SESSION I: Pop-Up Talks

1) **Harvey Beck**, OFGEM
2) **Chris Hankin**, Imperial College London
3) **Anna Railton**, Smith Institute
4) **Julian Frost**, JESIP Cabinet Office
5) **Mike Colechin**, Energy Technologies Institute

Specialist: **Patrick Reed**

ATKINS cep UKERC UK Energy Research Centre

Imperial College London

Grantham Institute Climate Change and the Environment

What are the tradeoffs?

Challenges and the State-of-the-Art for Discovering Tradeoffs & Vulnerabilities in Deep Uncertainty Frameworks

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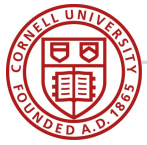
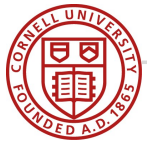
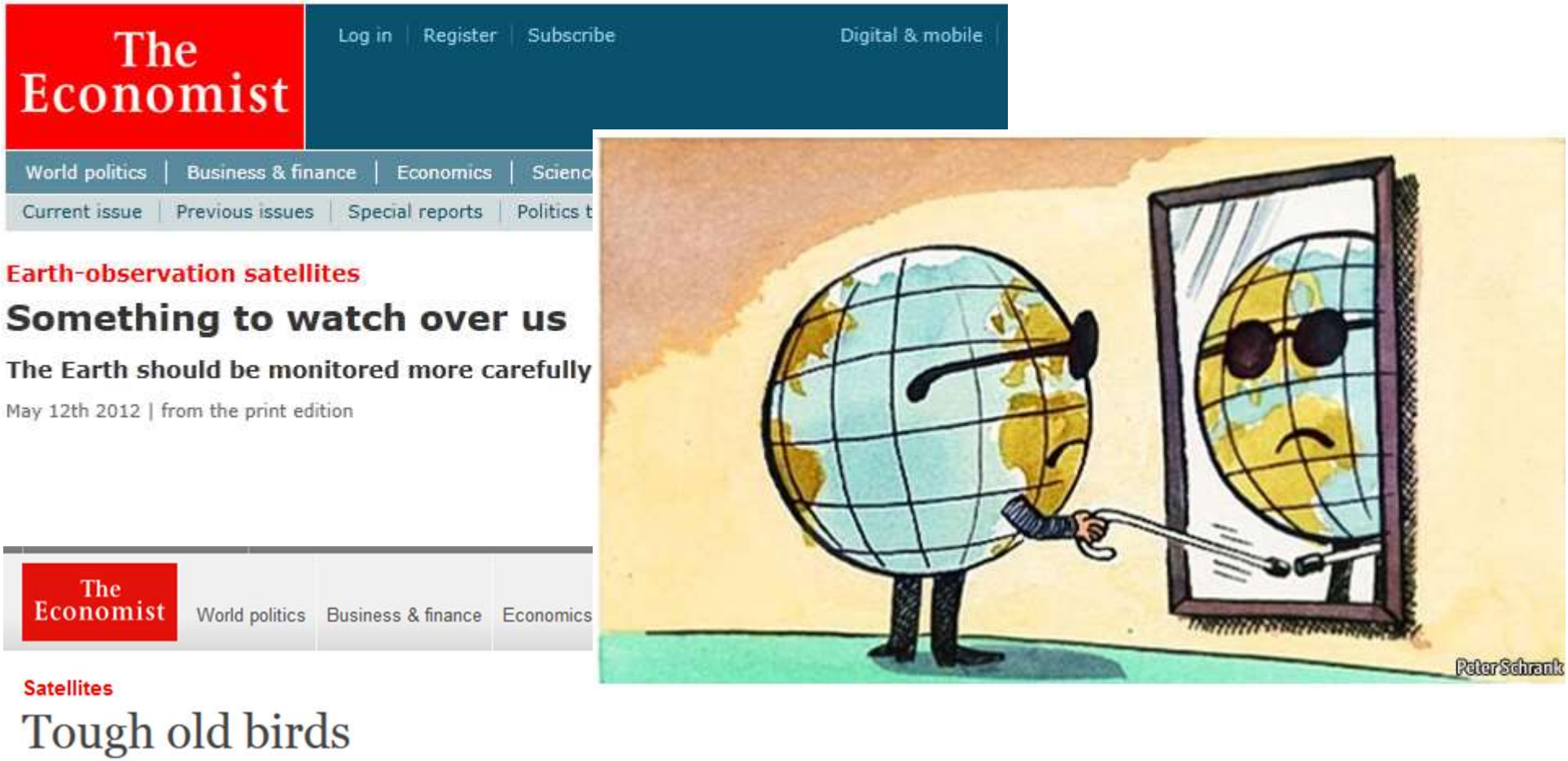


Two Key Points

(1) Often operational models and workflows reinforce status quo decision making, institutional change requires an integration of elicitation, computation, and MO decision making feedbacks (Example #1: The Aerospace Corp)

(2) Effective MO search can be critical for increasing "robustness" and understanding of stakeholder "robustness conflicts" given complex, adaptive decisions (Example #2: The Research Triangle)



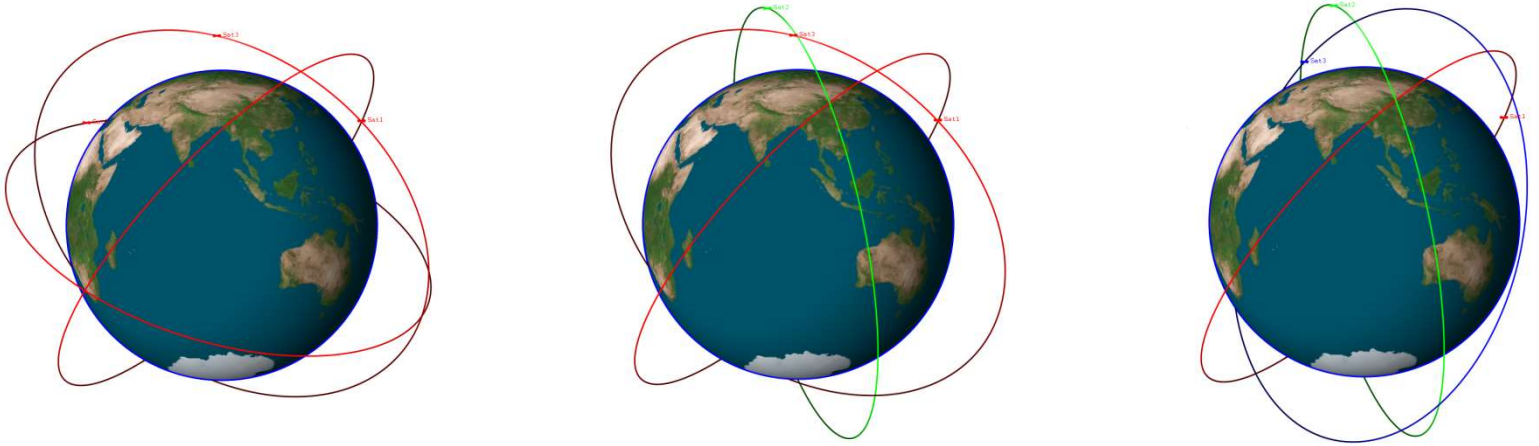


A brief tour of innovations within The Aerospace Corp's design workflow

Satellite Constellation Design Challenges

Launch image reprinted courtesy of NASA

- Problem Properties:
  - Near-term decisions impact future performance
  - Adaptive observations to capture periods of time key tradeoff decisions must be made
  - **Build-up → reconfiguration → replenishment** (dynamic & adaptive policy required)



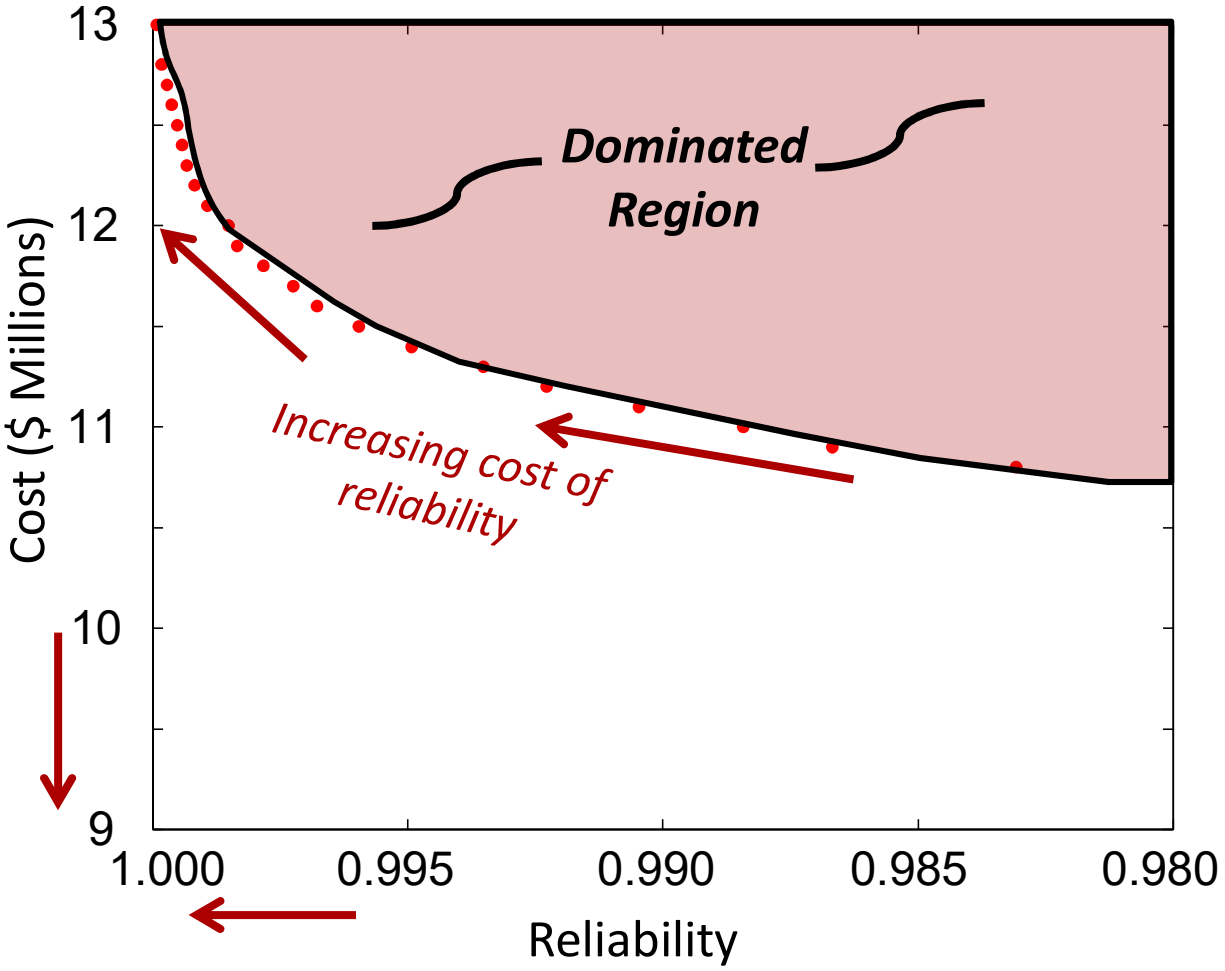
Current Constellation

Optimized Configuration in 2012

Optimized Configuration in 2018

Time

Looking for non-dominated solutions (tradeoff)

