Incorporating Risk into Asset Management Decisions

Case Study of the Impact of Uncertain Climatic Effects on Long-Term Asset Needs

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CH2M Hill – Washington, D.C.

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Study Background

- **NCHRP 08-71**: Methodology for Estimating Life Expectancies of Highway Assets
  - *Research Team:* Prof. Samuel Labi, Prof. Kumares C. Sinha, Dr. Kevin M. Ford, Mr. Mohammad Arman, Prof. Zongzhi Li, Dr. Arun Shirole, Mr. George Stam, and Mr. Paul Thompson
  - *Panel Members:* Dr. Andrew Lemer, Mr. Mark B. Nelson, Mr. Don Clotfelter, Dr. Gerardo Flintsch, Mr. Lacy D. Love, Ms. Sheila Moore, Mr. Eric Pitts, Mr. Michael Plunkett, Mr. Nastaran Saadatmand, Dr. Nadarajah "Siva" Sivaneswaran, and Mr. Raymond S. Tritt

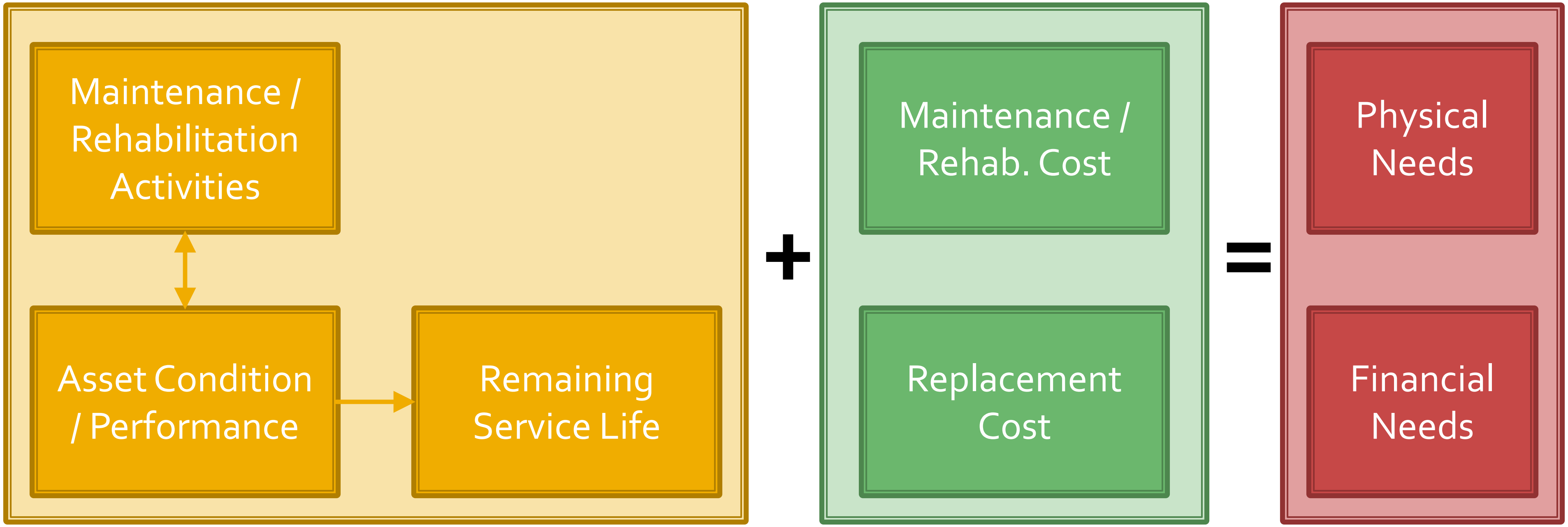
Study Website: **https://engineering.purdue.edu/LEHA/**

Presentation Outline

- State-of-Practice
- Uncertainty Framework
- Case Study
  - Climate Uncertainty
  - Bridge Life Prediction
  - Long-term Needs

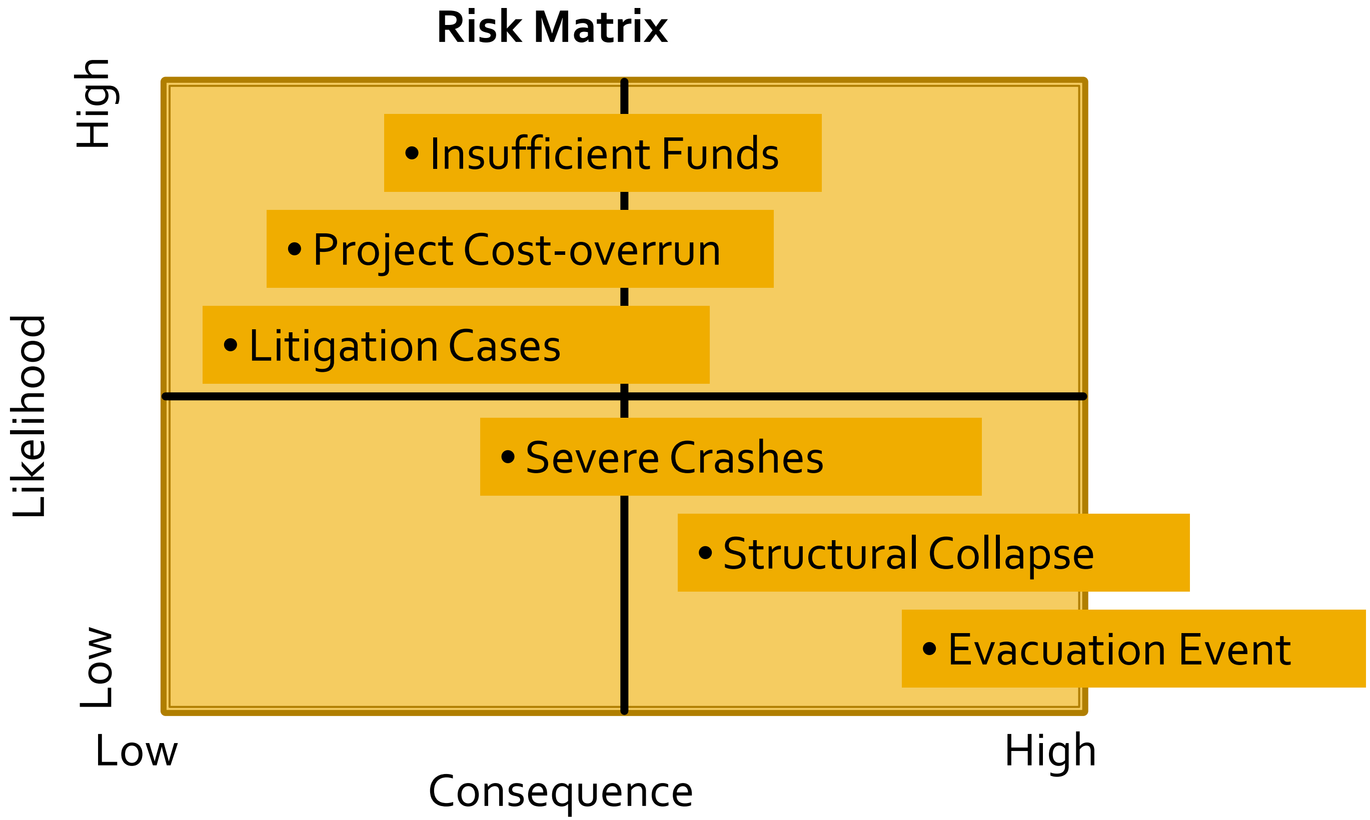
State-of-Practice:
Needs Assessment

- Reliance on Expert Opinion
- Estimates treated as Certain
  - Activity Timings, Costs, & Effectiveness and Service Life



