Electric Power System Performance in Natural Hazards

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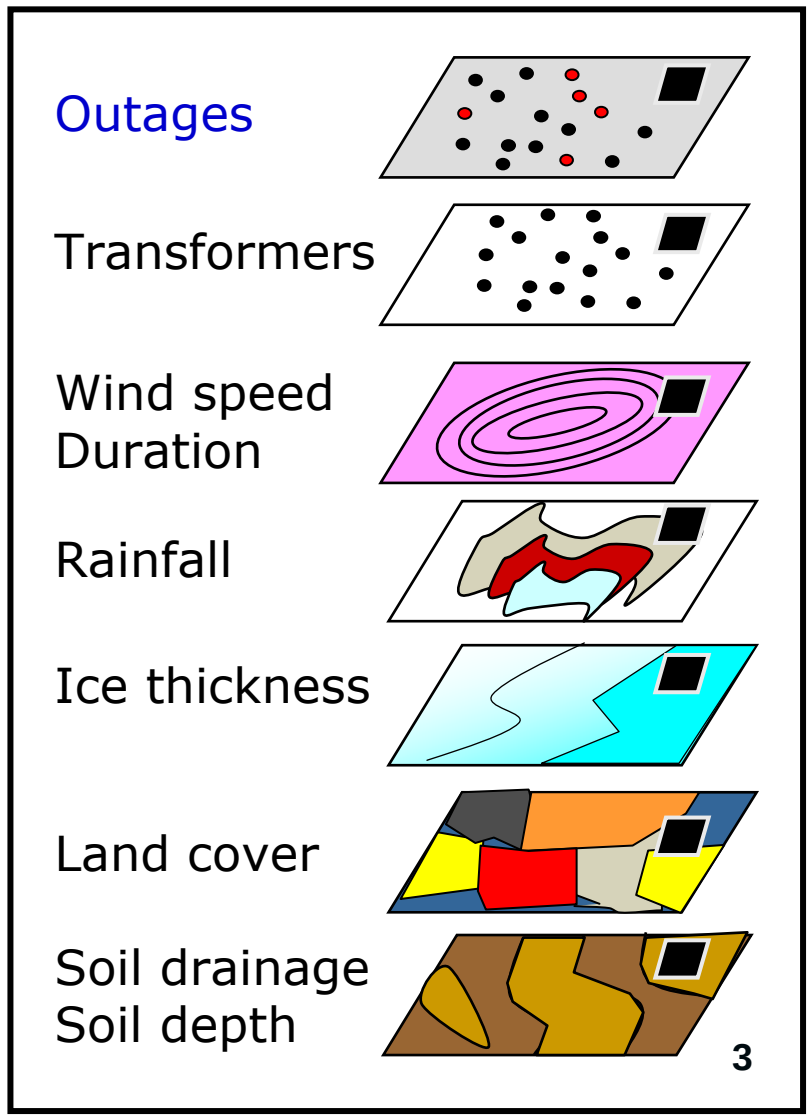
Research Overview

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



Statistical Models

1. Poisson generalized linear model (GLM)

   $y \sim \text{Poisson}(\mu)$ $\quad\quad$ $\ln(\mu) = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n$

   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)

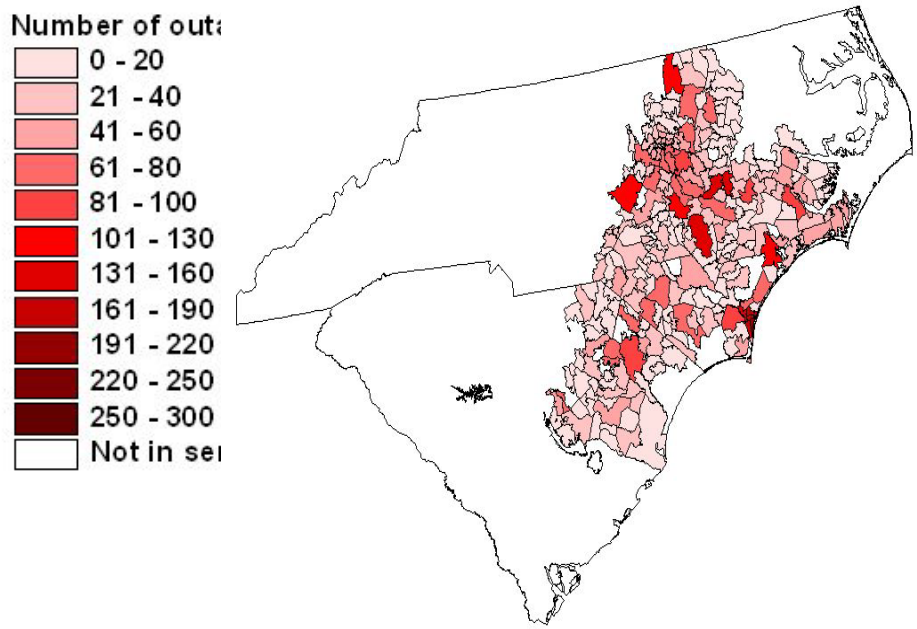
   Like (1), but different assumption about errors

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:



Expected number of outages by zip code

Potential Uses

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

Q2. When will power be restored in each area?