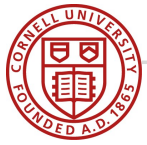


Kasprzyk et al. 2009

Multi-Objective Evolutionary Optimization

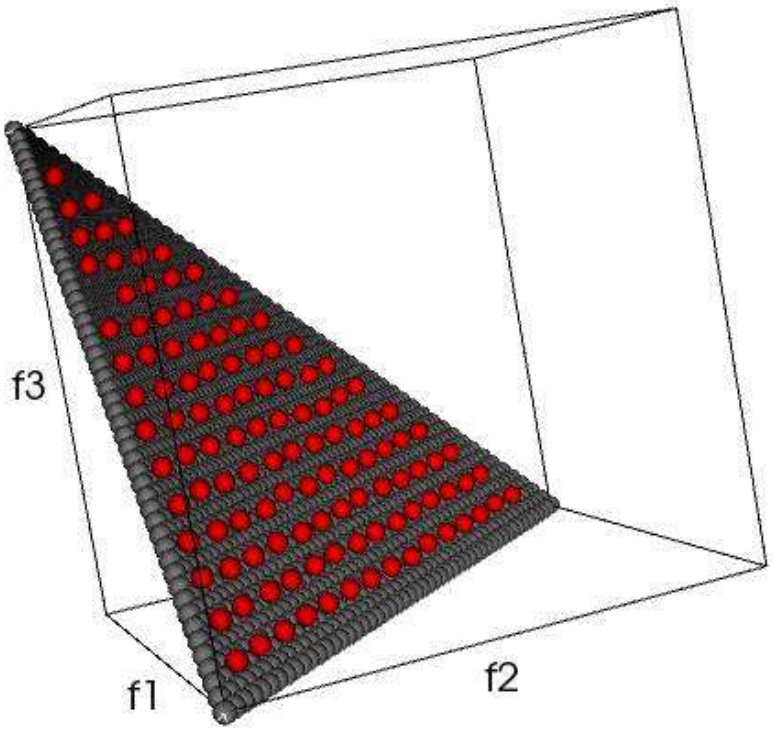
Heuristic method: flexibility for stochastic problems with unknown gradients

Search balances convergence and diversity



Multi-Objective Evolutionary Optimization

Three-objective Test Problem

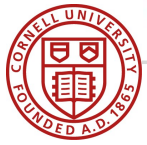


Heuristic method: flexibility for stochastic problems with unknown gradients

Search balances convergence and diversity

Borg MOEA: efficient, reliable performance broad range of applications

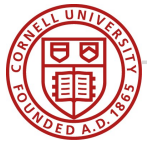
Reed, P.M., D. Hadka, J.D. Herman, J.R. Kasprzyk, and J.B. Kollat. 2013. Evolutionary Multiobjective Optimization in Water Resources: The Past, Present, and Future. *Advances in Water Resources*, 51, 438–456. [Invited Submission for 35th Anniversary Issue].



High-Performance Computing (HPC) enables us to answer questions in minutes instead of centuries for this example

Consequences of confining multi-billion dollar irreversible decisions to a laptop? Rational?

Reed, P.M. and Hadka, D., "Evolving Many-Objective Water Management to Exploit Exascale Computing", Water Resources Research, 50(10): 8367-8373.



Genetic Resources for Innovation & Problem Solving

Stakeholder Interviews

- Identify Design Parameters
- Identify Key Objectives
- Identify Constraints

Variables
Assumptions
Constants
...

Requirements
Goals
...

Application Program Interfacing (API)

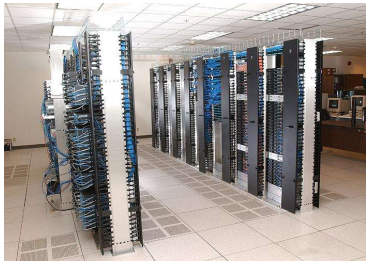
- Identify existing modeling tools
- Integrate with modeling tools through API
- Build new models if necessary
- Expose API to optimization tools

Design Parameters
Key Objectives
Constraints

Multi-Objective Optimization

Massively parallel search using multi-objective evolutionary algorithms (MOEAs)

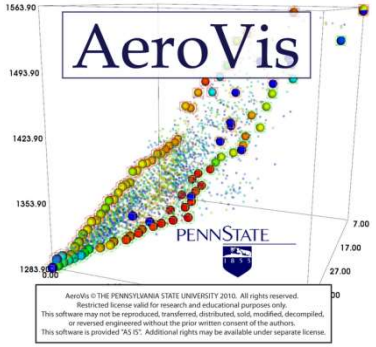
Borg MOEA for many-objective optimization



Explore, Visualize, Communicate

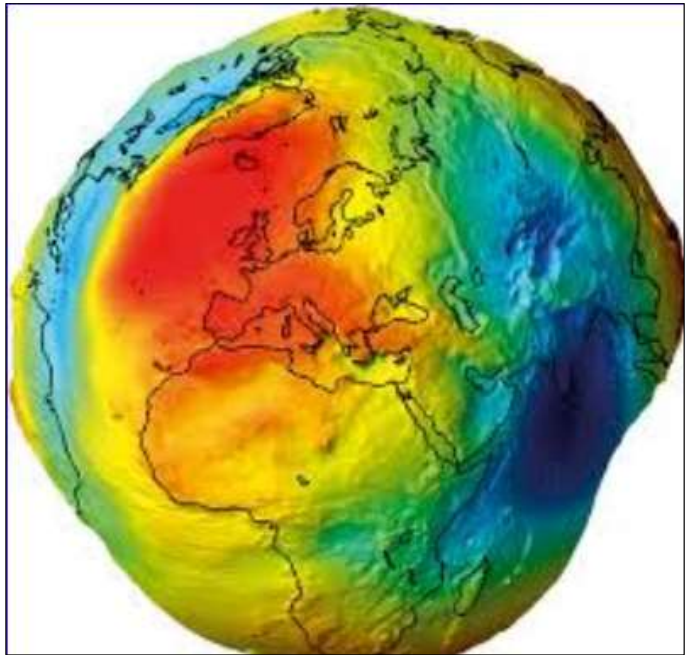
Watch designs "evolve" and identify key interactions between design parameters, objectives, and constraints

