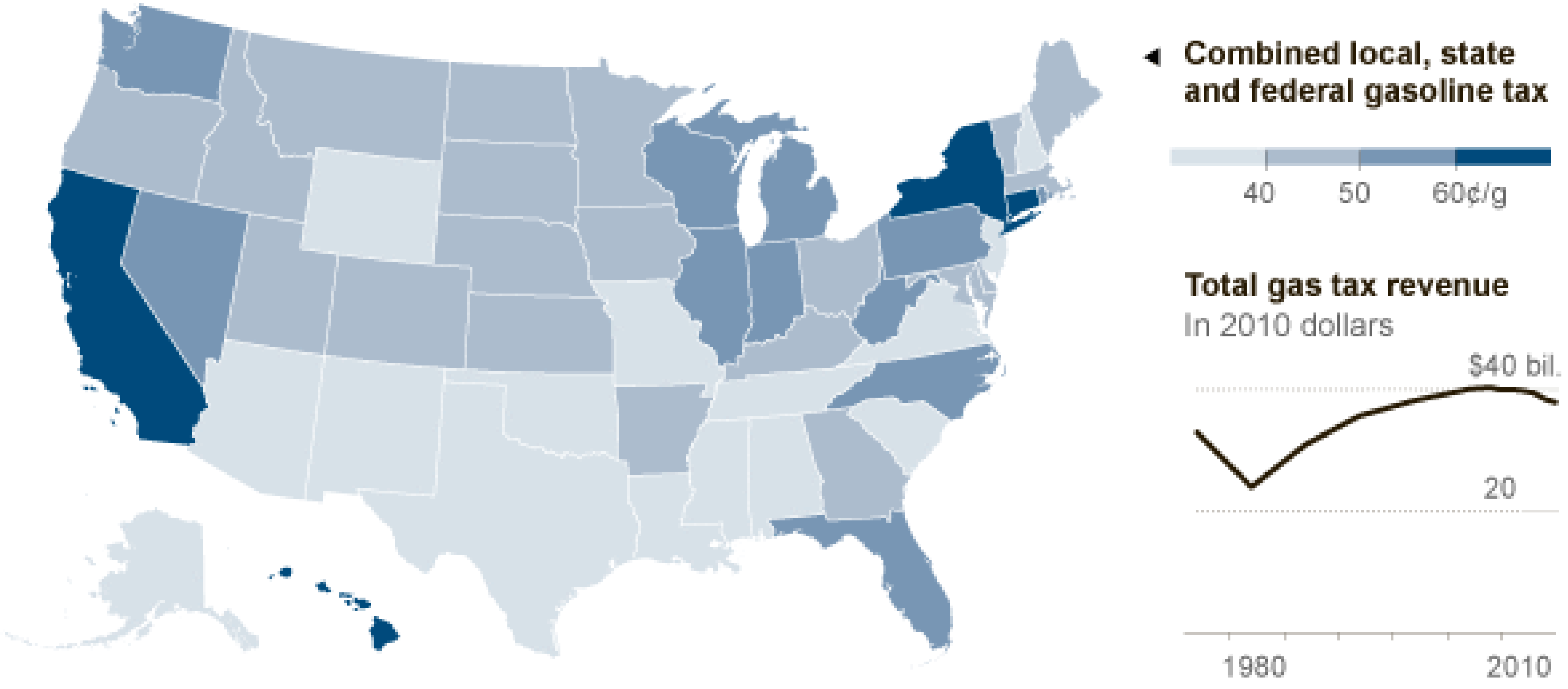


Governments are being forced to do more with less

The New York Times

Feb 14, 2013

Governments Look for New Ways to Pay for Roads and Bridges



Gas Taxes Fail to Keep Up Because most states do not tie their gasoline tax to inflation, taxes are worth less over time. Increased fuel efficiency also means consumers are using less gas.

Sources: American Petroleum Institute; Tax Policy Center

Infrastructure spending is at an all-time low

More Potholes? This Might Be Why.

Infrastructure spending as a percentage of G.D.P. has fallen to the lowest level in decades.

Source: U.S. Census Bureau

The New York Times

Public Works Funding Falls as Infrastructure Deteriorates

By BINYAMIN APPELBAUM AUG. 8, 2017

A water main and sewer renovation project in Somerville, Mass., this month. Public works projects have slowed across the country. Brian Snyder/Reuters

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Life cycle cost analysis is a key element of addressing infrastructure funding gap

ASCE GRAND CHALLENGE

Reduce life cycle costs by 50% by 2025*

Areas of focus
- Resilience
- Innovation
- Life cycle costs
- Performance standards

*$4.6 trillion needed in infrastructure investment by 2025
$2 trillion is unfunded

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Asset management allocation tools are critical to economically-efficient infrastructure

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Roads D

Solutions to Raise the Grade

Fix the federal Highway Trust Fund by raising the federal motor fuels tax, and explore alternative, long-term funding mechanisms.

Increase investment at all levels of government to reduce the backlog of rehabilitation needs.

Use asset management best practices to prioritize projects and improve the condition, security, and safety of assets while minimizing costs over its entire life span.

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Tools for economically-efficient management of pavement networks

Competitive Paving Prices

Life Cycle Cost Analysis

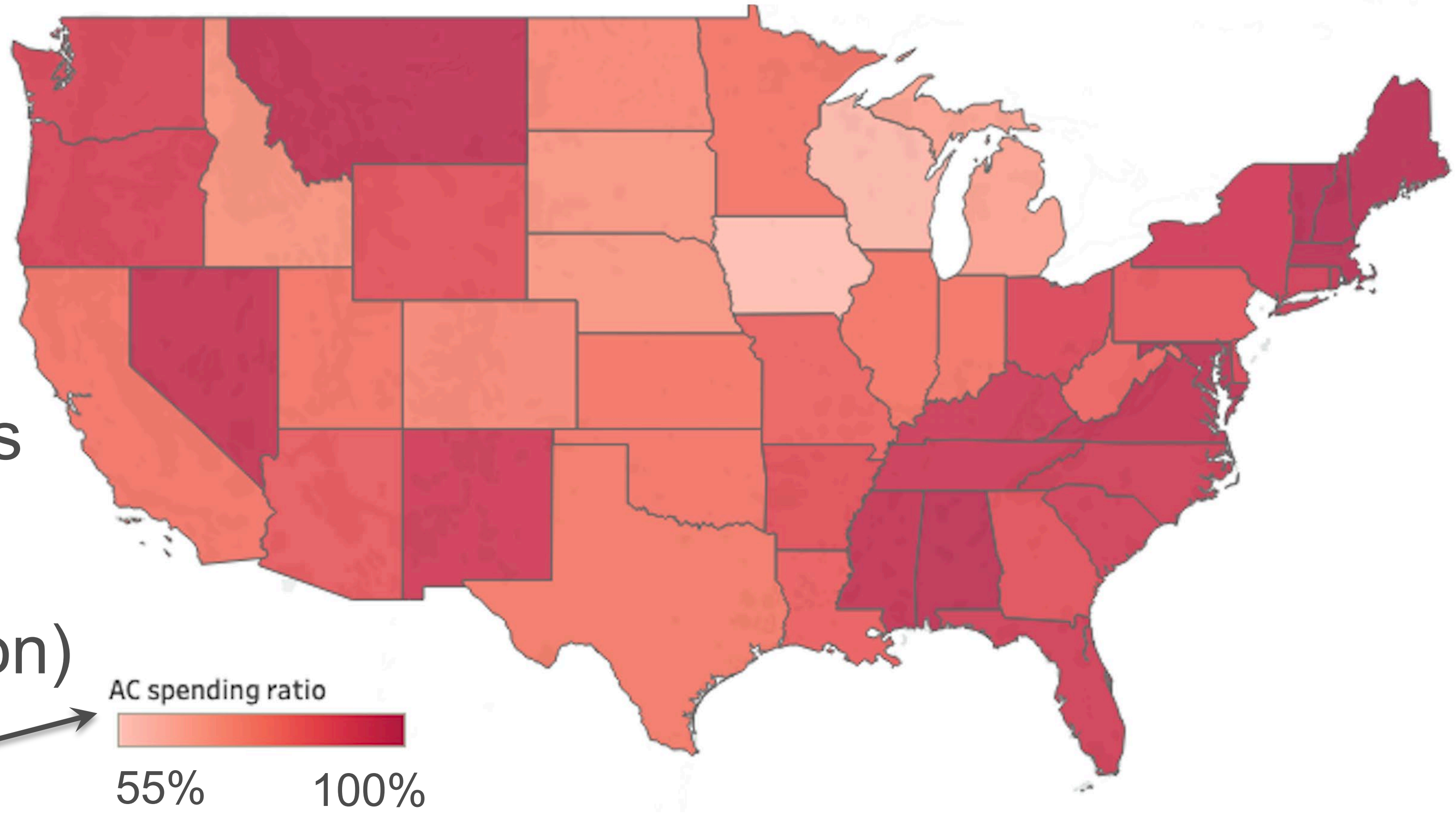
Asset Management

Does the presence of competition between material substitutes impact pavement material prices?

Statistical analyses of Oman BidTabs* data using these parameters:

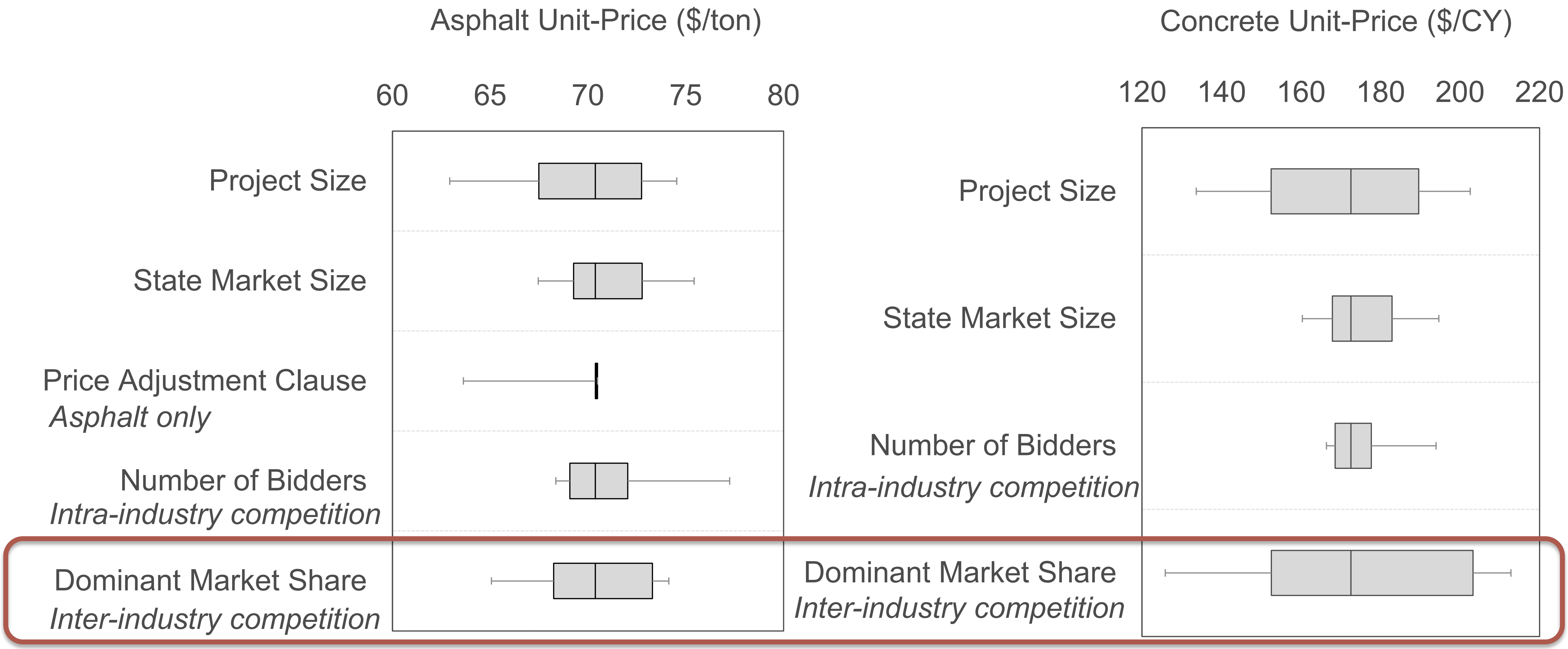
- Project size (quantity)
- State market size (annual spending)
- Price adjustment clauses (asphalt only)
- Number of bidders (intra-industry competition)
- Dominant market share (% spending on AC; inter-industry competition)

