Professor Rachel Davidson
School of Civil and Environmental Engineering
Cornell University

Introduction

Since 1999, Professor Davidson has collaborated with five major electric power companies on research that aims to help the companies better manage extreme natural events—hurricanes, ice storms, and earthquakes. These efforts can be grouped into four main areas: (1) statistical modeling to estimate the number and geographic distribution of outages in hurricanes and ice storms, (2) statistical and discrete event simulation modeling to estimate restoration times after hurricanes, ice storms, and earthquakes, (3) optimization modeling to determine the theoretical "best" way to conduct a post-earthquake restoration process, and (4) statistical modeling to estimate the effect of tree trimming frequency on electric power reliability.

Outage counts

Industry collaborators: Dominion Virginia Power, Duke Energy, Progress Energy Carolinas, Southern Co.

Negative binomial regression and spatial generalized linear mixed models have been developed for hurricanes and ice storms to estimate the expected number of outages in each zip code (or grid cell) in the service area as functions of characteristics of the power systems, region, and storms. These models are based on an extensive database that includes wind speed, wind duration, rainfall, ice thickness, land cover type, soil drainage and depth, as well as the inventory and outage data provided by the companies. Geographic Information Systems (GIS) was used to establish the spatial relationships among the data. As a storm approaches, these models can be used to develop maps showing the number of outages (or outages per km^2, for example) expected in each zip code. Such maps should be useful for predicting the impact of the storm and determining how to deploy tree and line crews and repair materials.

[1] Davidson, R., Liu, H. Sarpong, I. Sparks, P., and Rosowsky, D. 2003. Electric power distribution system performance in Carolina hurricanes. *Natural Hazards Review* 4(1), 36-45.
[2] Liu, H., Davidson, R. Rosowsky, D. and Stedinger, J. 2005. Negative binomial regression of electric power outages in hurricanes. *Journal of Infrastructure Systems* 11(4), 258-267.
[3] Liu, H., Davidson, R., and Apanasovich, T. Spatial generalized linear mixed models of electric power outages due to hurricanes and ice storms. *Reliability Engineering and System Safety*, in review.

Outage durations and restoration times

Industry collaborators: Dominion Virginia Power, Duke Energy, Progress Energy Carolinas, Southern Co.

Cox proportional hazard and accelerated failure time models are being developed to estimate the expected durations of outages caused by hurricanes and ice storms as functions of characteristics of the power systems, region, and storms. These outage durations are then translated into expected restoration times for each zip code in the service areas. Like the outage count models, these are based on a large database of historical outages. The models for Dominion, Duke, and Progress should be complete in June 2006; work is just starting for Southern Company. These models should be helpful in giving customers more accurate early estimates of when they should expect their power to be restored, thus improving customer satisfaction.

Industry collaborator: Los Angeles Department of Water and Power (LADWP)

Since earthquakes are much less frequent than hurricanes and ice storms, only limited historical data is available for them, and therefore, a statistical modeling approach to estimating restoration times is not possible. Instead, we developed a discrete event simulation that explicitly mimics the real-life LADWP restoration process, enabling development of restoration curves (percentage of customers restored vs. time) with uncertainty bounds, a dynamic map showing the spatial distribution of outages changing over time, and information on how personnel and repair materials are used throughout the process. The model is based on interviews with LADWP personnel, emergency response plans, and the post-Northridge earthquake restoration report. Since it explicitly represents the actual process that LADWP goes through to restore services, the model offers a risk-free, virtual environment in which the company can experiment with different restoration strategies and examine their effects on expected restoration times. A similar type of simulation could be developed for hurricanes and the results could be compared to those from the statistical restoration models.

[4] Liu, H., and Davidson, R. Statistical estimation of electric power restoration times in hurricanes and ice storms, in preparation.
[5] Çağnan, Z., and Davidson, R. Discrete event simulation of the post-earthquake restoration process for electric power systems. *International Journal of Risk Assessment and Management*, in press.
[6] Çağnan, Z., Davidson, R., and Guikema, S. Post-earthquake restoration planning for Los Angeles electric power. *Earthquake Spectra*, in press.

Restoration optimization
Industry collaborator: Los Angeles Department of Water and Power (LADWP)

Building on the LADWP restoration simulation model, two optimizations were developed to determine how to schedule inspection and repair tasks, and how many crews of different types to have and where. While the restoration model describes how the restoration works currently, the optimizations suggest the "best" way to conduct it. Comparison of restoration times based on the current LADWP plan and the theoretical best restoration times estimated by the optimizations provide one way to evaluate if the restoration is fast enough, if it can be improved, and if so, how.

[7] Guikema, S., Xu, N. Davidson, R., Nozick, L., and Çağnan, Z. Optimization of crews in post-earthquake electric power restoration. *Proc., 8th U.S. National Conf. on Earthquake Engineering in San Francisco, CA, April 18 - 22, 2006.*
[8] Xu, N., Guikema, S., Davidson, R., Nozick, L., Çağnan, Z., and Vaziri, K. Optimizing scheduling of post-earthquake electric power restoration tasks. *Earthquake Engineering and Structural Dynamics, Special Issue: Electric Power*, in review.

Tree trimming effectiveness
Industry collaborator: Duke Energy

Negative Binomial regression and Poisson generalized linear mixed models were developed to estimate the effect of tree trimming frequency on the expected number of outages in storm and non-storm conditions. This type of model could be useful in determining how frequently to trim trees and which particular circuits to focus trimming efforts on to get the largest improvement in reliability.

[9] Guikema, S., Davidson, R., and Liu, H. 2006. Statistical models of the effects of tree trimming on power system reliability. *IEEE Transactions on Power Delivery* 21(3).

Possible future work
Professor Davidson would be interested in continuing research similar to that described above. The following are three examples of areas in which we see the potential for research advances. First, there is a need to move to estimating hurricane impact in terms of physical damage (e.g., number of broken cross arms and poles, spans of wire down) instead of just outages (any permanent fault). This would help determine more directly how many repair personnel and materials are needed and where to deploy them. Data has not been available to accomplish this in the past. Second, tree-related variables should be incorporated into the statistical outage and restoration time models. Trees play a critical role in causing hurricane damage, but appropriate data has not been identified to make this possible yet. Third, a discrete event simulation of the post-hurricane restoration process could be used to help assess the relative effectiveness of different possible restoration strategies. The companies' decision variables (e.g., how many repair teams to have) are not represented explicitly in the statistical models, and therefore, their impact on restoration times cannot be examined directly using statistical models.