Provide an accessible visualization roadmap of key tradeoffs to Decision Maker



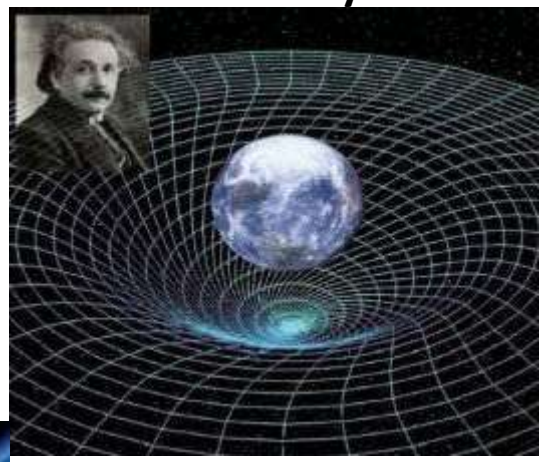
Big Consequences Hidden in Small Errors

Earth's Actual Mass Distribution



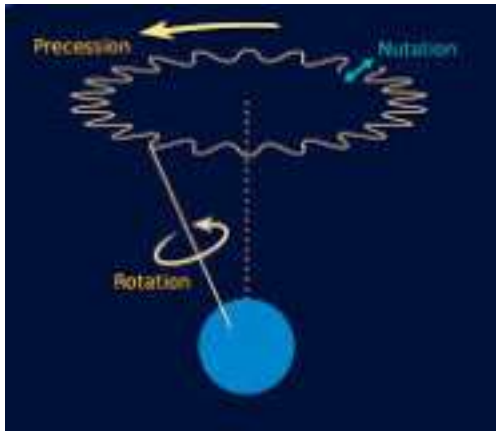
Tides

Relativity

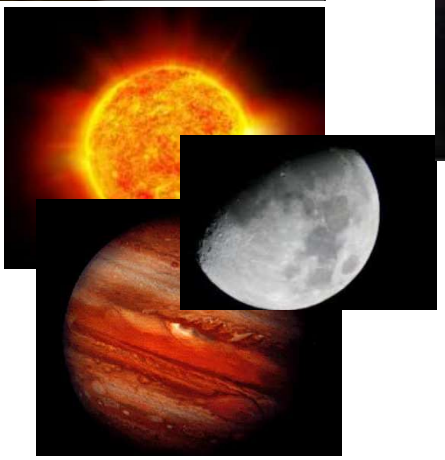


Drag

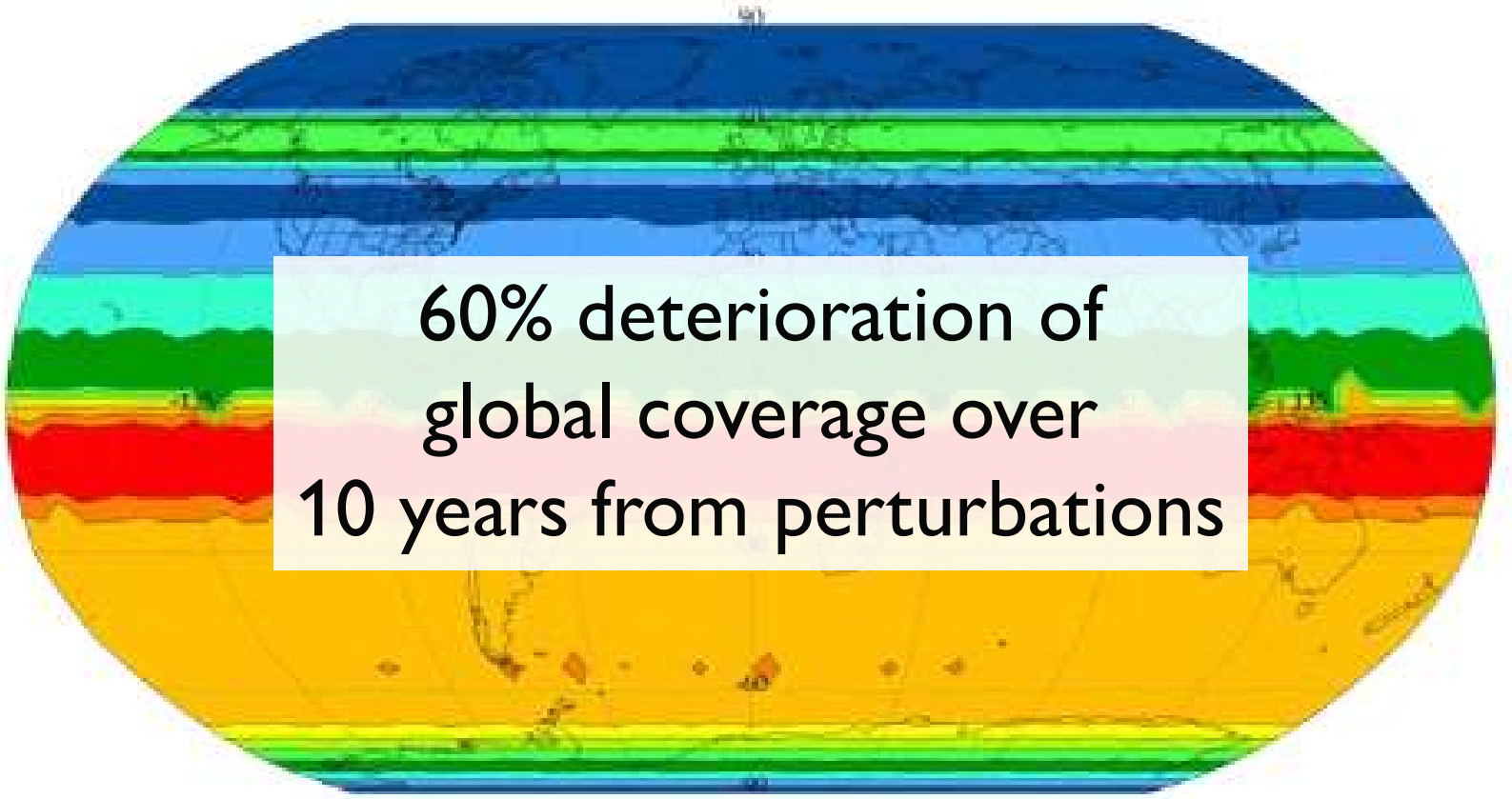
Nutation, precession



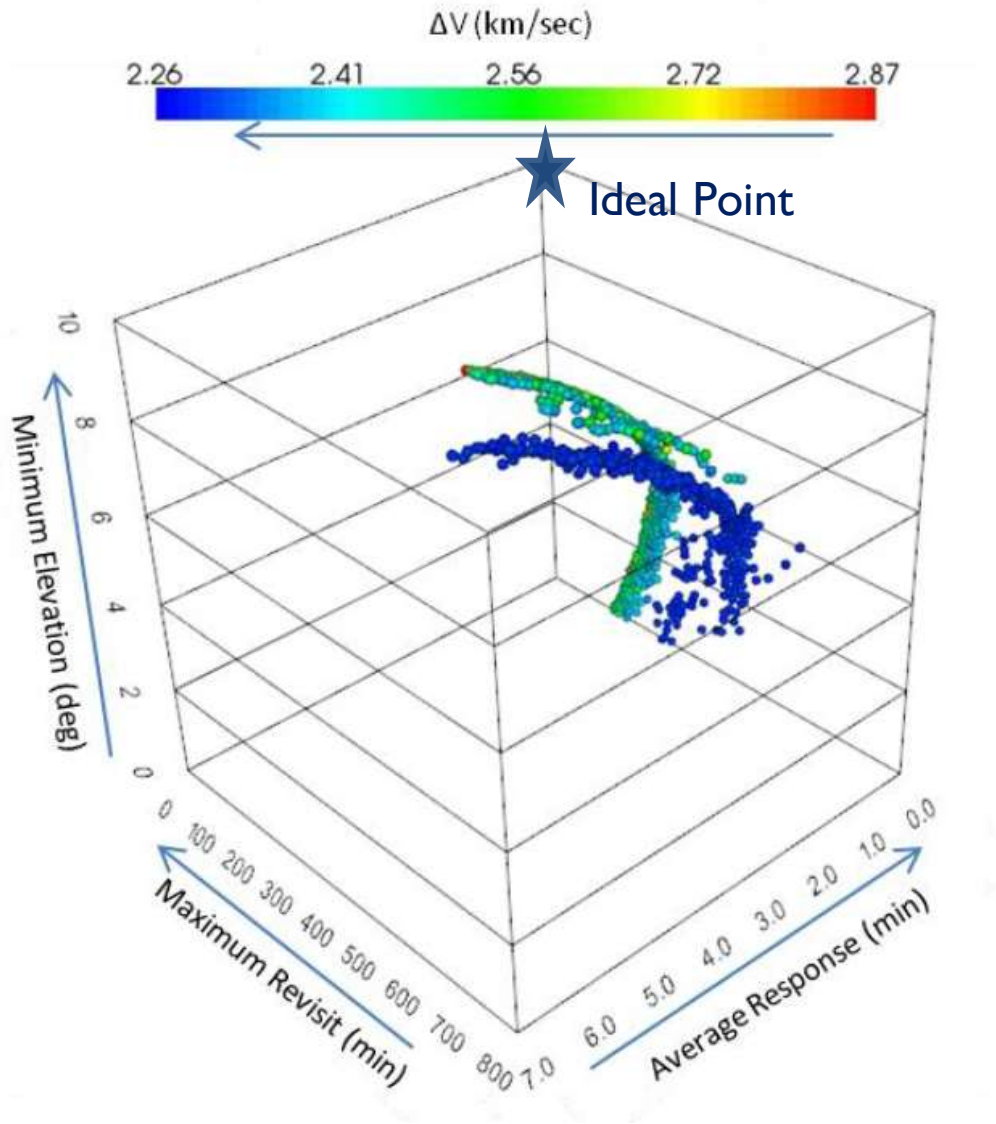
Third-body effects



Patented DRAIM 4 Satellite Global Coverage Results

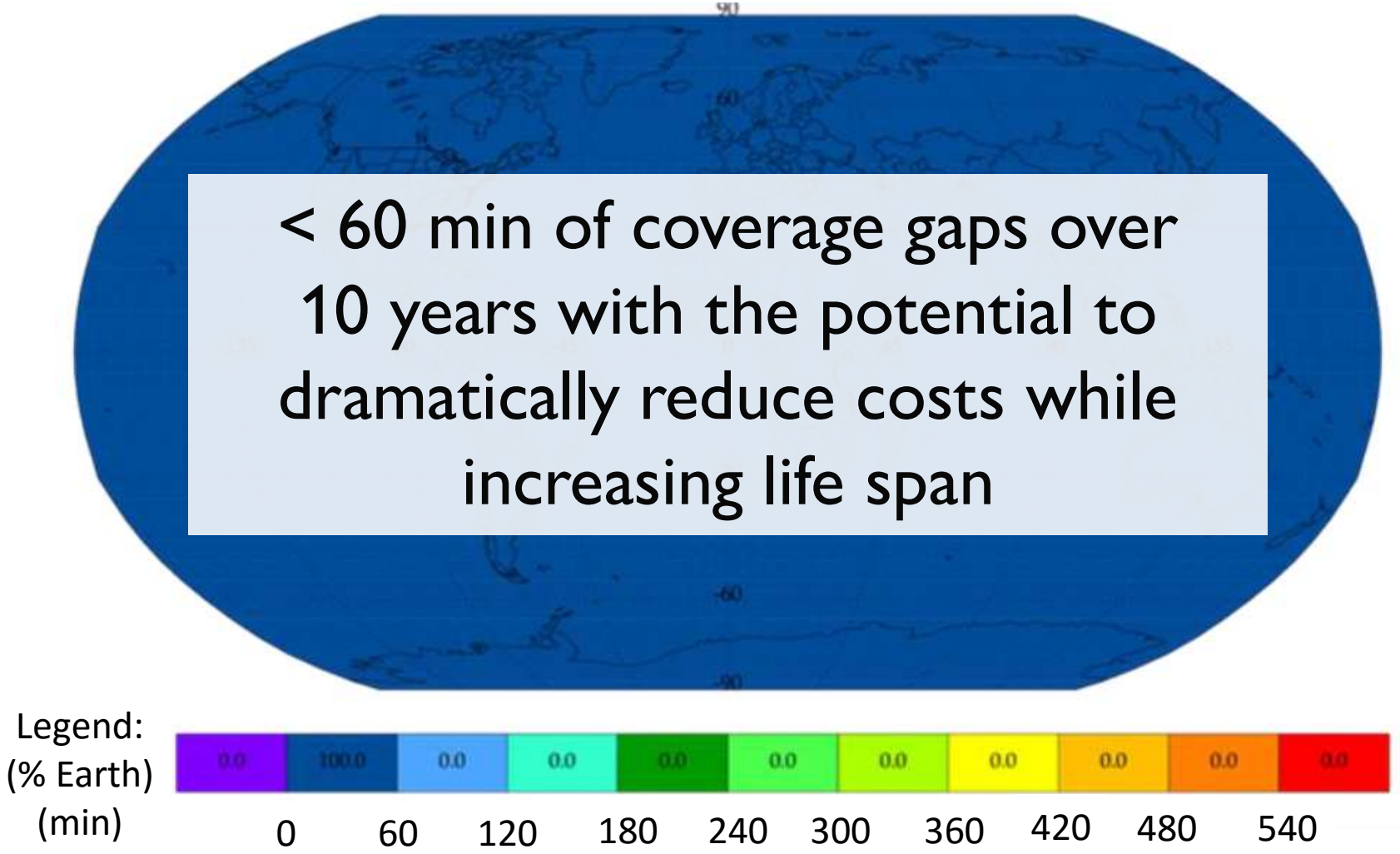


Example Tradeoffs When Exploiting Perturbations



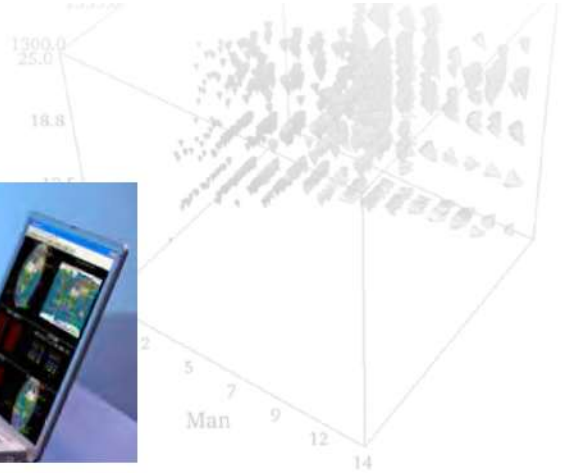
Discovered 4 Satellite Passive Control Results

< 60 min of coverage gaps over 10 years with the potential to dramatically reduce costs while increasing life span



Ferringer, M., M. DiPrinzio, T. Thompson, K. Hanifen, W. Whittecar, and P. Reed (2014), A Framework for the Discovery of Passive-Control, Minimum Energy Satellite Constellations, Space 2014 AIAA/AAS American Institute of Aeronautics and Astronautics, San Diego, CA.

