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The importance of incorporating uncertainty into pavement life cycle cost and environmental impact analyses

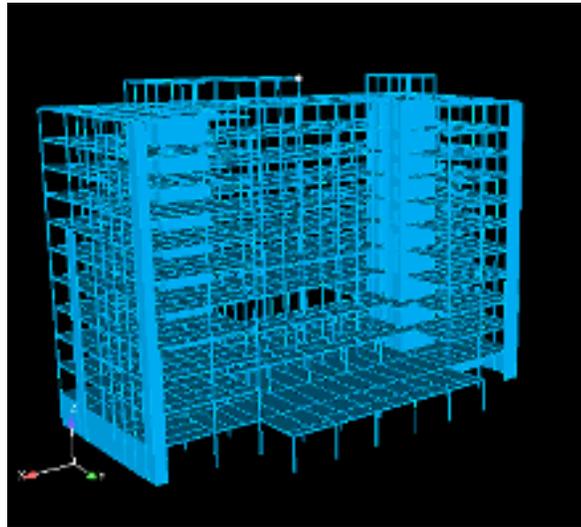
Jeremy Gregory, Arash Noshadravan,
Omar Swei, Xin Xu, **Randolph Kirchain**

Pavement LCA 2017

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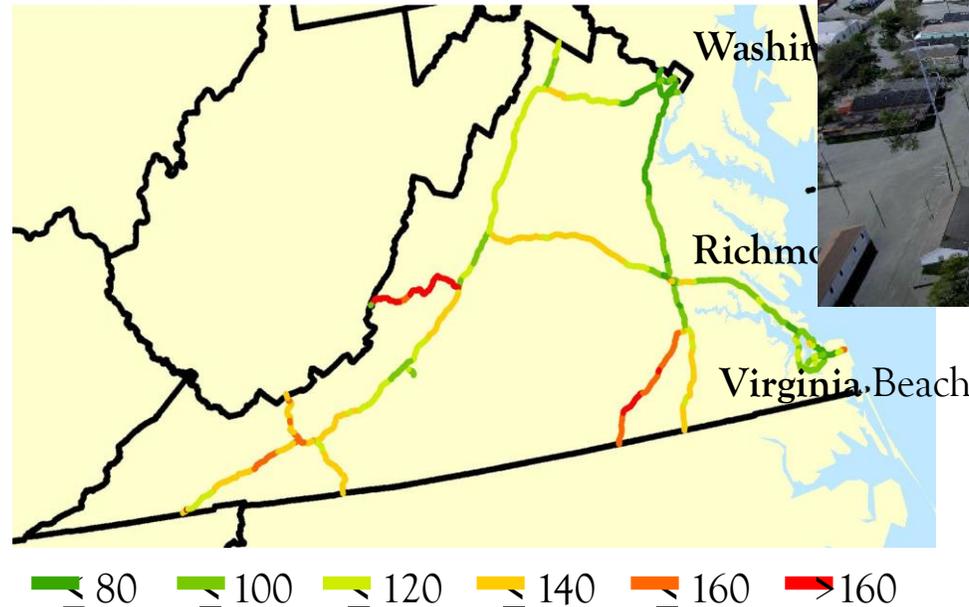
Uncertainty is pervasive in engineering decisions...

- System design for safety



<http://www.luxinzheng.net/en/practical.htm>

- Infrastructure planning



- Natural hazards



<http://www.npr.org/2016/09/30/495794999/new-maps-label-much-of-new-orleans-out-of-flood-hazard-area>

