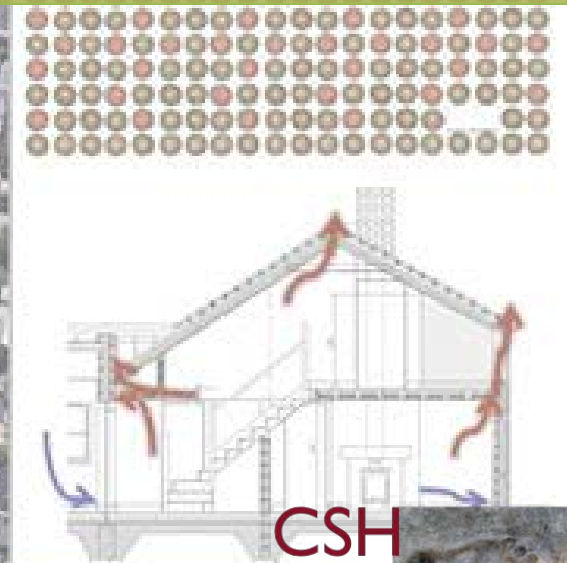
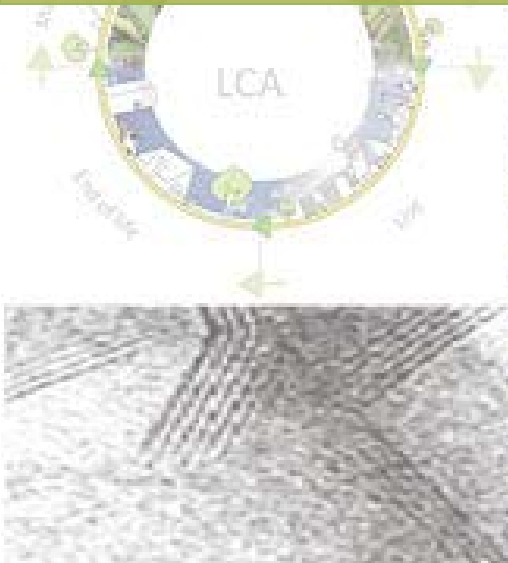


Life cycle cost and environmental assessment research at MIT's Concrete Sustainability Hub

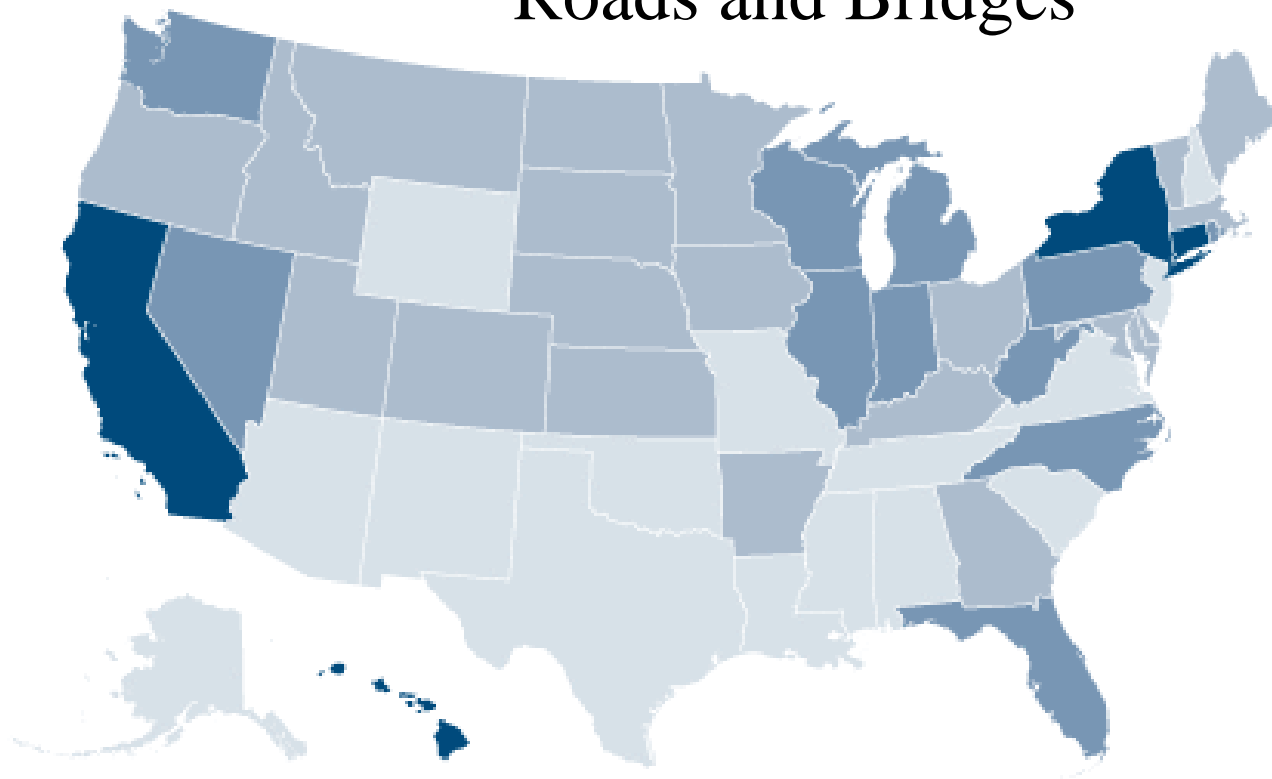
Jeremy Gregory



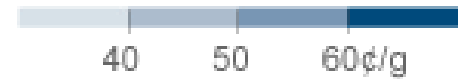
Governments are being forced to do more with less

The New York Times Governments Look for New Ways to Pay for Roads and Bridges

Feb 14, 2013

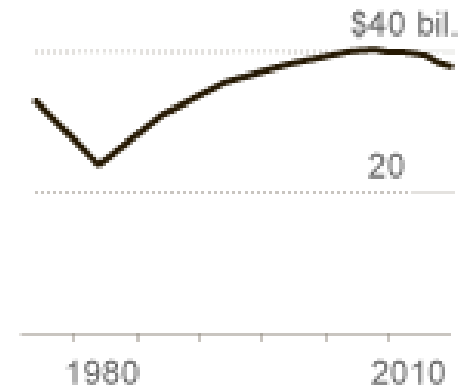


◀ Combined local, state and federal gasoline tax



Total gas tax revenue

In 2010 dollars

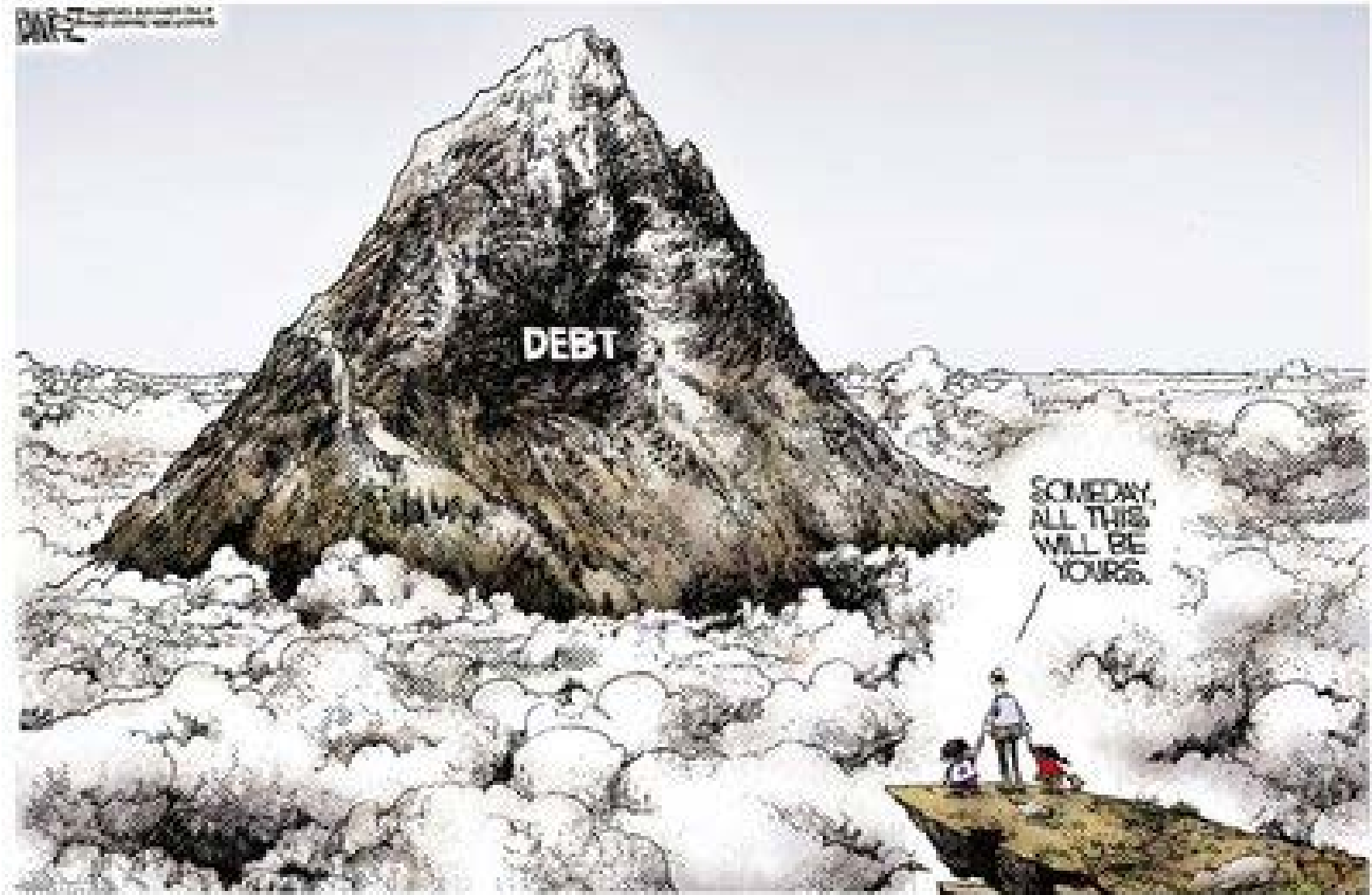


Gas Taxes Fail to Keep Up Because most states do not tie their gasoline tax to inflation, taxes are worth less over time. Increased fuel efficiency also means consumers are using less gas.

Sources: American Petroleum Institute; Tax Policy Center



Our actions today affect the financial health of future generations



www.foamfor.com/04art0001



Our actions today affect the environmental health of future generations



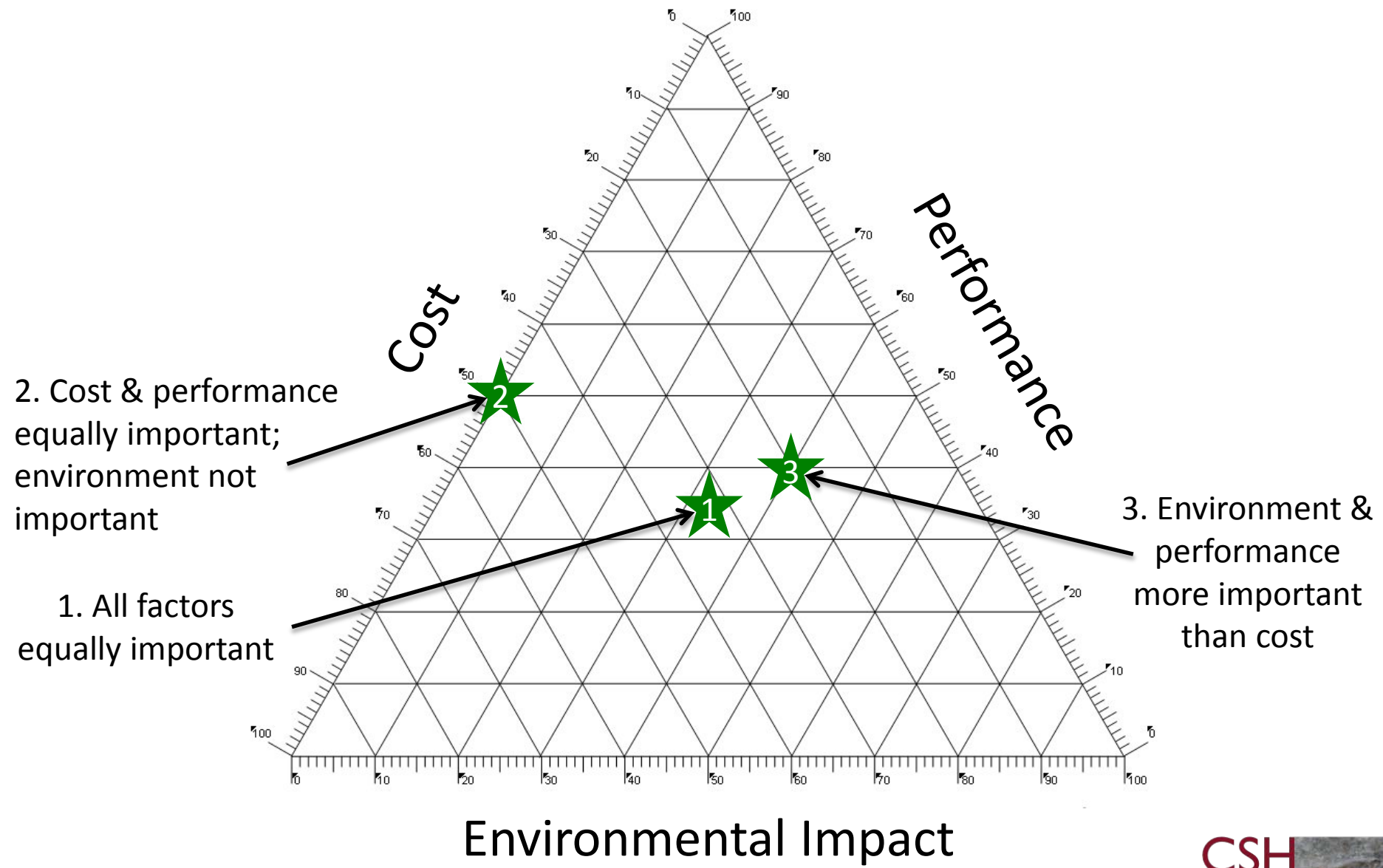
A life cycle approach can quantify future impacts



http://upload.wikimedia.org/wikipedia/commons/7/7f/Life_Cycle_Thinking_Product_System.jpg