State-of-Practice:
Risk Management

- Focus has been on project-level and loss-of-life events



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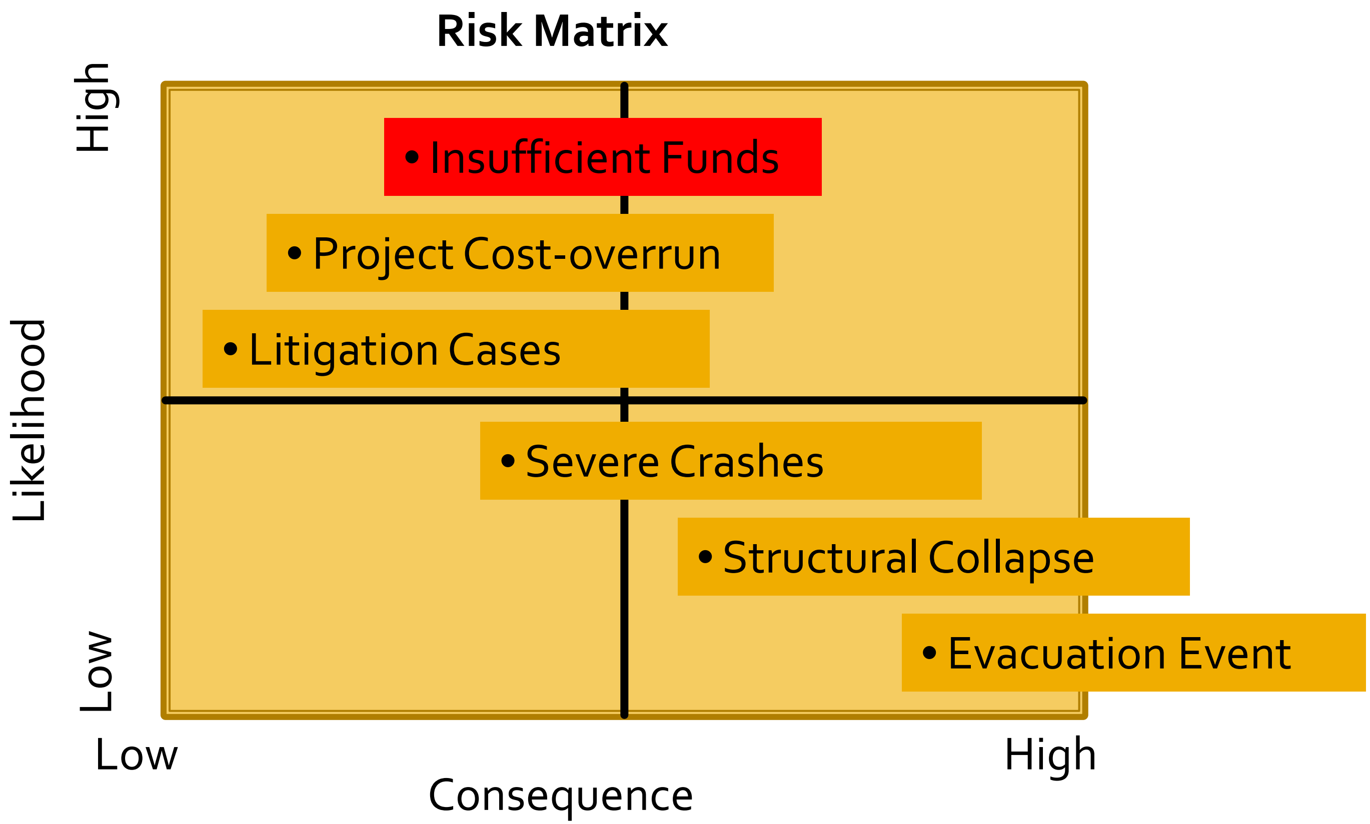
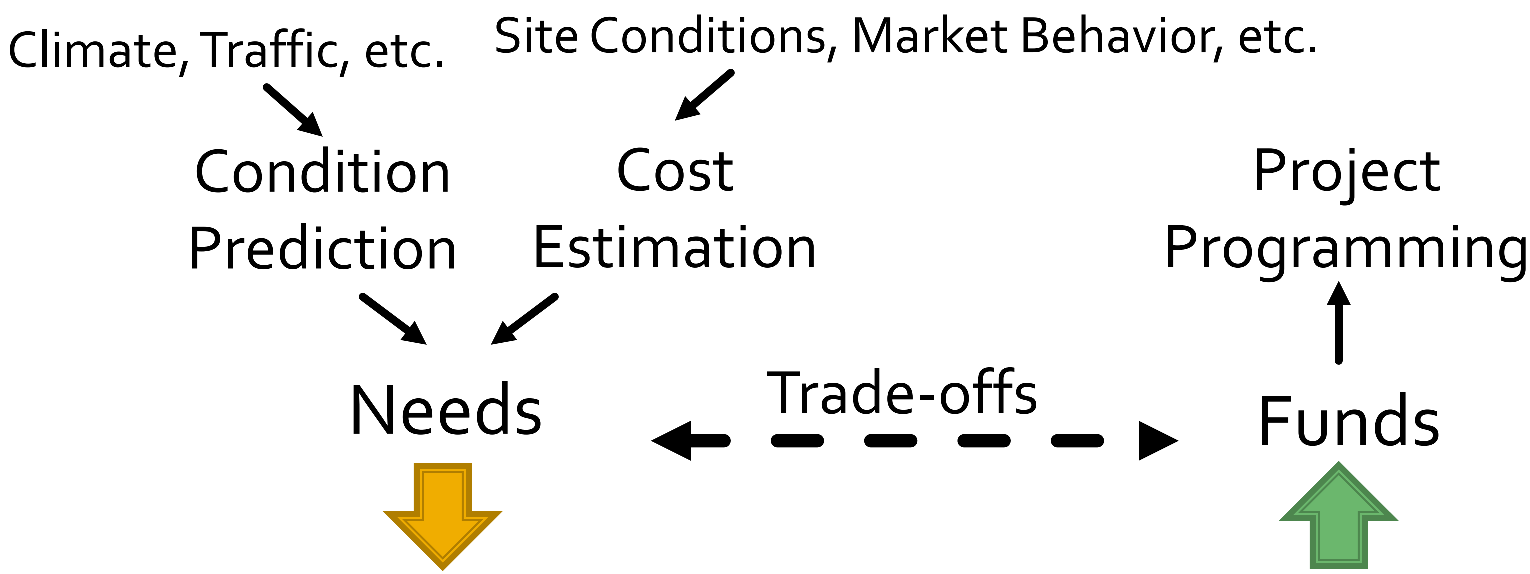


Risk of Insufficient Funds



- Policy-makers
  - Tax Allocation
  - PPP
  - Toll Road Leasing
  - Stimulus
- Travel Demand
  - Gas Tax Revenue
  - Toll Revenue
- Designated Funds

