Assessing Power Distribution Resilience Hardening Effectiveness Using Combined Physics-Based and Data-Driven Modeling

William Hughes¹, Peter Watson², Diego Cerrai¹, Wei Zhang¹, Amvrossios Bagtzoglou¹, Emmanouil Anagnostou¹

¹University of Connecticut Department of Civil and Environmental Engineering
²Los Alamos National Laboratory

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Damage Modeling and Disaster Mitigation Lab - DM2L
Motivation

• **Problem**: To reduce storm-related power outages, utility companies invest large sums of money in grid maintenance.

• It is hard to quantitatively estimate the effects *and* cost benefit analysis of grid hardening to inform effective actions.
Methods

Solution: Create a dynamic weather damage model also sensitive to different infrastructural characteristics. Combines:

● *Machine learning* outage prediction models
● *Structural analysis* of the pole-wire system
Structural Modeling

- Generate **fragility** scores to predict pole failure probability from structural models
- Based on detailed infrastructure characteristics (age, pole class, conductor size, etc.)
Outage Prediction Model

- **Machine learning model** trained on historic storm and outage data
- Case study of state of Connecticut over past 16 years

Variables Including:

**Weather**
- Wind
- Temperature
- Precipitation

**Vegetation**
- Leaf area
- Trimming

**Topographic**
- Elevation
- Soil
- Land cover

**Infrastructure**
- Line length
- Asset counts
- Structural fragility
The Flow of Information

Infrastructure Data → Vegetation Data → Aggregate to Circuit → Machine Learning → Outage Predictions and Cost-Benefit

- Infrastructure Data
- Vegetation Data
- Physics Simulations
- Structural fragility
- Weather Predictions
- Weather Data
- Machine Learning
- Hardening
Model Results and Sensitivity

Cross Validation Results

Model has Reasonable Accuracy

Predicts outages within 50% error

Canopy Coverage

The Variables have Intuitive Dynamics

We can force the model with representative hardening scenarios

Structural Fragility
Grid Hardening

• **Simulate hardening scenarios** by altering related variables

Percent outage reduction (left) and reductions per investment (right) for different strategies
Results

- Interactions between and effectiveness of different strategy combinations
Spatial Effects

- Reveal **differential benefits** and highlight **vulnerable regions**

Outages reduced (left) and cost-effectiveness (right) under 10% hardening
Prioritization

- Prioritize investments under constrained budgets

Optimal spending for tree removal under varying budget

Reduced outages against budget
Summary and Conclusions

• **Outage prediction model** developed combining physics-based and machine learning models for resilience assessment

• Model demonstrates reasonable accuracy and variable sensitivities

• **Grid hardening benefits** are simulated to develop prioritized under limited budgets

• Future efforts can extend to include outage durations and affected customers considering different social and economic consequences

• Provisional patent in works for commercialization and utility use
Thank you!

Questions?

william.hughes@uconn.edu
manos@uconn.edu
eversource.uconn.edu

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