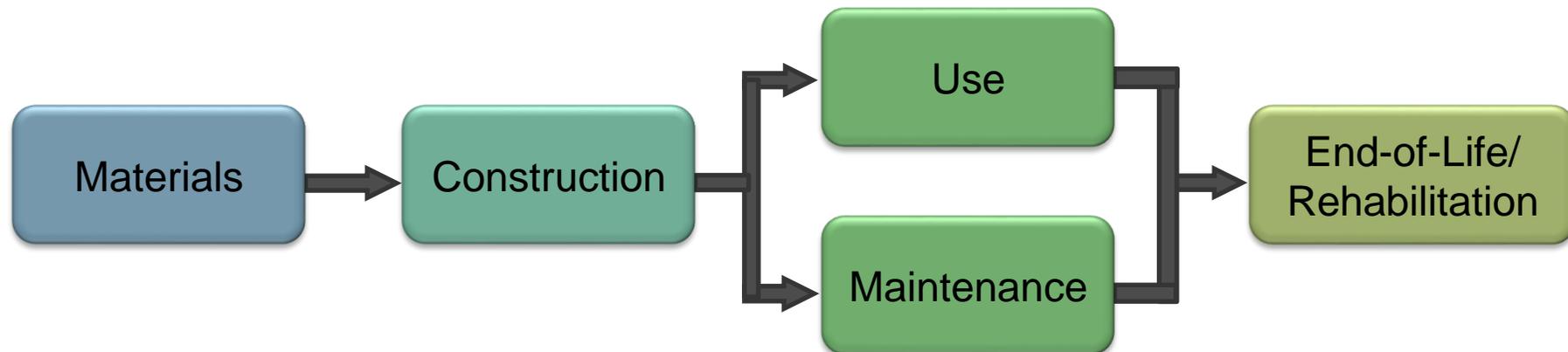
Uncertainty is pervasive in engineering decisions...

Uncertainty is pervasive in pavement LCA & LCCA

Uncertainty in:

- Initial & future costs
- Material quantities
- Pavement deterioration
- Use phase models
- Environmental impacts
- ...

We can leverage uncertainty to support robust decisions



Barriers to incorporating uncertainty in LCA & LCCA

1. There is limited guidance on how to conduct an uncertainty analysis

2. Characterizing uncertainty is difficult

3. People have a hard time processing outcomes of uncertainty analyses



First steps in developing uncertainty guidance

Key steps in comparative uncertainty analysis

Identify uncertain quantities

Characterize uncertainty

Conduct & interpret uncertainty analysis



Identify uncertain quantities

Quantity	Description	Example
Empirical quantity	<ul style="list-style-type: none">Measurable (in principle) with a <i>true</i> value	Electricity consumption, particulate emissions
Model domain parameter	<ul style="list-style-type: none">Define scope of system with an <i>appropriate</i> value	Temporal or geographic boundaries
Value parameter	<ul style="list-style-type: none">Represent aspects of analyst preferences with an <i>appropriate</i> value	Discount rate, allocation factor

Others include decision variables and outcome criterion (LCIA metrics)