Every engineering decision is a balance of three main factors



Tools

- Performance: MEPDG or DOTs
- Cost: LCCA
- Environmental Impact: LCA

Hub research improves existing tools by:

- Incorporating uncertainty
- Quantifying risk
- Highlighting data that are key impact drivers

Goal

- Pavement design that balances:
- Performance
 - Cost
 - Environmental Impact

This enables designers and decision-makers to:

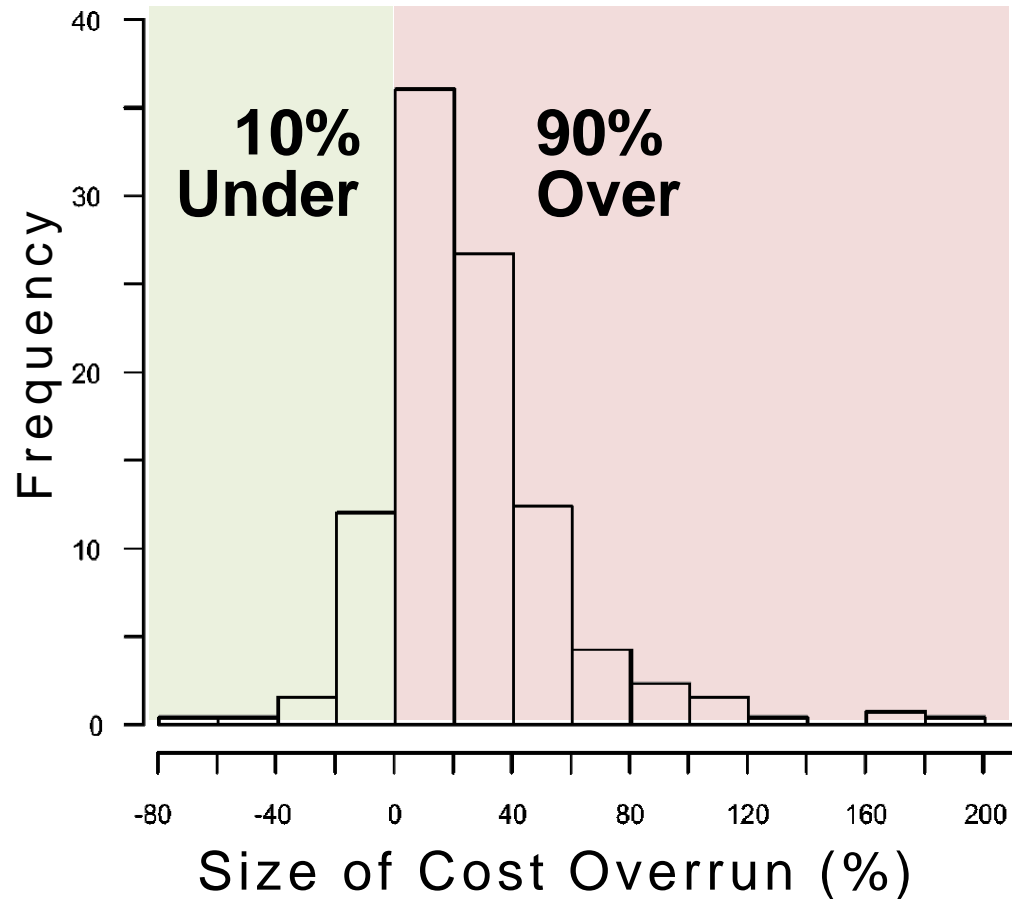
- Focus on key drivers of decisions
- Understand risk and uncertainty in decisions
- Make more informed decisions



Life Cycle Cost Analysis



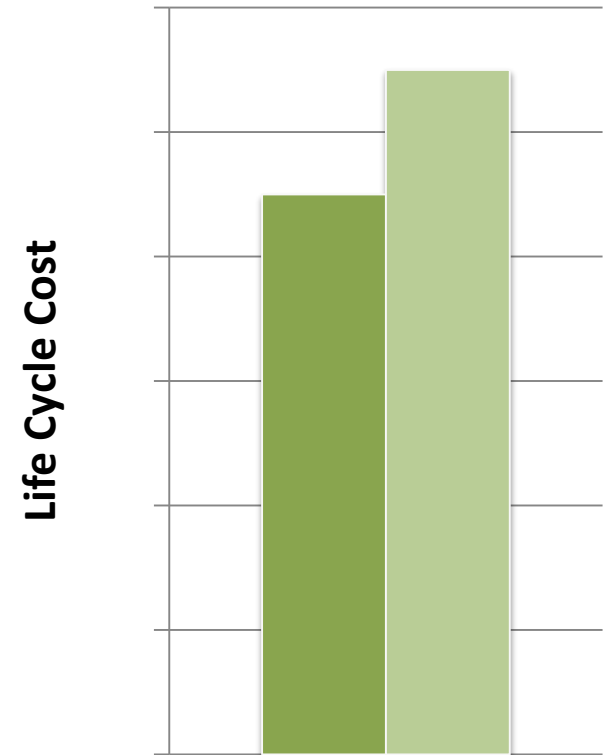
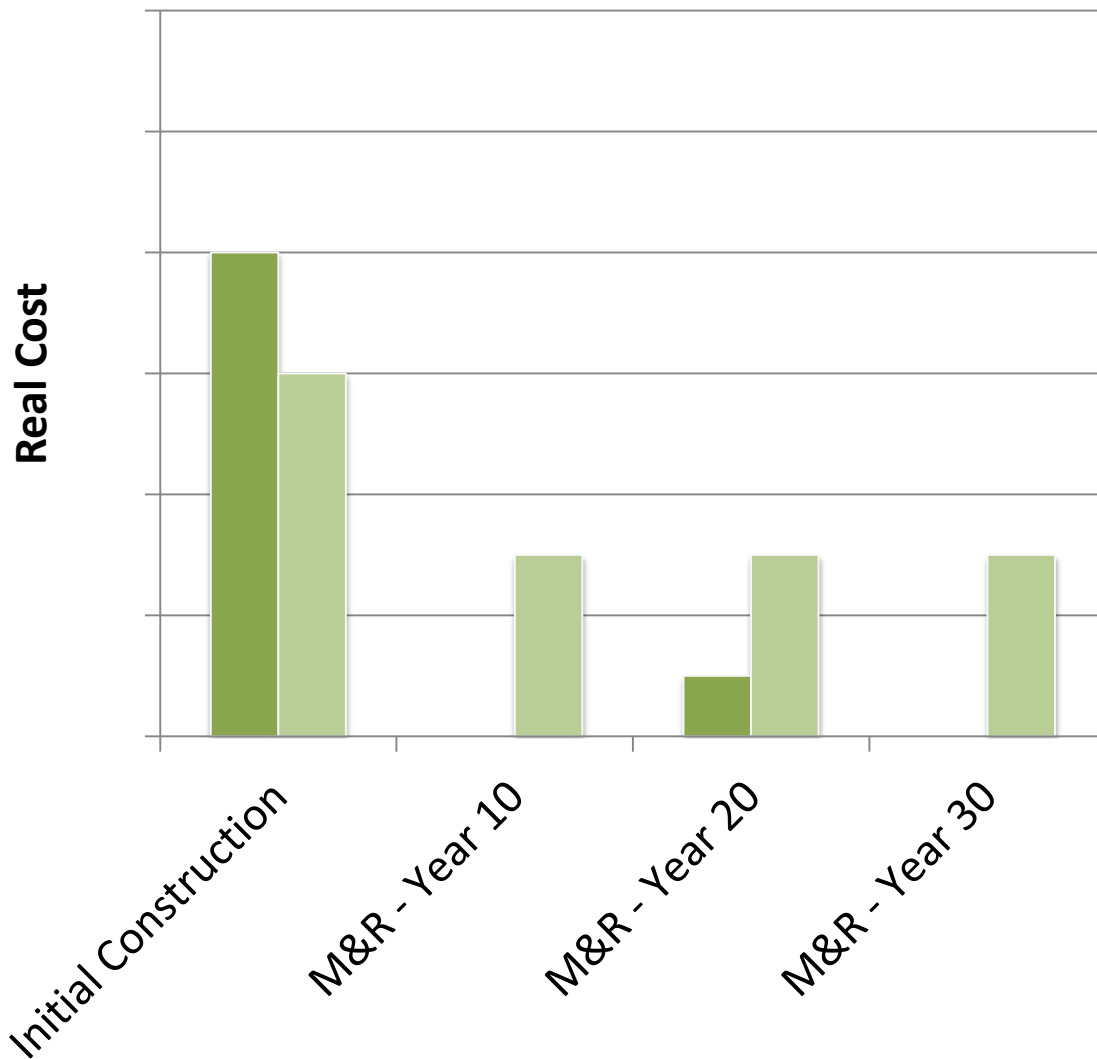
Cost Overruns in Infrastructure Projects



Flyvbjerg, Skamris & Buhl, *Transport Reviews*, 2003



It is important to have a life cycle perspective

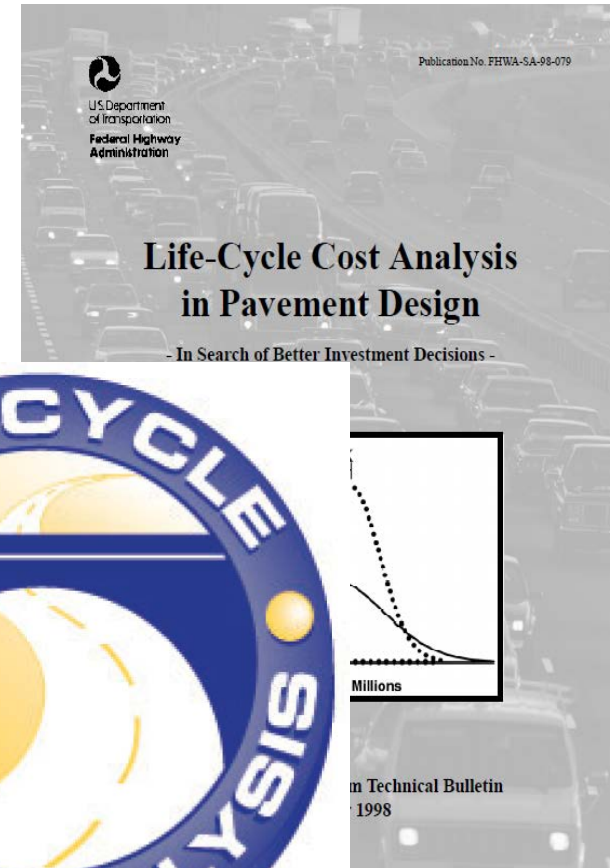


Lower initial cost does not necessarily translate to lower life cycle cost

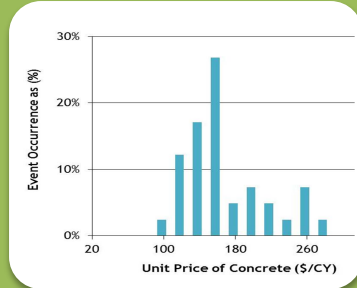


CSHub LCCA research aims to leverage and extend

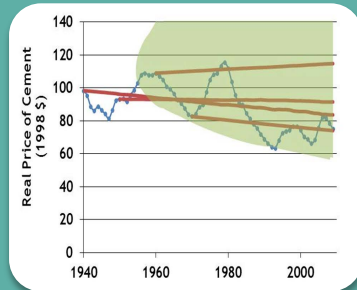
- Leverage existing tools:
 - FHWA's LCCA Technical Bulletin
 - FHWA's RealCost tool
- Extend existing methods:
 - Quantify sources of risk in infrastructure investment
 - Characterize drivers and trends around those risks
- Strengthen link between design and LCCA tools



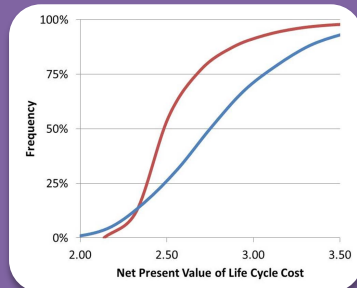
Hub LCCA research has provided three key insights