10-Year Average Percent Spending on AC

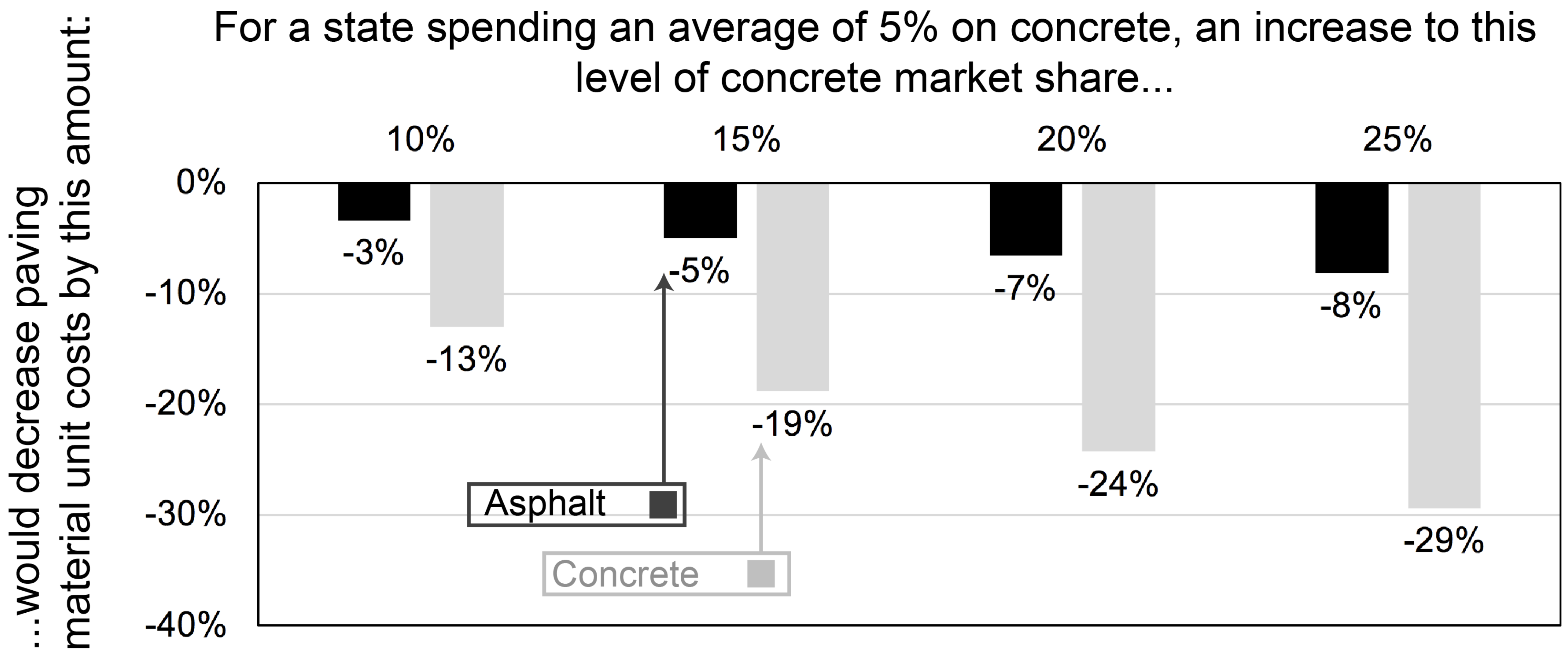


*2005-2015, 47 states, 298k pay items, 164k jobs

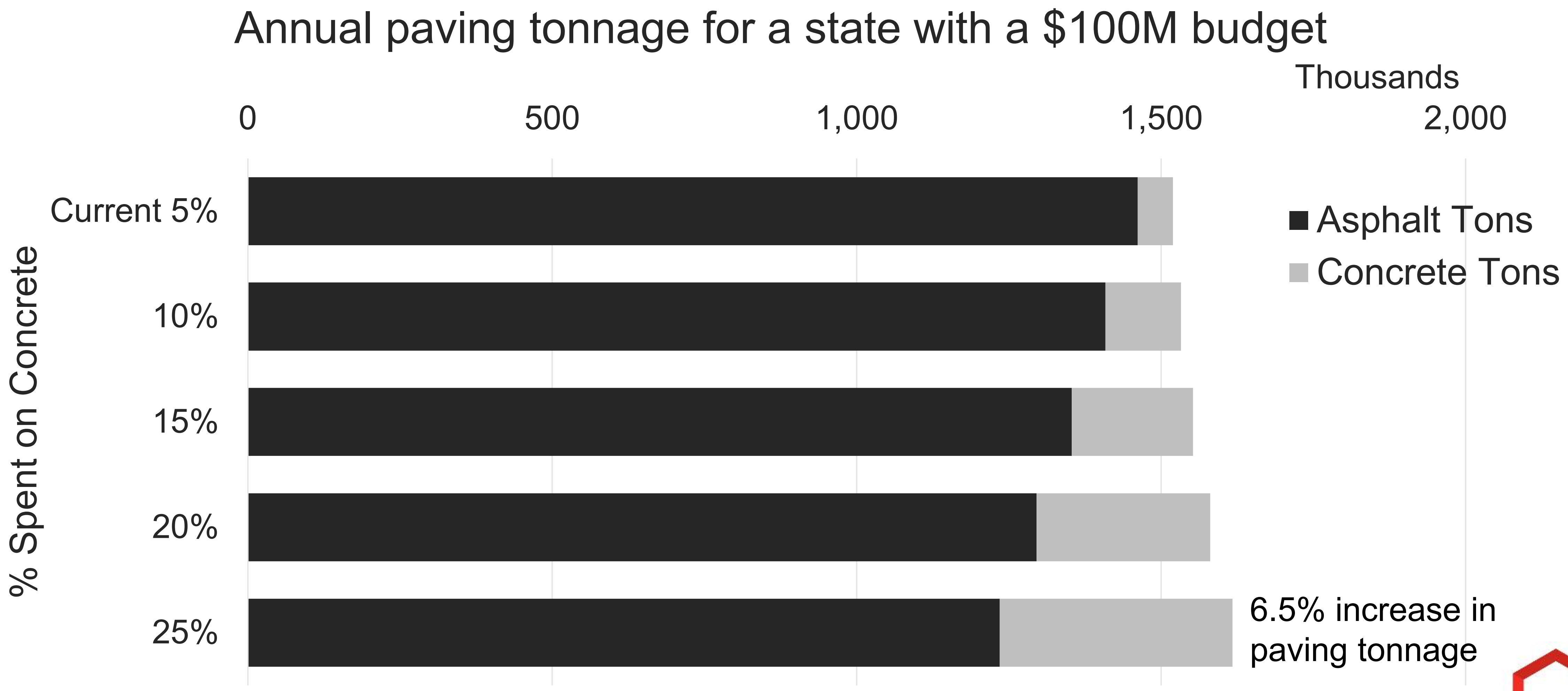
Statistical model shows large impact of inter-industry competition



Lower unit-prices for bid items are correlated with increased concrete spending



Increased competition can translate into more paving



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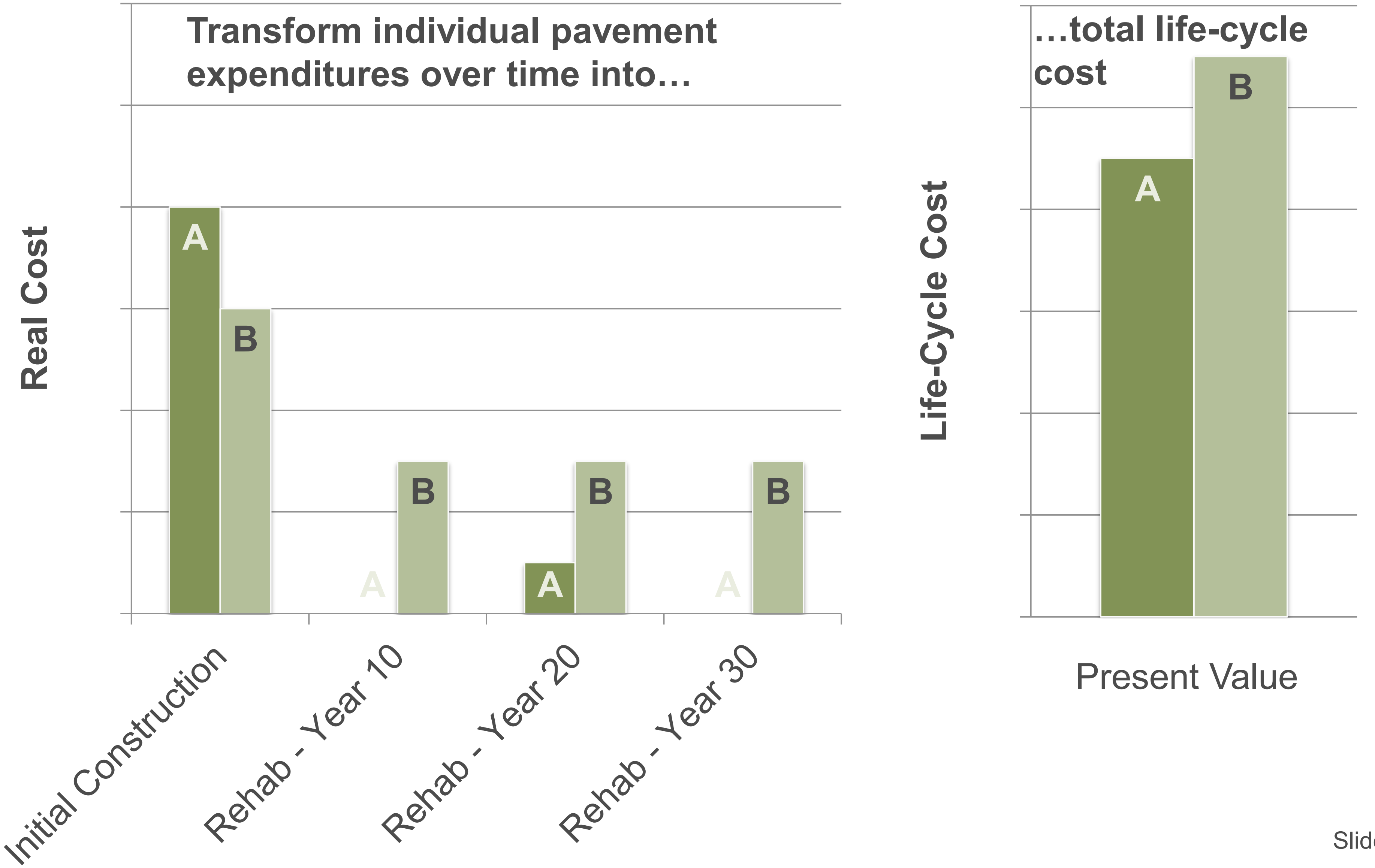
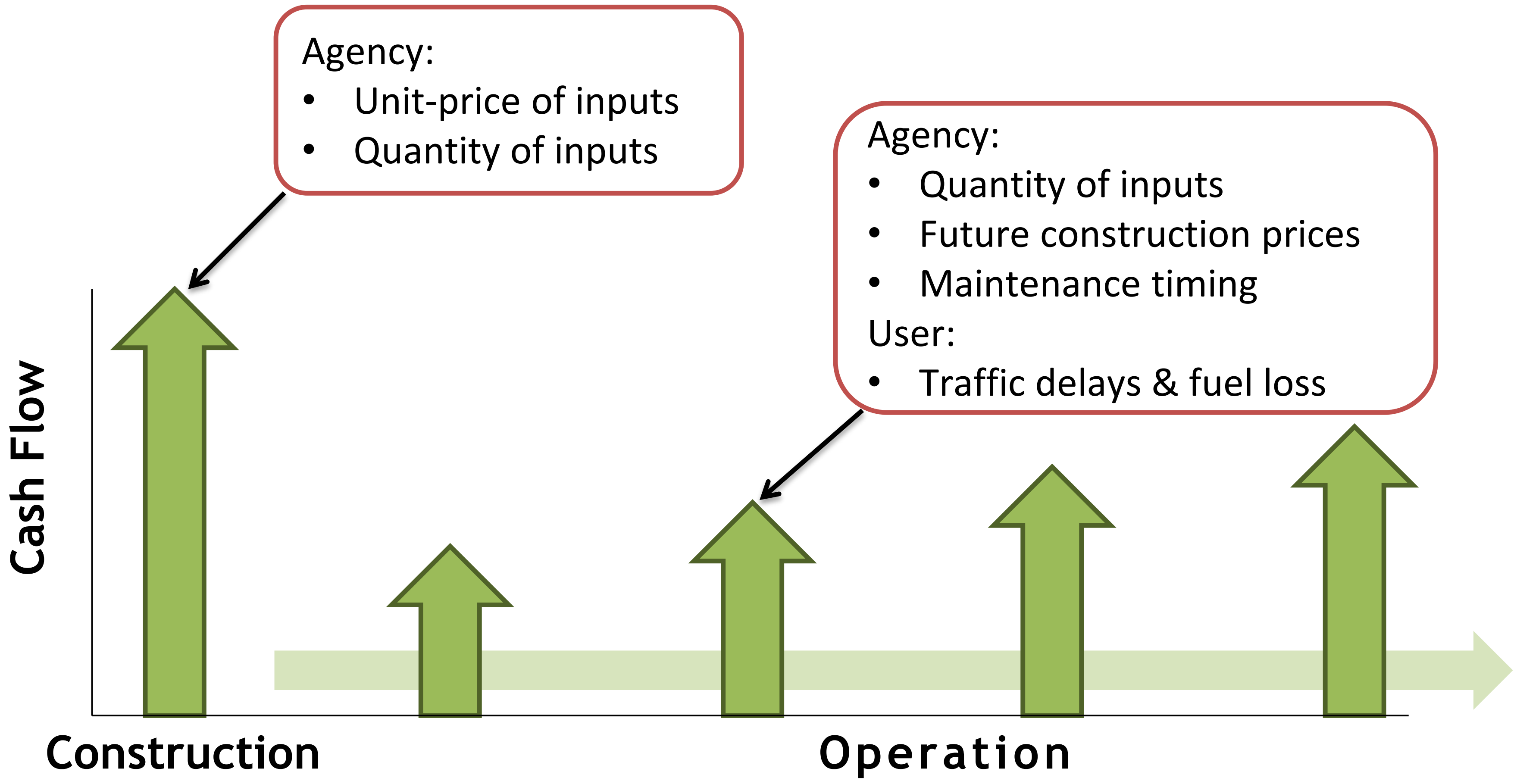
LCCA – Life-cycle cost analysis: Method for evaluating total costs of ownership

