# Chance-Constrained Optimization for Critical Infrastructure Protection

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## Purpose, Approach, and Goal

**Motivation**
CC models: How to make highly reliable decisions under uncertainty, with controlled risk?

**Challenges:**
- CC models are computationally intractable
- Existing algorithms not scalable to practical sized problems

**Key goal:**
Solution of large scale CC models


CC : A natural and impactful modeling choice for securing infrastructure

## Key R&D Results and Significance

- **Summary:**

1. Design of a theoretical scheme to approximate CC optimization models
2. Demonstrate the importance of CC optimization on a power system network

- **The result for the one key goal:**

Proven the importance of this new mathematical technique to securing critical infrastructure, via an electricity network

- **Lessons Learned**

Development of a general algorithm for CC optimization is challenging and requires more investment

- **Follow-on plans/activities**

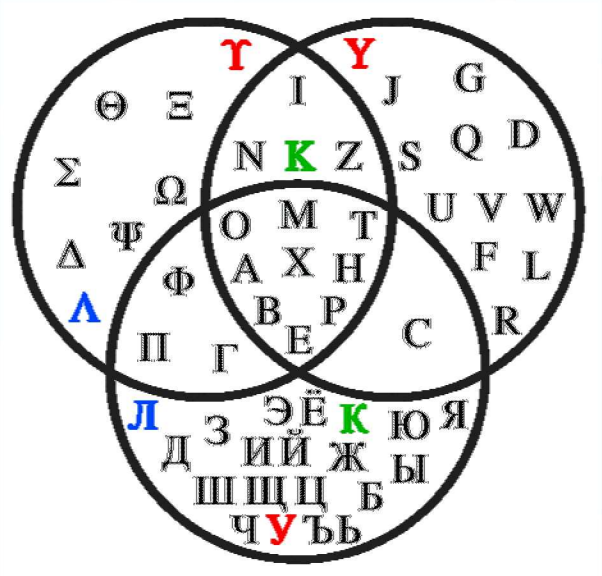
Seek investment for furthering goal of developing general CC solvers

- **Publications, awards, staff development & IP**
- Bismark Singh, Jean-Paul Watson. "*Approximating Two-Stage Chance-Constrained Programs with Classical Probability Bounds*". In second review.
- Bismark Singh, Bernard Knueven, Jean-Paul Watson. "*A Chance Constrained Model for Stochastic Unit Commitment*". In review.
- Competitive Travel Award by: EURO WG on Stochastic Modelling: 6 recipients worldwide

# Theoretical Accomplishment

Bismark Singh, Jean-Paul Watson. "*Approximating Two-Stage Chance-Constrained Programs with Classical Probability Bounds*". In second review.

- *Success*: New scheme to develop theoretical bounds on a CC problem.



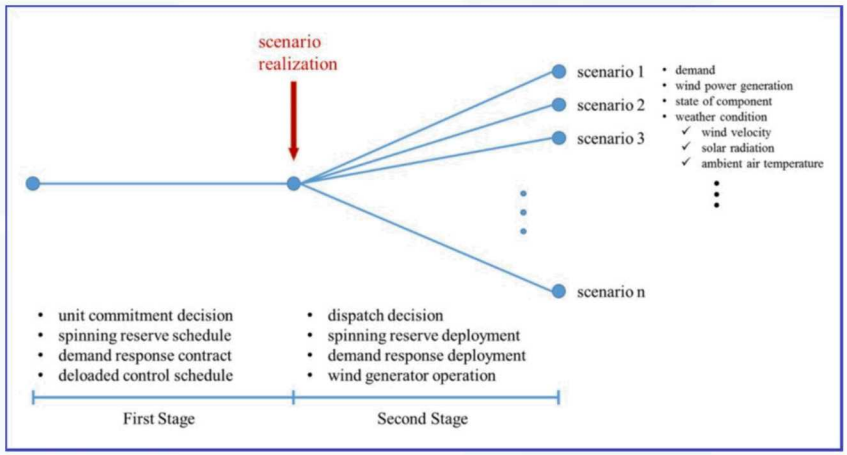
Key idea:
a CC can be expressed as a union of events, and we can approximate this union.
Prior research did this only for the relatively tractable "one-stage" CC models

*To do*: Apply to a practical problem.

# Practical Accomplishment

Bismark Singh, Bernard Knueven, Jean-Paul Watson. "*A Chance Constrained Model for Stochastic Unit Commitment*". In review.

- *Success*: Demonstration of applications of CC to a critical national security problem – electricity power systems.




Key idea:
by explicitly acknowledging that generators can run a bit over their prescribed ratings, we can save billions of dollars a year. Prior research has not acknowledged this.

*To do*: Theoretical advances for faster computational times.