Uncertainty is pervasive, but tractable



Considering possible futures is plausible, valuable



Risk is a key perspective for decision makers

Uncertainty is Pervasive in Pavement LCCA

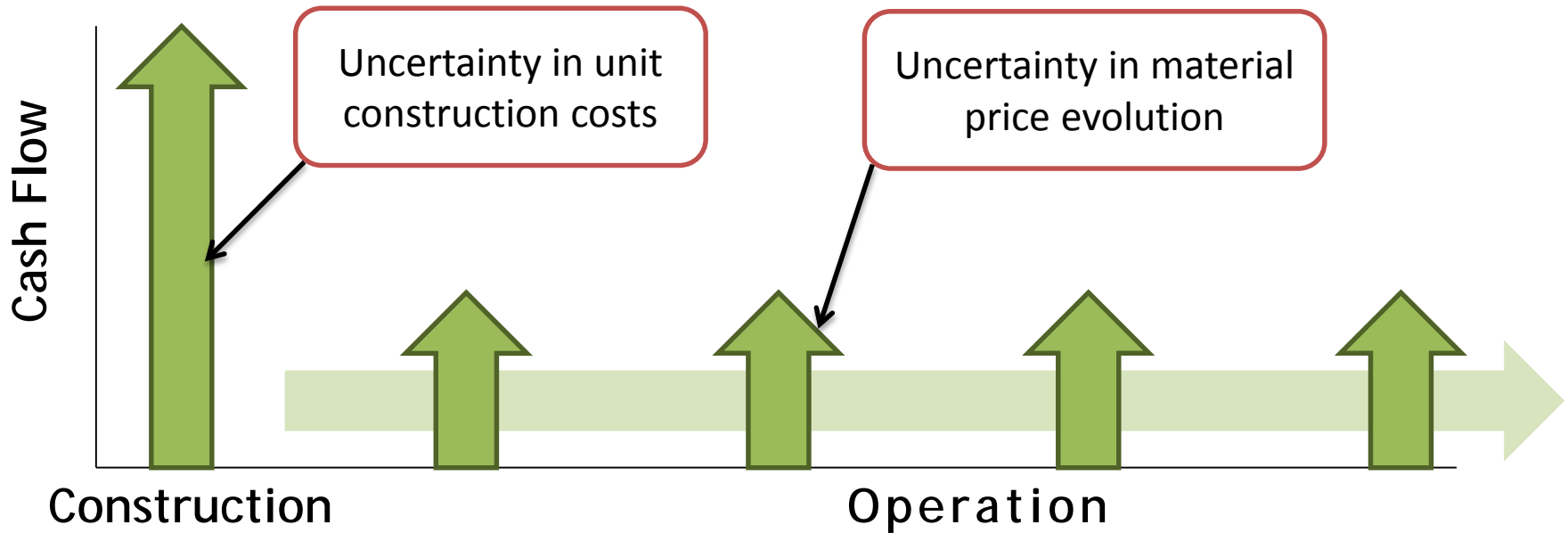
Decisions
long before
construction



Long
life-Cycle



Uncertainty
& Risk



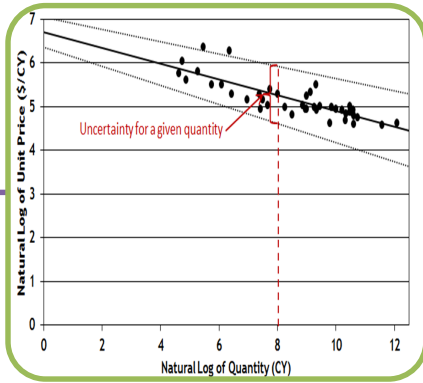
Incorporate uncertainty into design inputs, initial construction costs, and future material prices



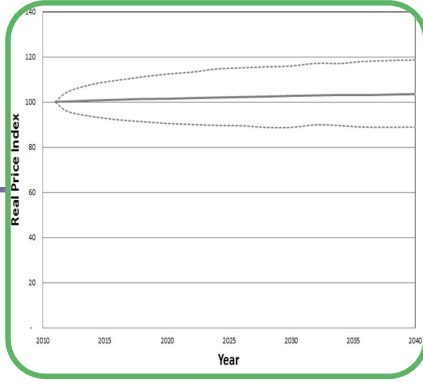
CSHub LCCA Methodology

Statistically Characterize Uncertainty

Present



Future

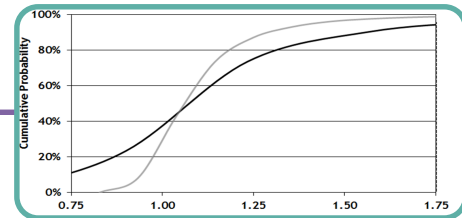


**MEPDG
Output**

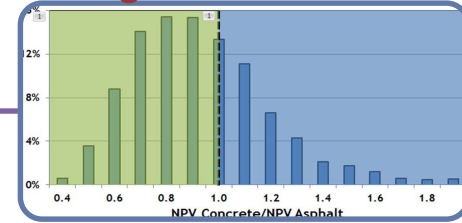
**LCCA
Model**

Propagate uncertainty to understand risk

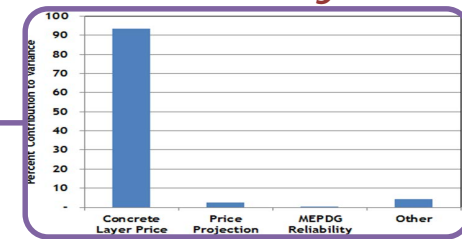
Relative risk



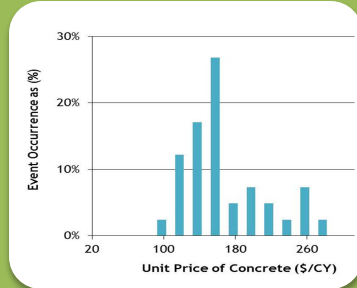
Is the difference significant?



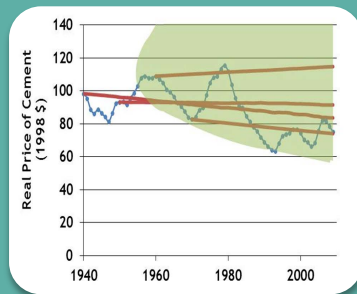
Characterize drivers of uncertainty



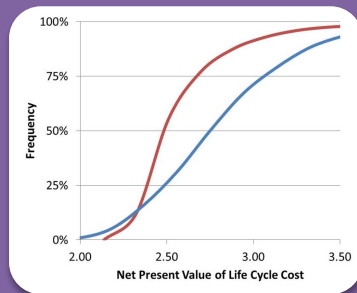
Hub LCCA research has provided three key insights



Uncertainty is pervasive, but tractable

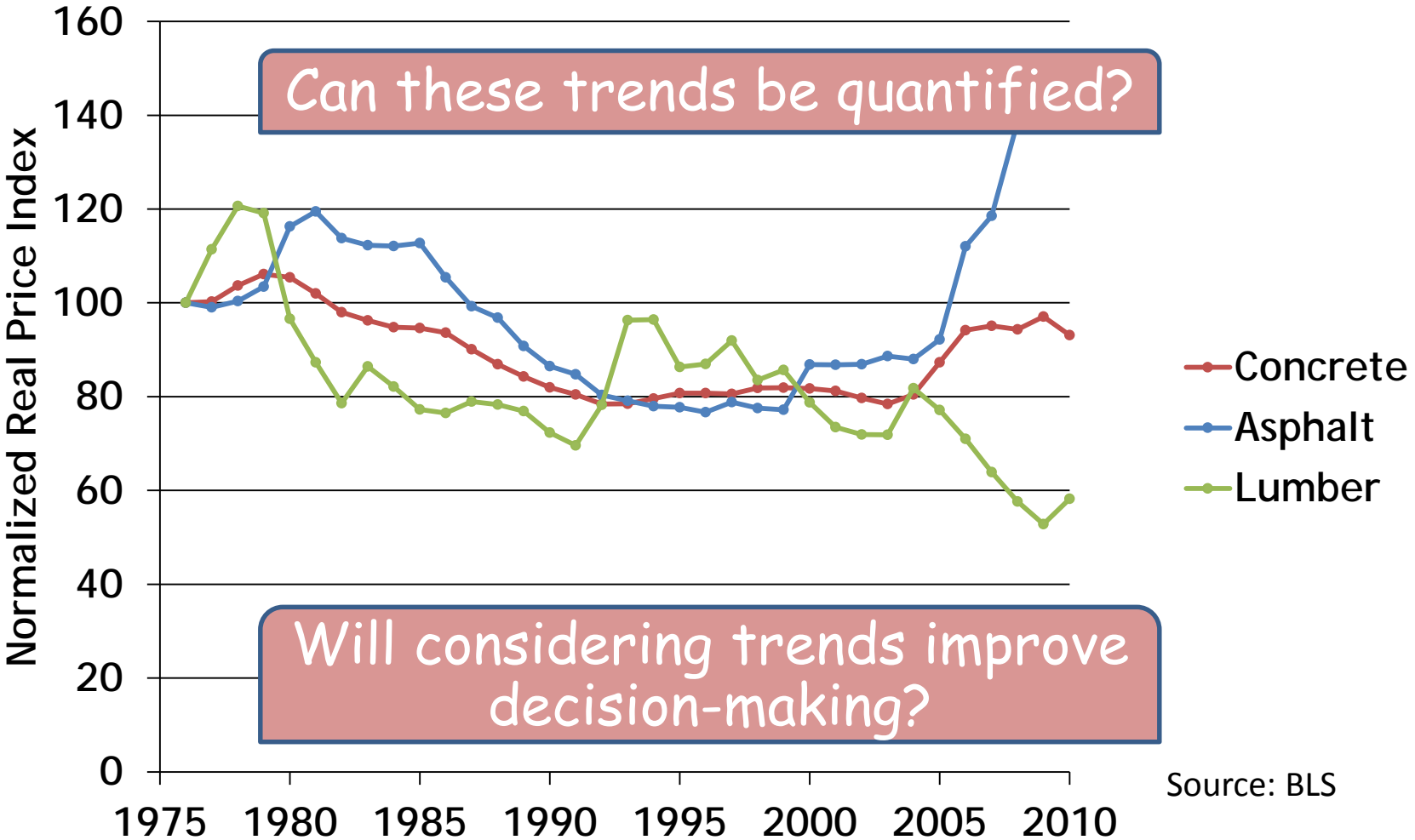


Considering possible futures is plausible, valuable



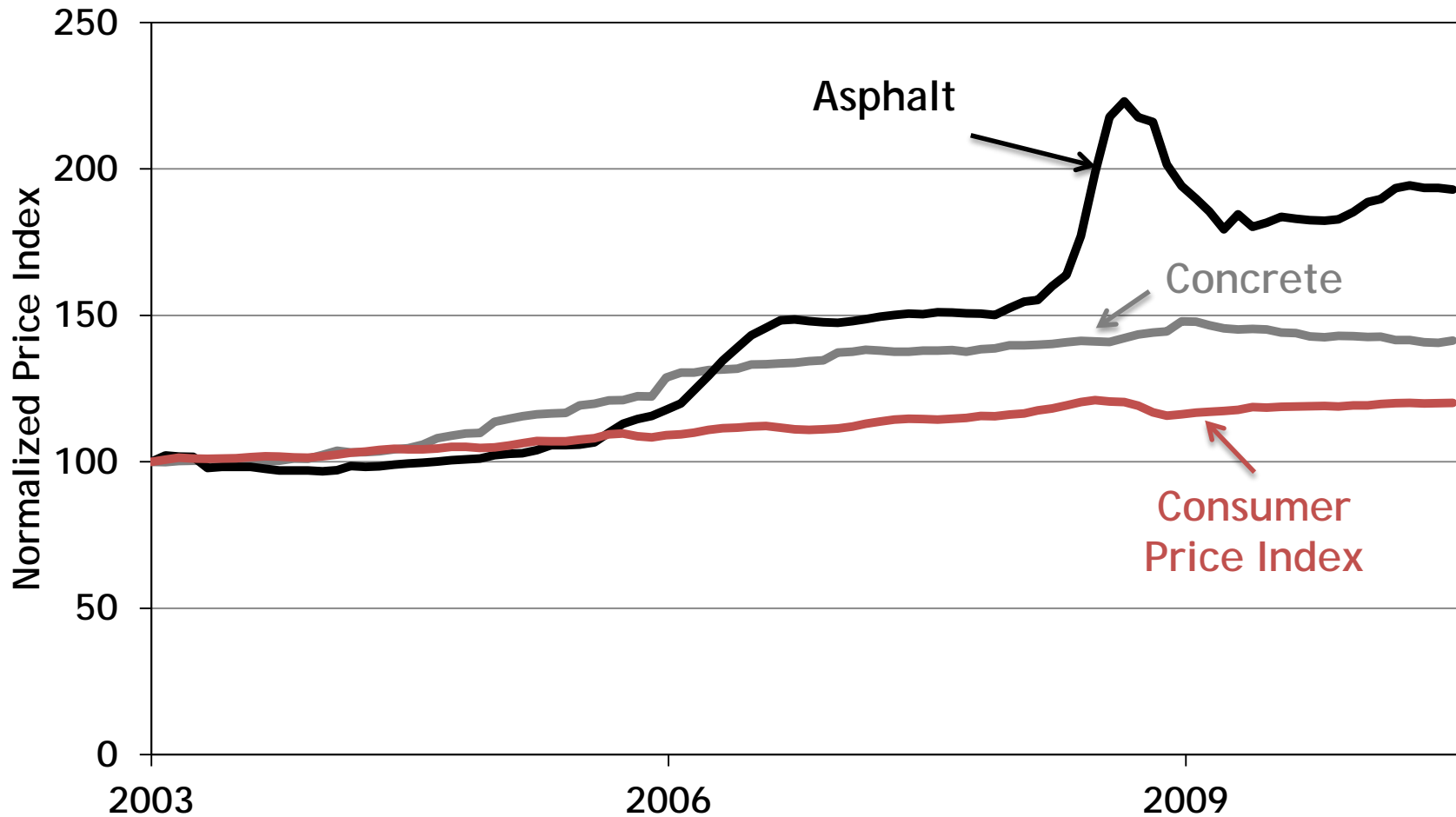
Risk is a key perspective for decision makers