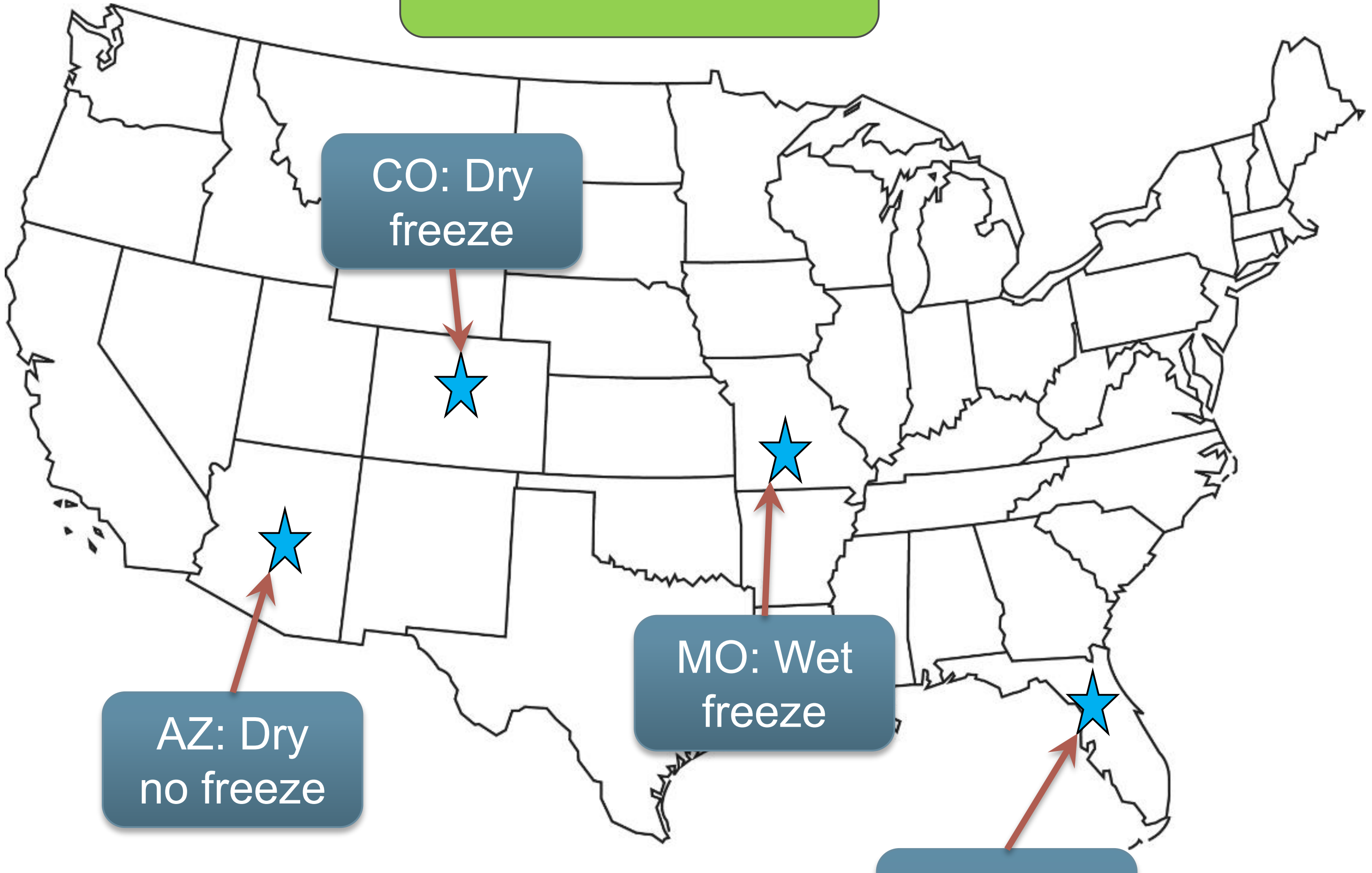


CSHub created probabilistic cost estimates for entire life-cycle



CSHub conducted LCCAs for a wide range of scenarios

4 Locations



Pavement design and maintenance schedules developed by Applied Research Associates (ARA), Inc

3 Traffic Levels

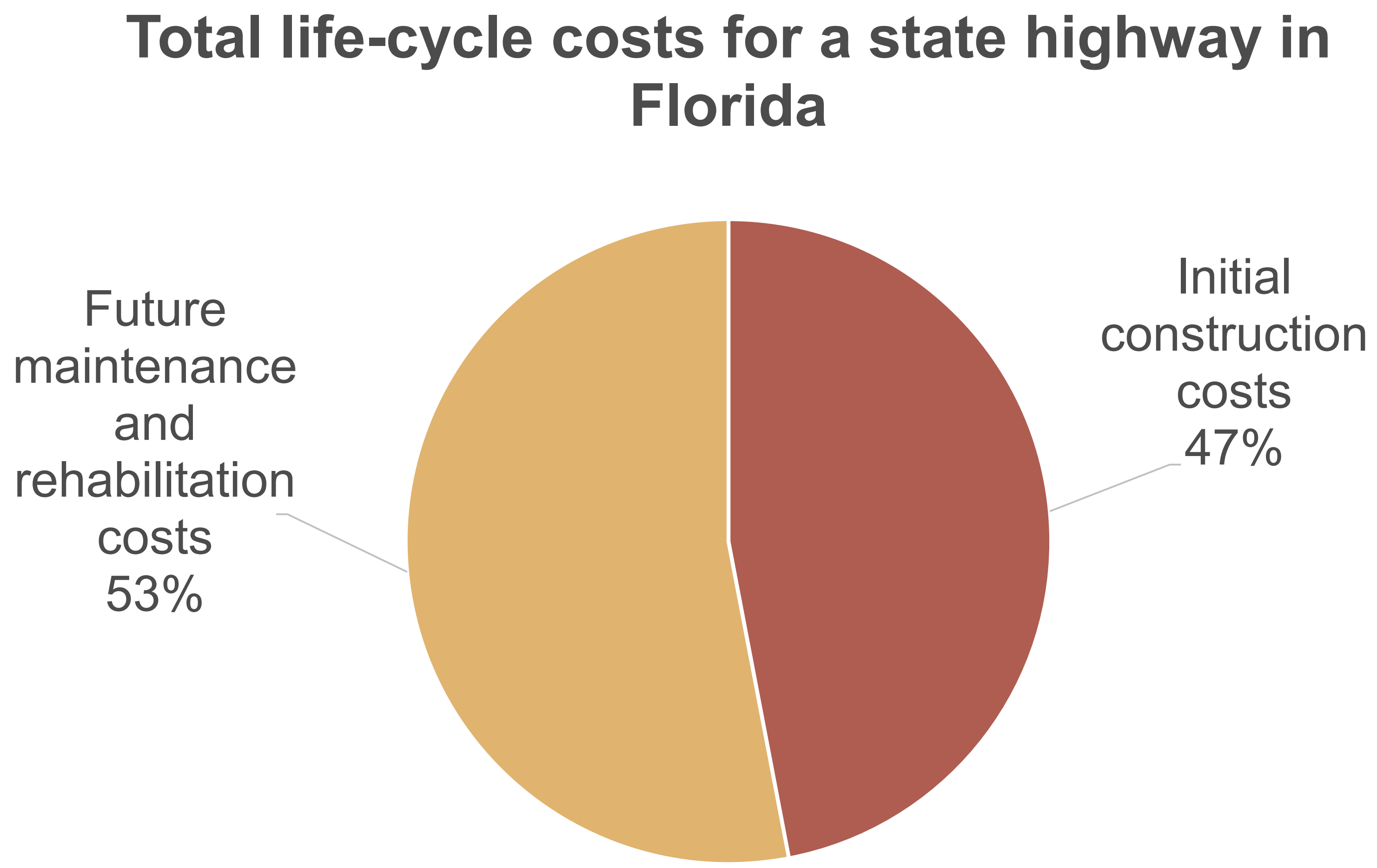
- Rural local street/highway
- Rural state highway
- Urban interstate

Several framing conditions

- Pavement designs
- Maintenance schedules
- Design life
- Analysis period

Life cycle matters

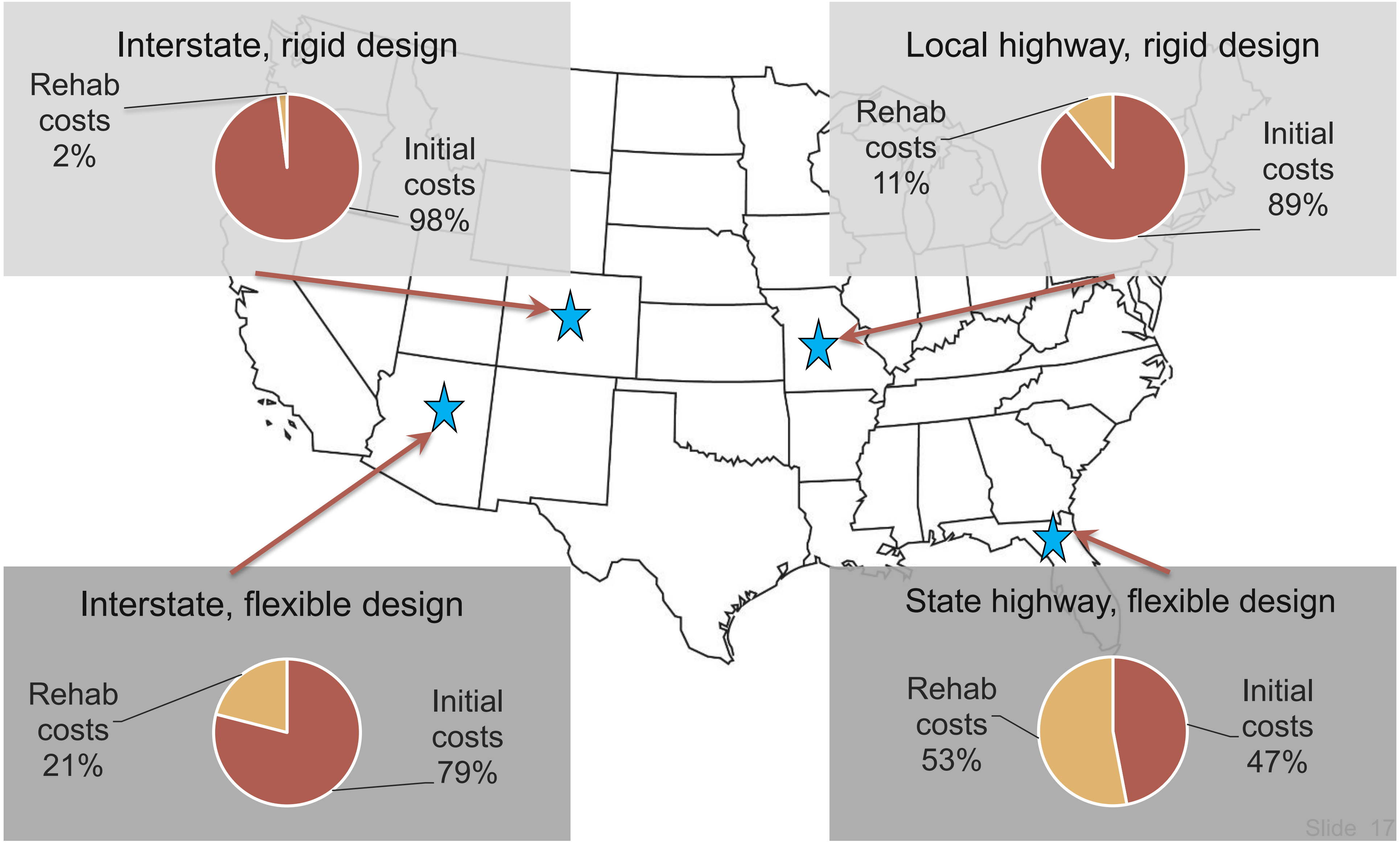
Future costs can be significant



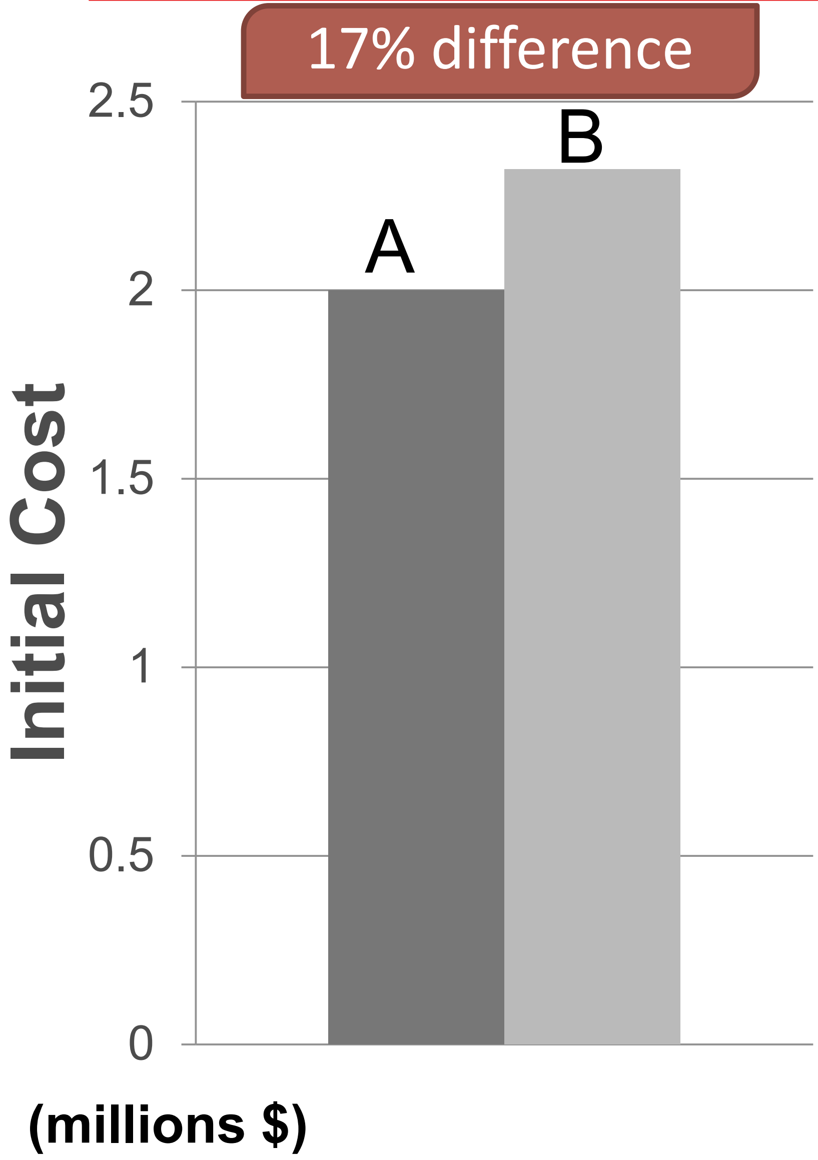
Flexible pavement design developed by Applied Research Associates (ARA), Inc,: AADTT 1k/day; 4 lanes; Wet-no-freeze-FL; FDOT-based rehabilitation schedule; Analysis period = 50 years.