Morgan and Henrion 1990

Slide 7



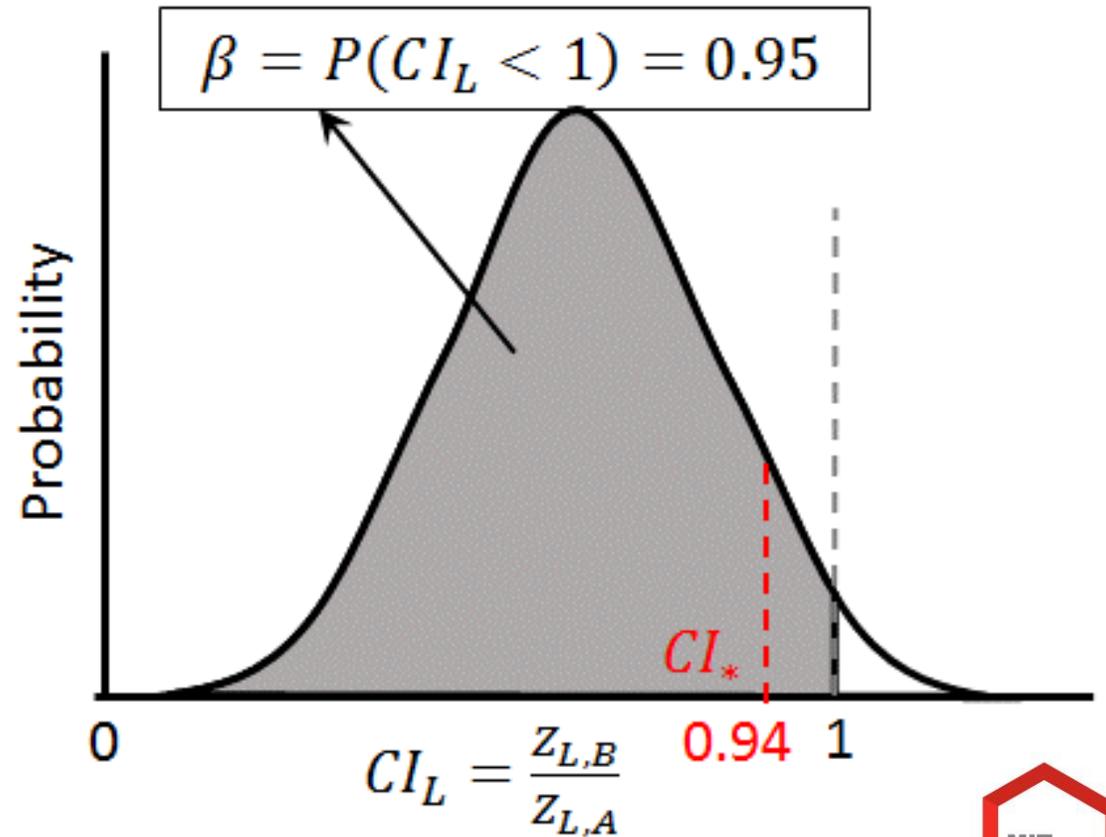
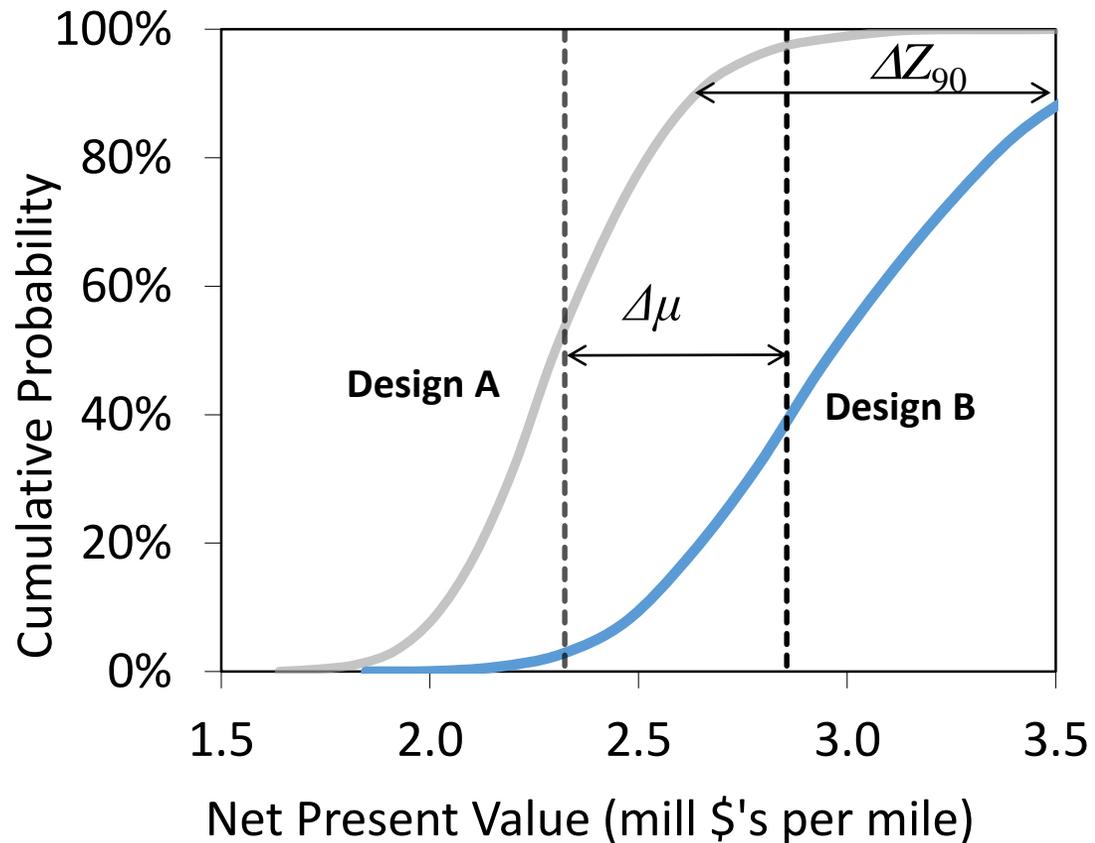
Characterize uncertainty