From The Aerospace Corporation 2009 Annual Report*

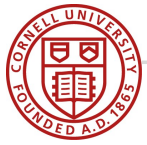


"GRIPS is currently being used in support of several National Reconnaissance Office programs within imagery intelligence and signal intelligence. As a result of the insights developed through GRIPS results, system-level specifications are being modified, and decisions that were made decades ago are being reconsidered."

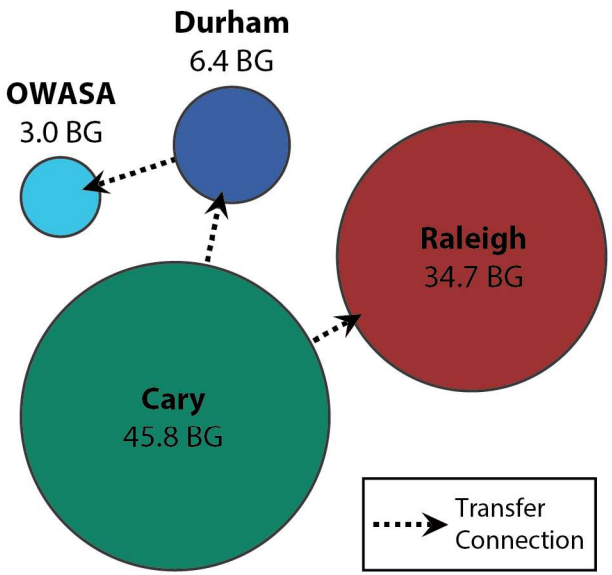
*Source: http://www.aero.org/corporation/AerospaceAR.pdf

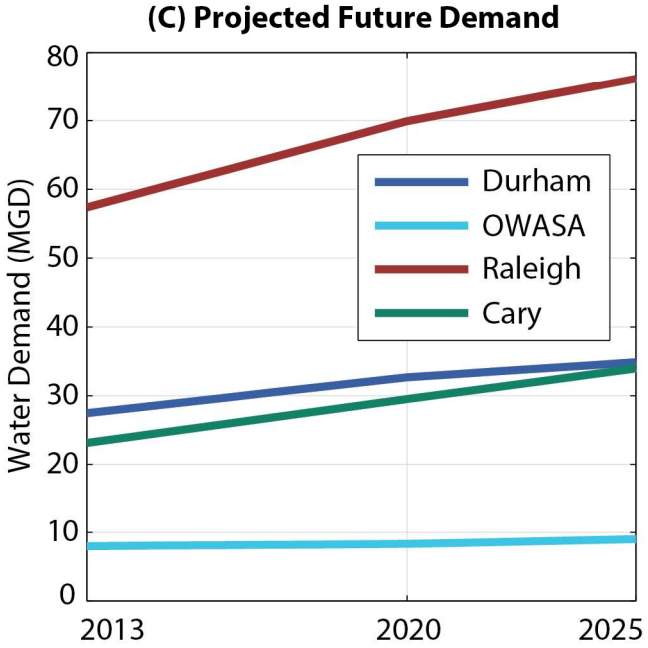
http://www.forbes.com

Balancing multi-stakeholder **“robustness tradeoffs”**, mixing dynamic ROF triggers & scalable search



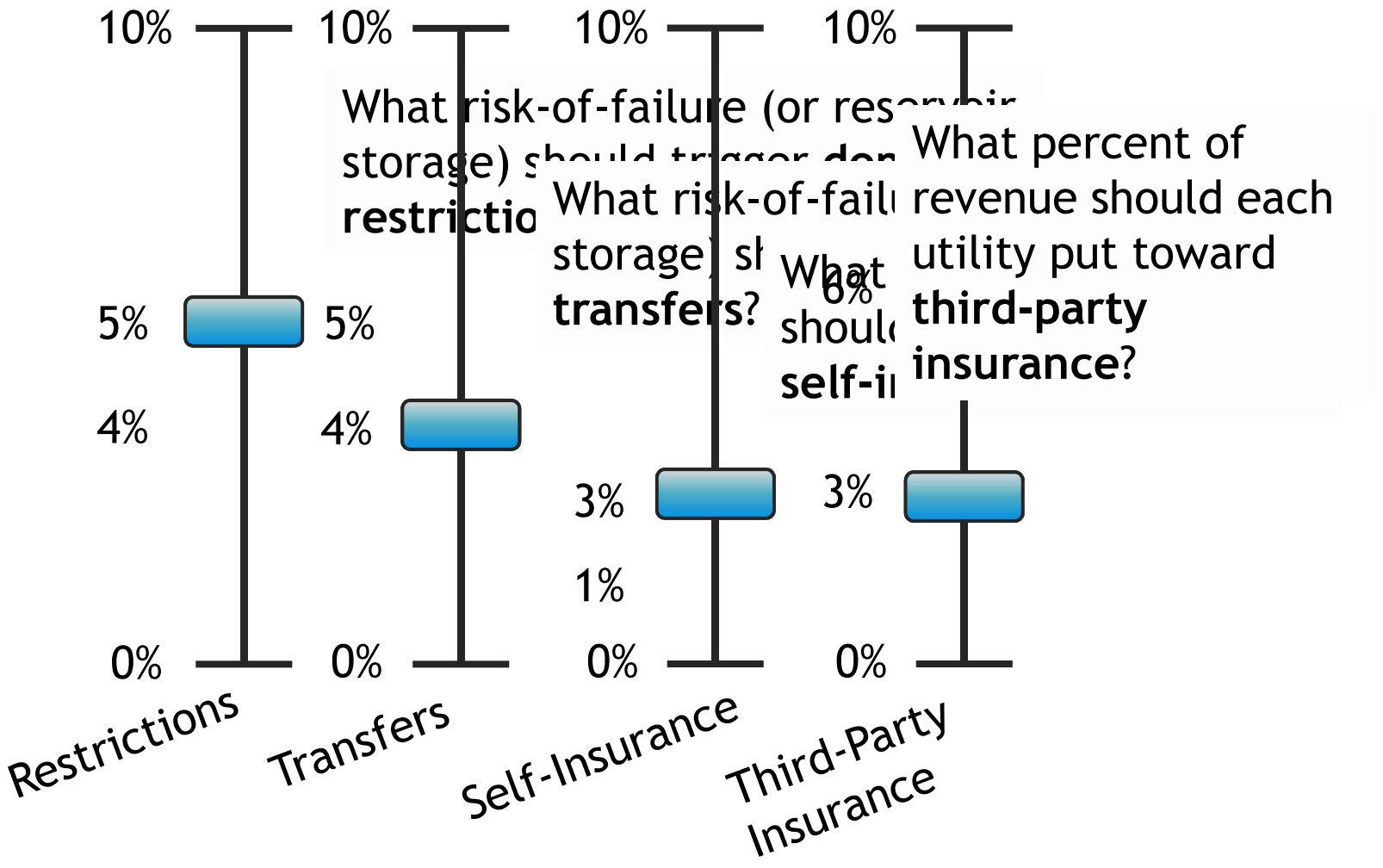
Overview of 'Research Triangle' Water Utilities: North Carolina, USA





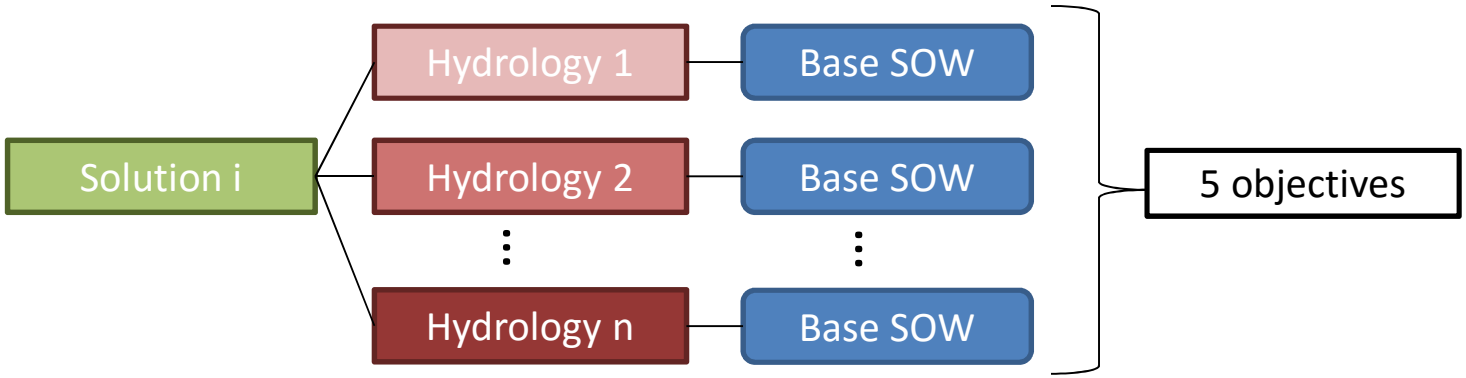
- Transition from water abundance to scarcity
- Storage/demand ratios allow intra-regional transfers

Each utility has four decision variables to model drought management actions



Well-Characterized Uncertainty Optimization

(WCU optimization)



Five objectives defined by the utilities

Reliability (Max): # years where reservoir storage > 20%

Percent Jordan Lake Allocation (Min): % exploited regionally

Restriction Frequency (Min):

years with drought conservation measures enacted

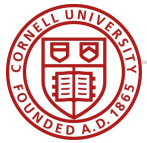
Average Financial Losses (Min):