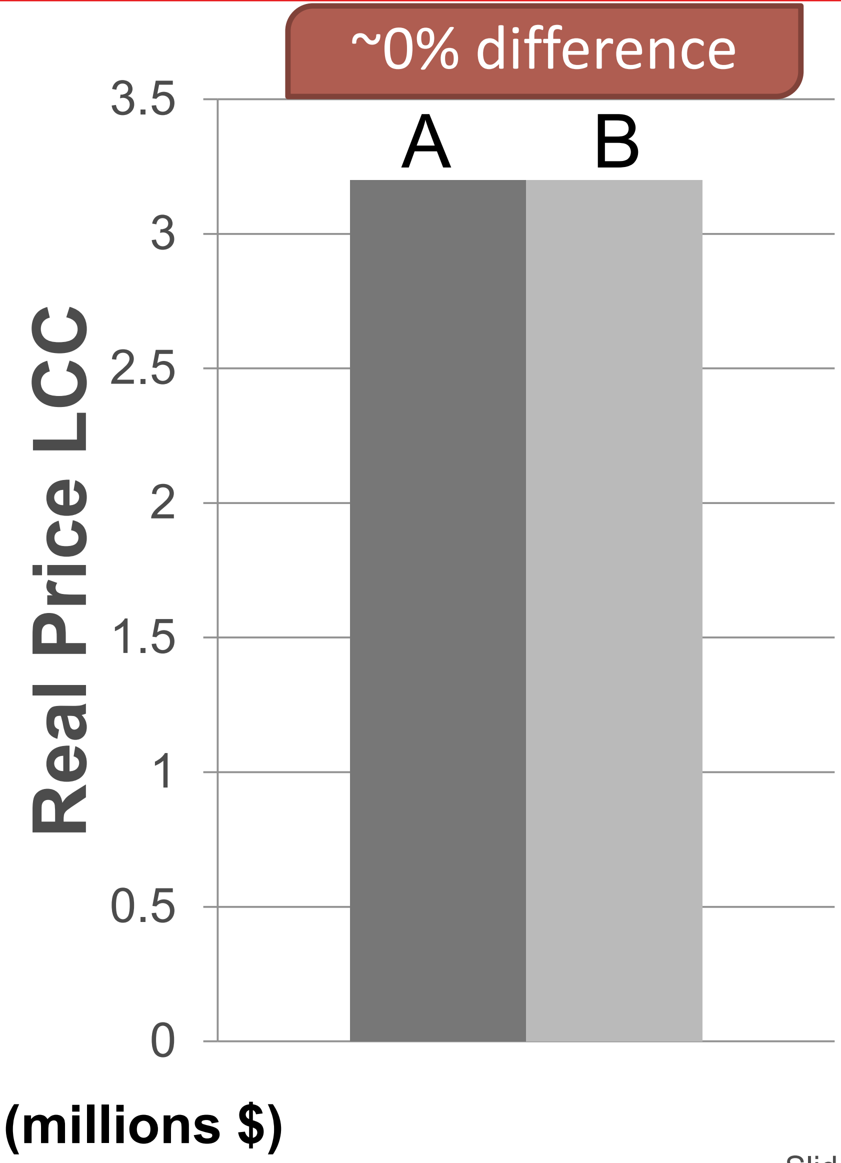
Context matters

Costs vary with location, traffic level, & pavement design

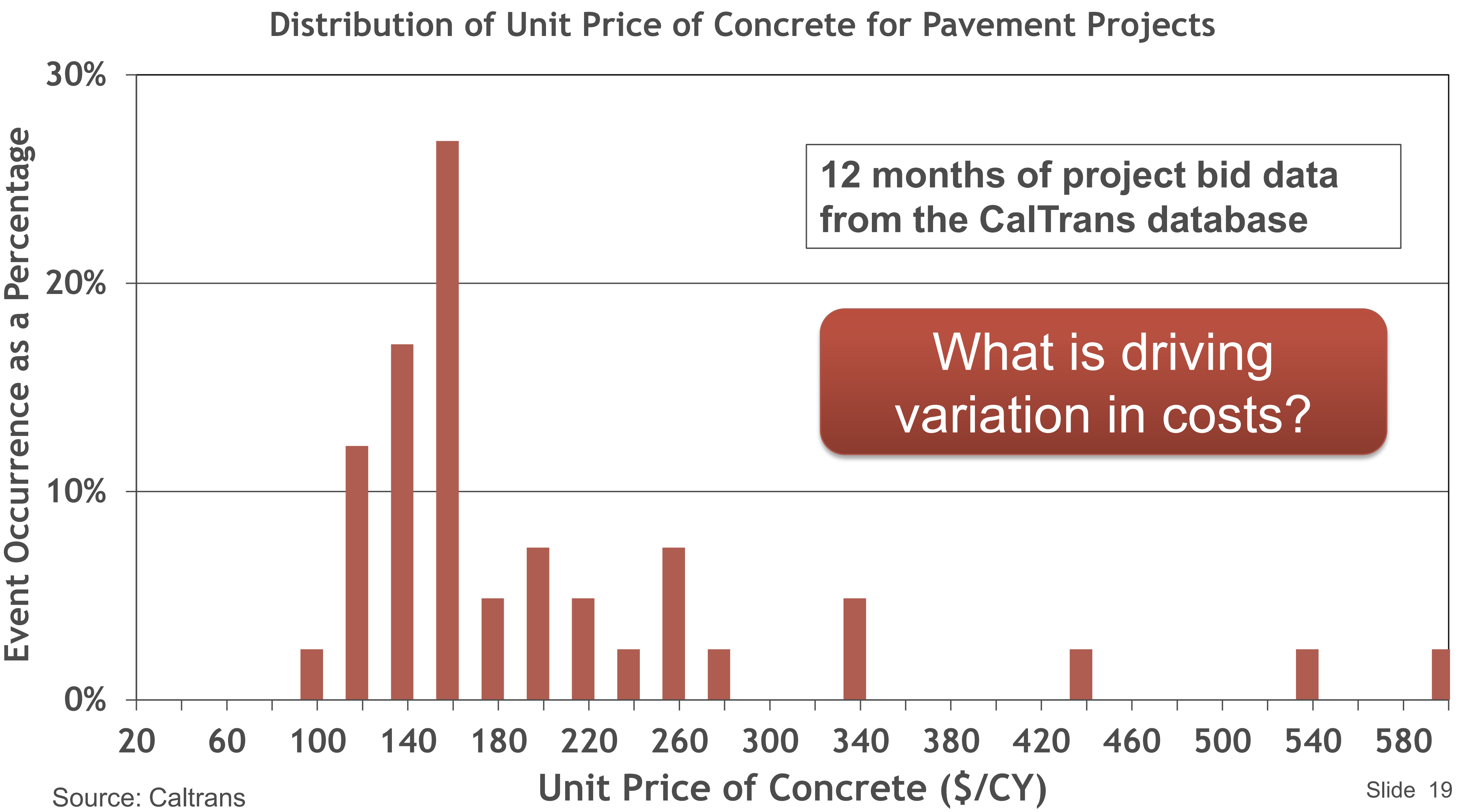


Life cycle perspective alters relative competitiveness



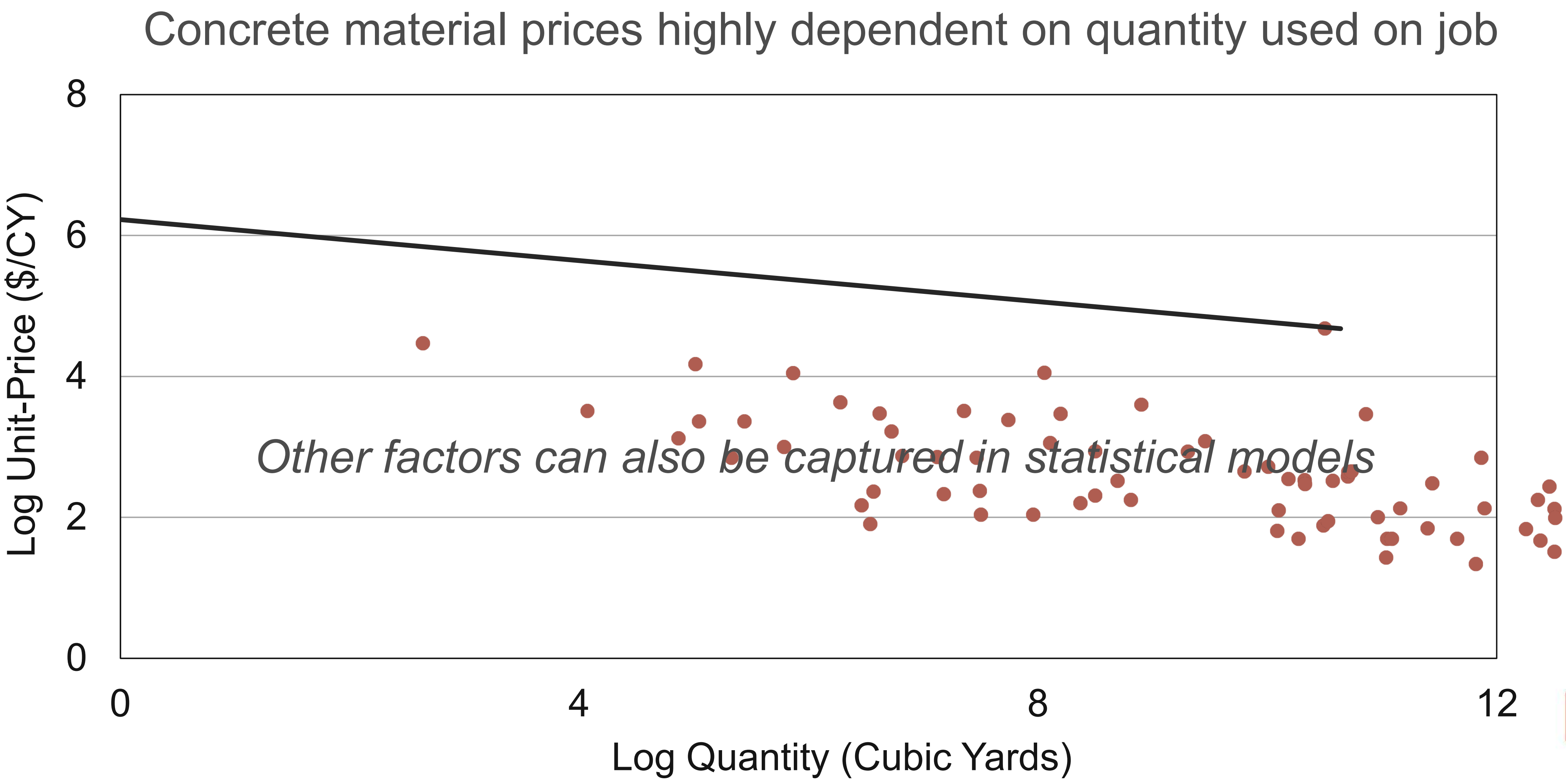


There is significant variation in initial costs

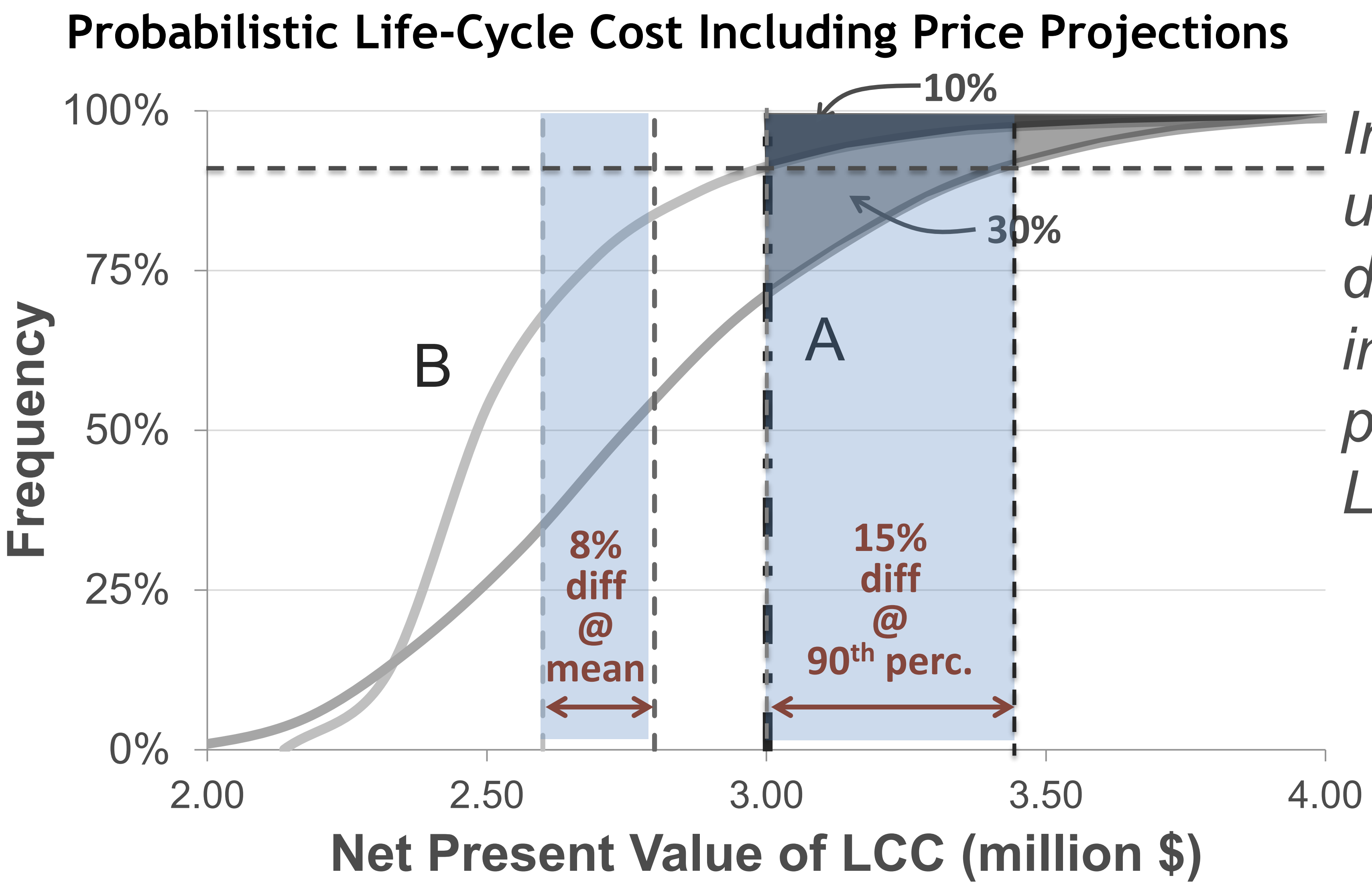


Source: Caltrans

Capture drivers of initial cost and variation through statistical models



Probabilistic analysis provides insight on relative risks



Initial cost is usually major driver of variation in comparative pavement LCCAs

Tools for economically-efficient management of pavement networks

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Life Cycle Cost Analysis

Asset Management

FHWA has issued new performance management rules due to MAP-21

FHWA motivation: *improve decision-making* through performance-based planning and programming

Key elements of asset management plans:

- Life cycle planning
- Risk management analysis
- 10-year financial plan

Pavement network performance management process

Set targets → Measure performance → Implement strategies to meet targets

% Good
% Poor

Pavement Management System

Which strategies?
At what cost?