Quantity	Characterization	Data Source
Empirical quantity	<ul style="list-style-type: none">• Weighted probability distribution	Measurements, estimates, data quality estimates
Model domain parameter	<ul style="list-style-type: none">• Range of continuous or discrete values with equal likelihood	Analysis scope
Value parameter	<ul style="list-style-type: none">• Range of continuous or discrete values with equal likelihood	Possible range

Conduct & interpret uncertainty analysis

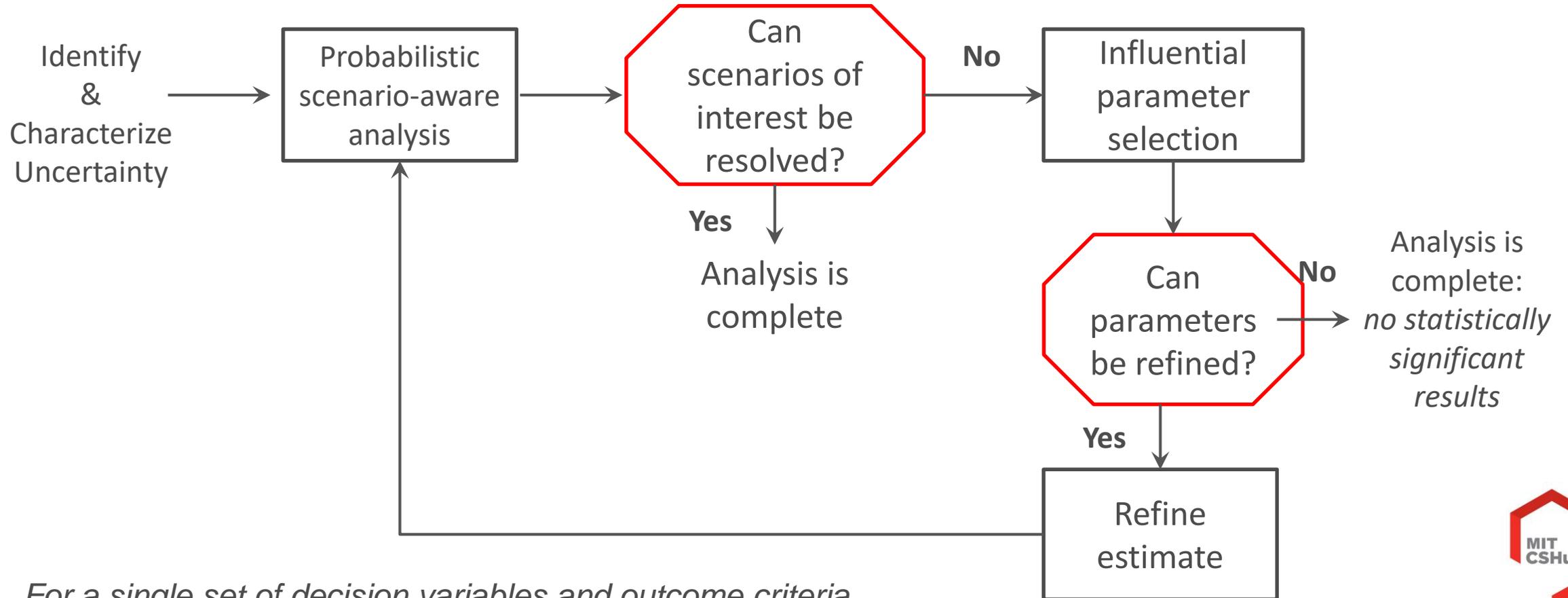
Monte carlo practical for most analyses

Comparison indicator for statistical significance test