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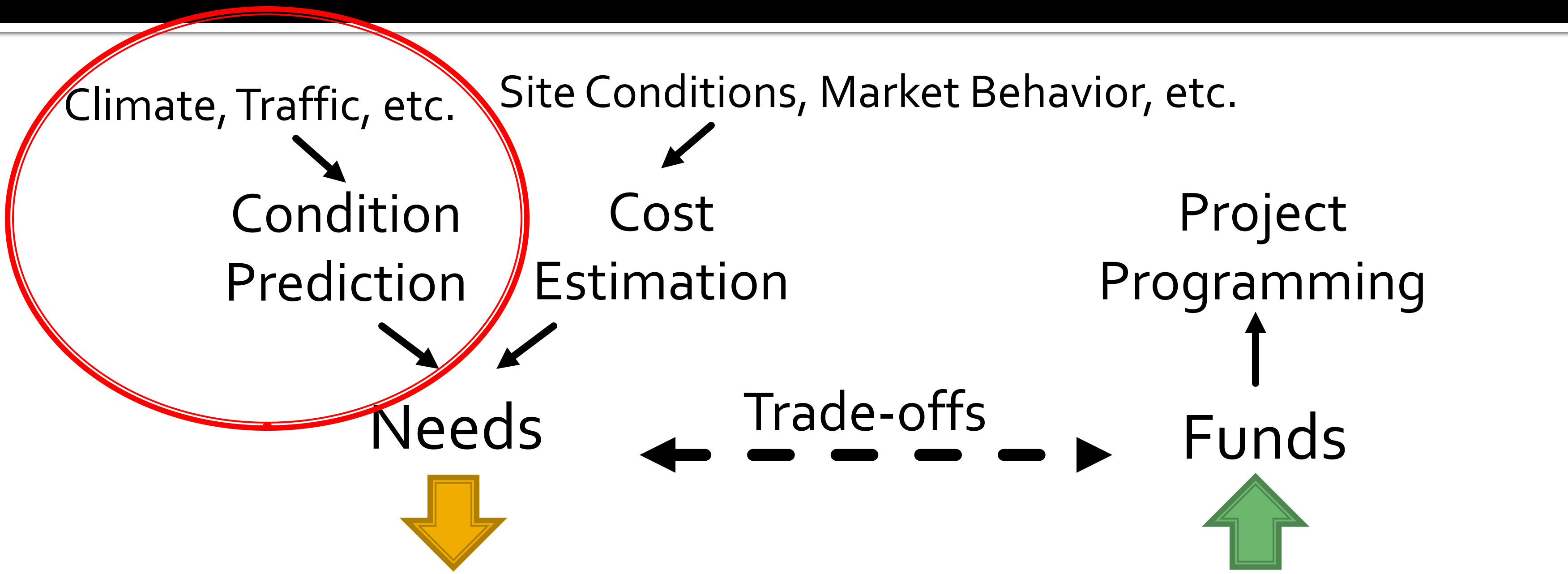

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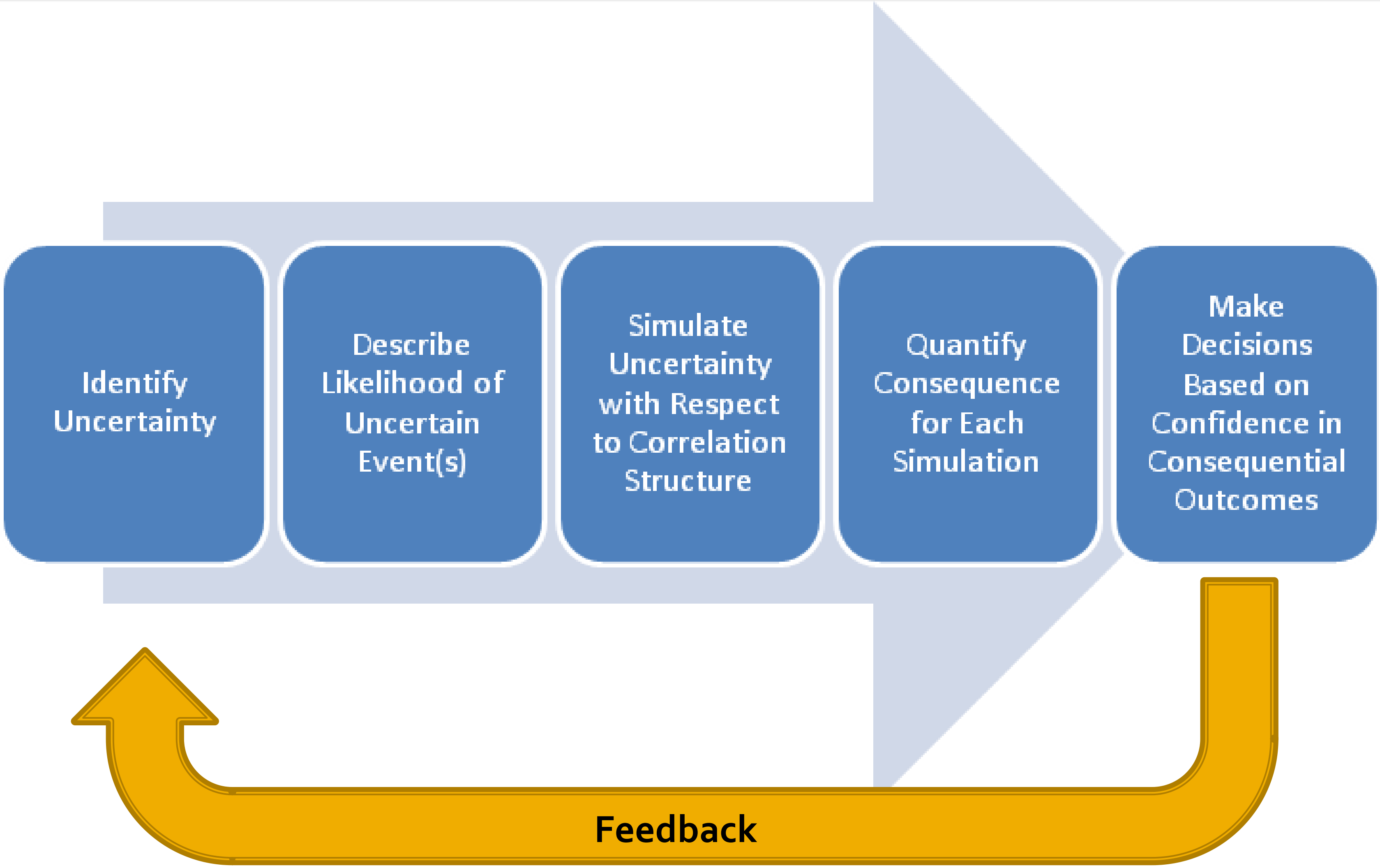
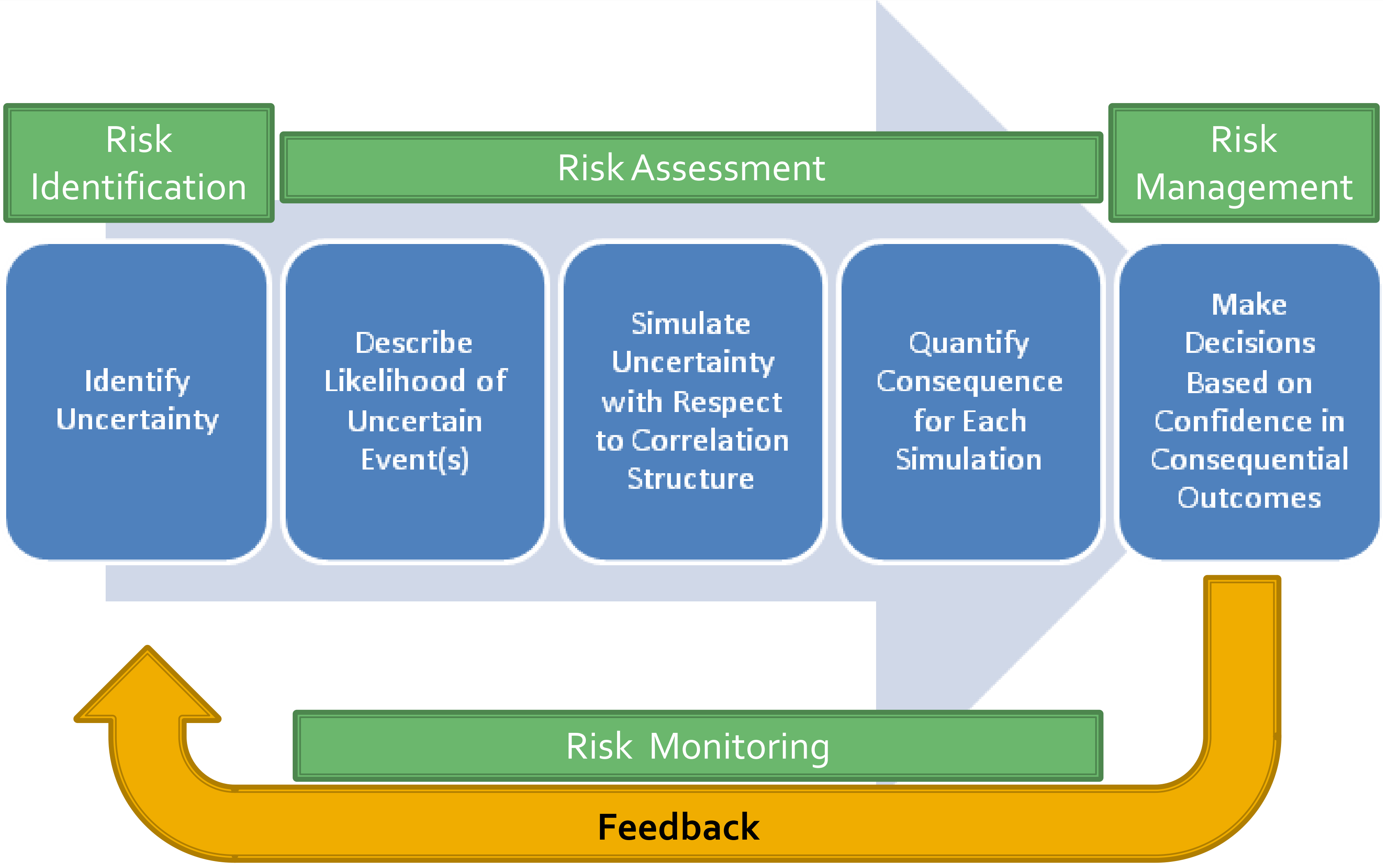
Uncertainty Framework