How to allocate funds to obtain best performance at lowest cost?

Many approaches to allocate funds

Pavement Segment	Pavement Condition Index
A	45
B	47
C	51
D	52
E	56
F	62
G	67

- How to prioritize which segments to repair?
- Will targets be met?
- Which strategies should be used?
  - Many short term fixes?
  - Few long-term fixes?

An optimization modeling approach is required to answer these questions: Performance-Based Planning

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Goal of MIT asset management research: improve allocation decisions

Performance-based planning through
Performance-based budget allocation

Current & historical pavement network data → Projection of network performance → Make decisions to allocate resources

Objective: prioritize projects that maximize performance and minimize cost

Why is this a challenge?

The scale of the problem for state pavement networks is daunting

Making decisions about …
… which preservation, overlay, or reconstruction activity
to apply to
… which segment
at
… what time (now or future)?

Thousands of pavement lane-miles

➕ Dozens of technologies to maintain or replace pavements

➕ Fixed budget

➕ Future budget and road condition = ?

What is the best plan?

Budget Allocation

Allocating limited funds to the set of activities that meet the goals of the network operator

How to Overcome the Challenge?

Practical network allocation involves two interlinked tasks

Segment-level Decision

- What is the best POR strategy **for this segment**? (This will involve a sequence of POR activities over time)

Network-level Decision (Allocation)

- What set of best POR strategies will give us the best **network performance** but still be within our budget?

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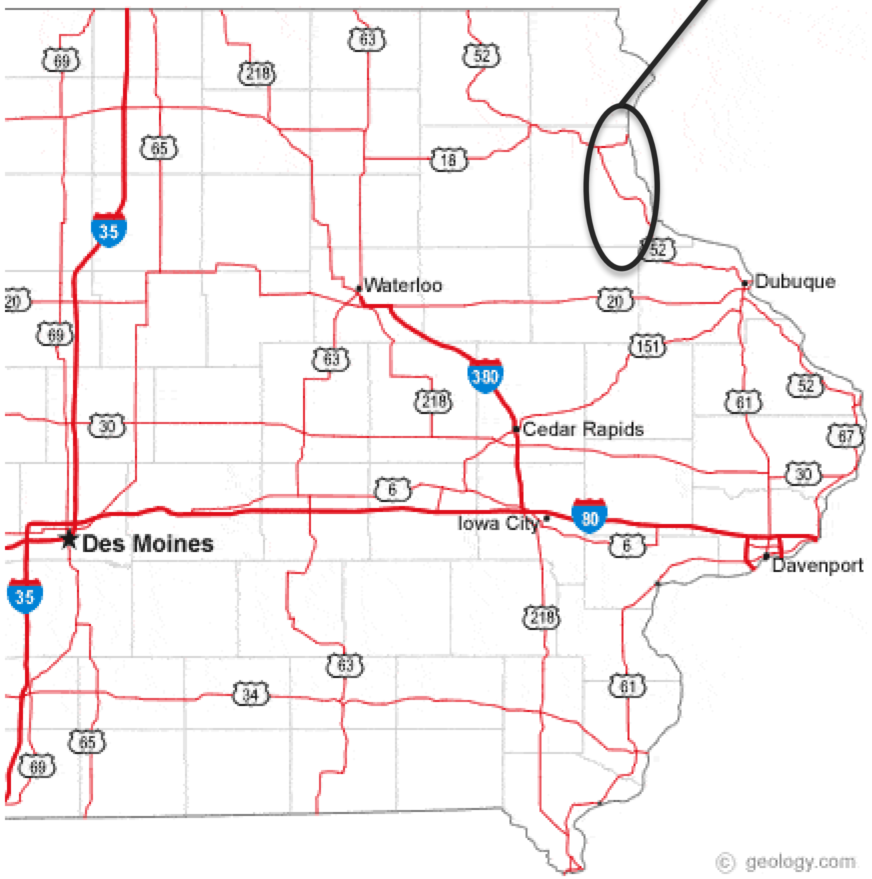
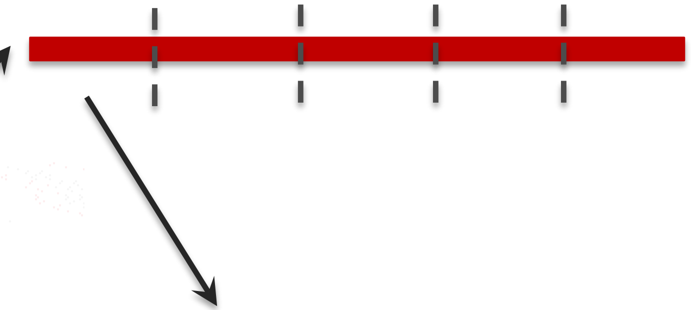
Implementing Two Stage Budget Allocation Algorithms





Segment	Best POR Alternatives	
—	Pres1	Over2
—	Pres2	Over3
…		
—	Pres3	Recon4

PMS Data
Current & historical pavement network data

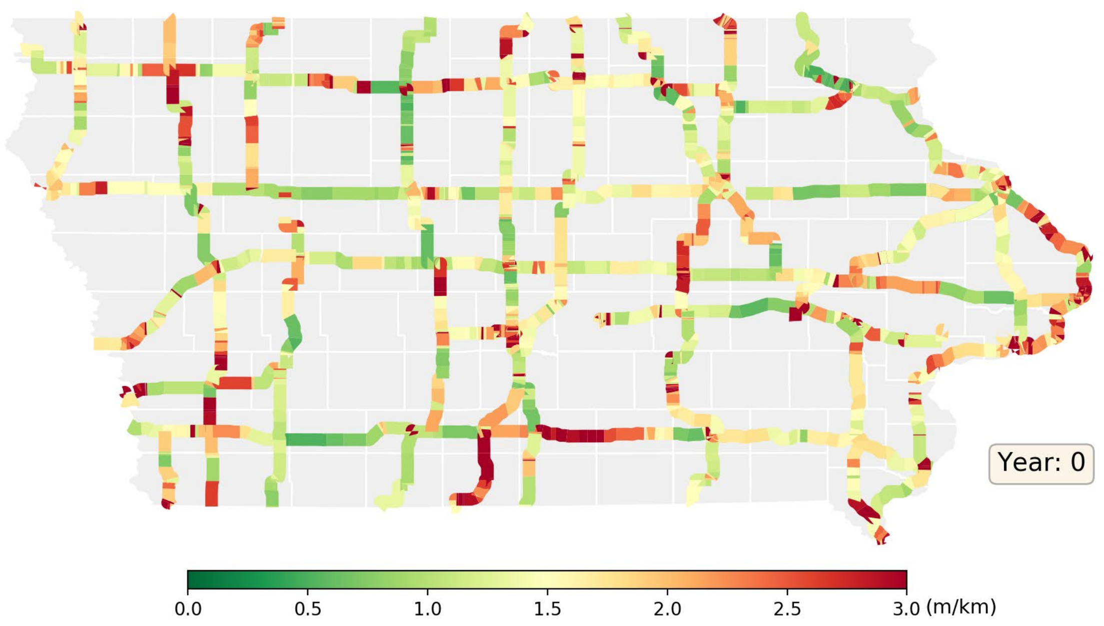
Project Performance
Identify best POR alternatives for each *segment*

Allocate Resources
Select a set of best POR options for *network*

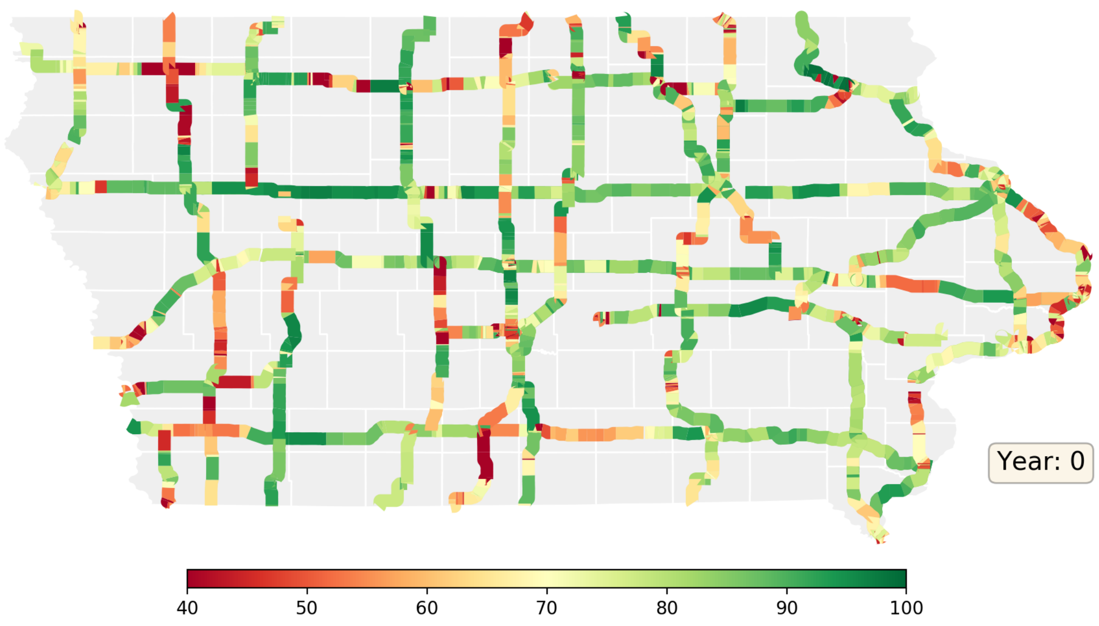
Case study – Iowa U.S. route system

- Iowa PMS 2017
- 9,550 lane miles
- Pavement type: asphalt, asphalt overlay composite, and concrete
- Initial traffic-length weighted IRI (TWIRI) = 1.65 m/km
- Initial traffic-length weighted PCI (TWPCI) = 76.3

IRI distribution for U.S. route network in Iowa

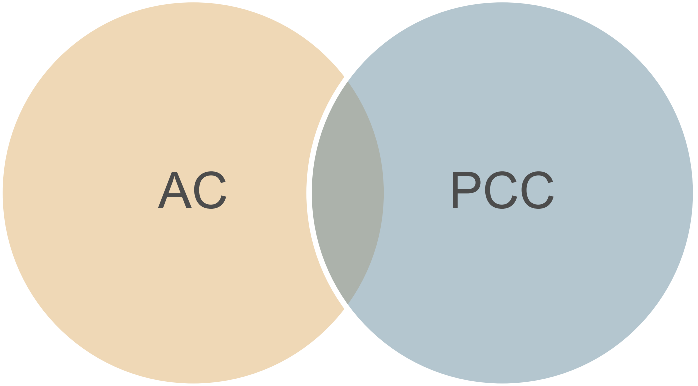


PCI distribution for U.S. route network in Iowa

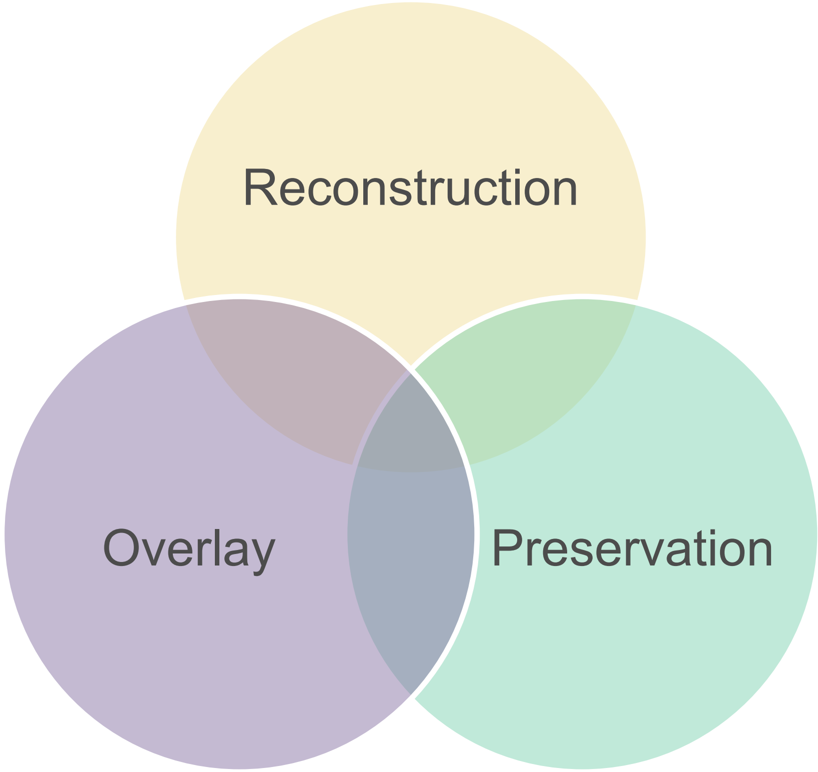


Data source: Iowa DoT Open Data

Treatment strategies

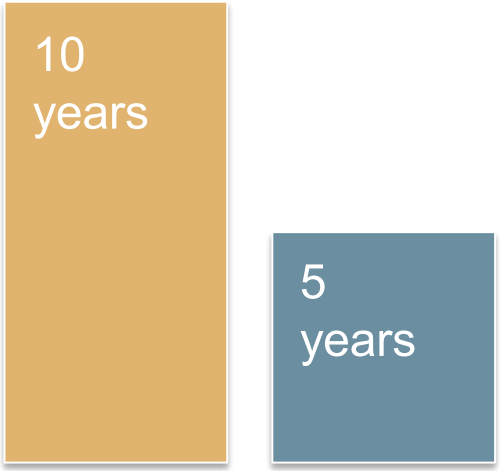


Materials



Treatment types

- Short-term: preservation + thin overlay
- Long-term: thick overlay + reconstruction