Method

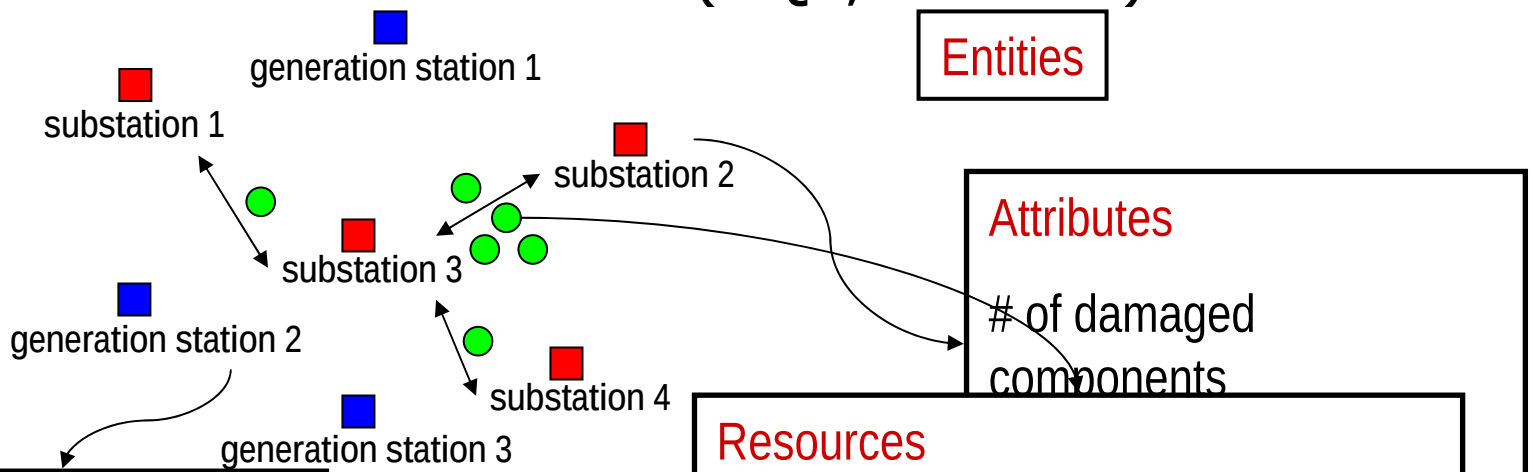
- GIS overlay to get data for each outage (instead of grid cell)
- Fit statistical survival analysis models to relate outage durations to system, land, storm characteristics
  - Accelerated failure time (AFT) $\ln(T)=\mathbf{x}\beta + \varepsilon$
  - Cox proportional hazard (CPH) $h(t,x,\beta)=h(t)\exp(\mathbf{x}\beta)$

    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)



Entities

Attributes

# of damaged components

Resources

Events

Inspection

Damage assessment

Repair

Reenergizing

Attributes

Type of station

Distance to epicenter

Critical restart time limits

Global va

Status of

earthqu

Duration

Repair material of different types

As events take place, variable values get updated.

By tracking variable values as we step through time, we simulate process.

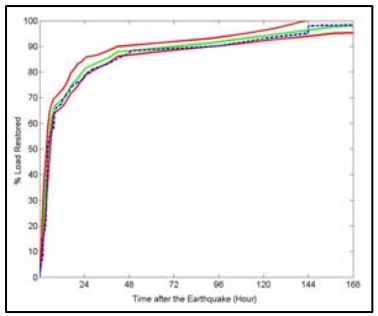
Task durations and amount of repair material are random variables

→Final restoration time is uncertain.

→Repeat process 100 times to get a pdf of restoration time.

Q2. When will power be restored in each area?

