Electric Power System Performance in Natural Hazards

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## Research Overview

| Q1. How many outages will there be and where? | Dominion, Duke, Progress, Southern | Hurricanes Ice storms |
| Q2. When will power be restored in each area? | Dominion, Duke, Progress, Southern LADWP | Hurricanes Ice storms Earthquakes |
| Q3. How fast is possible? How would that be achieved? | LADWP | Earthquakes |
| Q4. How much does tree trimming affect outage frequency? | Duke | Non-storm times |
Q1. How many outages will there be and where?

Method

- Overlaid all data in GIS
- Found values in each grid cell
- Fit statistical models to relate number of outages to system, land, storm characteristics

Outages
Transformers
Wind speed
Duration
Rainfall
Ice thickness
Land cover
Soil drainage
Soil depth
Statistical Models

1. Poisson generalized linear model (GLM)
   \[ y \sim \text{Poisson}(\mu) \quad \ln(\mu) = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n \]
   Like regression but when \( Y \) is count data

2. Negative binomial model
   Like (1), but different assumption about distribution of counts (\( Y \))

3. Poisson generalized linear mixed model (GLMM)
   Like (1), but different assumption about errors

4. Spatial Poisson GLMM
   Like (3) but include spatial correlation b/t outages
Q1. How many outages will there be and where?

As storm approaches, apply model to get for each area unit:

Potential Uses
- Estimate overall impact of storm
- Help determine how many tree and line crews to deploy and where

Expected number of outages by zip code
Q2. When will power be restored in each area?

Method
- GIS overlay to get data for each outage (instead of grid cell)
- Fit statistical survival analysis models to relate outage durations to system, land, storm characteristics
  - Accelerated failure time (AFT)  \( \ln(T) = \mathbf{x} \beta + \varepsilon \)
  - Cox proportional hazard (CPH)  \( h(t, \mathbf{x}, \beta) = h(t) \exp(\mathbf{x} \beta) \)
    Like regression but for time (nonnegative, possibly censored data)
- Simulate from outage duration to restoration time
  - Estimate covariate values for each outage
  - Apply model to get expected outage duration
  - Calculate outage finish time
  - Find time at which X% of customers in area are restored
Q2. When will power be restored in each area?

Discrete event simulation (EQs, LADWP)

As events take place, variable values get updated. By tracking variable values as we step through time, we simulate process. Task durations and amount of repair material are random variables. Final restoration time is uncertain. Repeat process 100 times to get a pdf on restoration time.
Q2. When will power be restored in each area?

Potential Uses
- Tell customers expected restoration time
- Explore ways to speed up restoration
- Estimate economic, social loss from outages

Adequacy of resources

- 95% of customers restored
- 90% of customers restored
- 75% of customers restored
- 50% of customers restored
**Q3. How fast is possible? How can that be achieved?**

**Method**

- Build optimization models (genetic algorithms) to minimize $\text{SAIDI}_{eq}$ by changing:
  - Inspection, damage assessment, repair schedules
  - Number, locations of different crew types
- Compare current and optimization-generated restoration strategies using restoration simulation model

\[ \text{SAIDI}_{EQ} = \text{Area above curve} = \text{avg. time each cust. is w/o power} \]
Q3. How fast is possible? How can that be achieved?

Potential Uses
- Assess how fast is fast enough
- Determine if there’s a way to speed restoration
Q4. How much does tree trimming affect outage frequency?

**Method**
- Statistical modeling like for outage counts but by circuit

**Output**
- Estimate change in number of outages given change in tree trimming frequency
- Identify which circuits would result in greatest outage reduction

**Potential uses**
- Determine best tree trimming frequency
- Prioritize circuits for trimming
Possible Future Research

- Build on work related to same 4 questions, especially outage count and restoration
- Move from outage to damage estimation
- Merge tree and outage modeling
- Use discrete event simulation for storms
- Do long-term analysis of outages and outage durations
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Relevant Publications

- Liu, H., and Davidson, R. Statistical estimation of electric power restoration times in hurricanes and ice storms, in preparation.