Segment evaluation period

*AC: asphalt concrete, PCC: Portland cement concrete

Excess fuel consumption of vehicles caused by pavement design and maintenance

Pavement-vehicle interaction (PVI)

Pavement Deflection

Pavement Roughness

Currently included in PBP models

Deflection & Roughness → **Excess Fuel Consumption** → **Economic & Environmental Impacts**

Key conclusion: leverage four strategies

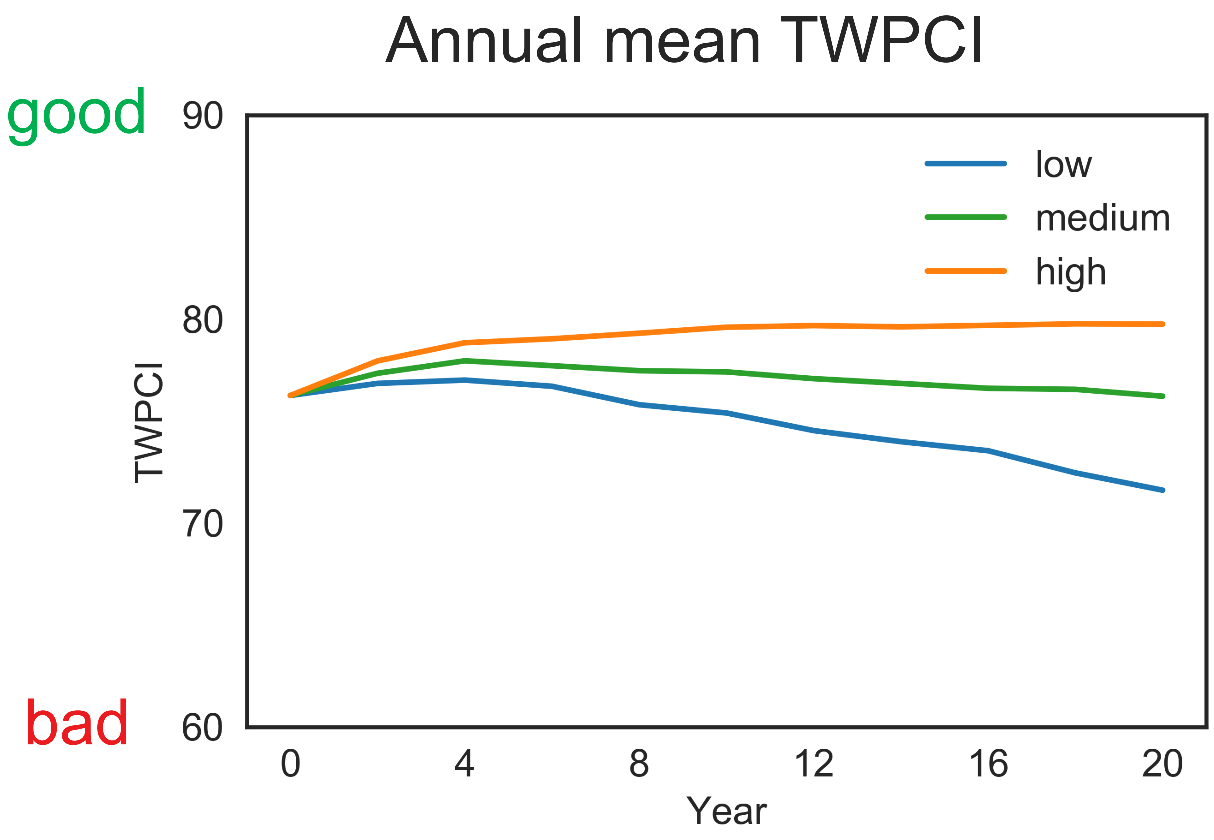
Sufficient budget

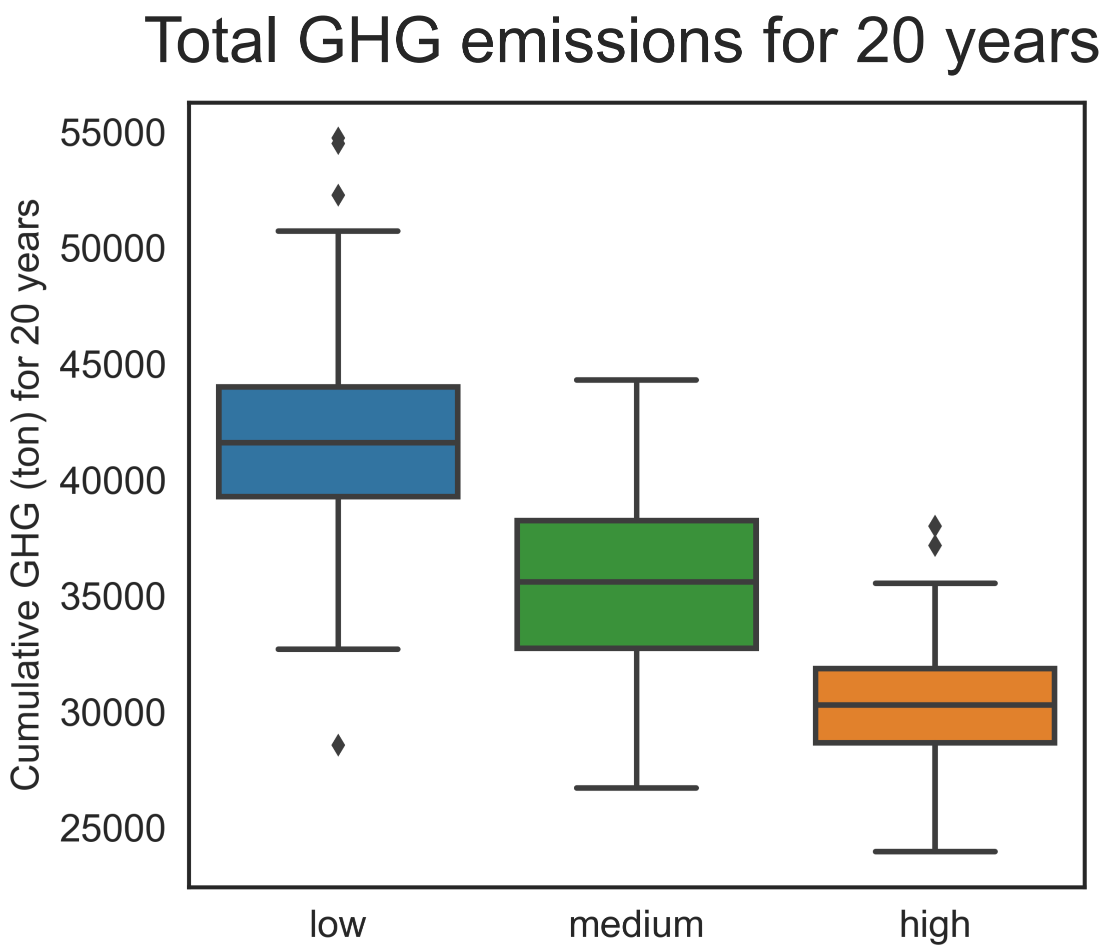
Mix of pavement types

Mix of short and long-term fixes

Long evaluation periods

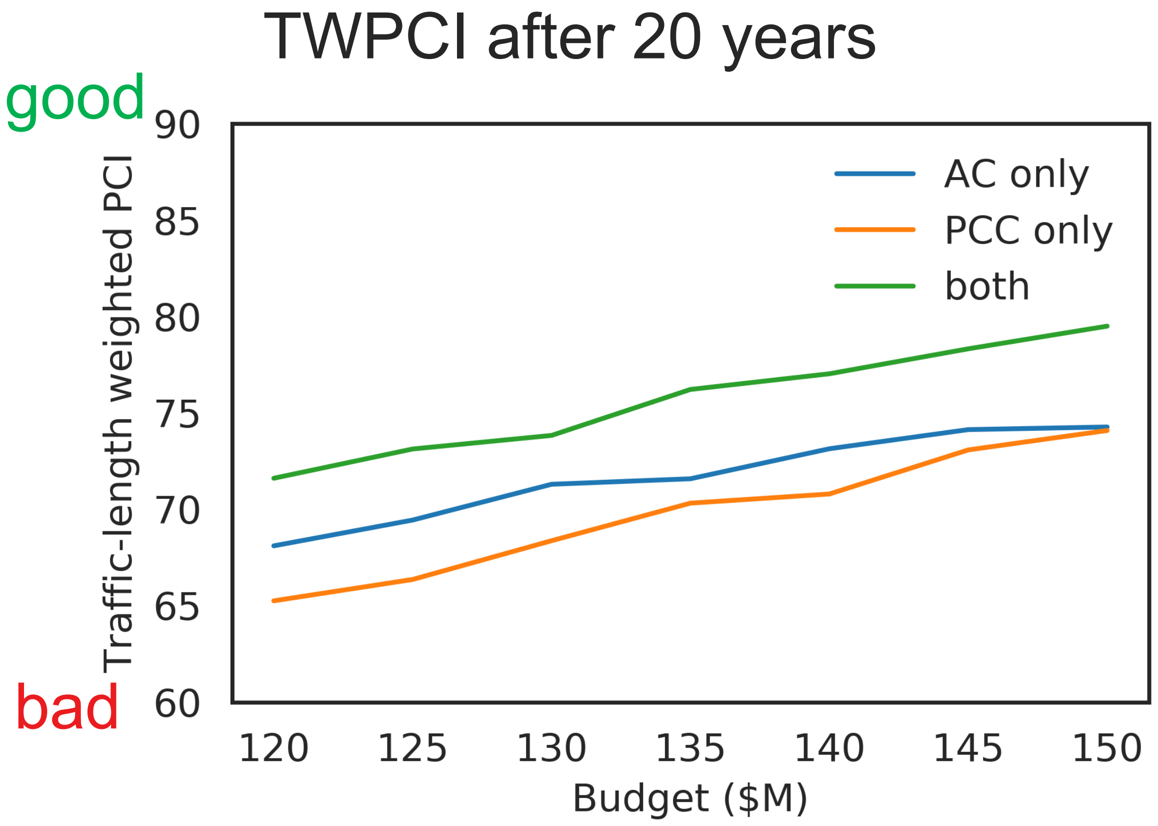
Sufficient budget: increasing budget level improves network performance and reduces GHG emissions

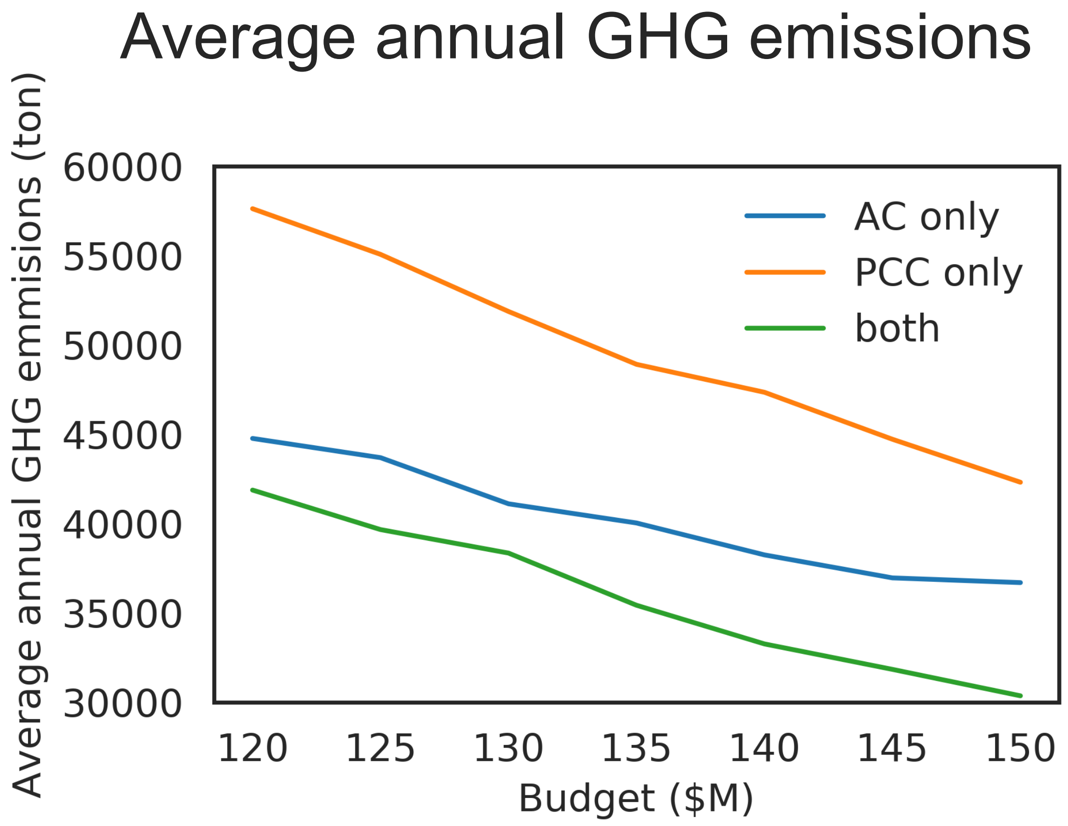




Mix of pavement types: Diverse materials improve network performance and reduce GHG emissions

