RISK and ECONOMIC COSTS OF A TERRORIST ATTACK ON THE ELECTRIC SYSTEM

Presentation for the CREATE Economics of Terrorism Symposium

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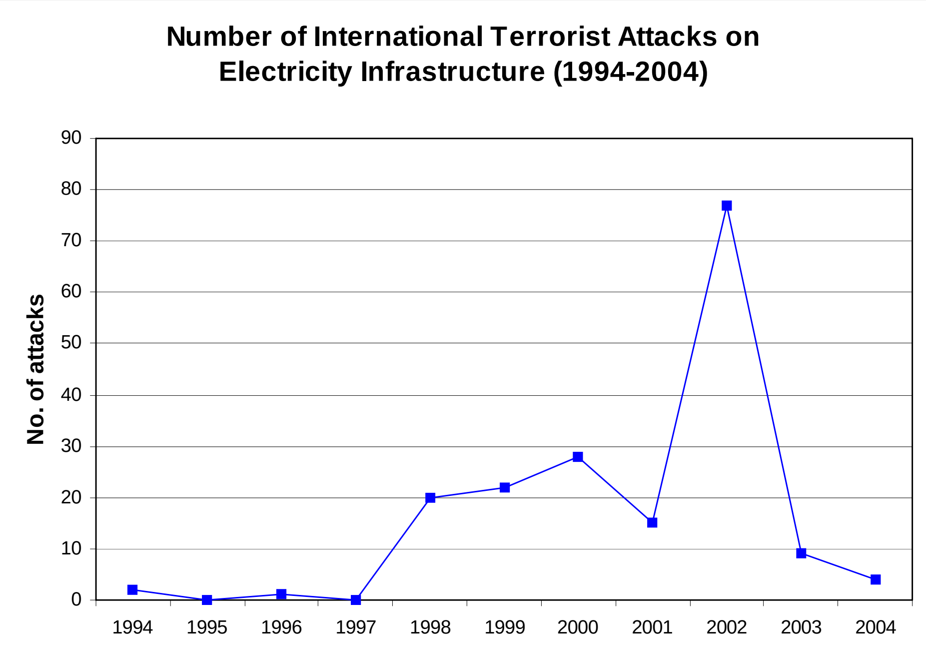
Goal

Develop tools for economic accounting of disruption effects from terrorist attacks on electricity systems

Rationale

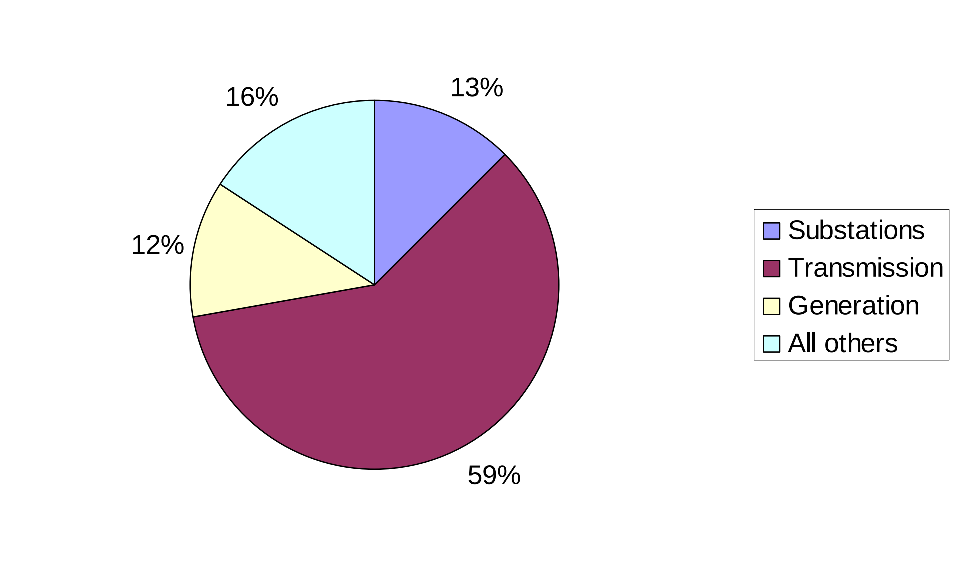
- Emphasis of federal policy on critical infrastructure, including electric power
- Electric power has been a proven target of terrorist attacks internationally
- The U.S. is increasingly dependent on electric power
- Electric power systems are potentially vulnerable due to locational and usage characteristics

Electric Power Infrastructure is a Proven Target of Terrorism: Trends in International Terrorist Attacks on Electric Power, 1994-2002



Countries include Colombia, Spain, France, Russia, Albania, Turkey, Brazil, Chile, Georgia, Indonesia, Iraq, Israel, Kashmir, Kosovo, Latvia, Nepal, Pakistan, Paraguay, Peru, Sri Lanka, Sudan, Sweden and Tajikistan.

