Hardening Power Distribution System Infrastructure Against Hurricanes: Overview of the Expertise of the Guikema Research Group

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Hardening electric power distribution infrastructure against hurricanes is a complex problem involving both (1) assessing the impacts of hurricanes within a risk-based framework and (2) allocating limited resources to best manage hurricane risk to power distribution systems. Dr. Guikema's research group at Texas A&M University is doing work on many aspects of this problem. Briefly, this work focuses on identifying weak links in the system, estimating the probability of a failure due to these weak links, and then allocating scarce resources among the many possible alternatives to best harden the system. This abstract gives a brief overview of this on-going work as well as planned future work.

Dr. Guikema completed his Ph.D. in Engineering Risk and Decision Analysis at Stanford University after earning three previous degrees in Civil Engineering. He was then a postdoctoral researcher with Rachel Davidson at Cornell University where his work focused on statistical modeling of the effects of tree trimming policies on power system reliability, modeling power outages during hurricanes, and optimizing the restoration of electric power after earthquakes. Dr. Guikema is currently an Assistant Professor in the Zachry Department of Civil Engineering at Texas A&M University where he is supervising nine research students who are working on infrastructure risk and reliability modeling projects. He is also the Principal Investigator on a project sponsored by Southern Company, a project titled "Statistical Modeling to Support Hurricane Response Planning for Southern Company" among other projects. Dr. Guikema's research focuses on the following three main areas:

1. **Large-scale statistical modeling of infrastructure network failures [e.g., 1-6].** This work focuses on electric power system outages during hurricanes, the effects of tree trimming on power system reliability, and breaks in pipe networks. Dr. Guikema's students working in this area are developing advanced hierarchical Bayesian outage estimation models while simultaneously increasing the understanding of the factors that influence the reliability of electric power systems during hurricanes. This work is providing a better basis on which resources can be allocated to harden systems.
2. **Probabilistic Risk Analysis (PRA) and Bayesian modeling [e.g., 4-9].** Unlike the first area of research, this work focuses on estimating system failure risk when there is not a large data set available. This work involves developing better Bayesian probability methods for estimating the reliability of complex systems. Dr. Guikema's work in this area has led to fundamental advances in methods for using sparse data to formulate informative priors in Bayesian probability models, significantly strengthening the basis on which resource allocation decisions can be made. This work could be directly applicable to the problem of estimating electric power system damage during hurricanes on the basis of limited damage data.
3. **Combining decision analysis and optimization for allocating scare resources to harden systems [e.g., 10-16].** This work focuses on using the best available risk estimates to allocate highly limited resources to best harden complex systems against hazards on the basis of optimization and decision analysis. This work has been done in a variety of fields, including inter-planetary space systems, electric power systems, and the Texas highway network. This work provides models to suggest good resource allocations and to quantify the gain in system reliability and robustness due to hardening activities, and it could be used to select hardening options for reinforcing electric power systems.

All of this work is based on a sound understanding of the infrastructure systems being addressed combined with a thorough knowledge of risk analysis, probability modeling, decision analysis, and optimization. All these areas are needed in order to best protect electric power systems. Work in risk analysis and statistical modeling is important but alone is not sufficient to make resource allocation decisions. However, combining this modeling with sound decision analytic methods for allocating resources provides a strong basis for choosing among options to harden electric power distribution systems.

The future work of Dr. Guikema's research group will seek further integration of (1) large-scale statistical models, (2) Bayesian risk analysis models, and (3) decision analytic optimization models to improve decisions about how best to harden complex systems against hazards. While hurricane impacts on power systems will be a major focus on this work, Dr. Guikema's research will continue to be multi-hazard and inter-disciplinary. Only by examining multiple systems and multiple hazards (including terrorist attacks) can the synergies between hardening activities be analyzed and taken advantage of to protect systems in the most efficient and effective manner. Sound risk and decision analysis procedures are the key to making this work.

References

1. **Guikema, S.D.**, R.A. Davidson, and H. Liu. 2006. "Statistical Models of the Effects of Tree Trimming on Power System Outages," *IEEE Transactions on Power Delivery*, in press [scheduled to appear in July 2006].
2. **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*, San Francisco, April 18-22, 2006.
3. **Guikema, S.D.** and R.A. Davidson. 2006. "Modeling Critical Infrastructure Reliability with Generalized Linear Mixed Models," *Probabilistic Safety Assessment and Management (PSAM) 8*, New Orleans, May 2006.
4. **Guikema, S.D.** 2005. "A Comparison of Reliability Estimation Methods for Binary Systems," *Reliability Engineering and System Safety*, Vol. 87, No. 3, pp. 365-376.
5. **Guikema, S.D.** and M.E. Paté-Cornell. 2005. "Probability of Infancy Problems for Space Launch Vehicles," *Reliability Engineering and System Safety*, Vol. 87, No. 3, pp. 303-314.
6. **Guikema, S.D.** and M.E. Paté-Cornell. 2004. "Bayesian Analysis for Launch Vehicle Reliability," *Journal of Spacecraft and Rockets*, Vol. 41, No. 1, pp. 93-102.
7. **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.
8. Paté-Cornell, M.E., R.L. Dillon, and **S.D. Guikema**. 2004. "On the Limitations of Redundancies in the Improvement of System Reliability," *Risk Analysis*, Vol. 24, No. 6, pp. 1423-1436.
9. Paté-Cornell, M.E. and **S.D. Guikema**. 2002. "Probabilistic Modeling of Terrorist Threats: A Systems Analysis Approach to Setting Priorities Among Countermeasures," *Military Operations Research*, Vol. 7, No. 4, pp. 5-23.
10. **Guikema, S.D.** 2006. "Incentive Compatible Resource Allocation in Engineering Design," *Engineering Optimization*, Vol. 38, No. 2, pp. 209-226.
11. 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.
12. **Guikema, S.D.**, R.A. Davidson, and Z. Cagnan. 2005. "Efficient Simulation-Based Discrete Optimization," *Winter Simulation 2004*, Washington, D.C., December 2004.
13. **Guikema, S.D.** and M.W. Milke. 2003. "Sensitivity Analysis for Multi-Attribute Project Selection Problems," *Civil Engineering and Environmental Systems*, Vol. 20, No. 3, pp. 143-162.
14. 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.
15. **Guikema, S.D.**, and M.E. Paté-Cornell. 2002. "Component Choice for Managing Risk in Engineered Systems with Generalized Risk/Cost Functions," *Reliability Engineering and System Safety*, Vol. 78, No. 3, pp. 227-238.
16. **Guikema, S.D.** and M. Milke. 1999. "Quantitative Decision Tools for Conservation Program Planning: Practice, Theory, and Potential." *Environmental Conservation*, Vol. 26, No. 3, pp. 179-189.