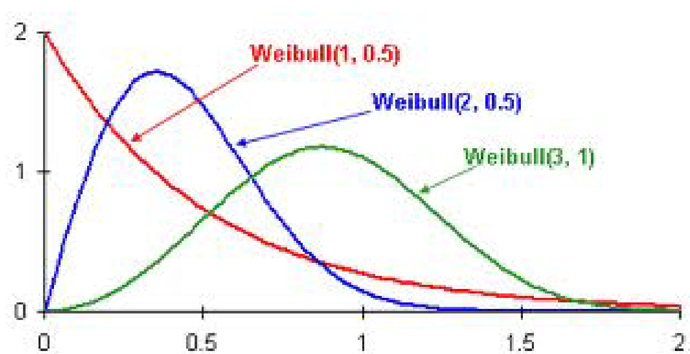


Uncertainty Framework

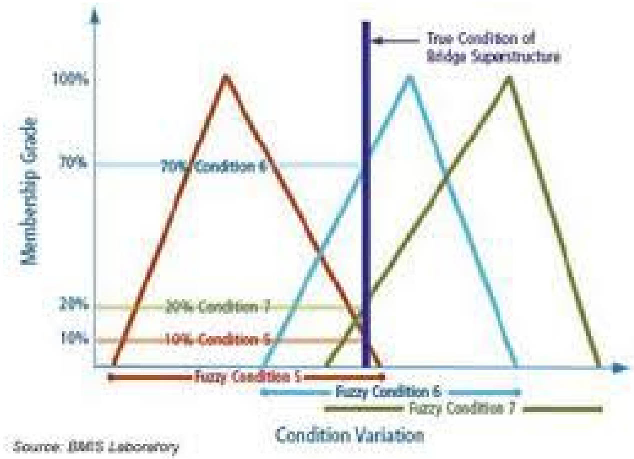


Uncertainty Framework

1) Identify Uncertainty
   - Aleatory vs. Epistemic
2) Describe Likelihood of Uncertain Event(s)
   - Probability vs. Possibility vs. Expert Opinion
     - Tests: K-S, A-D, χ^2, Likelihood Ratio



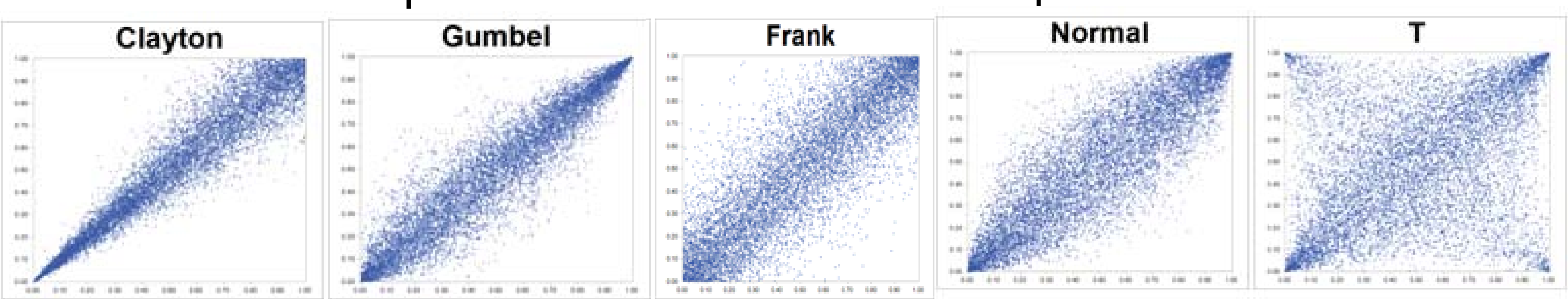
(Vose Software)



(Al-Wazeer et al., 2008)

Uncertainty Framework

3) Simulate Uncertainty with Respect to Correlation Structure
   - Sampling: Monte Carlo vs. Latin Hypercube vs. Reliability-Based vs. α-Cuts
     - Correlation: Joint Distribution Derivation vs. Cholesky Decomposition vs. Rank-Order Correlation vs. Envelope Method vs. Statistical Copulas



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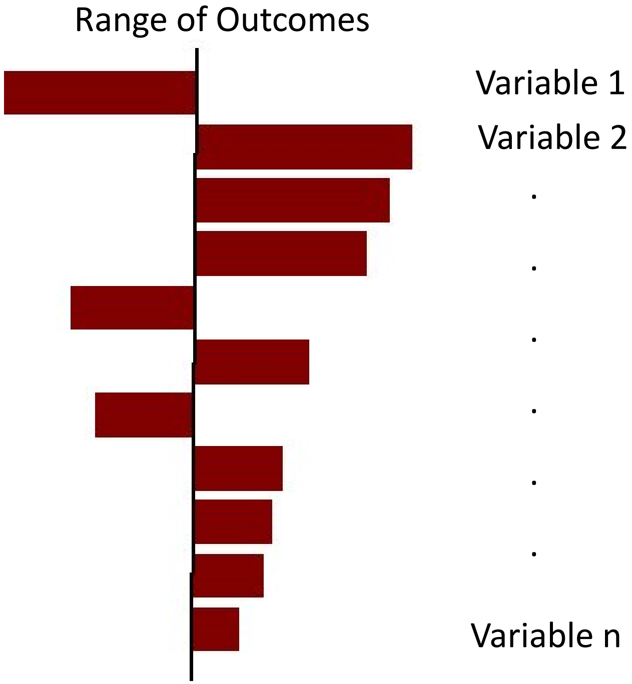
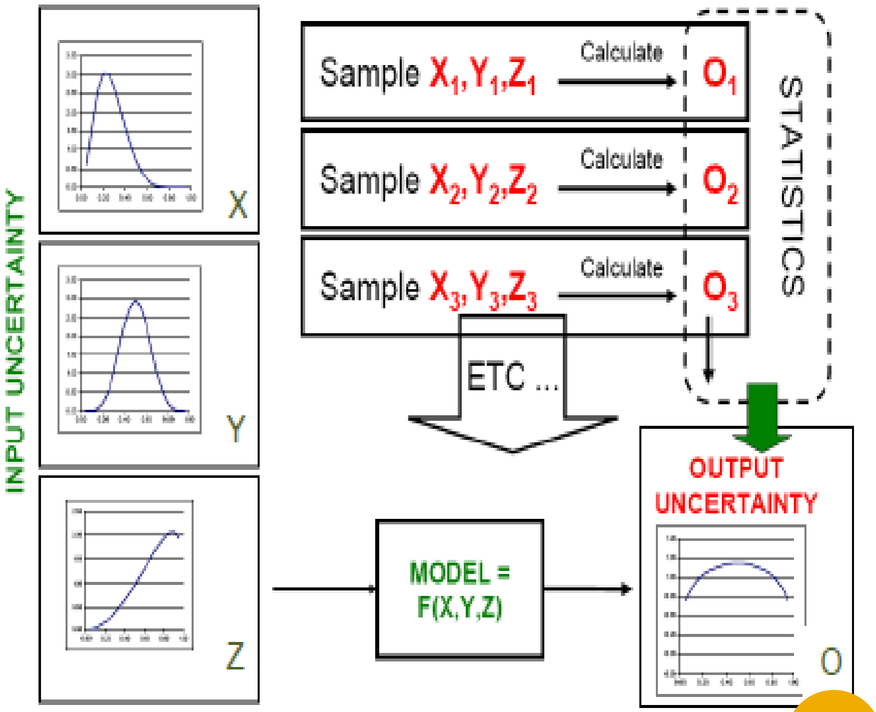
Uncertainty Framework