- AC only strategy: maintain more pavement area, but treatment effects are short
- PCC only strategy: treatment effects are long, but maintain less pavement area

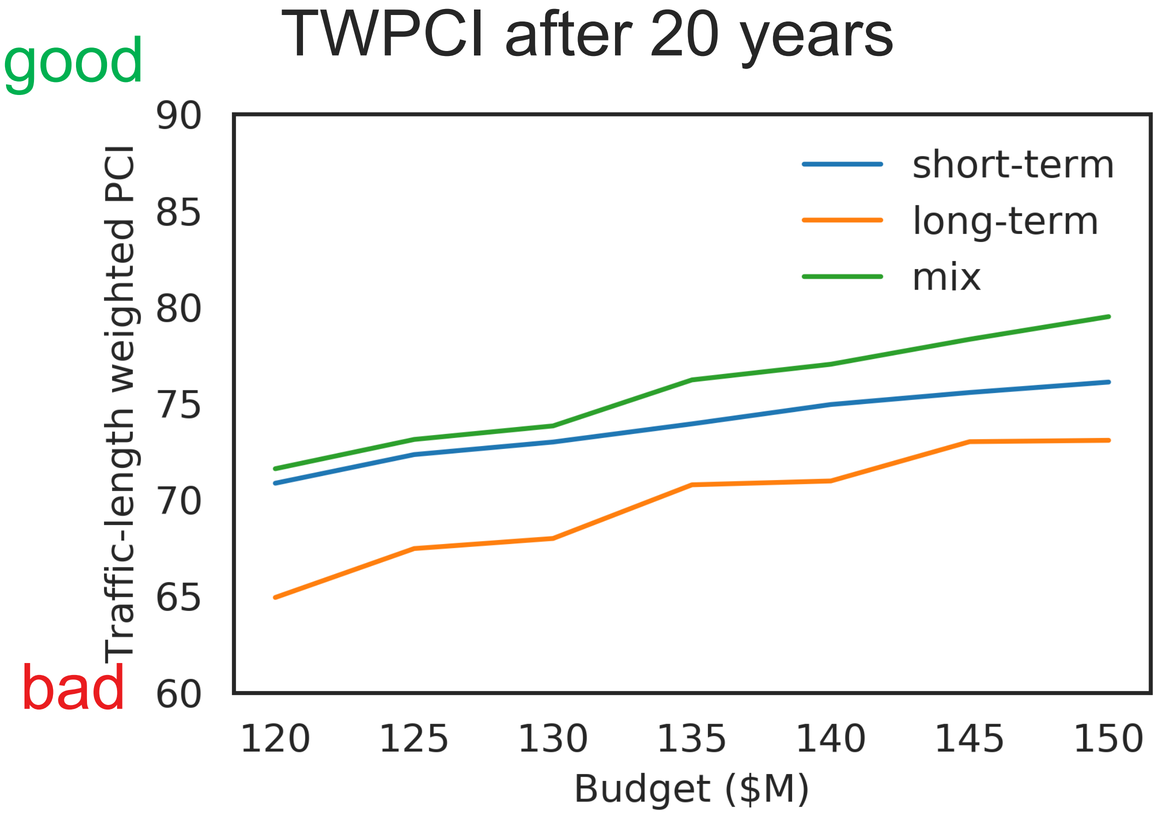


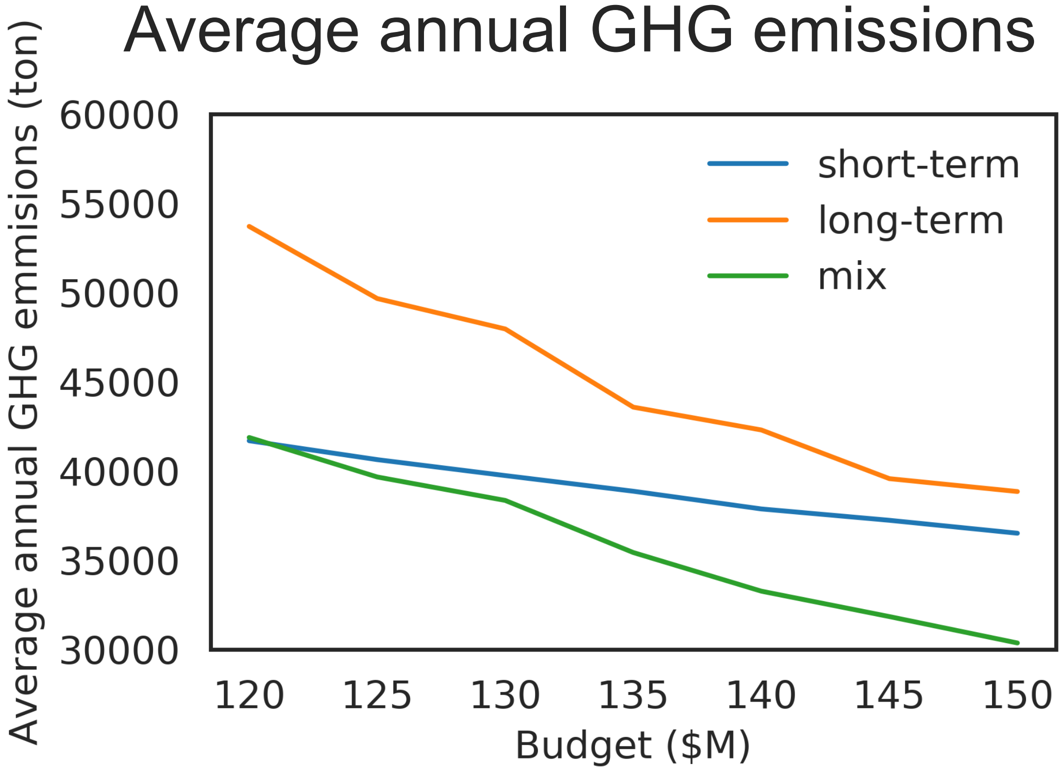


*AC: asphalt concrete, PCC: Portland cement concrete

Mix of fixes: Diverse treatment types improve network performance and reduce GHG emissions

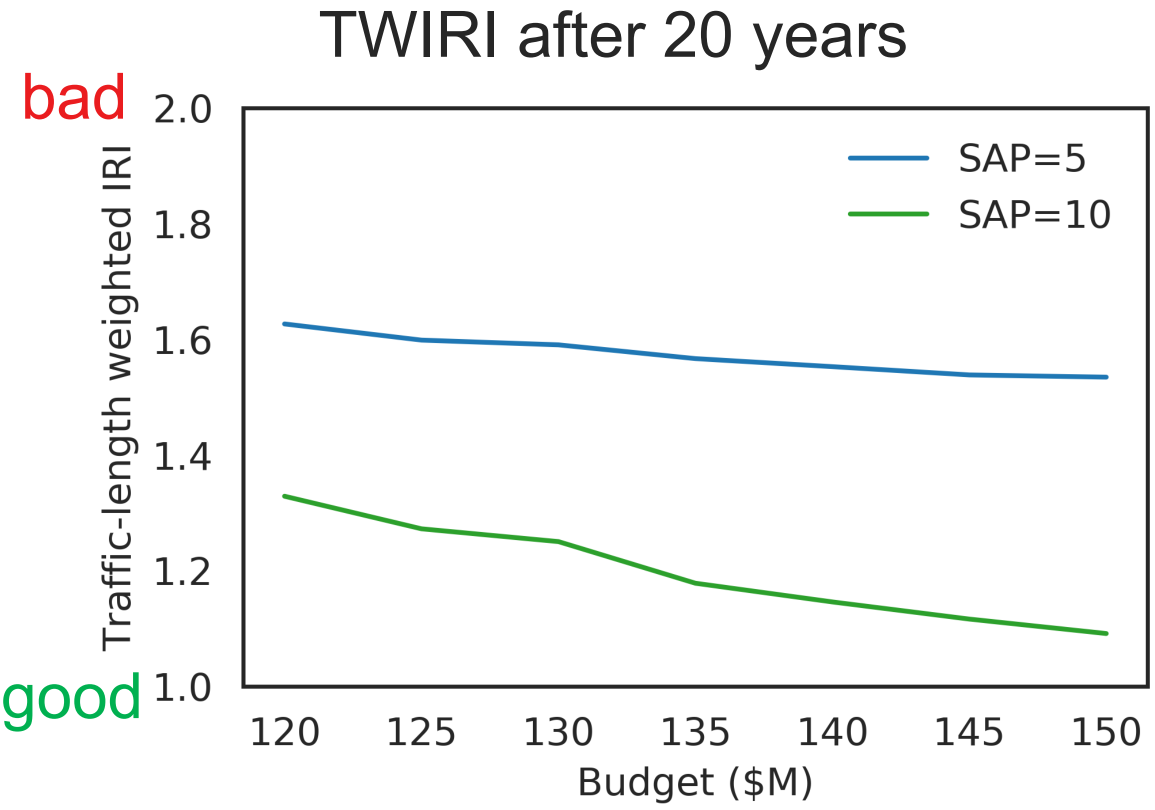
- Short-term strategy: maintain more pavement area, but treatment effects are short
- Long-term strategy: treatment effects are long, but maintain less pavement area

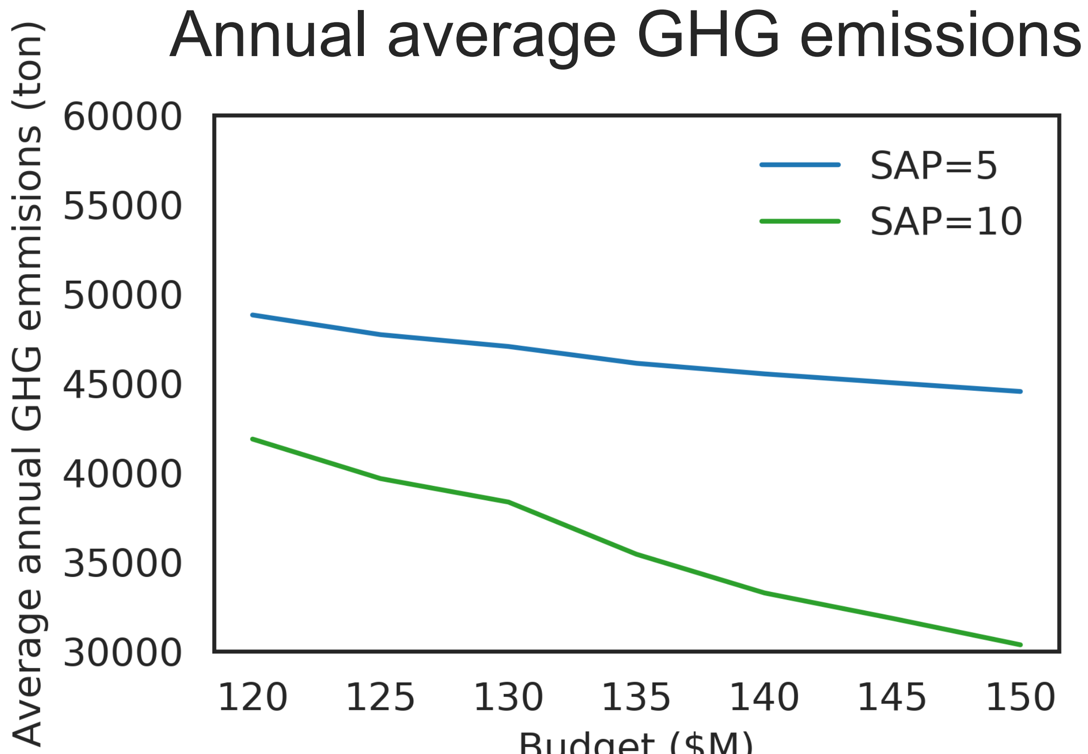




<u>Long evaluation periods:</u> Treatment actions with long-term benefits improve network performance and reduce emissions

- Segment analysis period (SAP) represents the period to evaluate benefits of treatments
- SAP=5: treatments with short-term benefits are preferable
- SAP=10: treatments with long-term benefits are preferable