A



% customers restored

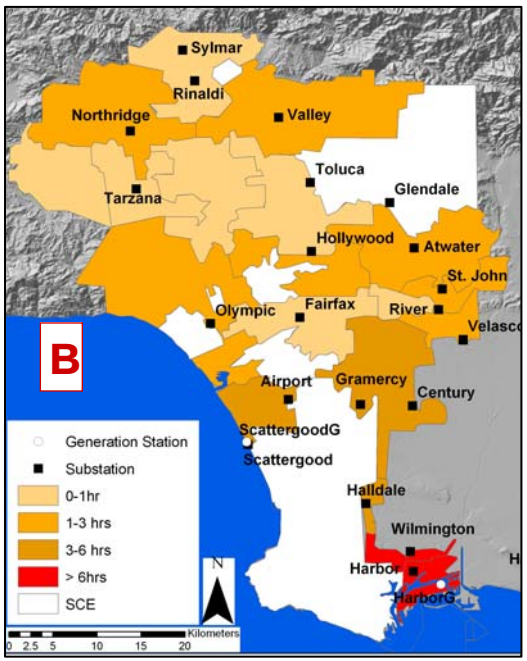
Time

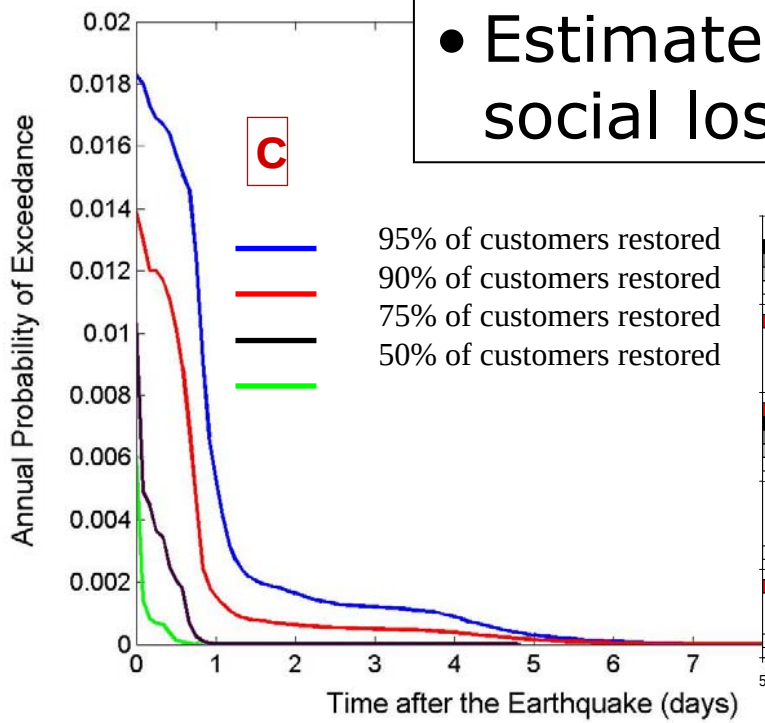
E

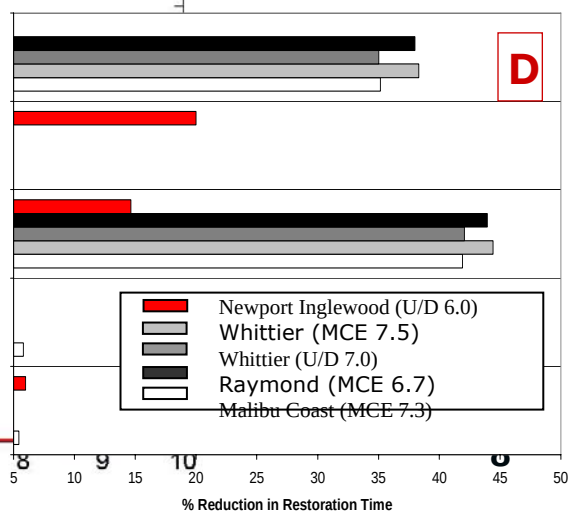
Adequacy of resources

Potential Uses

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



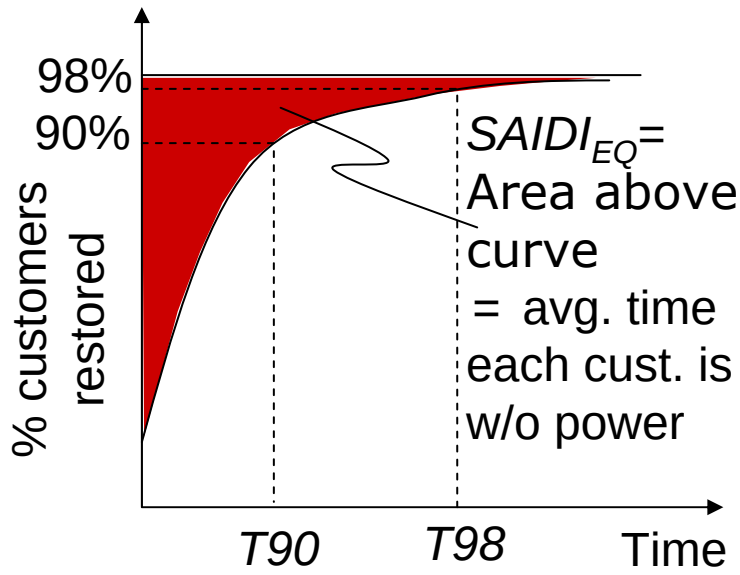




Q3. How fast is possible? How can that be achieved?