Revenue reductions + costs due to drought management

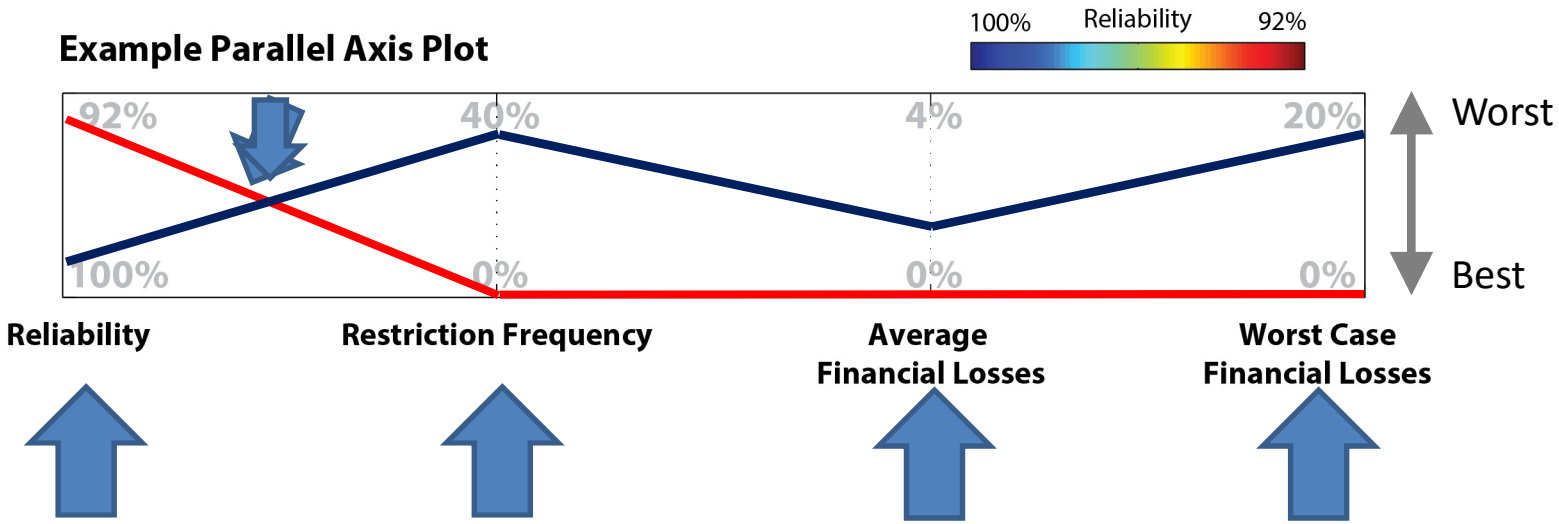
Worst-Case Financial Losses (Min):

Financial losses in the 1% worst scenario

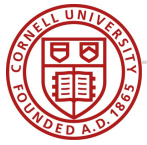
The worst-performing utility is optimized such that others will perform as well or better.

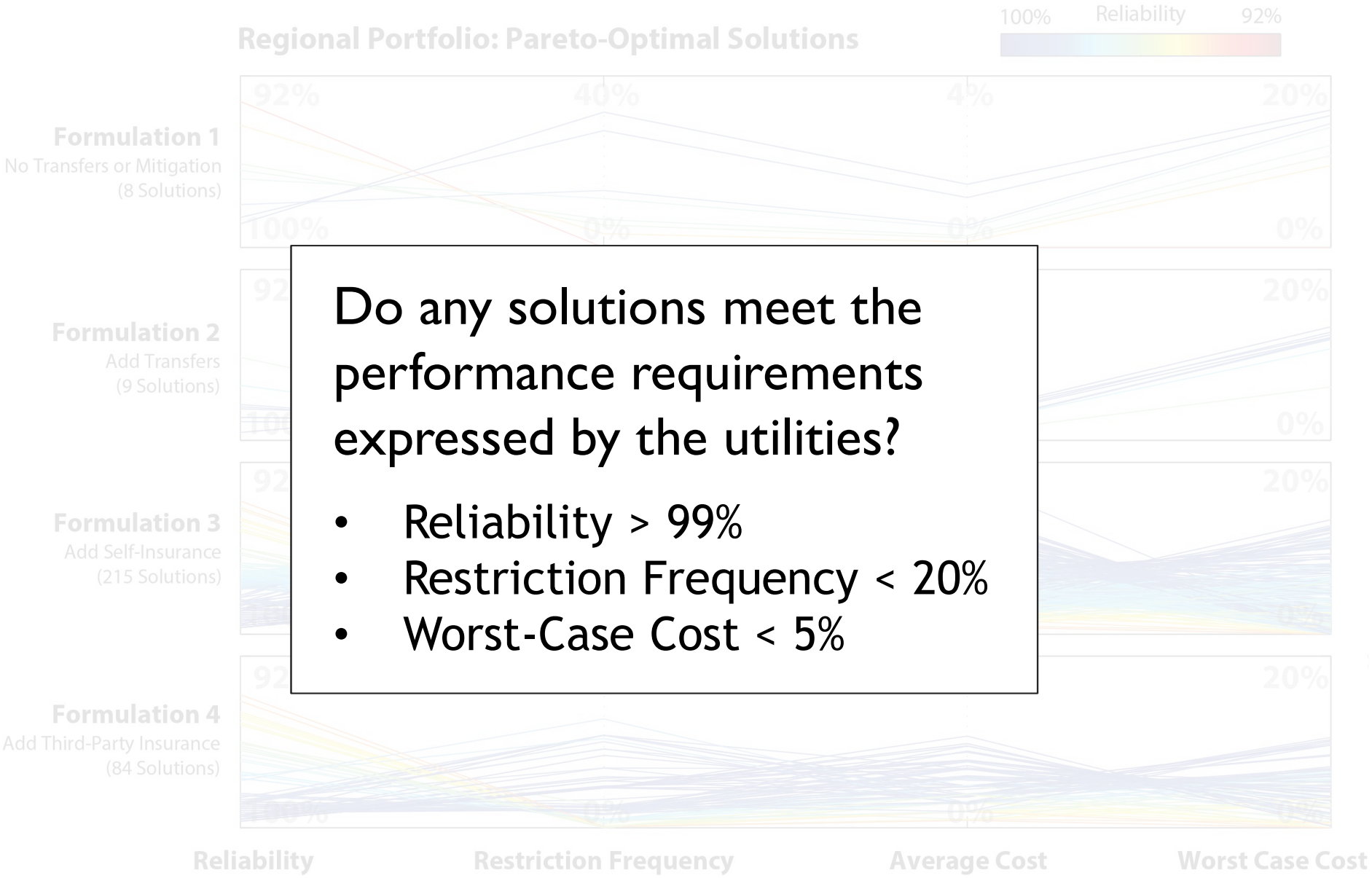


Parallel axis plots help stakeholders visualize tradeoffs between conflicting objectives



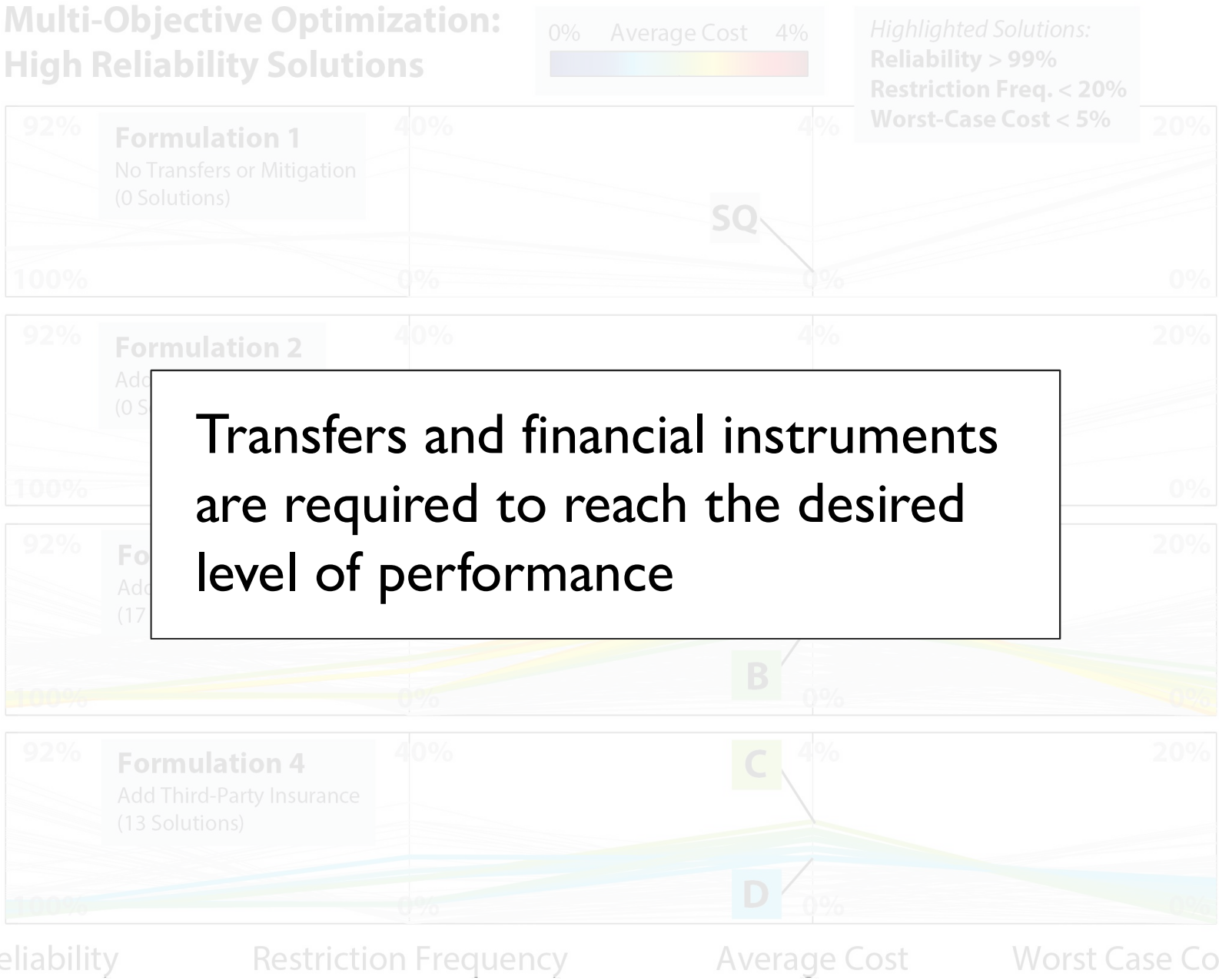
- Each line represents one solution
- X-Axis shows the four objectives to be optimized
- Y-Axis shows the objective value (performance)
- Crossing lines indicate tradeoffs