Major Construction Material Prices have Evolved Differently



Recent construction prices have not matched inflation

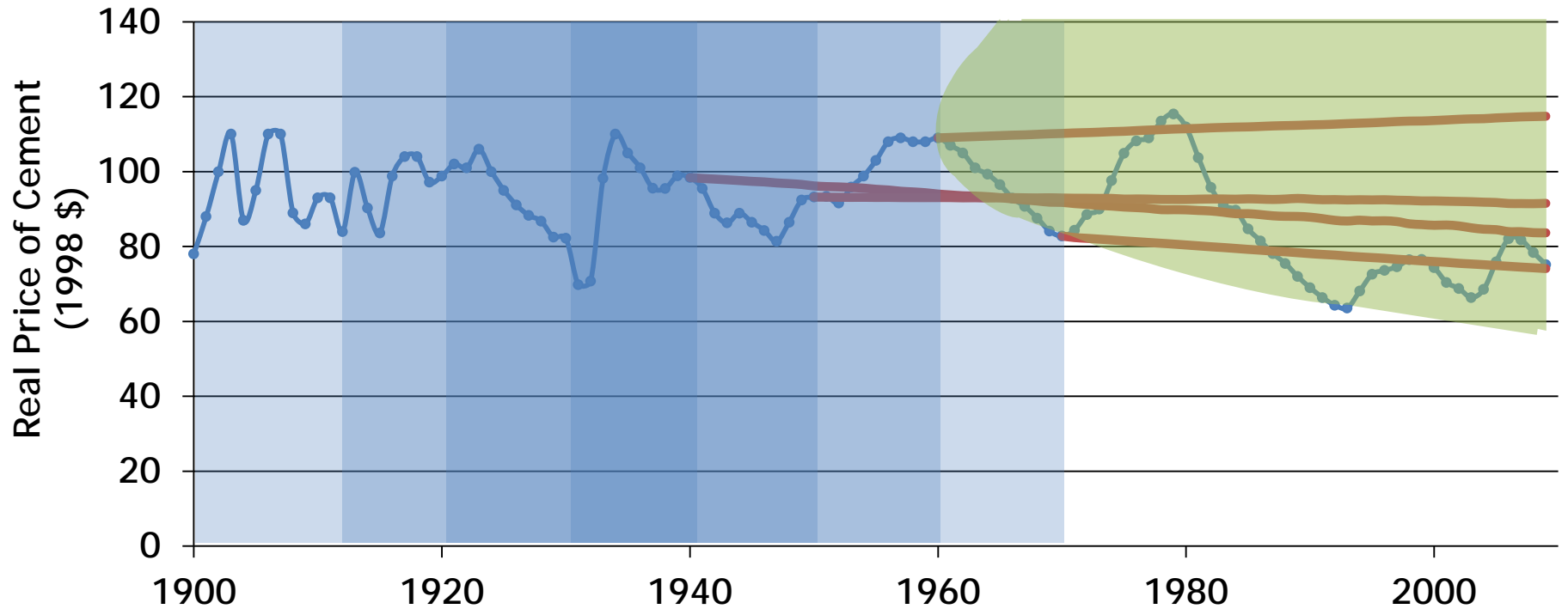
*Why then, should we assume future prices grow with inflation?
Can we account for this credibly?*



Effective Long-term Projections are Plausible, but ...

...while all forecasts are wrong ...

some forecasts are useful



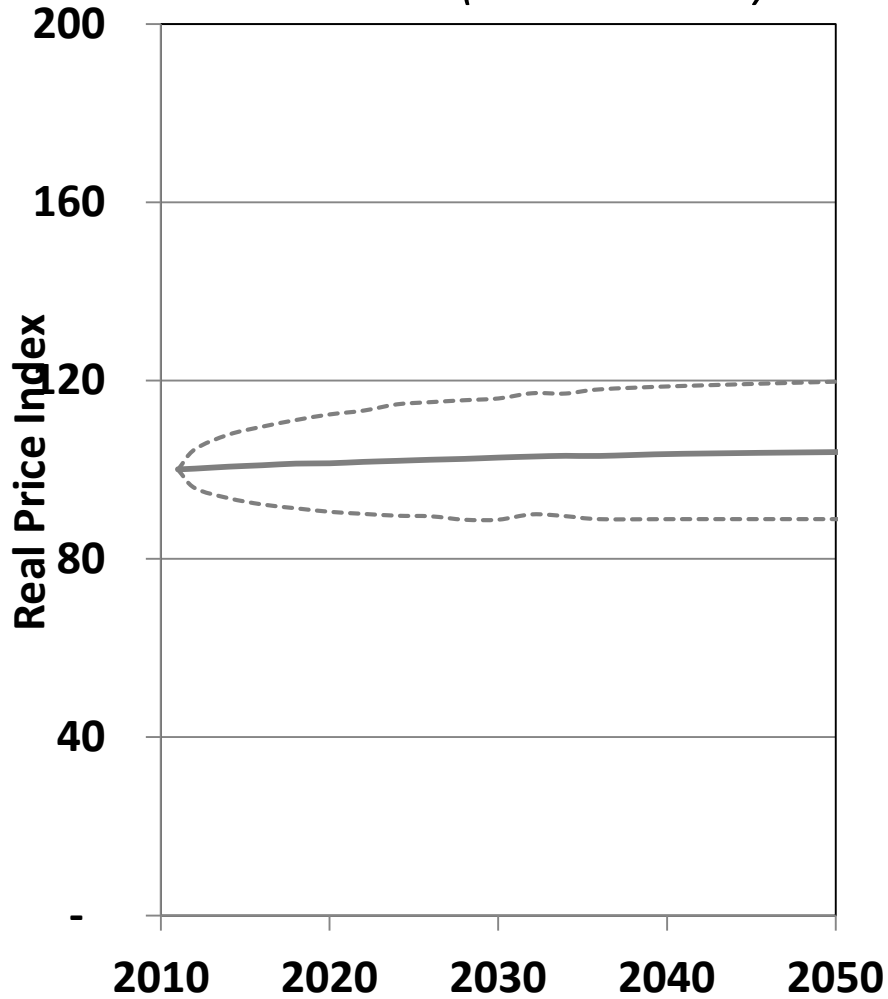
Source: USGS

Effective Forecasts ...

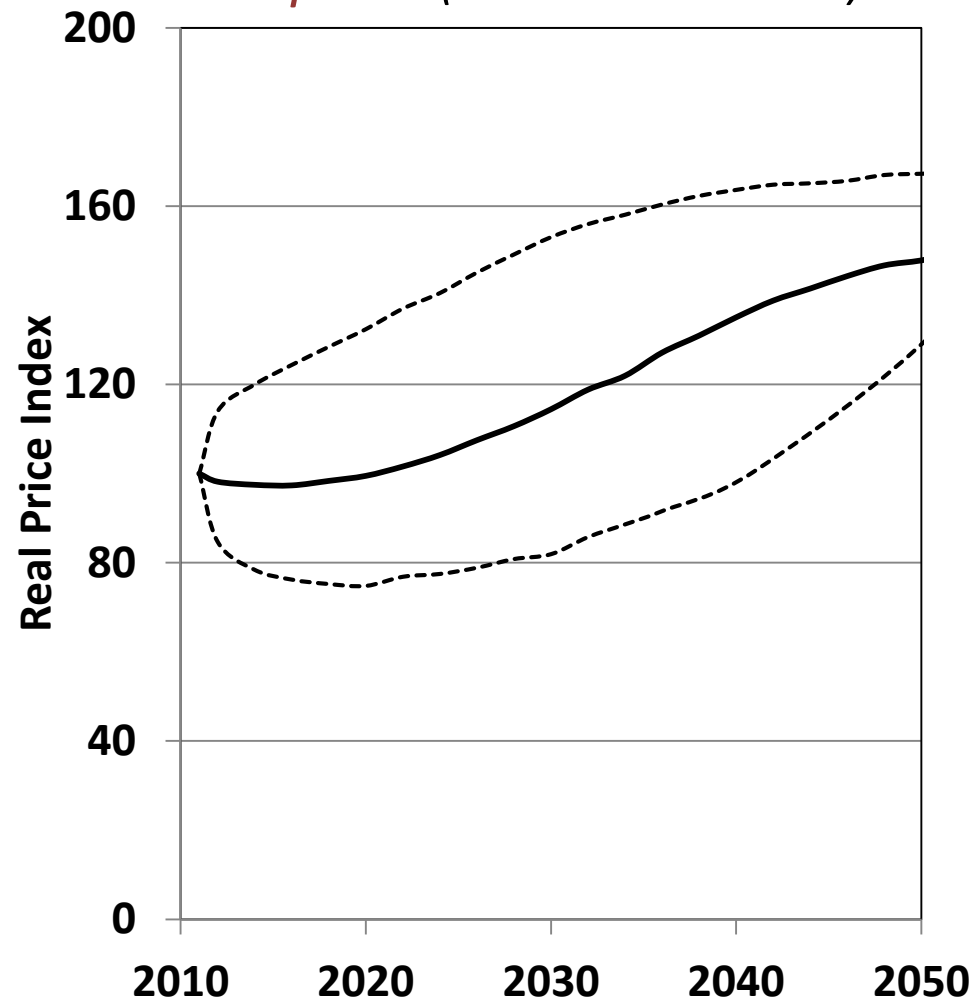
- Must be built from significant sets of data
- Must be viewed as probabilistic in nature

Real Price Forecasting Models

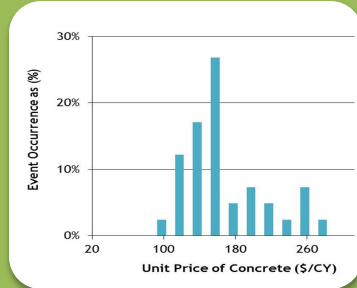
Concrete (Direct model)



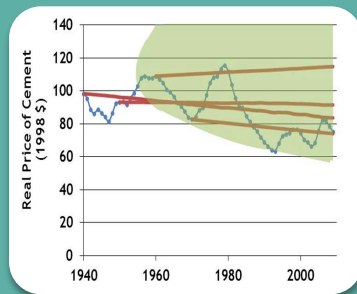
Asphalt (Constituent Based)



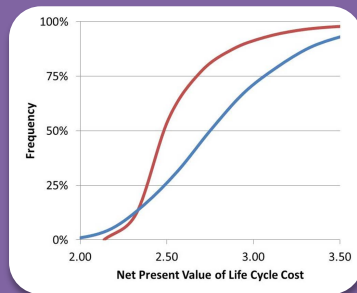
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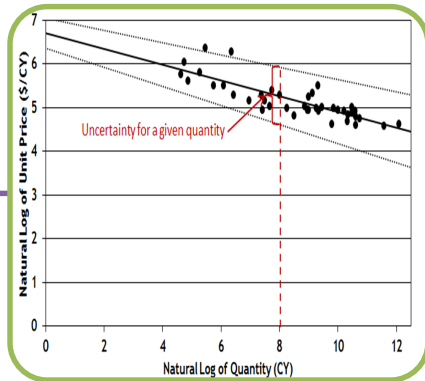


Risk is a key perspective for decision makers

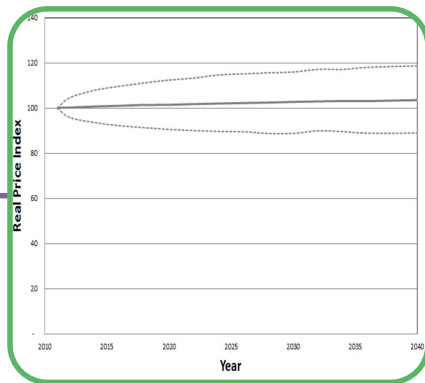
Applying the statistical characterization

Statistically Characterize Uncertainty

Present



Future

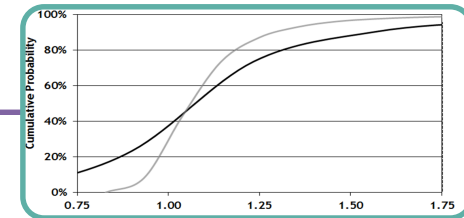


**MEPDG
Output**

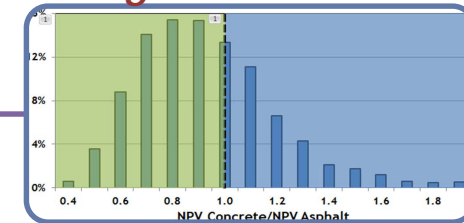
**LCCA
Model**

Propagate uncertainty to understand risk

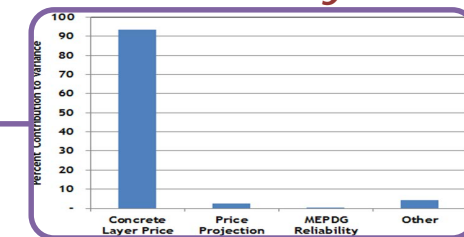
Relative risk



Is the difference significant?