Conduct & interpret uncertainty analysis

Robust comparative LCAs – Considering the full scenario space



For a single set of decision variables and outcome criteria

Comparative pavement uncertainty analyses

Identify uncertain quantities

Empirical parameters

Fuel efficiency – cars

Traffic growth factor

PCC thickness

AC thickness

AC milling energy

Model domain parameters

Design life

Analysis period

Scope*: albedo

Scope: PVI-deflection

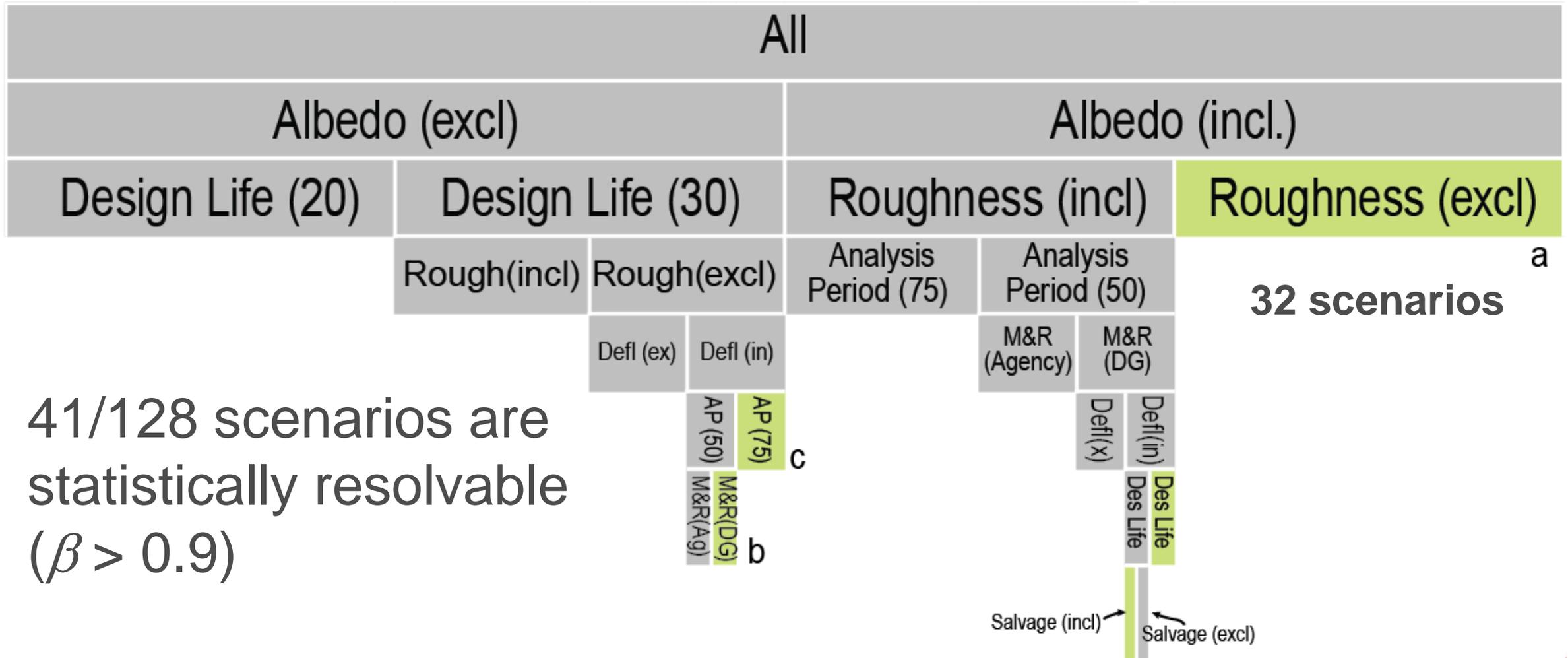
Scope: PVI-roughness

Value parameters

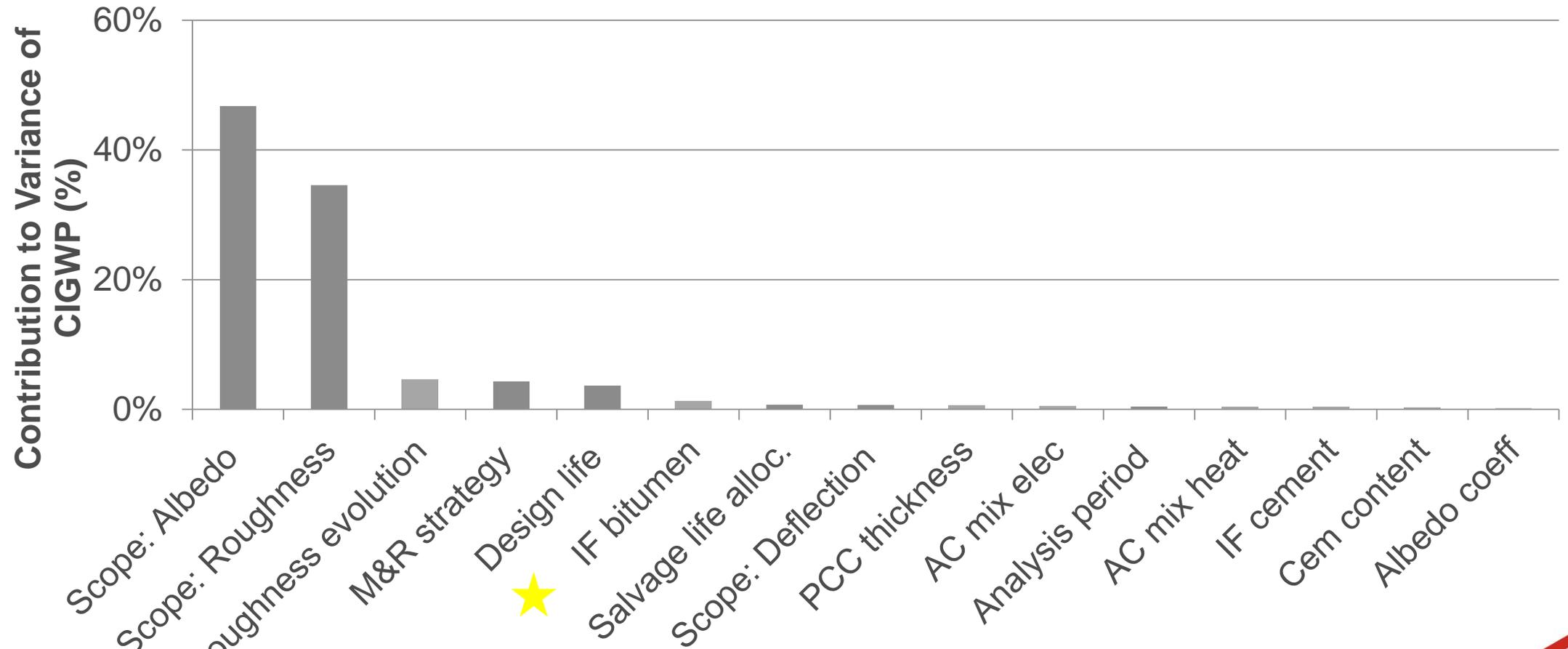