4) Quantify Consequence for Each Simulation

Sensitivity vs. Risk



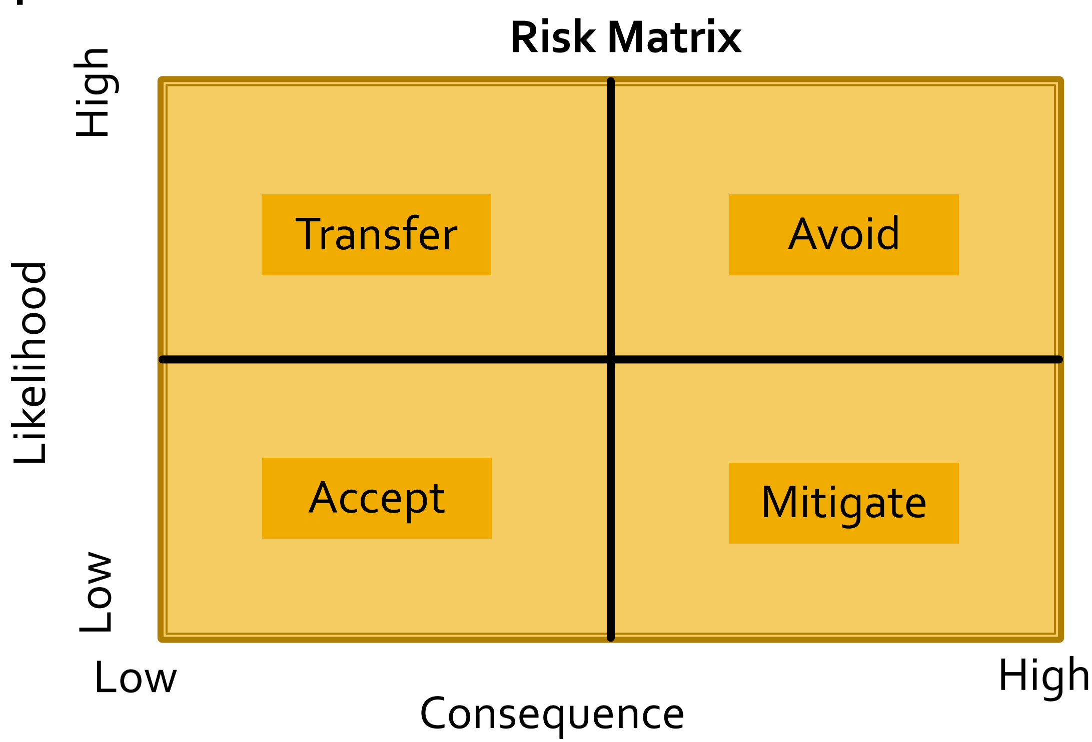
(Molenaar et al., 2006)



(van Dorp, 2009)

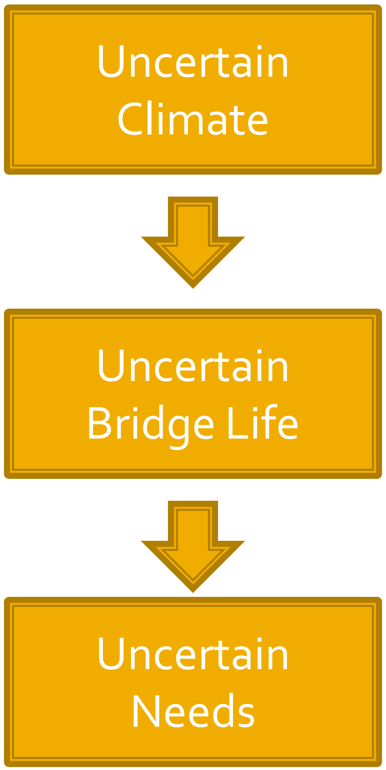
Uncertainty Framework

5) Make Decisions Based on Consequential Outcomes
   - Depends on Risk Tolerance



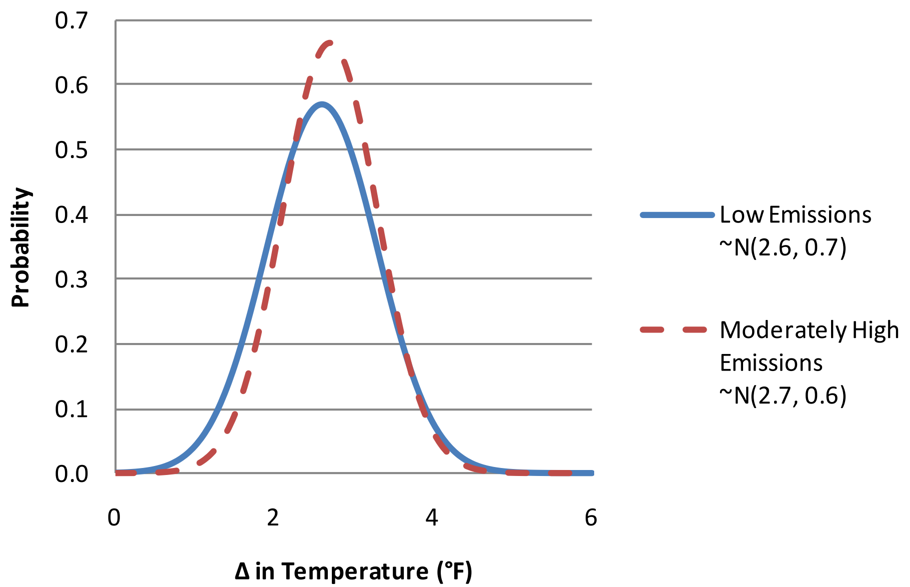
Case Study

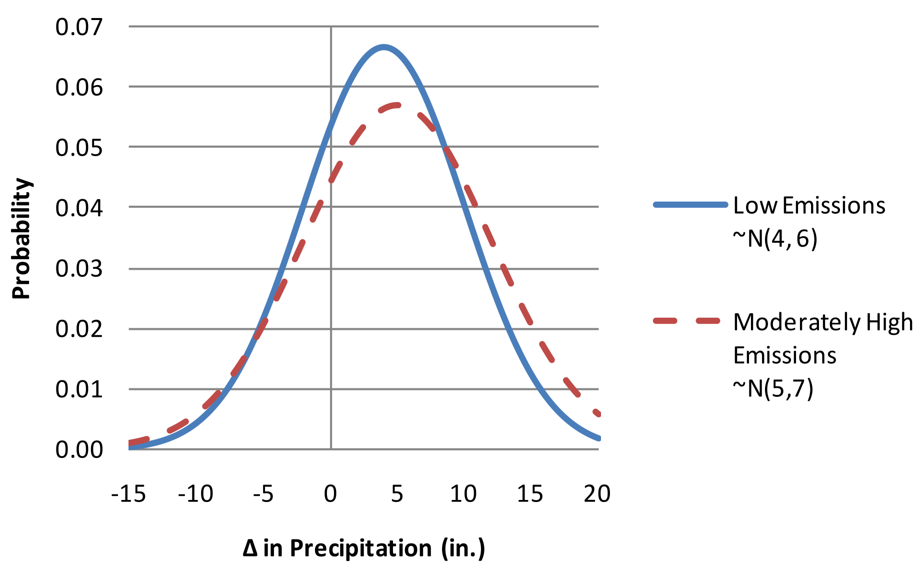
Risk-based Needs Assessment



Uncertain Climate

- Midwest climate from NOAA with 30 year change estimated via (ICF Intl., 2009)