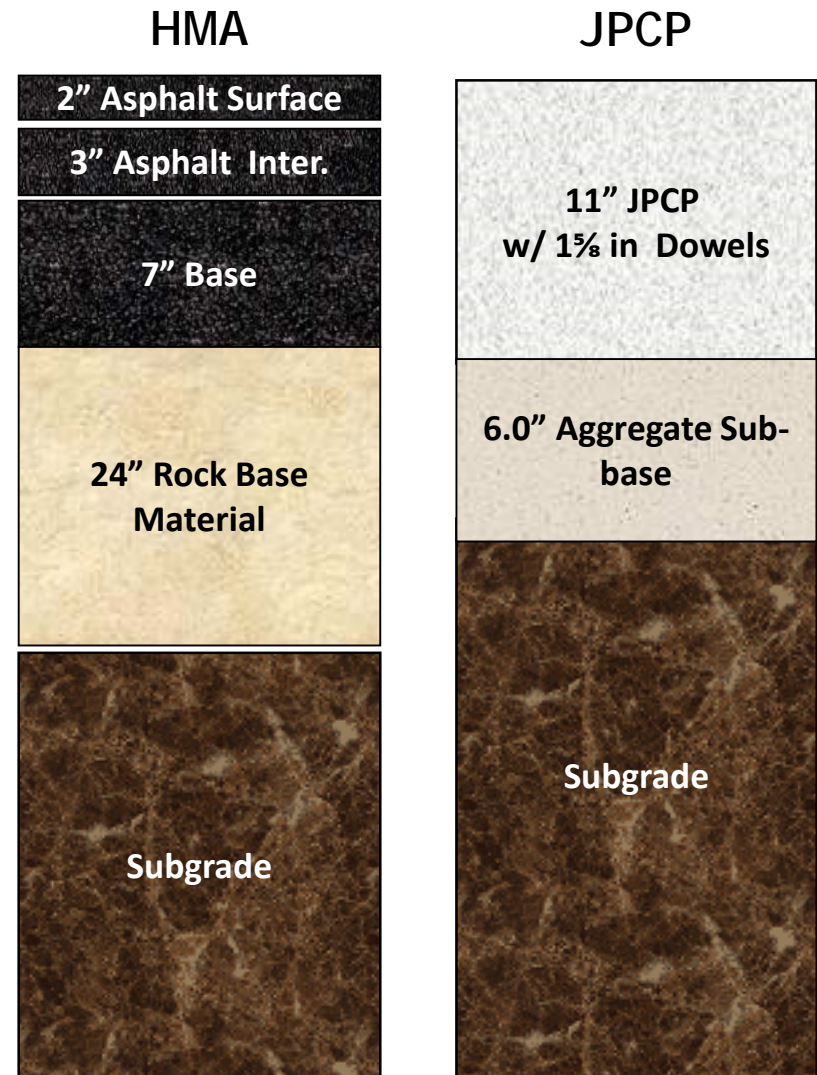


Characterize drivers of uncertainty



Sample insight from a Missouri case study

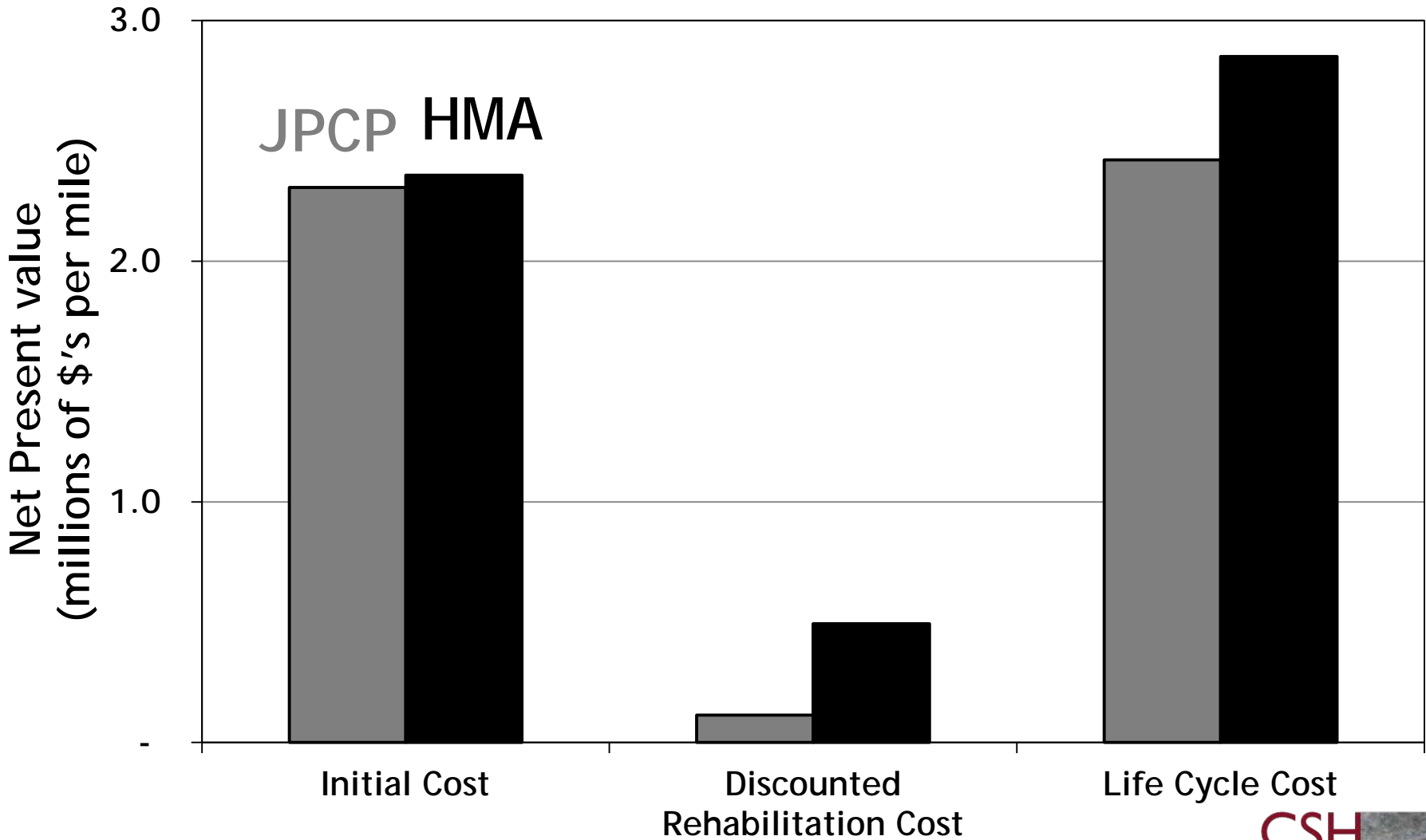
- Urban Interstate
 - Expected initial AADT of 78,000
 - Expected initial AADTT of 8,000
- Located in Joplin, MO
- Designs and maintenance schedules derived from the recently developed MEPDG software
- 50 year analysis period
- Real discount rate of 4%
- Designs created by independent design firm (ARA)