Salvage life allocation

Maintenance strategy

Use categorization and regression tree algorithms to analyze scenario space



Identify influential parameters via sensitivity analysis

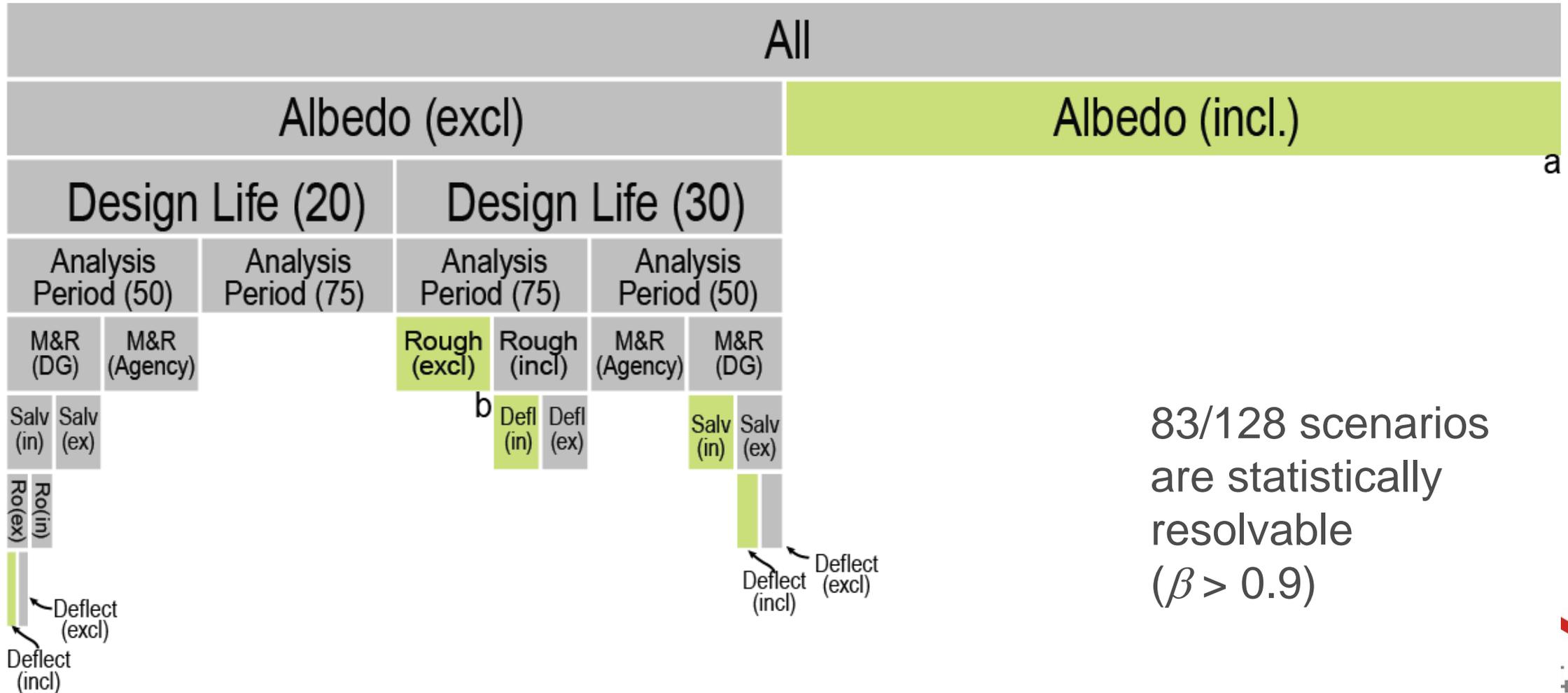


15 of 140 parameters shown

Results with refined influential parameters

Refine rate of roughness evolution and the impact factor for bitumen

$$\beta_{agg} = 0.80$$



83/128 scenarios
are statistically
resolvable
($\beta > 0.9$)

Interpret parameters & scenario uncertainty separately



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Thank you

Additional details:

- Gregory, J.R. et al., 2016. A Methodology for Robust Comparative Life Cycle Assessments Incorporating Uncertainty. *Environmental Science and Technology*, 50(12).
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- Swei, O., Gregory, J. & Kirchain, R., 2015. Probabilistic life-cycle cost analysis of pavements: Drivers of variation and implications of context. *Transportation Research Record: Journal of the Transportation Research Board*, 2523.
- Xu, X. et al., 2014. Scenario Analysis of Comparative Pavement Life Cycle Assessment. In *International Symposium on Pavement LCA 2014*. pp. 13–26.