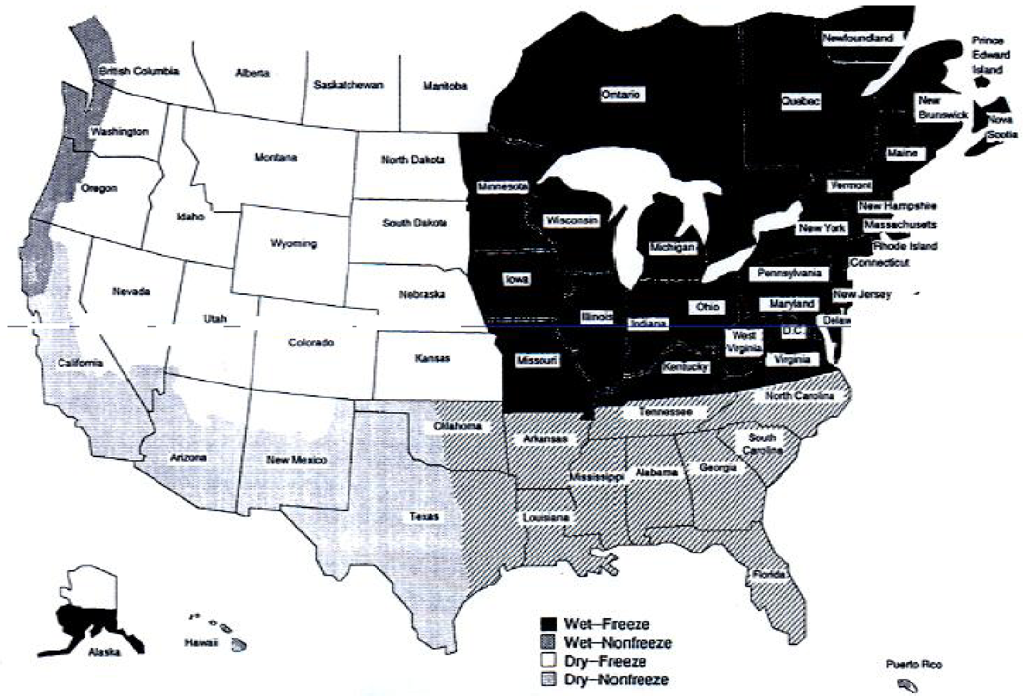




Normal Copula
Cov.=0.56

Uncertain Life

- Fit a Weibull distribution to the NBI
  - End-of-Life ≡ Sufficiency Rating ≤ 50%
  - Equal sample from the 4 major national climate regions



(Hadley, 1994)

Uncertain Life

- Bri

Where, α ≡ scaling factor; c ≡ calibrated coefficient using maximum likelihood estimation; l_k ≡ life expectancy factor k out of n significant factors.

Where, t ≡ time; γ ≡ location factor; α ≡ scaling factor; β ≡ shape factor.

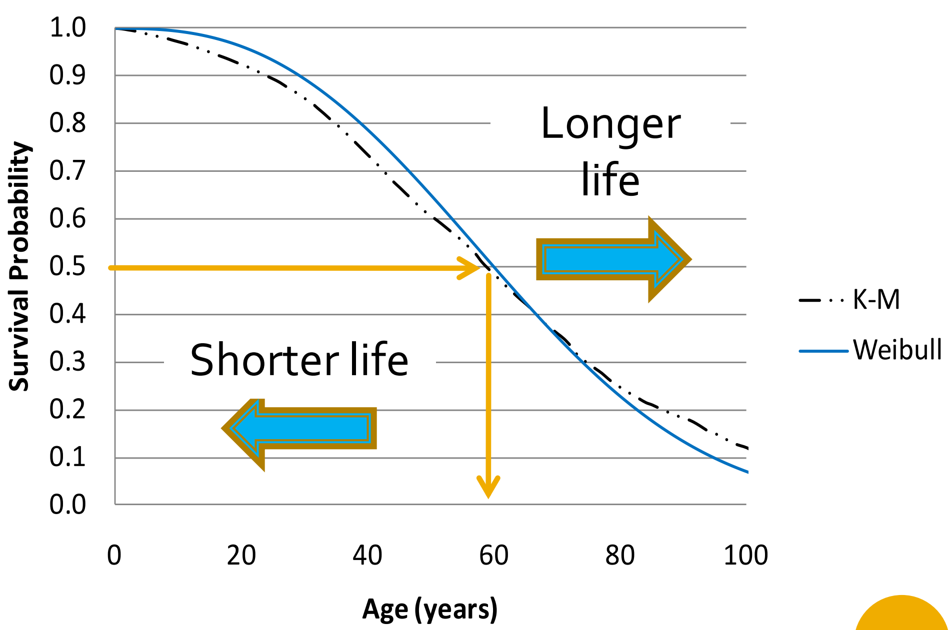
Life Expectancy F		
Constant		
Normal annual temperature (°F)	-0.628E-2	-17.199
Normal annual precipitation (in.)	-0.167E-2	-8.674
Geographic indicator (1 if rural, 0 otherwise)	0.459E-1	6.474
NHS indicator (1 if on NHS, 0		
Corrosive soil indicator (1 if c corrosive by NRCS, 0 otherw		
Material type indicator (1 if st		
Structure length (decimeters)	-0.765E-5	-6.035
Baseline Ancillary Factors	Parameter Estimate, β	t-Statistic
Shape Factor, β	2.623	185.168
Scaling Factor, α	68.871	363.000
Model Statistics		
Number of Observations	42,902	
Log-likelihood Function at Convergence	-26,785.79	
Restricted Log-likelihood Function	-40,397.73	