Key conclusion: leverage four strategies

Sufficient budget

Mix of pavement types

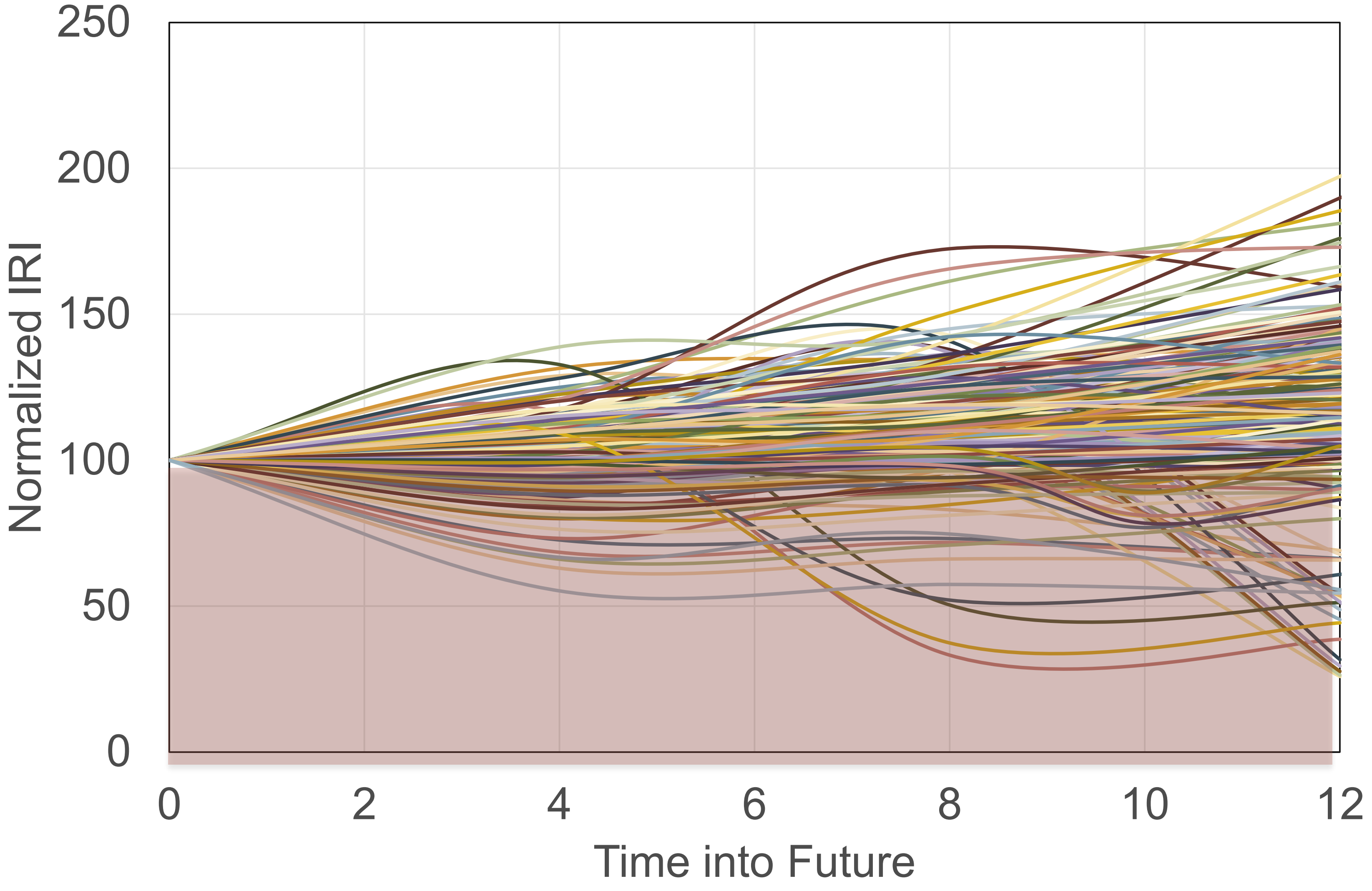
Mix of short and long-term fixes

Long evaluation periods

Benefits increase with higher budgets

Data analysis can be challenging

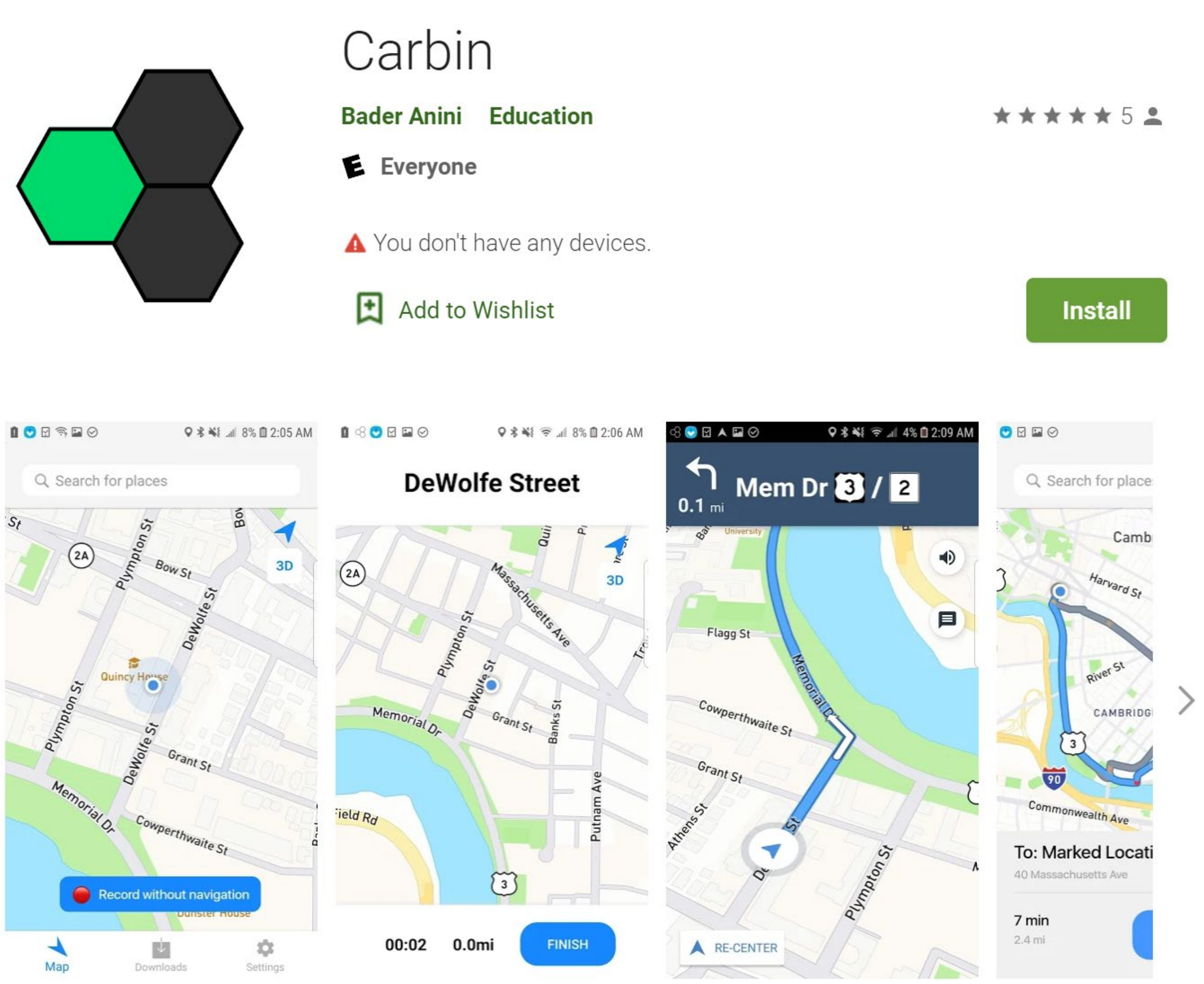
Evolution of many randomly selected segments and their IRI over time

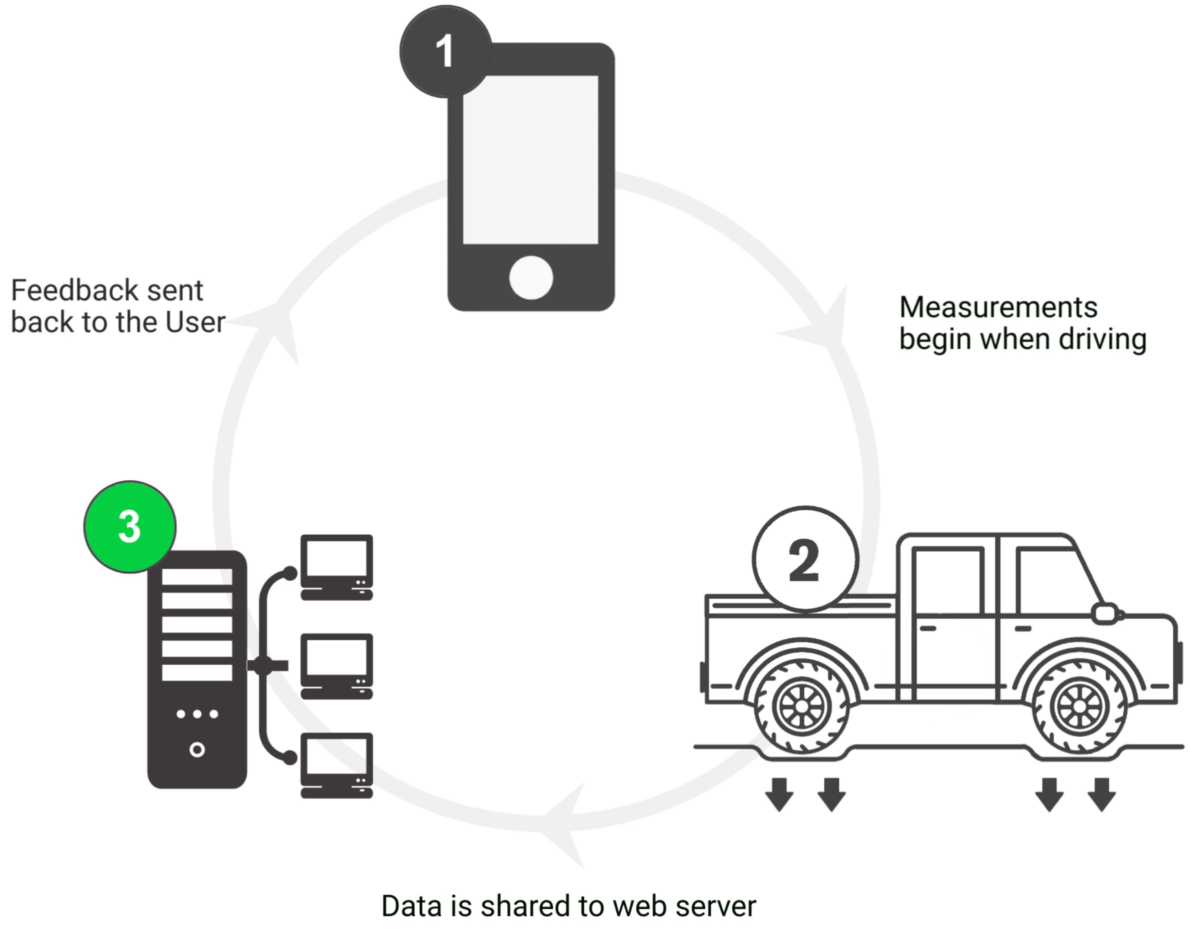


Many segments exhibit a decrease in their IRI over time

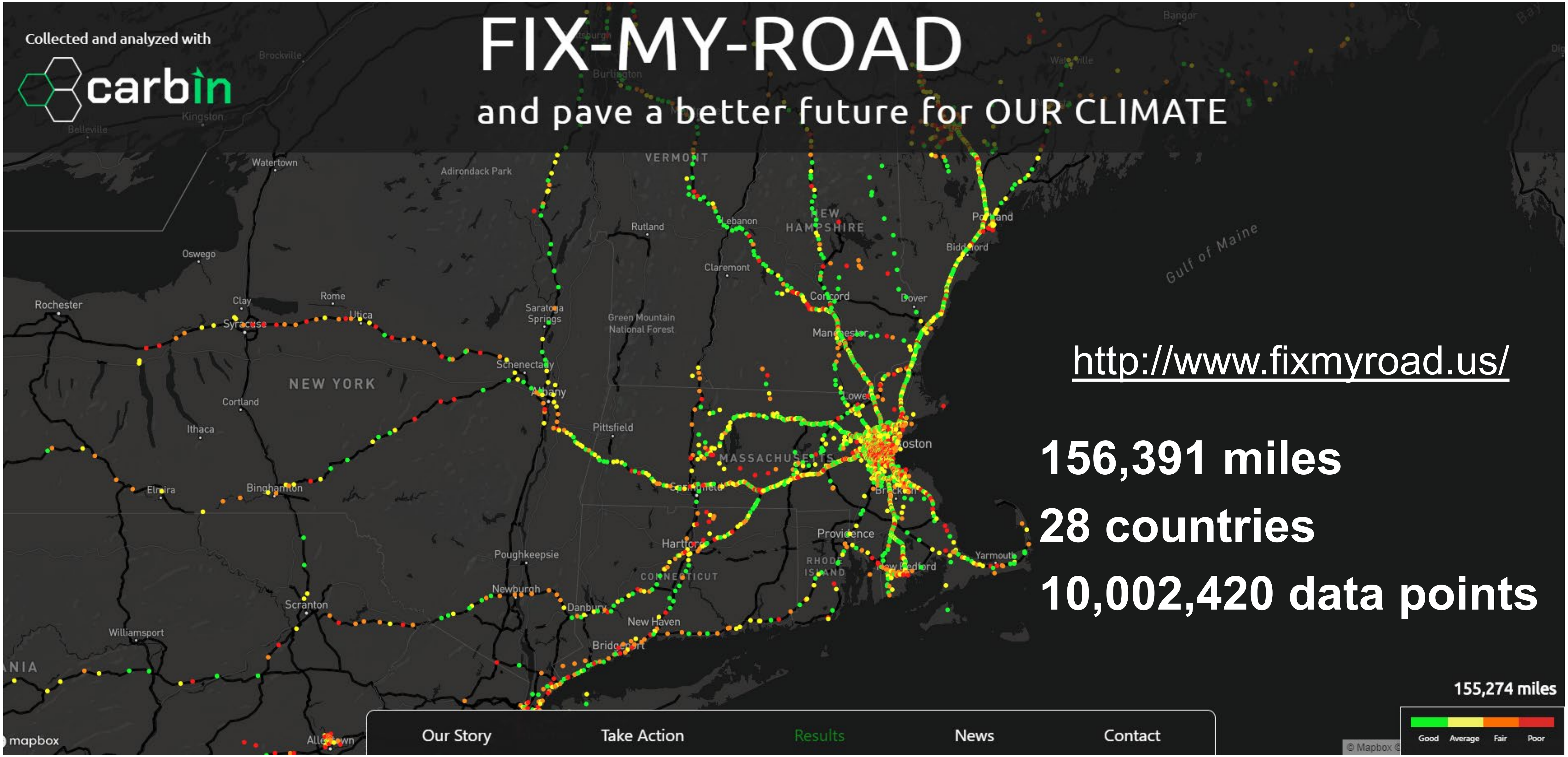
What is signal?
What is noise?

Measure pavement roughness using Carbin app





Crowdsourced data can support asset management



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Thank you

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