Broadening Scope Alters Relative Competitiveness

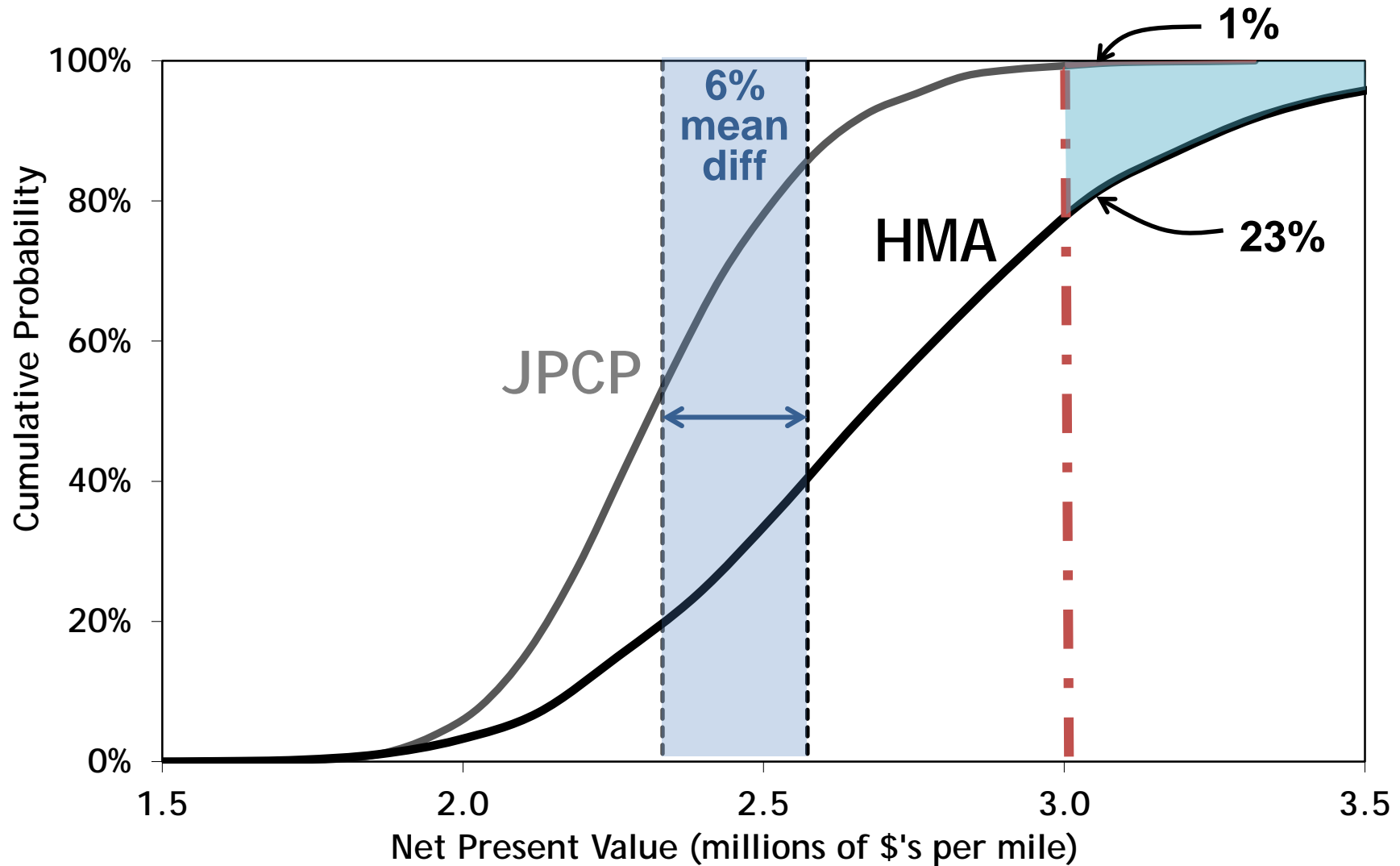
~ same

10% difference



Probabilistic Analysis Provides Insight on Relative Risks

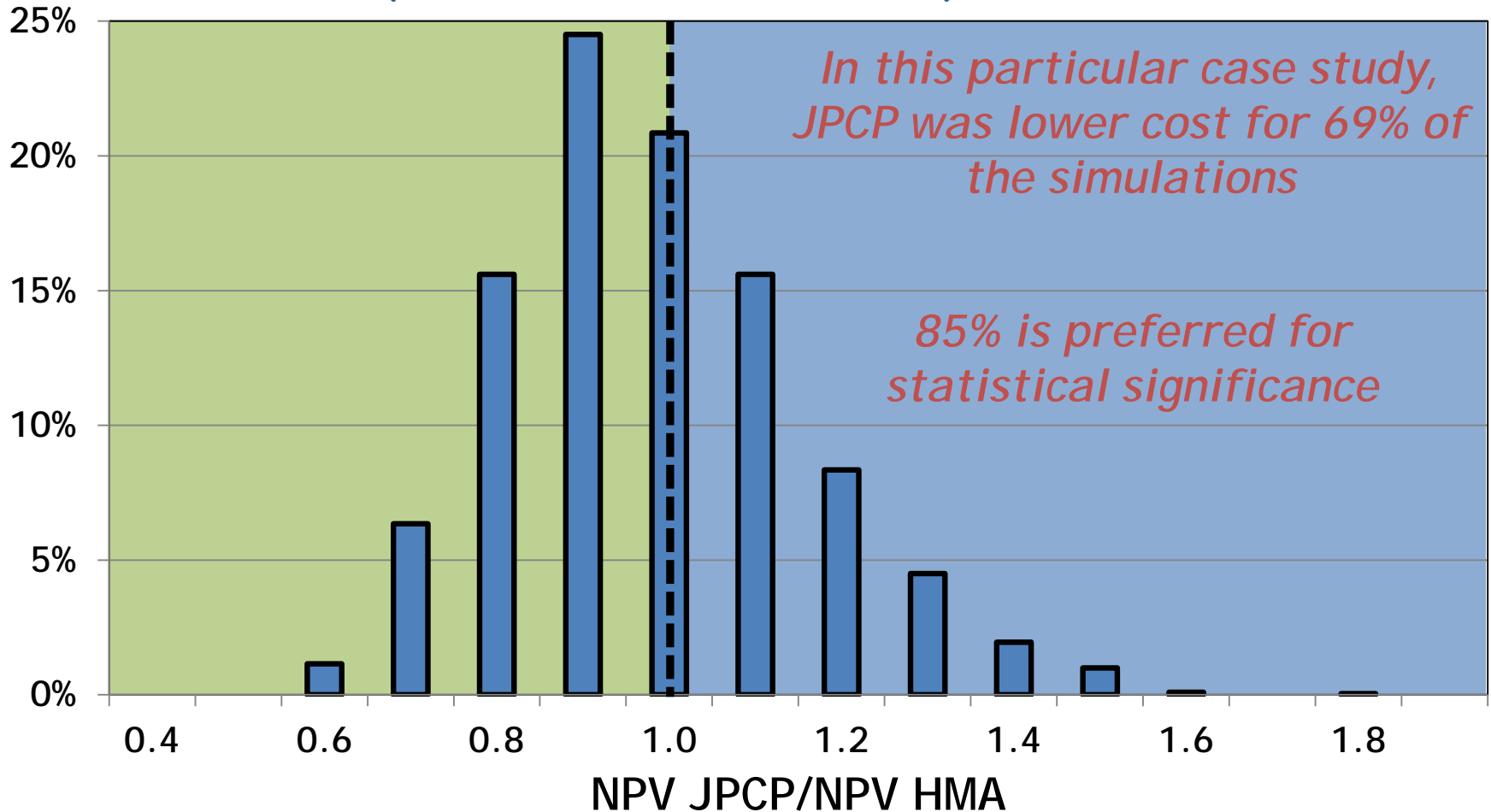
Probabilistic Life-Cycle Cost



How frequently does one alternative have lower cost?

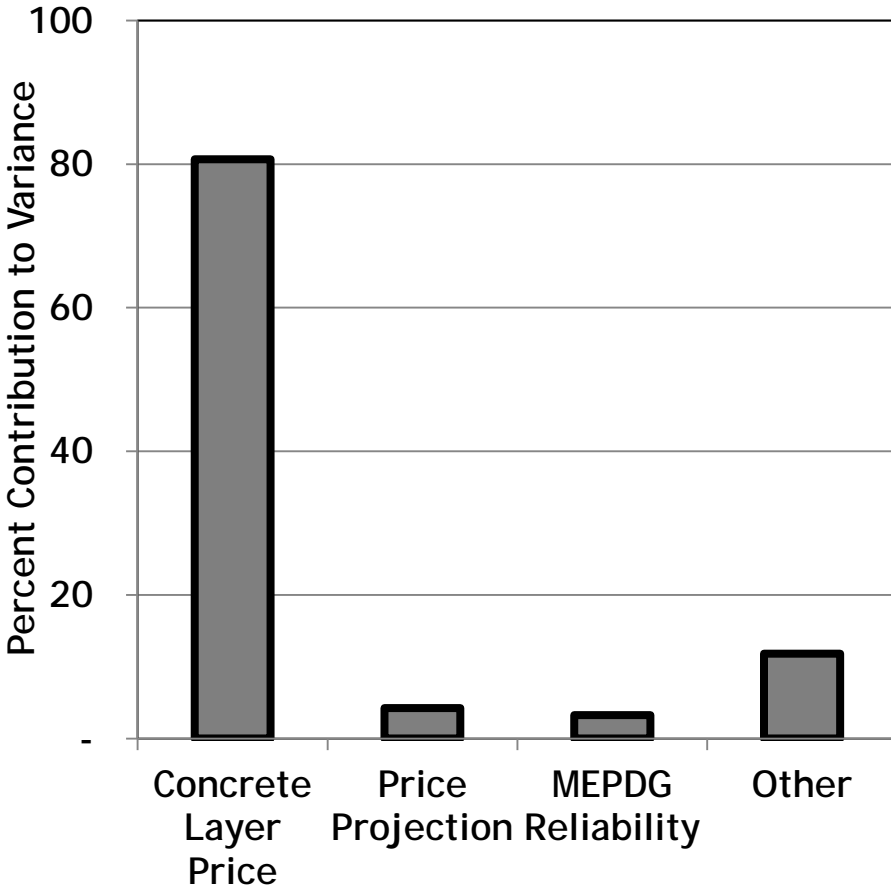
JPCP Lower Cost

HMA Lower Cost

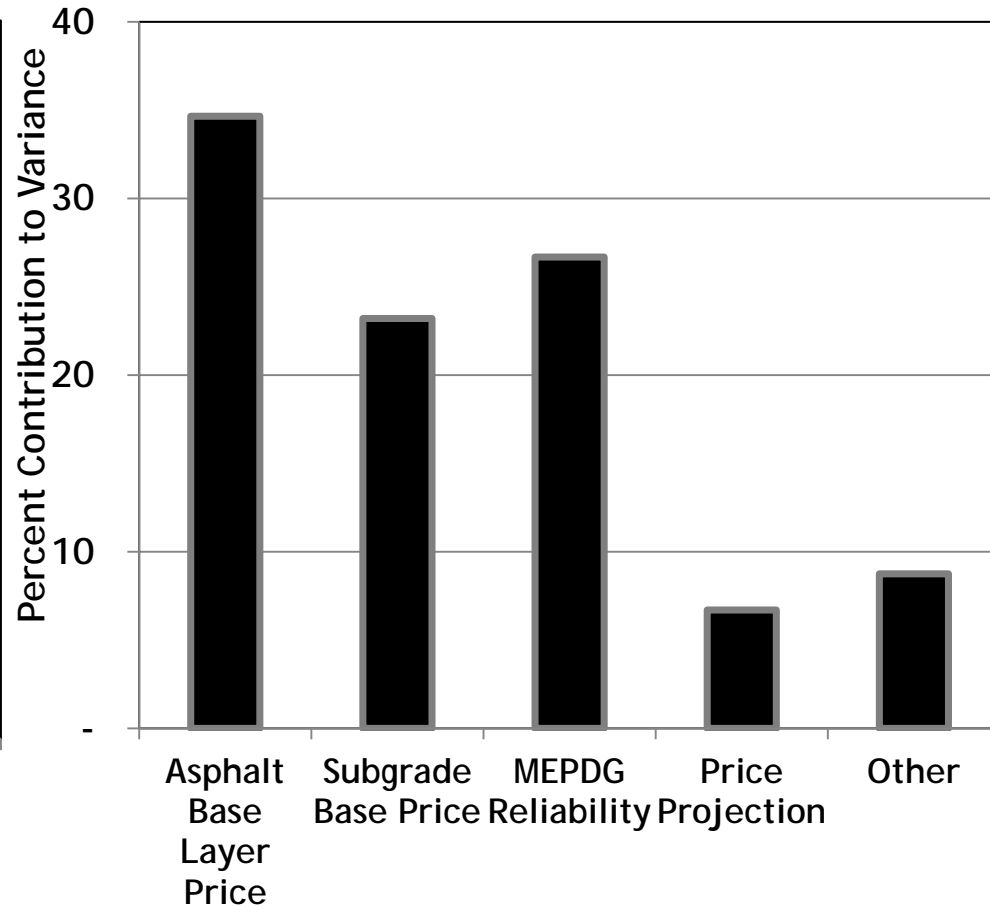


Method provides insight on drivers of uncertainty

JPCP



HMA

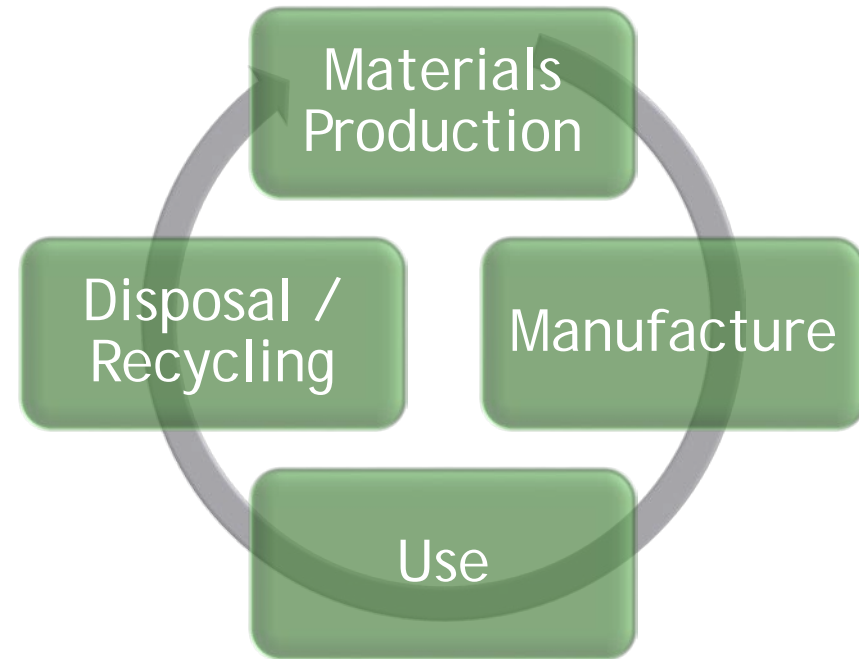
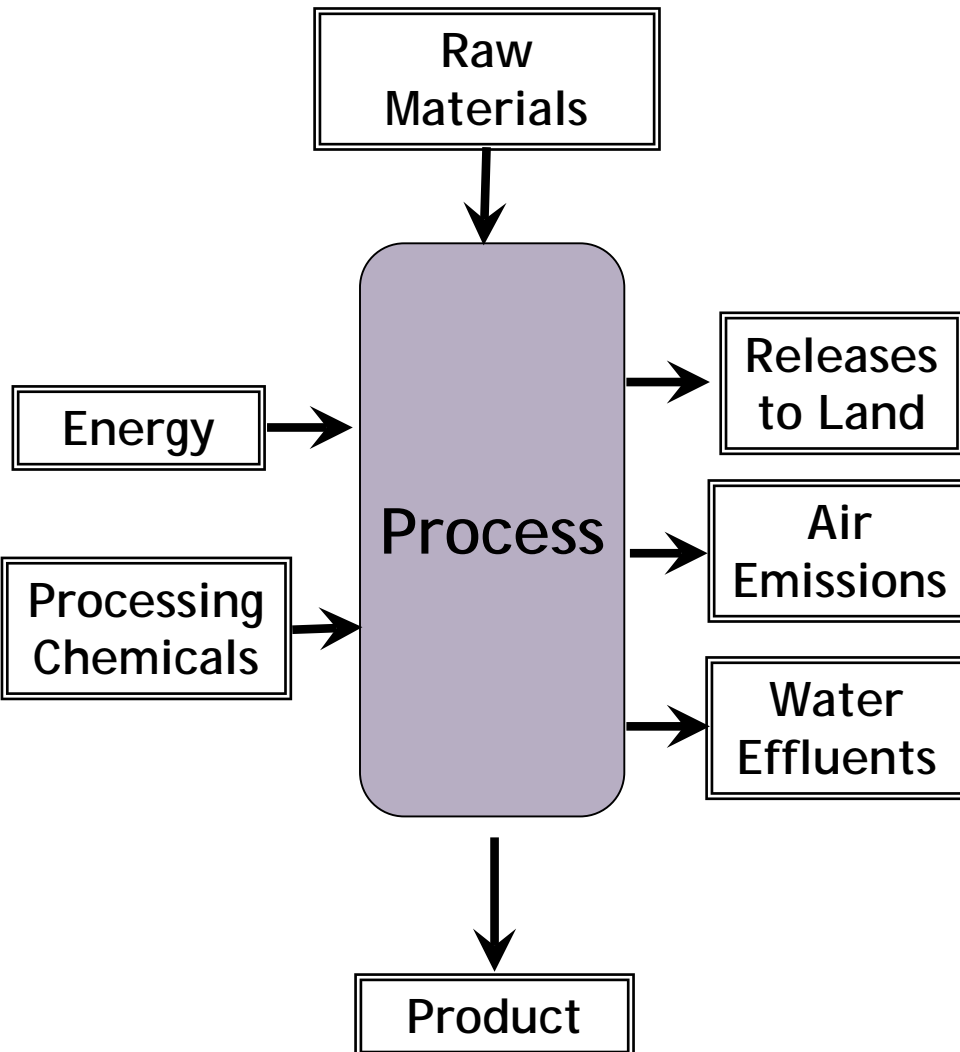


Life Cycle Assessment



Life cycle assessment: the tool for quantifying environmental impact

Process Inventory Life Cycle Impact



Pavement LCA scope

Scope includes all effects attributable to the pavement design.