Method

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



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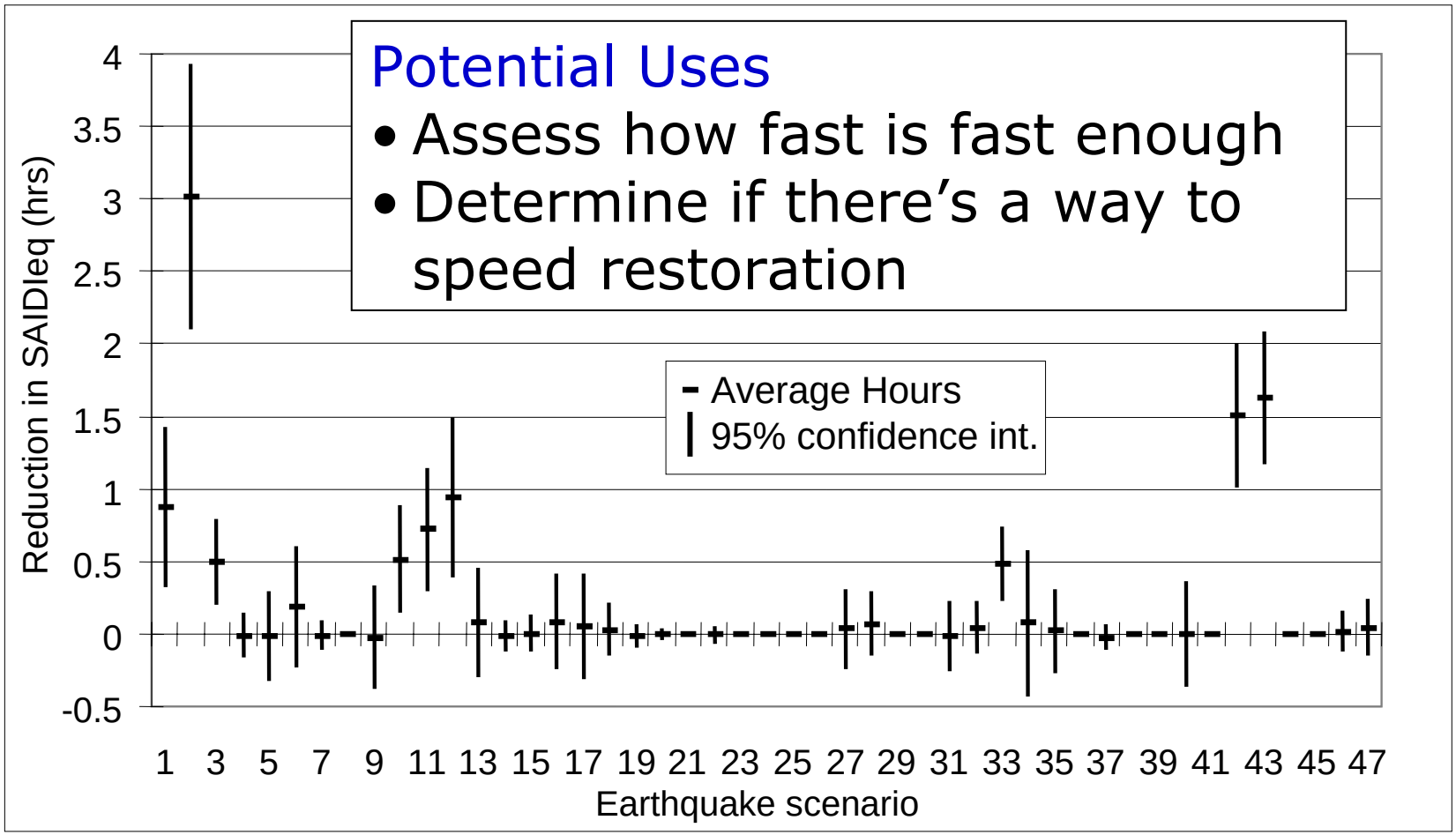

Q4. How much does tree trimming affect outage frequency?

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

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- Çağnan, Z., Davidson, R., and Guikema, S. Post-earthquake restoration planning for Los Angeles electric power. *Earthquake Spectra*, in press.
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- Xu, N., S.D. Guikema, R.A. Davidson, L.K. Nozick, Z. Çağnan, and K. Vaziri. "Optimizing Scheduling of Post-Earthquake Electric Power Restoration Tasks," submitted to *Earthquake Engineering and Structural Dynamics*, under review for publication in the special issue on Electric Power Equipment and Lifeline Systems.