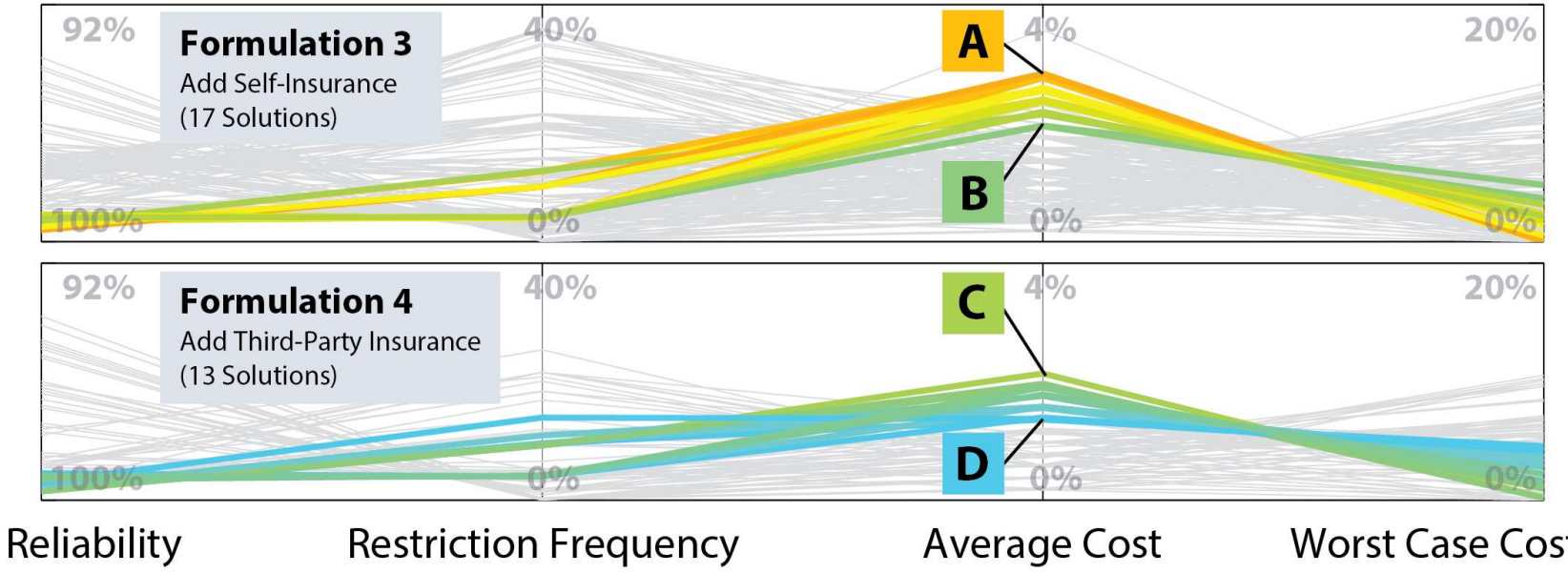
Do any solutions meet the performance requirements expressed by the utilities?

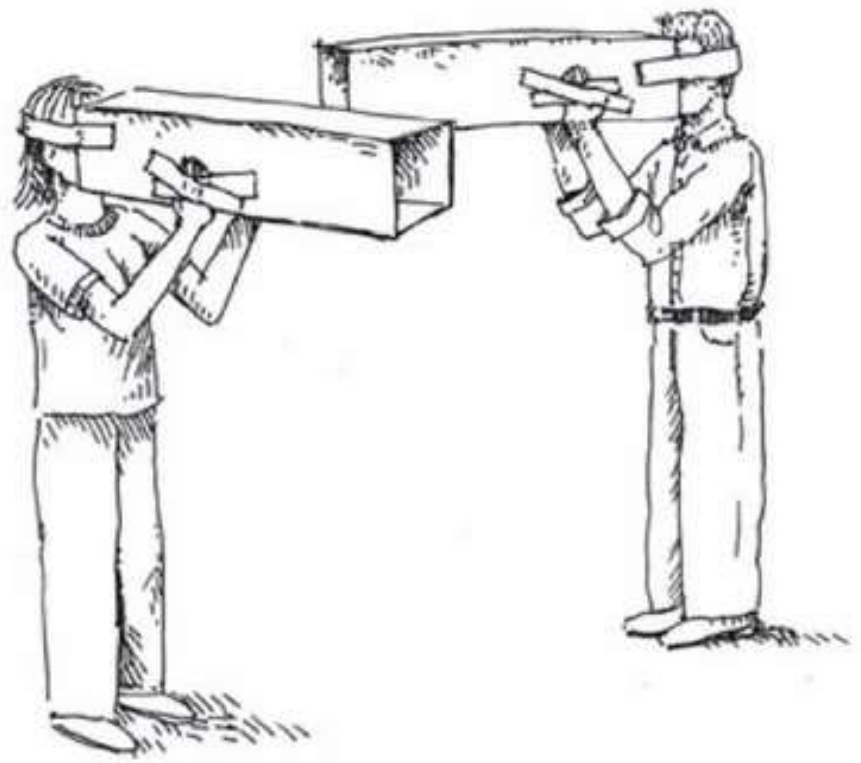
- Reliability > 99%
- Restriction Frequency < 20%
- Worst-Case Cost < 5%



Transfers and financial instruments are required to reach the desired level of performance

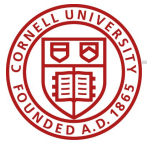
Are these preferred tradeoff solutions "robust"?





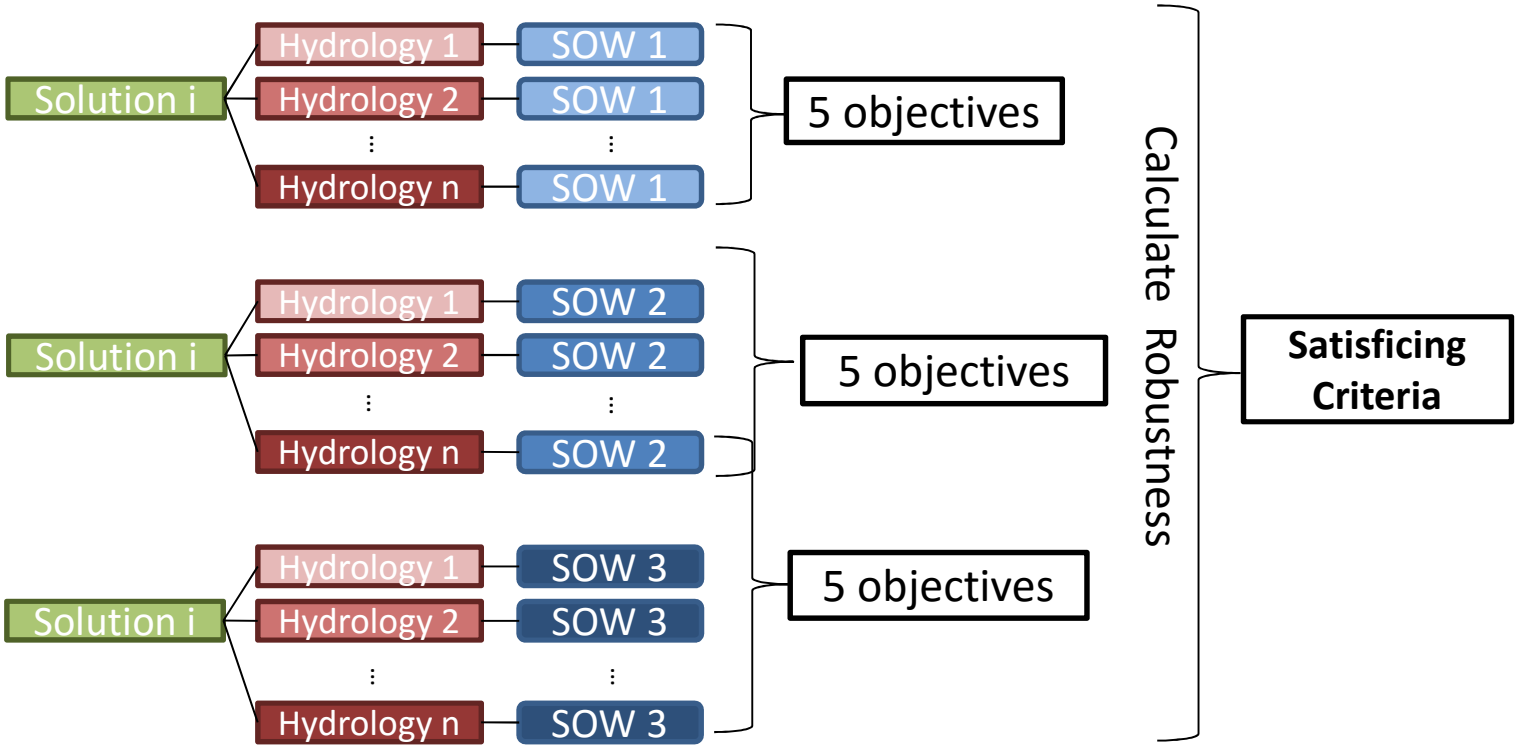
http://www.hockscqc.com/articles/tunnelvision/tunnel-vision.jpg

We've discovered the WCU optimization's *tradeoffs*—but what are the *vulnerabilities* if we're we're wrong about the future?



How does performance vary across 10,000 alternative Monte Carlo worlds?

(DU evaluation)