Stochastic Unit Commitment: a well studied optimization problem

# Project Metrics

- Publications
  - Bismark Singh, Jean-Paul Watson. "*Approximating Two-Stage Chance-Constrained Programs with Classical Probability Bounds*". In second review. SAND number: 842501
  - Bismark Singh, Bernard Knueven, Jean-Paul Watson. "*A Chance Constrained Model for Stochastic Unit Commitment*". In review. SAND number: 865314
  - Indirectly related:
    - Bismark Singh, David Pozo. " *A Guide to Solar Power Forecasting using ARMA Models*". arXiv:1809.03574 . SAND2018-10030 J
    - Bismark Singh, Steffen Rebennack, and Oleg Prokopyev. "*Two-Stage Stochastic Minimum s-t Cut Problems: Formulations and Complexity*". In review. SAND number: 842541
- Key Presentations
  - Department of Industrial Engineering, University of Pittsburgh, 2018
  - International Symposium on Mathematical Programming (ISMP), Bordeaux, 2018
  - Conference on Computational Management Science, Faculty of Economics, Norwegian University of Science and Technology , 2018
- Staff development
  - Bismark Singh, postdoc, supported by this grant
- Awards
  - Competitive Travel Award by: EURO WG on Stochastic Modelling: 6 recipients worldwide

# Project Legacy

*Key technical accomplishment*

- With a small investment, we have made a stab at solving CC optimization models
- Two peer-reviewed articles under review in recognized operations research journals

*How does this engage Sandia missions?*

- With use of our models, government planners can
  - Cost-effectively design national security infrastructure
  - Plan for "what-if" scenarios following system failure

*Plans for follow-on and partnerships?*

- Broad impact on R&D efforts related to power grid planning and resiliency, funded by agencies ranging from DOE/OE, DOE/EERE, DOE/FE, and DOE/ARPA-E.
- Leveraging Sandia's HPC facilities to rigorously secure electrical grids, natural gas networks, and transportation infrastructure
- *Ultimate goal:*First generic solution of this extremely difficult, challenging, and vital decision problem

# Significance for Sandia and/or the Broader Technical Community

Small investment with large potential gains:

- Extends Sandia's leadership in large scale stochastic optimization
- Provides crucial knowledge to infrastructure planners
- Yields new Pyomo capabilities: CC modeling and solution

## Summary Justification

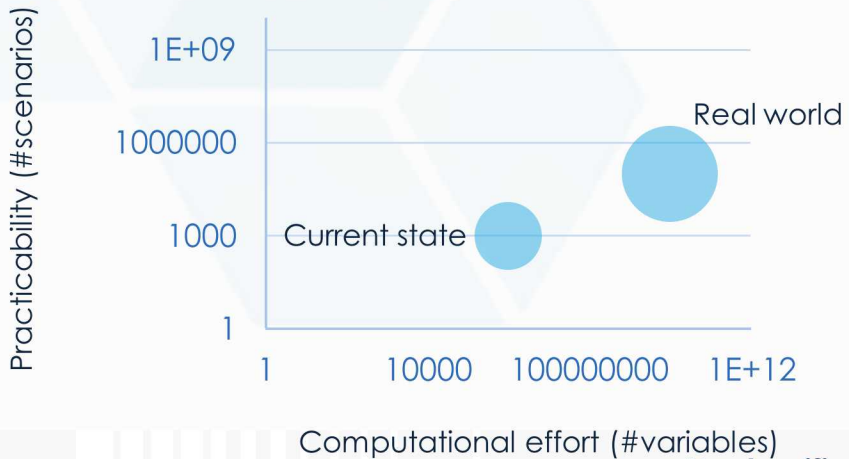
CC optimization is the natural choice for modeling reliability and resiliency of national infrastructure. This is an *open* and challenging problem to the optimization community and presents Sandia an opportunity to be the *first* to solve such problems at scale.

# Appendix: Chance Constraints (CC): Importance

**Motivation**: A natural and impactful modeling choice for securing infrastructure


CC models: How to make highly reliable decisions under uncertainty, with controlled risk?

**Challenge**: A known NP-hard problem




But… CC models are computationally intractable

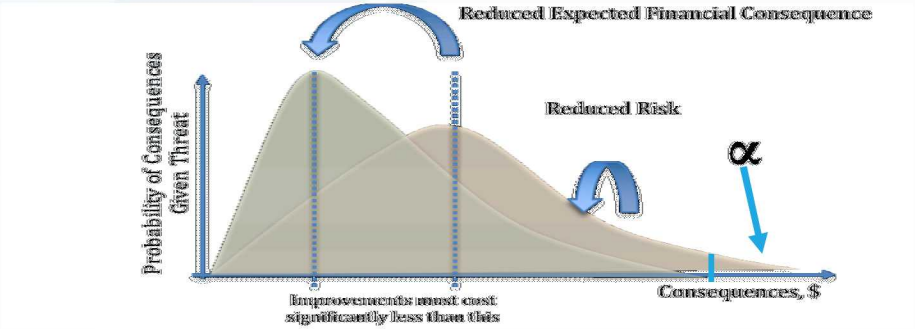
Existing algorithms not scalable to practical sized problems

# Appendix: Stochastic Optimization

Stochastic optimization enables decision making under uncertainty; we approximate uncertainty by sampling finitely many possible future scenarios, i.e., realizations of parameters

## Chance-Constrained (CC) Optimization:

- Subclass of stochastic optimization
- How to safeguard against *most* future scenarios?
  - End users specify their risk threshold $\alpha$




Key Idea in CC Optimization:
Protecting against any future outcome costs infinite money. So, control for risk and allow failure in some scenarios.

A tradeoff in **Risk** versus **Cost**

**Driver Application:** A resilient electrical grid protected