$$\left(\quad \sum_{k=1}^{n} c_k l_k \right)$$

$$S(t) = EXP\left[-1 * \left(\frac{t-\gamma}{\alpha}\right)^{\beta}\right]$$

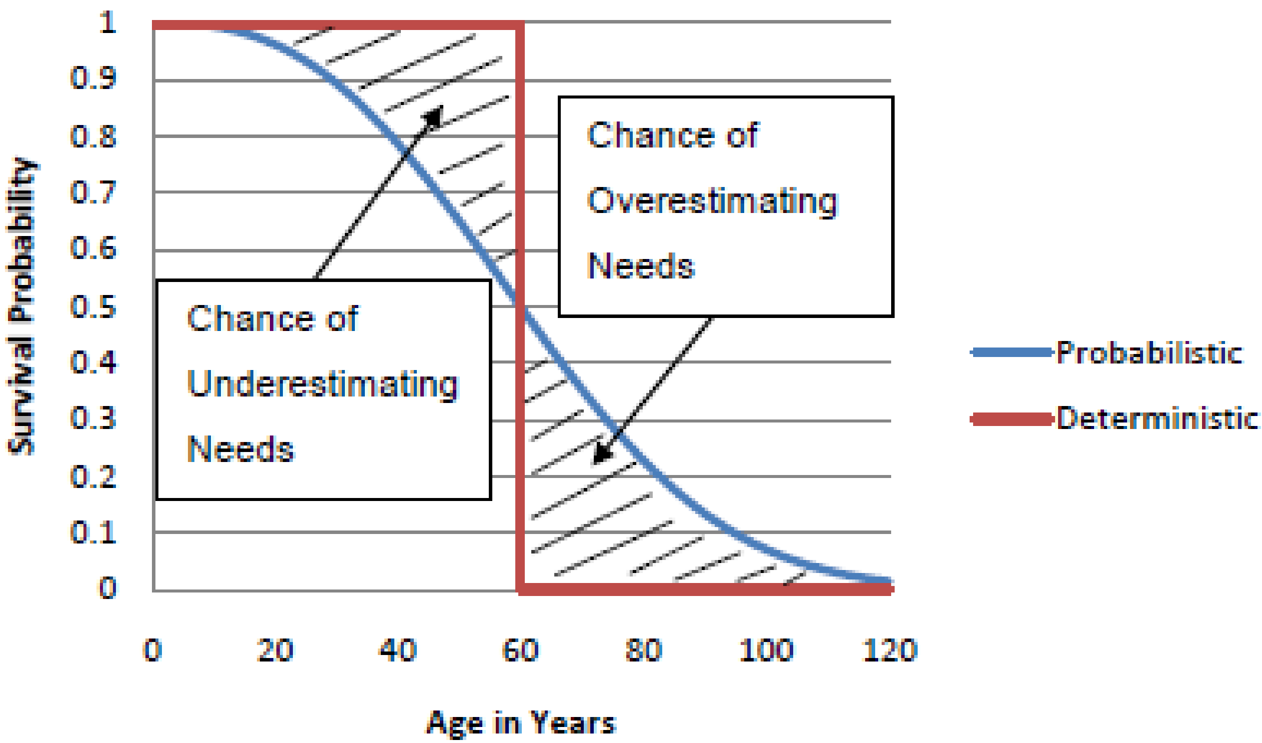
Uncertain Life

- Significant propensity towards **<u>longer</u>** life
  - Rural geographic region
- Significant propensity towards **<u>shorter</u>** life
  - Warmer and wetter climate
  - On NHS
  - Corrosive soil
  - Steel structure
  - Longer structure
- Median Life = 60 years



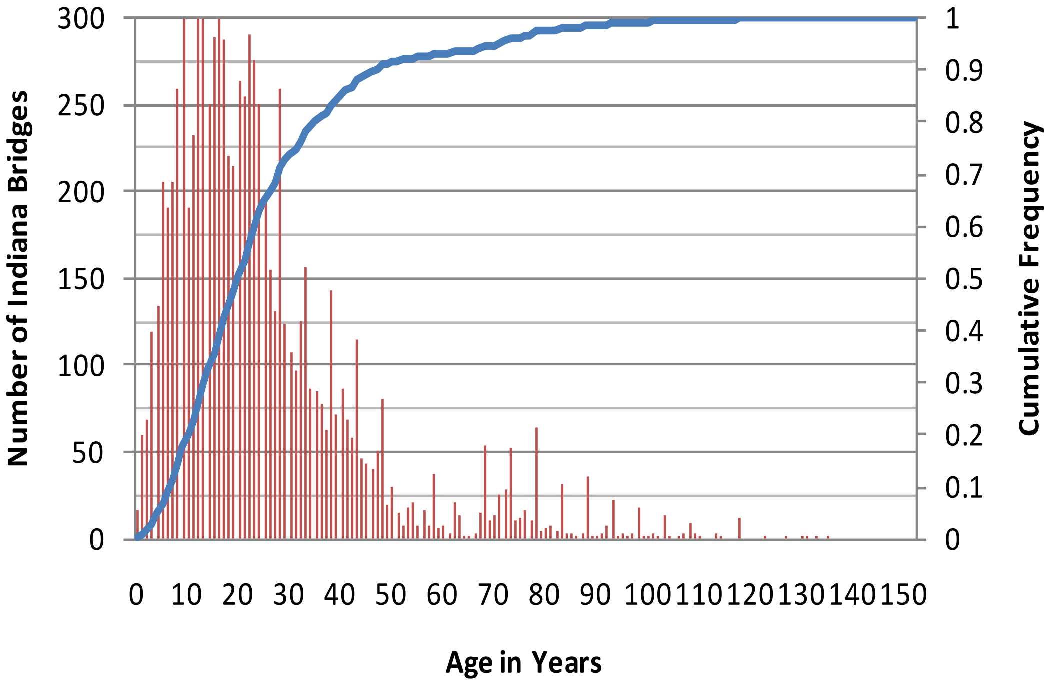
Uncertain Needs

- Typical practice – estimate needs based on # of assets approaching end-of-life in planning horizon
- Life estimate typically deterministic, but life is uncertain…



Uncertain Needs

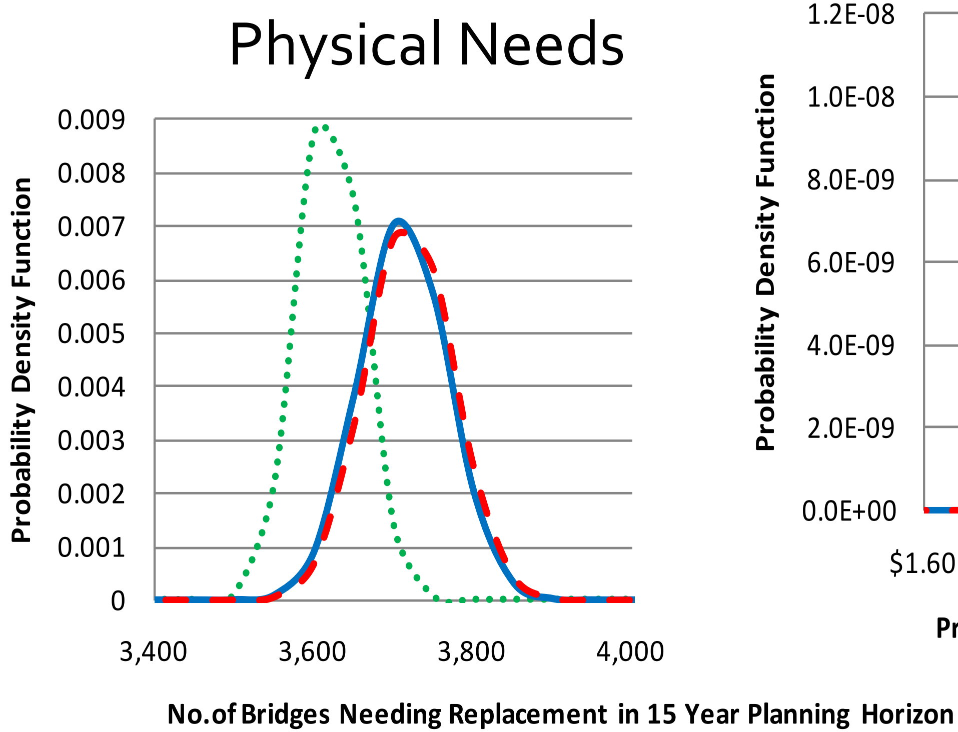
- For example, consider the Indiana Bridge stock
  - 75% of bridges under age 30 (as of 2009), if life expected to be 50-70 years
    - Risk underestimating needs in 15 year horizon