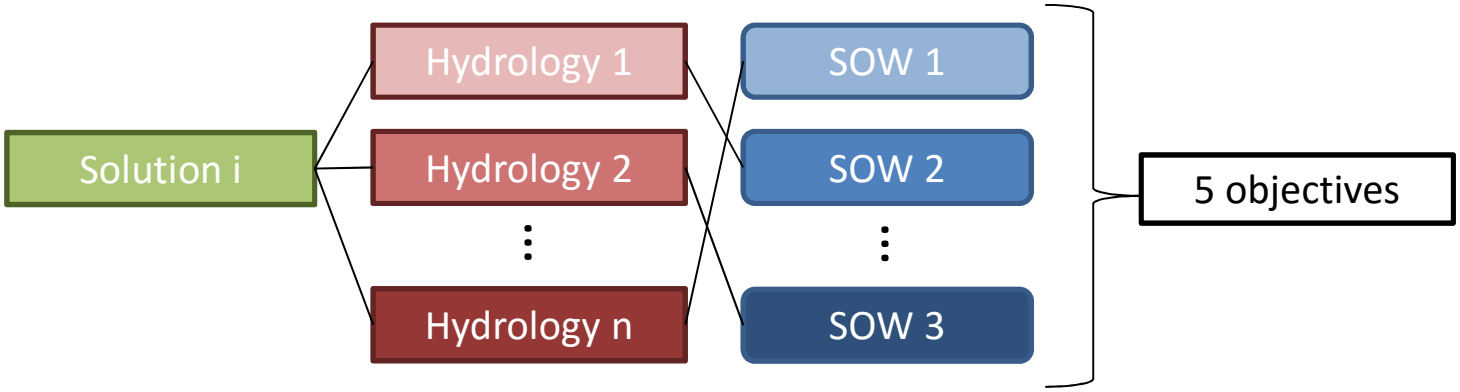


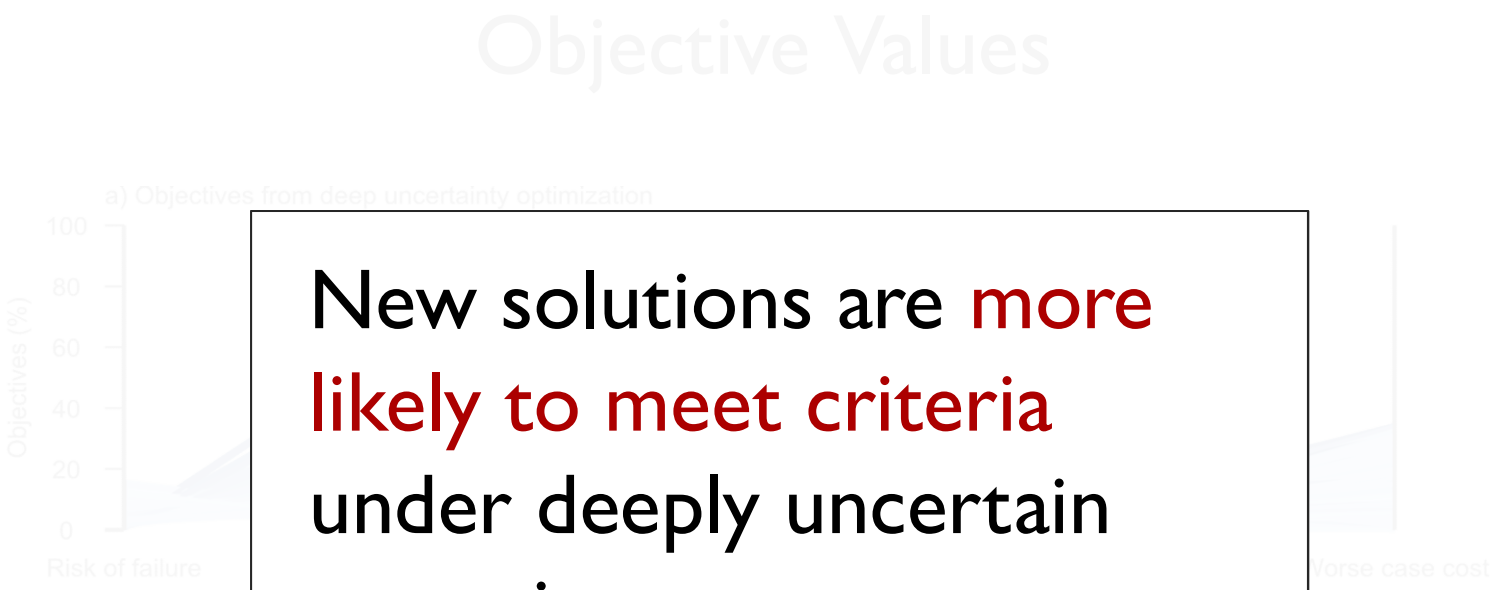
Robustness of solutions from well-characterized optimization

The originally projected "optimal" solutions are not robust for key stakeholders. Can we improve this regionally? Individually? How?

Will search across the deeply uncertain SOWs improve robustness?

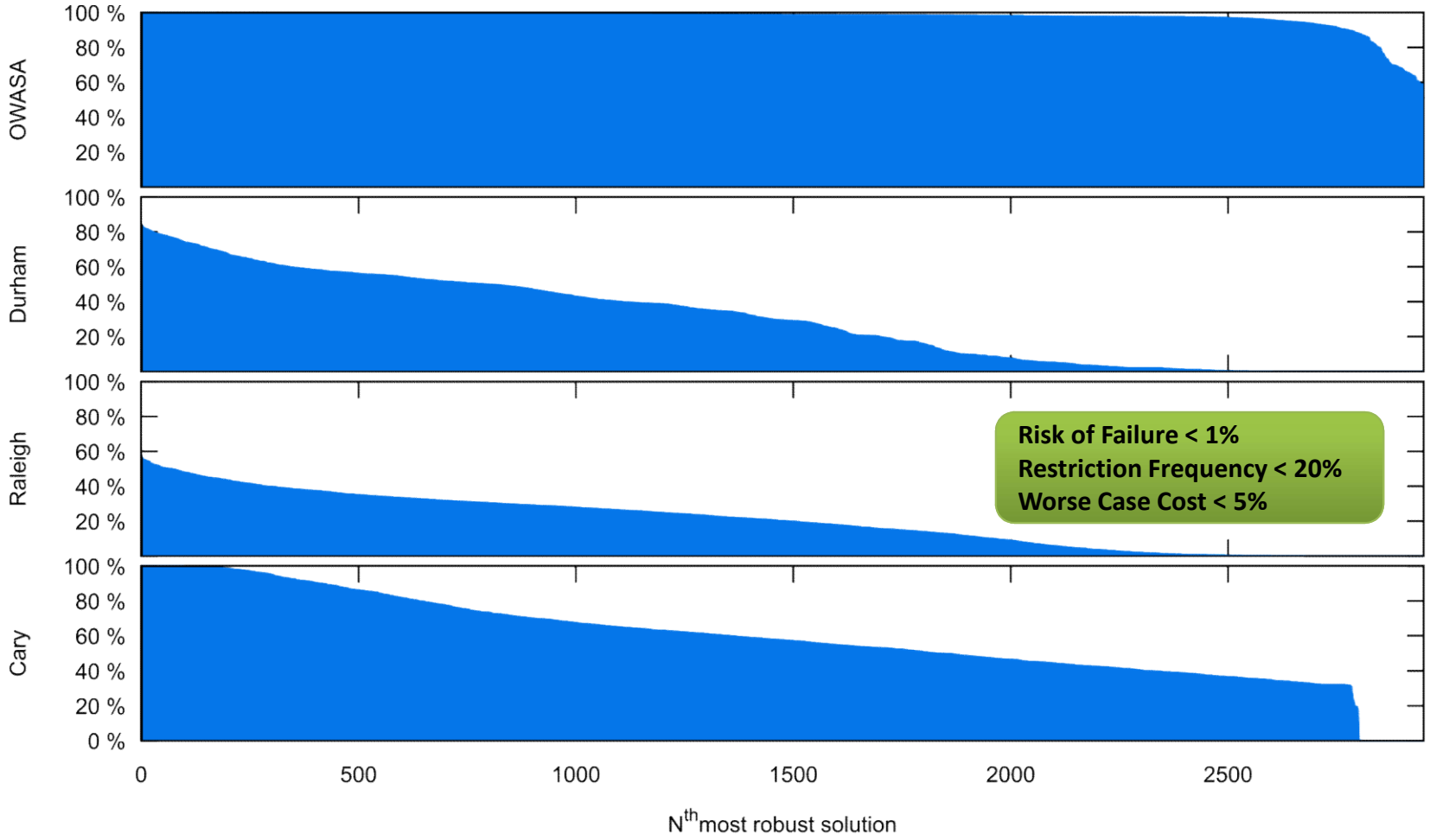
(DU optimization)

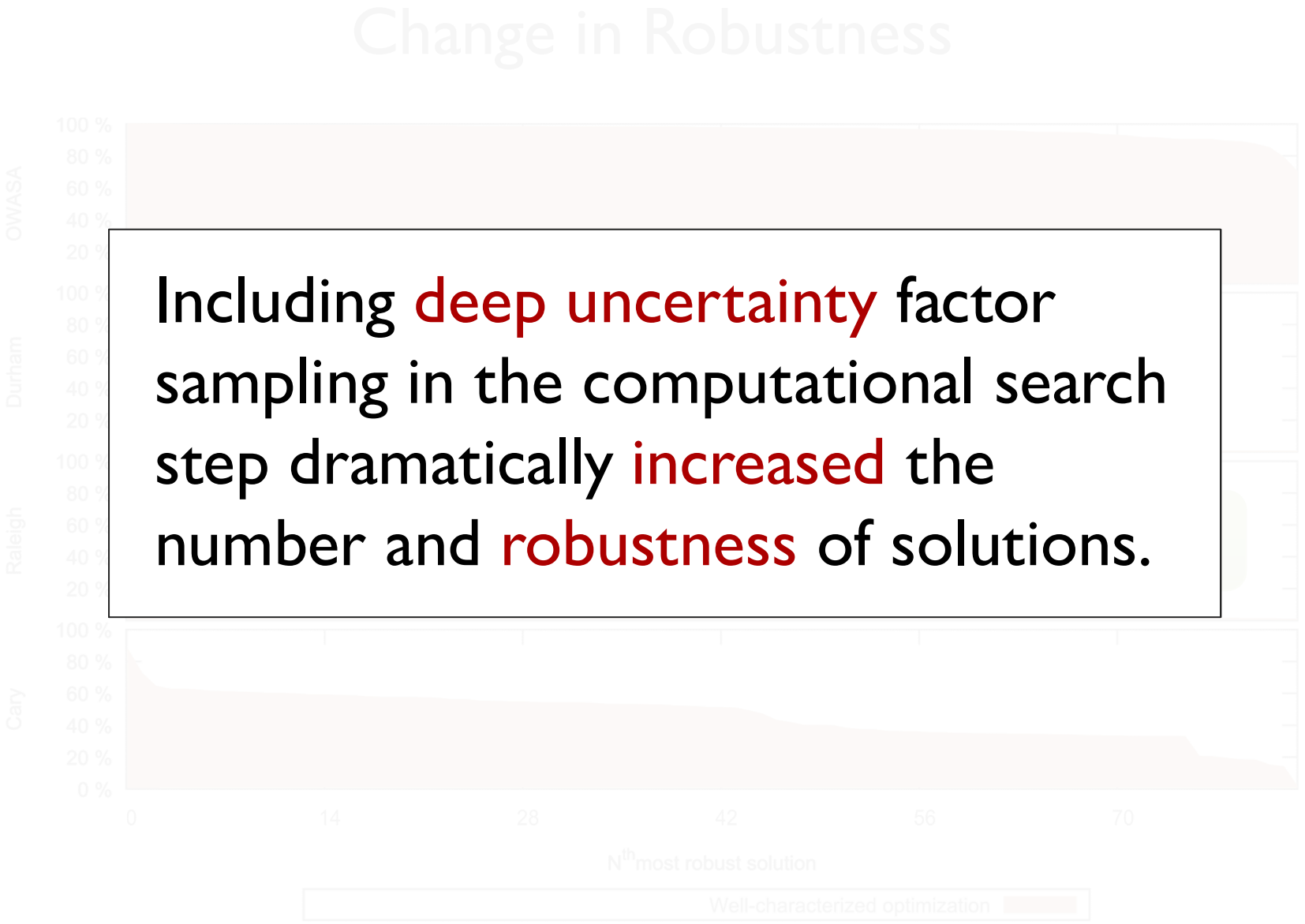




New solutions are more likely to meet criteria under deeply uncertain scenarios.