Of the total attacks about 60% took place in Colombia and 6.7% In Spain. The rest of the countries accounted for less than 5% each.

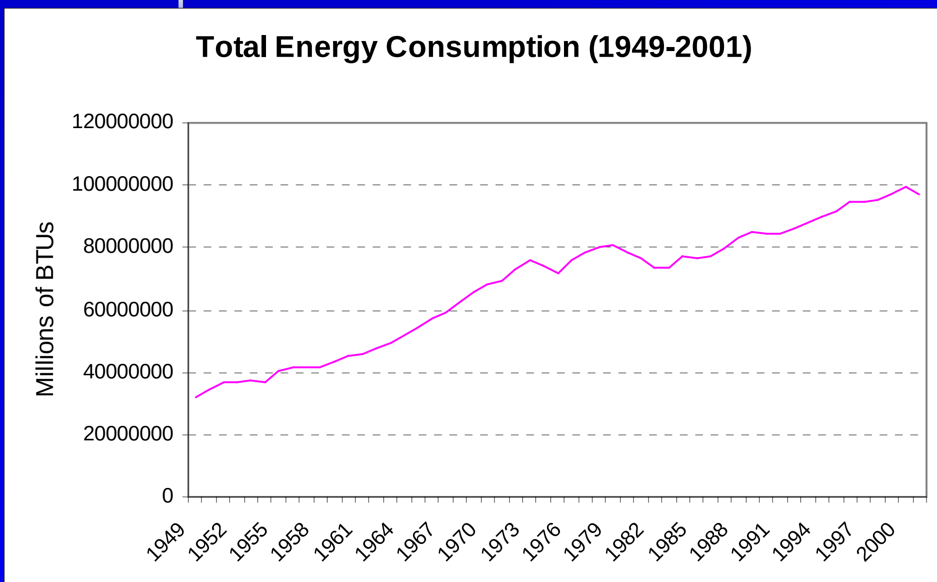


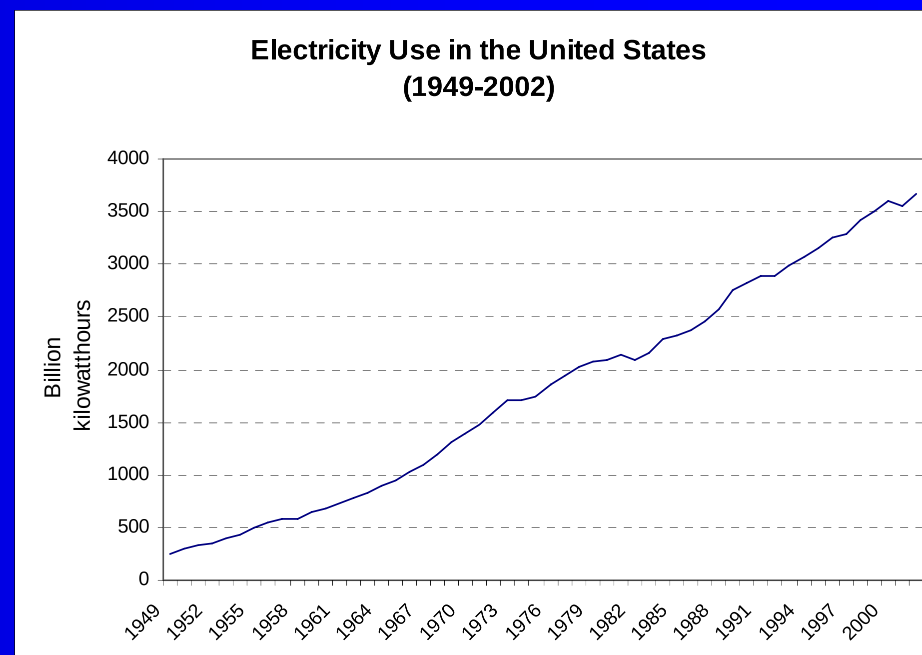
Generation includes power stations and dams.
Substations also includes transformers.
Transmission includes attacks on power grids, pylon and utility towers.
All others includes distribution, electric relays, human resources, junction boxes, offices, storage, vehicles, etc.