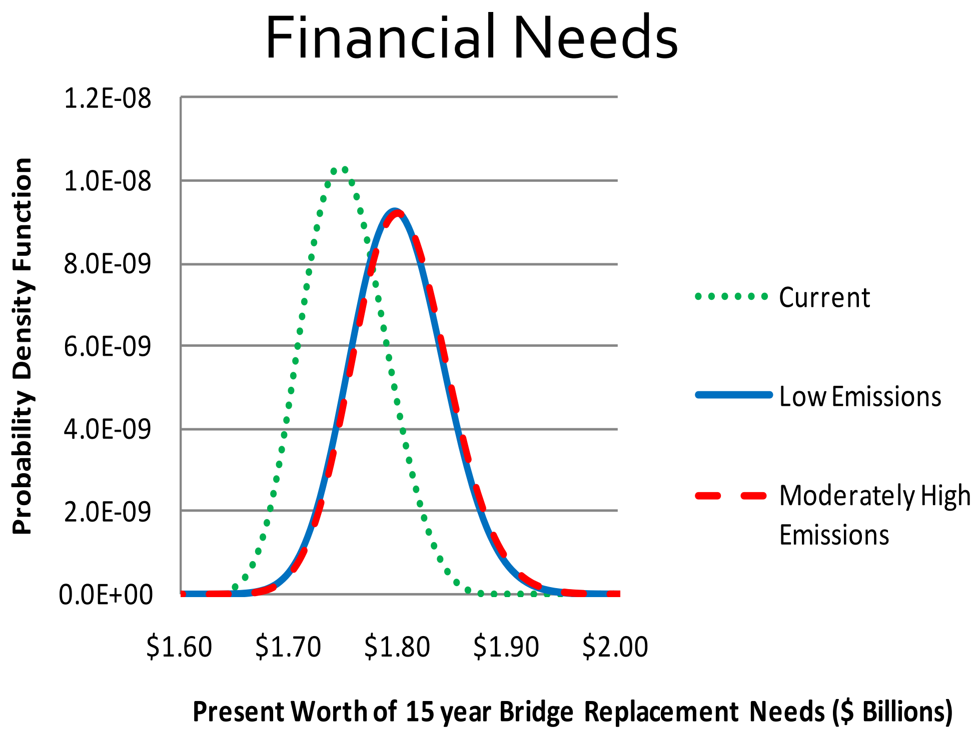


Uncertain Needs

- Inputs for Needs Assessment
  - Planning Horizon
    - 15 years
  - Activity Timings / Remaining Service Life
    - Replacement Only ~ 60 years on average
  - Activity Cost
    - Applied IBMS Cobb-Douglas equations (Sinha et al., 2009)
  - Interest Rate* (if assuming investment opportunities)

Uncertain Needs

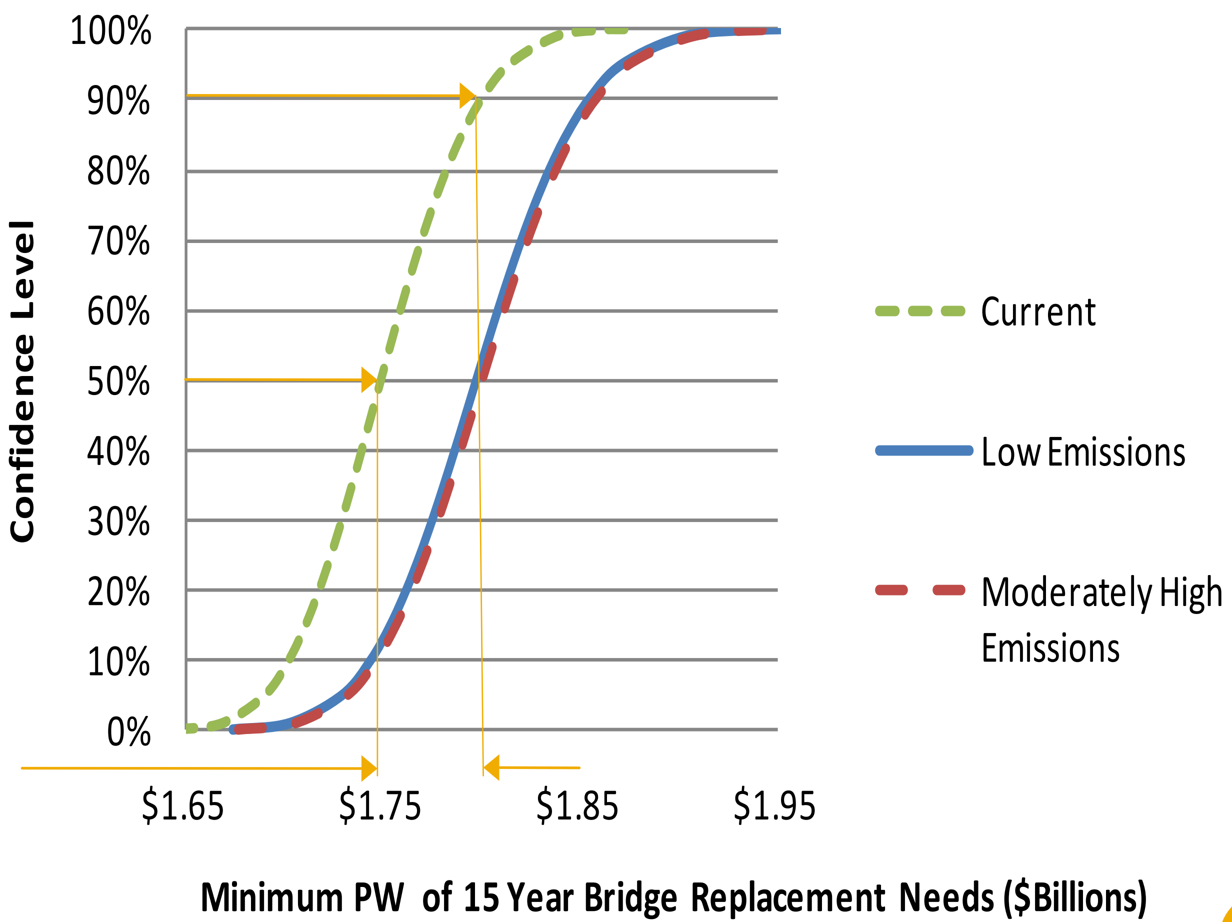




- Median Financial Needs
  $1.749B (current) vs. $1.798B (low) vs. $1.801B (mod. high)

Uncertain Needs

Example, Contingency Needed for 90% Confidence under Current Climate Conditions = $51M

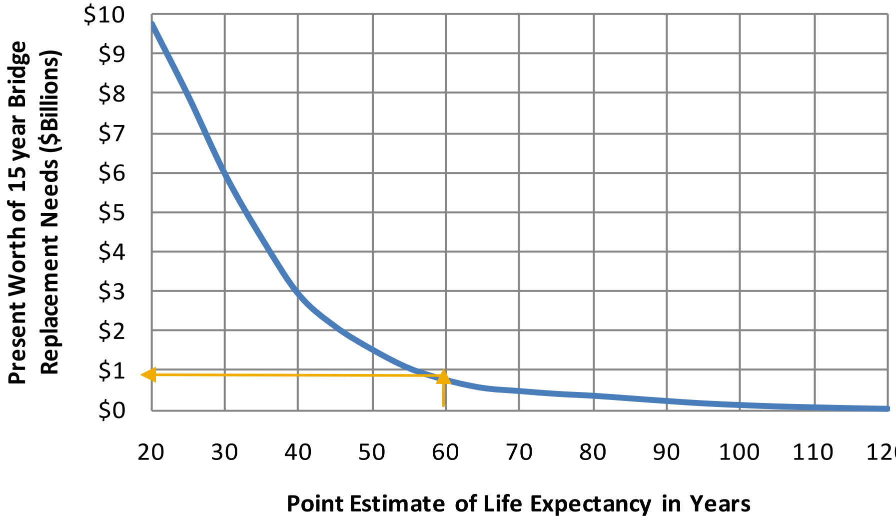


Uncertain Needs

- Needs by Point Estimate

  e.g., if assume 60 year life

  ➢ 15 yr needs = $760M



- In comparison to median estimates of previous scenarios:

Climate	Fiscal Under-estimation Relative to Median Value	Physical Under-estimation Relative to Median Value
No Change	$989 million	1,317 structures
Low Emissions	$1.038 billion	1,409 structures
Moderate Emissions	$1.041 billion	1,417 structures

Conclusions

- Summarily,
  - Future climate will likely cause a $49M-$52M increase and an additional 92-100 replacements over a 15 year horizon for Indiana bridge stock
  - If expert opinion = 60 year life, then Indiana bridge needs would be underestimated by 55-158%
  - If life expectancy models applied deterministically, then Indiana bridge needs would be underestimated by 25-162%
  - For 90% confidence in keeping Indiana bridges serviceable, a contingency fund of $30M-$58M is needed over the next 15 years