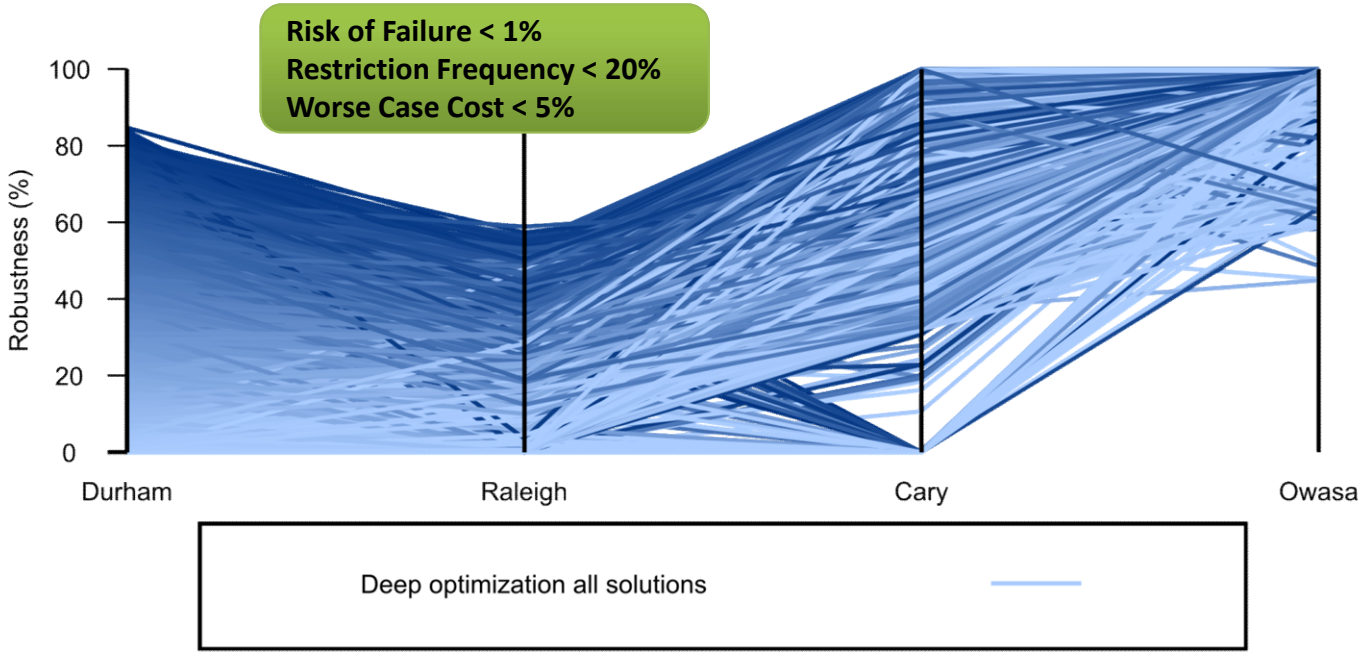
Robustness of solutions from deep optimization



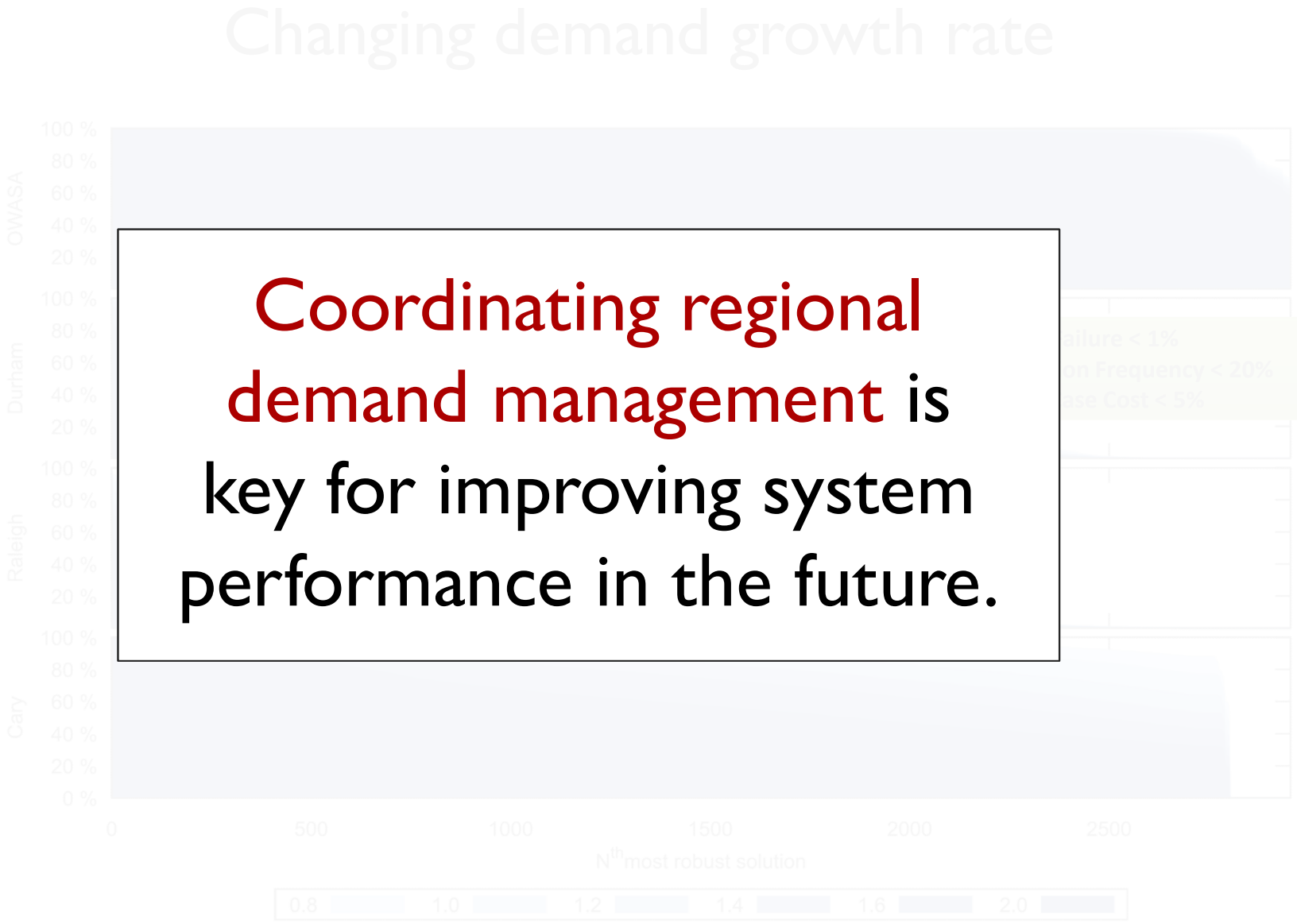


Including deep uncertainty factor sampling in the computational search step dramatically increased the number and robustness of solutions.

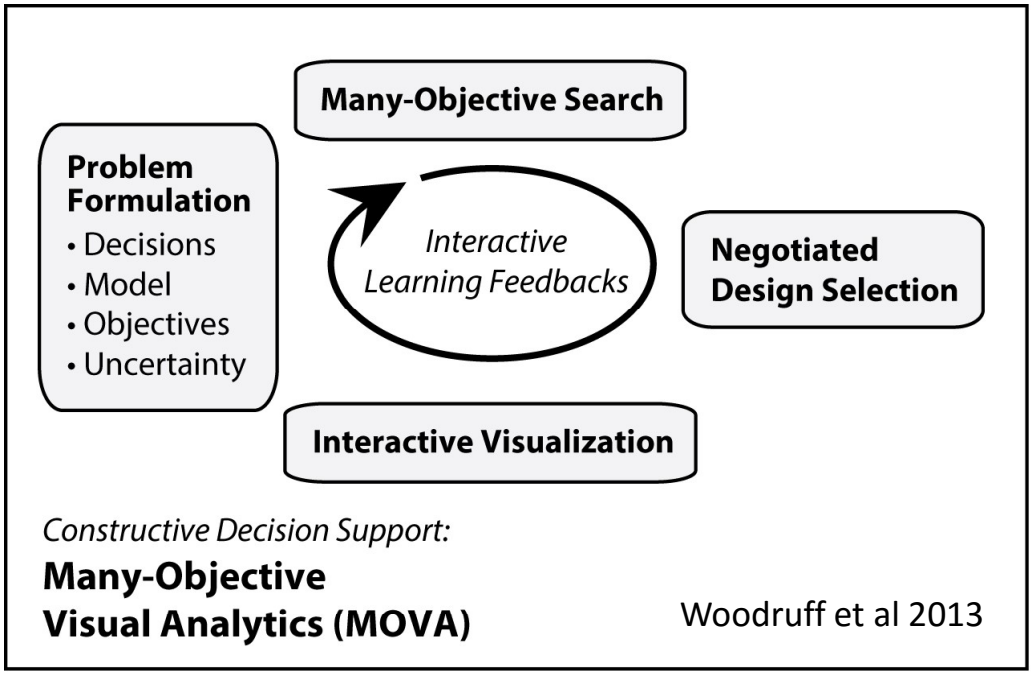
Balancing Robustness Conflicts



Moving from Light to Dark Blue designates increasing regional demand management



Coordinating regional demand management is key for improving system performance in the future.



Constructive Decision Support:

Many-Objective Visual Analytics (MOVA)

Woodruff et al 2013

To summarize:

(1) Rapidly explore multiple competing problem formulations (hypotheses)

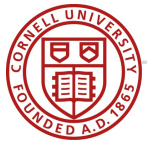
(2) Facilitate learning and visual tradeoff analysis

(3) Ensure decisions and monitoring recommendations are robust to many futures

Summation

(1) Ex #1: The Aerospace Corp: Institutional change required scalable software integration of elicitation, modeling, and MO decision making feedbacks

(2) Ex #2: The Research Triangle: MO search can be critical for increasing "robustness" and negotiating multi-stakeholder "robustness conflicts" given complex portfolios of highly adaptive decision options



Questions?

(1) Ex #1: The Aerospace Corp: Institutional change required scalable software integration of elicitation, modeling, and MO decision making feedbacks

(2) Ex #2: The Research Triangle: MO search can be critical for increasing "robustness" and negotiating multi-stakeholder "robustness conflicts" given complex portfolios of highly adaptive decision options