Incorporating use phase in pavement LCA is a recent innovation

- Extraction and production
- Transportation

• Onsite equipment

Materials

Construction

Use

Maintenance

End-of-Life/
Rehabilitation

- Pavement-Vehicle Interaction
 - Roughness
 - Deflection

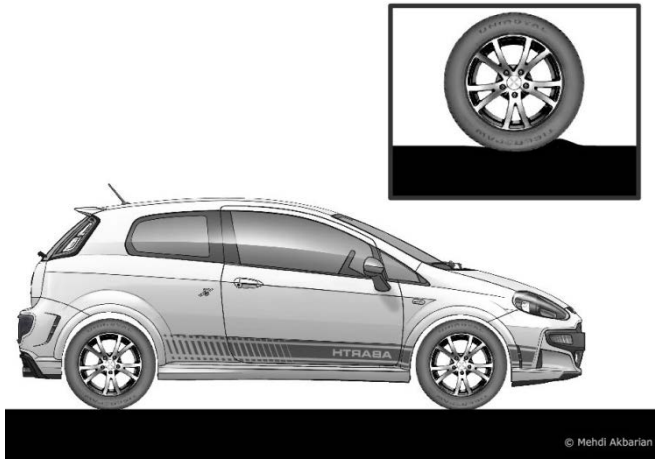
- Albedo
- Carbonation
- Lighting

- Excavation
- Landfilling
- Recycling
- Transportation

- Materials
- Construction



Model-based assessment of PVI



Pavement Deflection

MIT-Model



Pavement Roughness

MEPDG+HDM4

Structure and Material

Deflection & Roughness



Fuel consumption

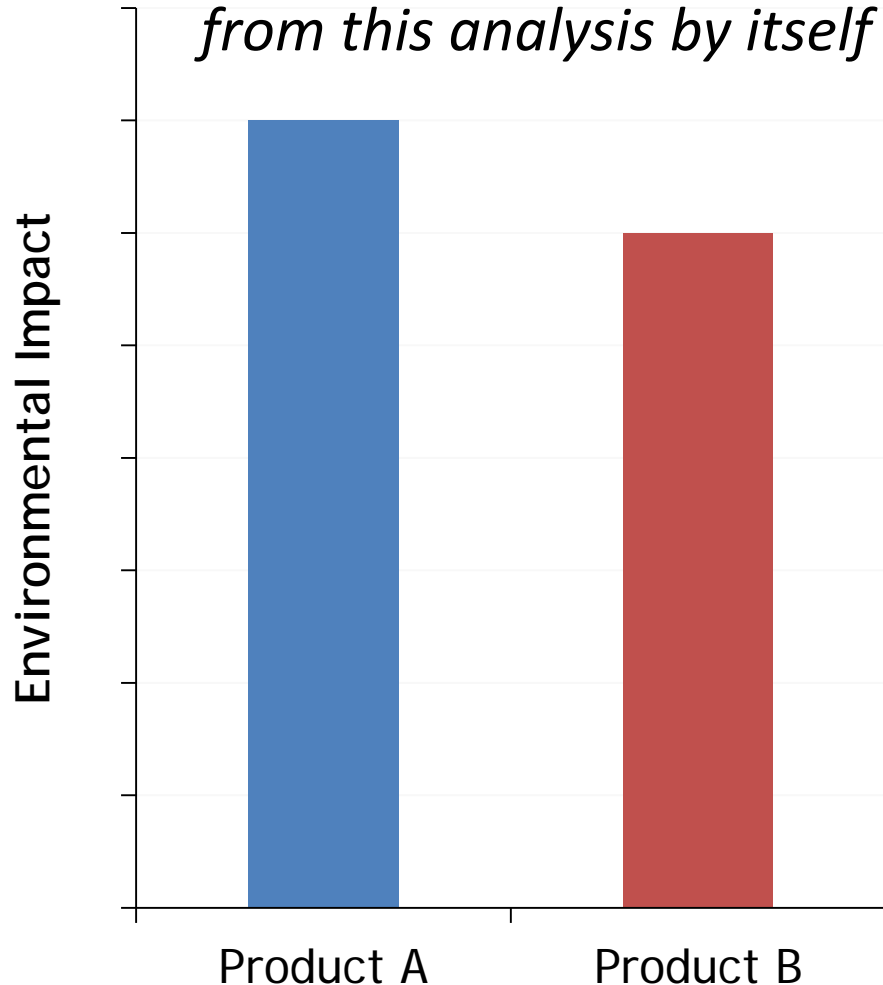


Environmental Impact



Incorporating uncertainty into pavement LCA

We cannot draw meaningful conclusions from this analysis by itself



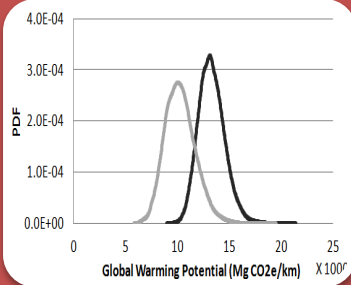
There is significant uncertainty in LCA data and scenarios

Incorporating uncertainty into LCA enables us to answer these questions:

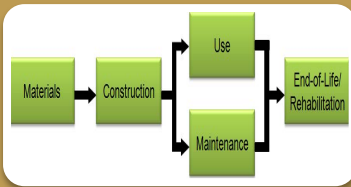
- *Is the difference between products statistically significant?*
- *What are the key drivers of the difference?*
- *Which parameters are most likely to change the relative impacts?*



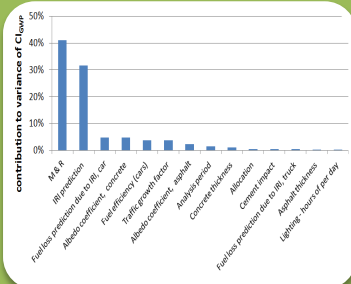
Hub LCA research has provided three key insights



Incorporating uncertainty facilitates robust decision-making



A full life cycle perspective is important

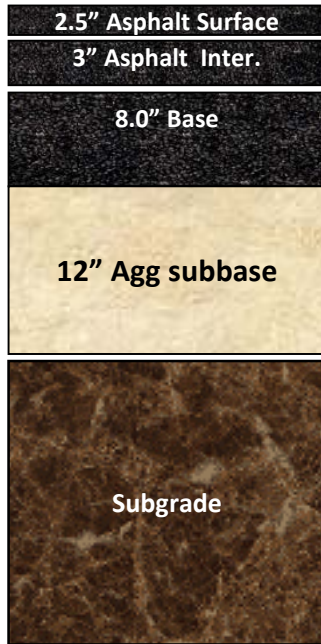


Uncertainty approach illuminates key drivers of differences in designs

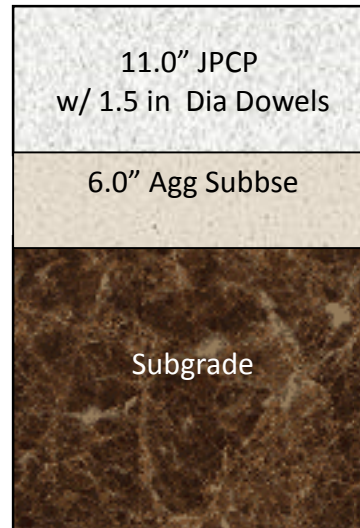


Case study: dry no-freeze urban interstate HW in Arizona

■ AC



■ PCC



Parameter	Value
AADTT two Directions	8000 vehicles/day
Number of Total Lanes- two Directions	6
AADTT Linear Annual Increase	3%
Climate: dry no-freeze	AZ
Soil Type	A-2-6

ADOT Rehabilitation Schedule

and

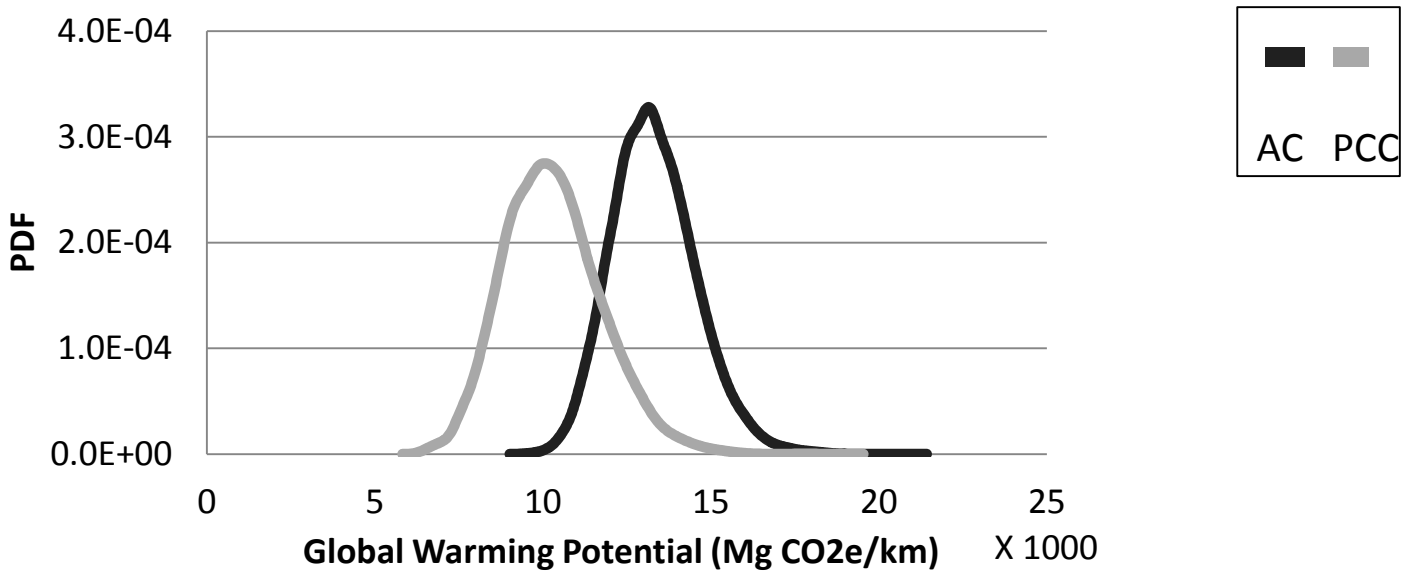
MEPDG Rehabilitation Schedule

**Functional Unit:
1 center-lane mile over a 50-year
analysis period**

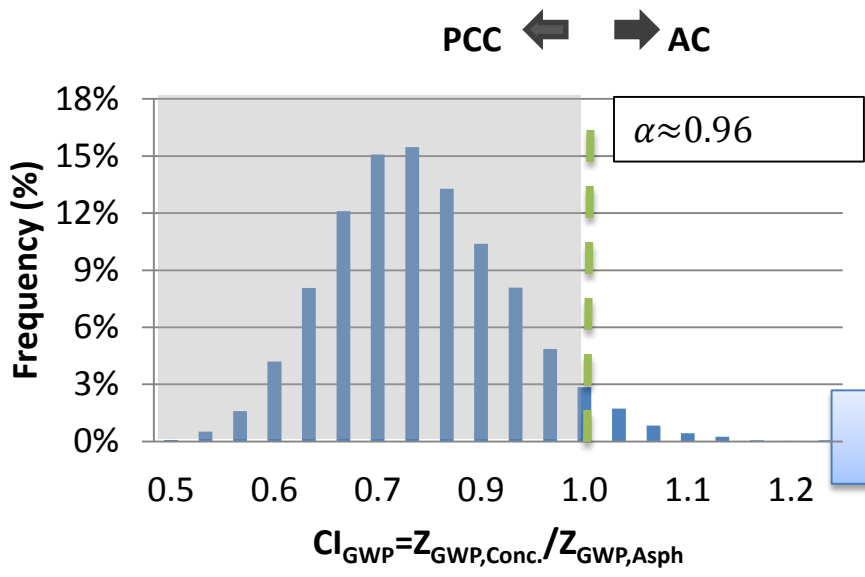
Designs created by independent design firm (ARA)



Is the difference statistically significant?



