Risk Analysis for Electricity Infrastructure Hardening
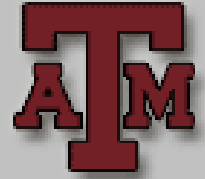
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Related Research Areas

Research Area	Problems Addressed	Sponsors
Statistical modeling of infrastructure failure risk	Power outages during hurricanes Effects of Tree Trimming on Power Systems Damage to pipe networks	Southern Company NSF (CU) San Antonio
PRA and Bayesian models	Risk estimation with little data Supporting hardening decisions (space, power, and water systems)	NASA, AF (SU) Philadelphia Southern Comp
Decision support models	Optimizing post-earthquake power restoration Hardening complex technical systems against terrorist threats Transportation Asset Management	LADWP (CU) NSF, AF, DoD (SU) TxDOT

Statistical Modeling

♦ How can we use available data to estimate outage and damage risk?

♦ Current & recent projects:

1. Estimating number & location of outages in Southern Company service area

2. Estimating effectiveness of tree trimming at reducing outages

3. Estimating damage to water distribution systems in San Antonio & Philadelphia

Statistical Approaches Used

1. Poisson GLM, Negative Binomial GLM, and Poisson GLMM

2. Zero-inflated models
   - Like (1) but account for extra zero counts

3. Bayesian hierarchical models
   - Similar to (1) and (2) except more flexible distributions, can capture additional variability and spatial correlation.
   - Yields more complete characterization of uncertainty
   - Computationally challenging!

PRA and Bayesian Modeling

♦ How can we estimate outage and damage risk when we do not have much data?

♦ Current & recent projects:

1. Estimating pole damage in hurricanes without damage data (Gulf Coast)

2. Estimating damage to water systems without complete knowledge of the system (Philadelphia)

3. Estimating failure probability of current Mars Rover missions with almost no data (NASA – JPL)

PRA & Bayesian Approaches Used

1. PRA (Probabilistic Risk Analysis)

   - Systems engineering approach for estimating and managing risk

2. Bayesian influence diagrams

   - Probabilistic representation of uncertainty and decision-making on the basis of both data and expert knowledge

3. Bayesian structural reliability models

   - Method for estimating likelihood of structural failure given external loads

   - Collaborative work with others at Texas A&M

Decision Support Modeling

◆ What should we do to harden systems given our best available risk estimates?

◆ Current & recent projects:

1. Optimizing power restoration process in Los Angeles after earthquakes

2. Efficiently allocating resources for construction and maintenance of transportation assets in Texas

3. Developing general methods for allocating reinforcement resources among many possible alternatives in complex systems

Decision Support Approaches Used

1. Decision analysis

   - Captures preferences & values of decision maker

2. Genetic algorithms, branch-and-bound, and other optimization techniques

   - Efficiently selects good hardening options from among a large set of alternatives

3. Simulation

   - Allows experimentation with "virtual" system to examine impacts of decisions

4. Game theory

   - Useful if intelligent threats are involved

Electricity Infrastructure Hardening: Some Key Questions

1. What can we do to harden the system?

   ◆ Reinforce physical system? Improve maintenance practices? Improve management practices? Improve restoration plan/process?

2. How effective and costly are these different options?

   ◆ Do we have data to estimate this? How do we measure effectiveness?

3. How do we choose which options to use in different portions of the system when hurricane impacts are highly uncertain?

Possible Future Research

◆ Develop Bayesian outage models to better capture uncertainty

◆ Focus on damage rather than outage estimation

   ▪ A combination of statistical, physical/structural, and PRA models

◆ Develop better tree trimming effectiveness models

◆ Develop a long-term hurricane risk model that accounts for possible global warming influences

◆ Tie this together in a system-wide optimization model to suggest good hardening options

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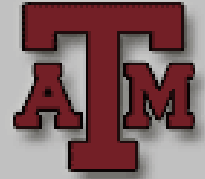
Selected Publications (1)

- **Publication List: http://ceprofs.tamu.edu/sguikema/pubs.htm**

- 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.

- Guikema, S.D. 2006. "Formulating Informative, Data-Based Priors for Failure Probability Estimation in Reliability Analysis," accepted for publication in *Reliability Engineering & System Safety*, January 2006.

- Cagnan, Z., R.A. Davidson, and S.D. Guikema. 2006. "Post-Earthquake Restoration Planning for Los Angeles Electric Power," accepted for publication in *Earthquake Spectra*, scheduled to appear in August 2006.

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- Guikema, S.D., N. Xu, R. Davidson, L.K. Nozick, and Z. Çağnan. 2006. "Optimization of Crews in Post-Earthquake Electric Power Restoration," *8th National Conference on Earthquake Engineering*.

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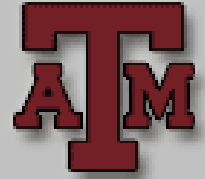
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- Guikema, S.D., R.A. Davidson, and Z. Cagnan. 2005. "Efficient Simulation-Based Discrete Optimization," *Winter Simulation 2004*, Washington, D.C., December 2004.

- Dillon, R.L., M.E. Paté-Cornell, and S.D. Guikema. 2005. "Optimal Use of Budget Reserves to Minimize Technical and Management Failure Risks During Complex Project Development," *IEEE Transactions on Engineering Management*, Vol. 52, No. 3, pp. 382-395.

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- Dillon, R.L., M.E. Paté-Cornell, and S.D. Guikema. 2003. "Programmatic Risk Analysis for Critical Engineering Systems Under Tight Resource Constraints: Applying APRAM," *Operations Research*, Vol. 51, No. 3, pp. 354-370.

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