The difference is statistically significant



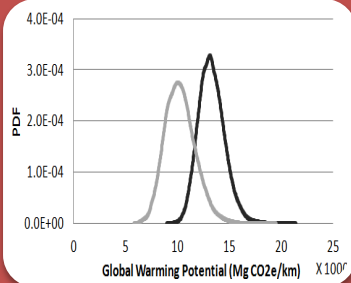
Comparison indicator :

$$CI_{GWP} = \frac{Z_{GWP,conc.}}{Z_{GWP,asph.}}$$

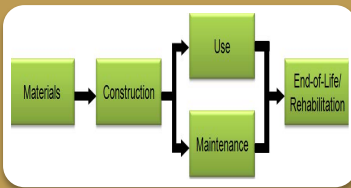
$$\alpha = P(CI_{GWP} < 1)$$

alpha% of the time PCC has lower impact

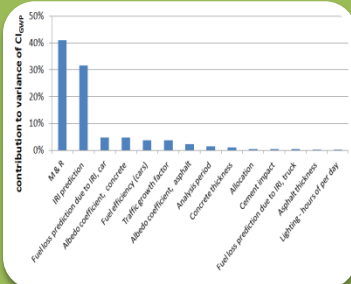
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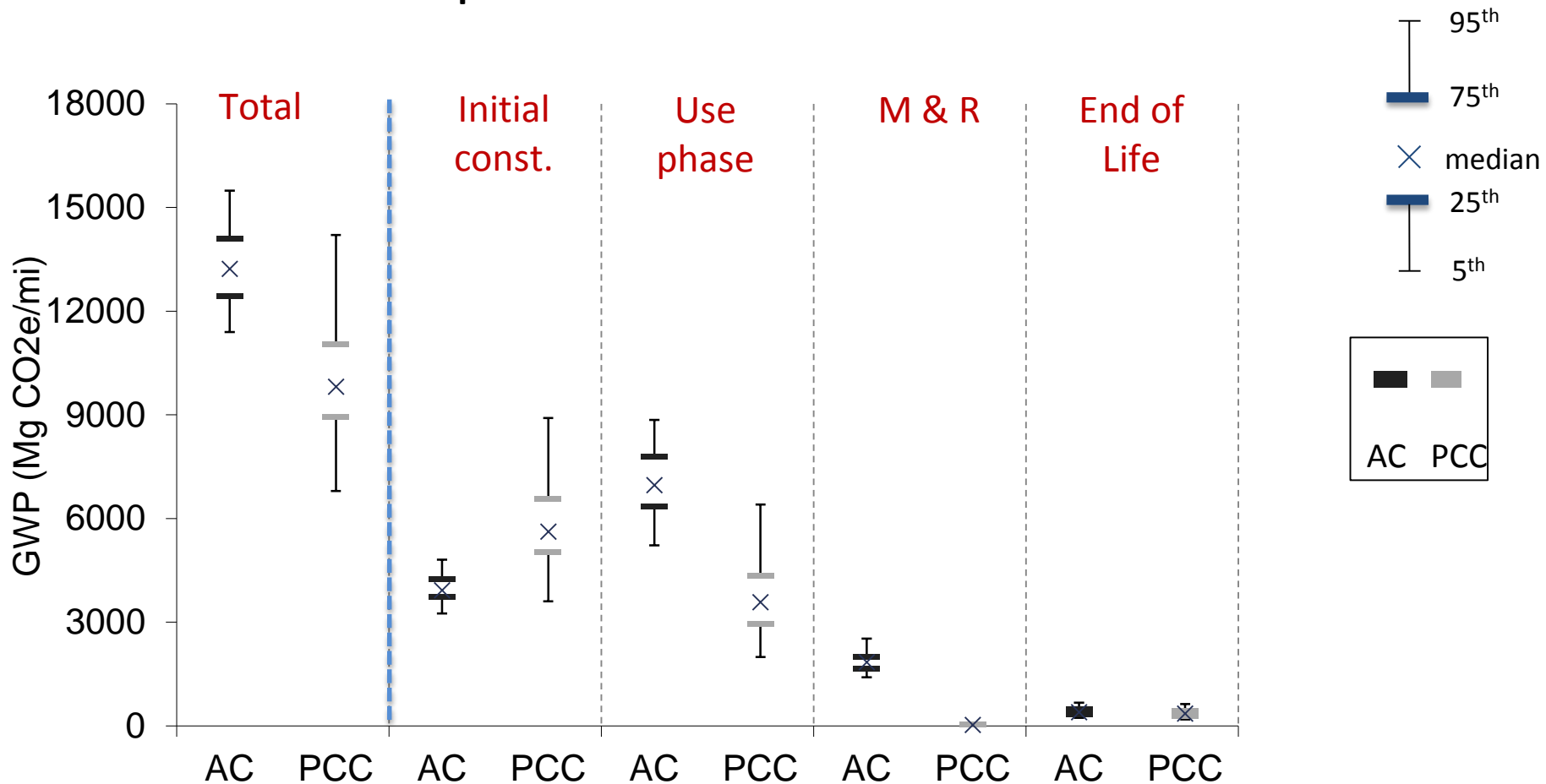


Uncertainty approach illuminates key drivers of differences in designs



Case study: dry no-freeze urban interstate HW in Arizona

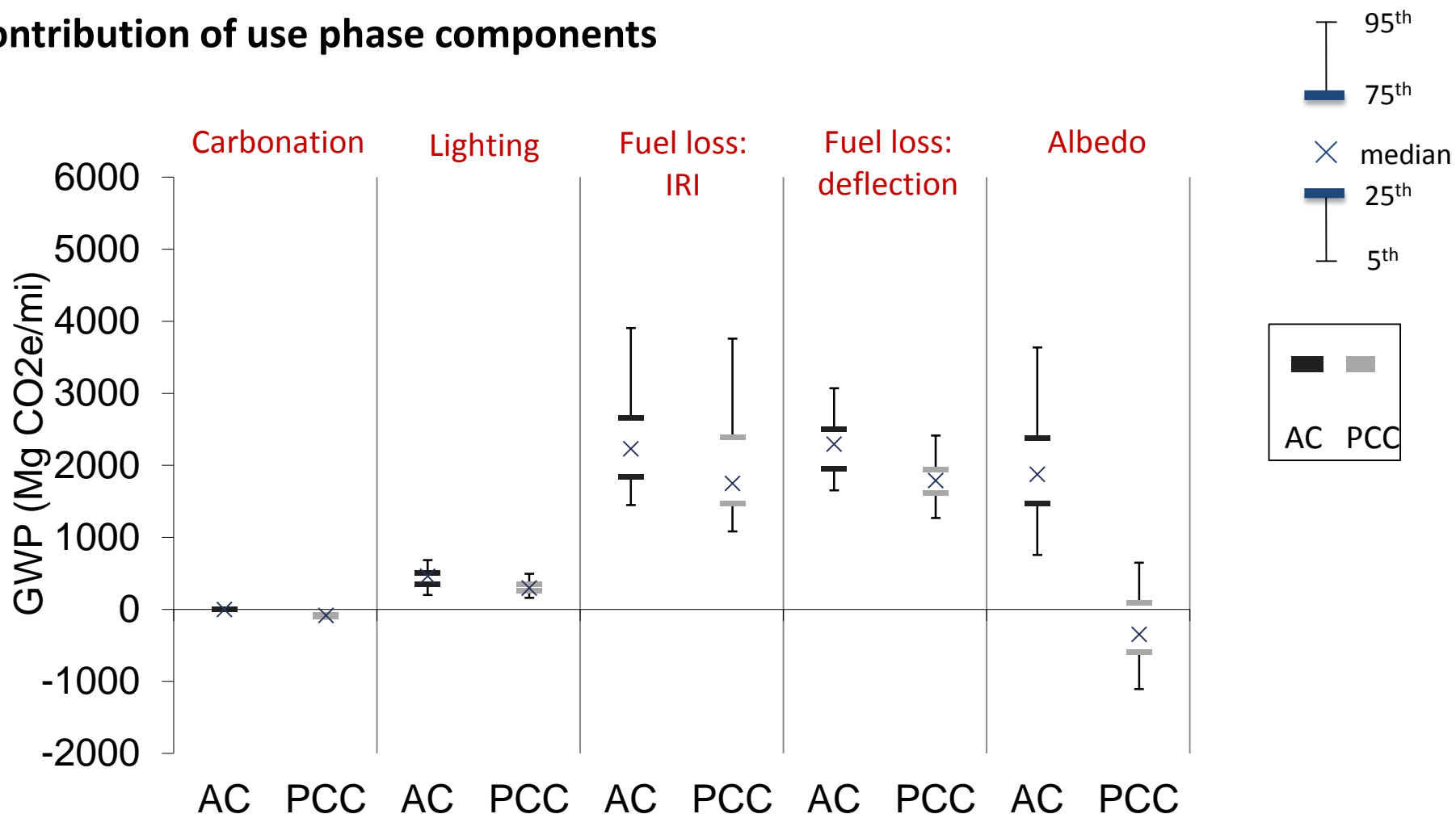
Contribution of different phases



Use phase is a significant driver of impact

Case study: dry no-freeze urban interstate HW in Arizona

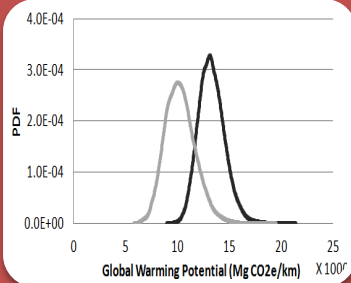
Contribution of use phase components



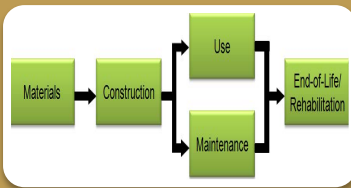
Use phase drivers are highly dependent on pavement design and context



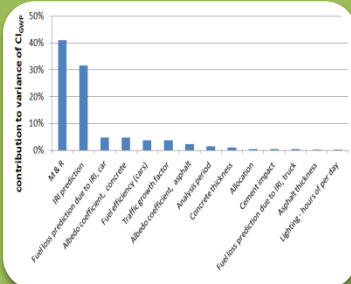
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Incorporating uncertainty facilitates robust decision-making



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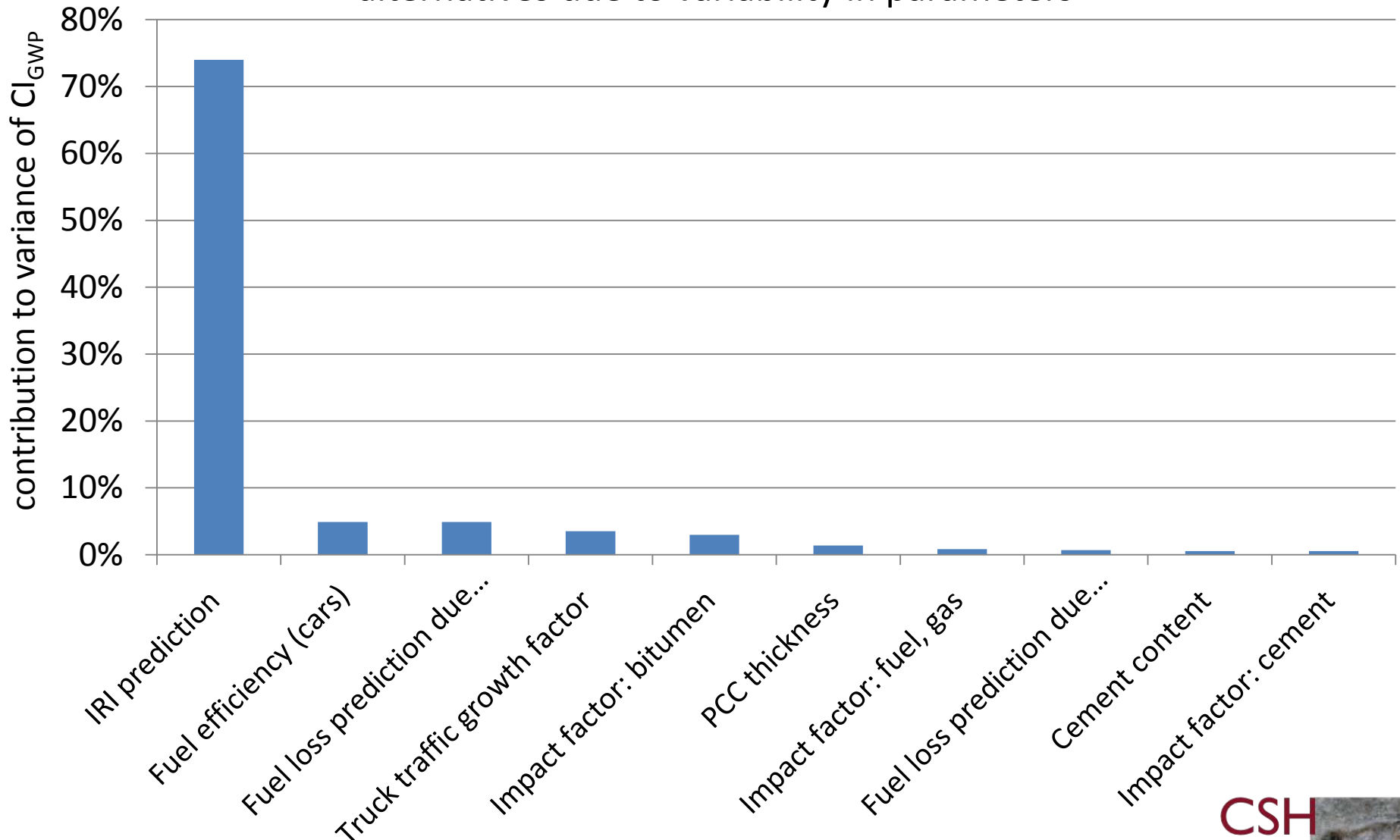


Uncertainty approach illuminates key drivers of differences in designs



The key drivers of differences between designs

Percentage variation in the difference between alternatives due to variability in parameters



Please contact me with any questions

Additional details:

[http://web.mit.edu/cshub/
jgregory@mit.edu](http://web.mit.edu/cshub/jgregory@mit.edu)