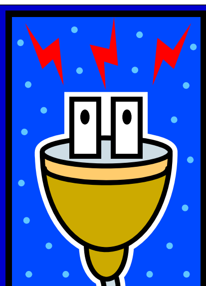
Source: compiled from mipt.org database.

Consequences - Large Potential Impacts of an Attack: Energy Consumption/Electricity Use, U.S.

Source: Graphed from Energy Information Administration (EIA), U.S. Department of Energy, *Annual Energy Review 2001, Energy Perspectives: Trends and Milestones 1949-2001;* from R. Zimmerman and T. Horan, "What are Digital Infrastructures" in R. Zimmerman and T. Horan, eds. *Digital Infrastructures* (Routledge 2004: p. 8). Not for distribution or citation without permission of the author and publisher.



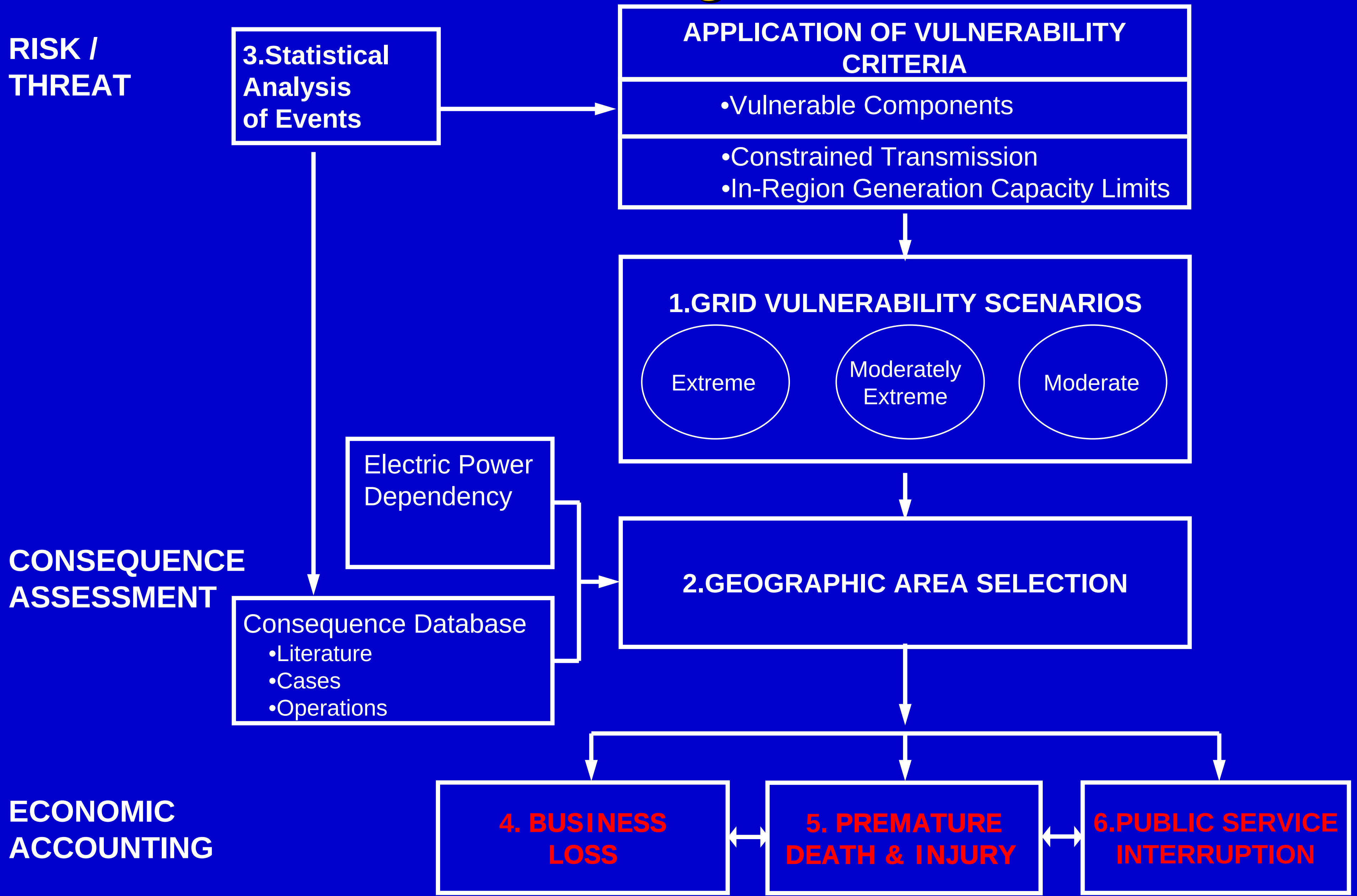




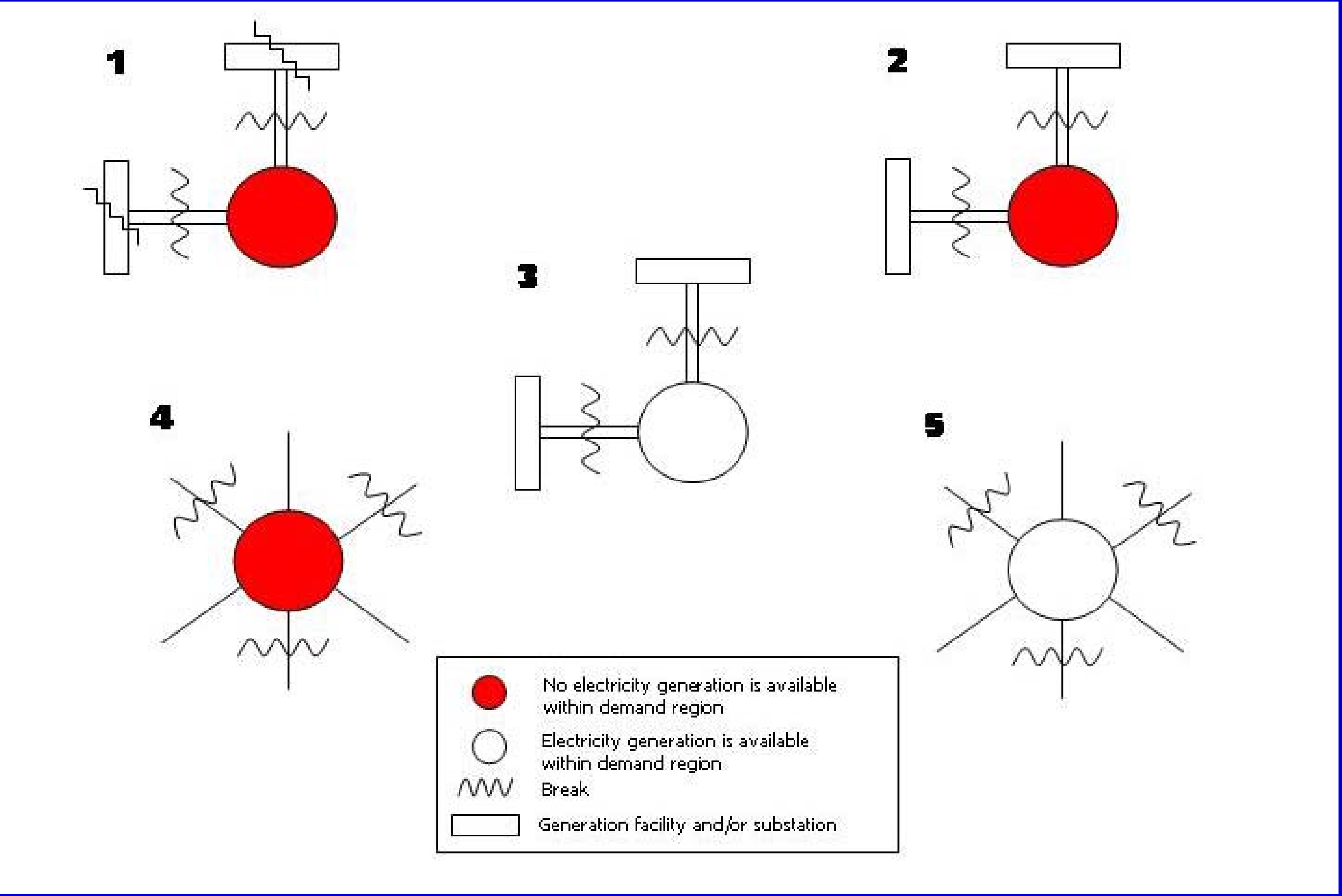
Prior Research: State-of-the-Art

- For vulnerable grid components, some studies (e.g., Wels 2003) identify failed components, but they are not used to project impacts
- For consequence assessment, infrastructure and electricity linkages are anecdotal or are concept-based models (e.g., Bush 2004; Lemon, Apostolakis 2004, 2005)
- Non-terrorist/terrorist approaches rarely combined
- Scenario-based rather than statistical modeling dominates estimation for terrorist (Salmeron et al. 2004) and non-terrorist failures (Masiello, Spare, and Roark 2004)

Approach: Details of Grid Scenarios – Economic Accounting



1. Grid Vulnerability Scenarios



2. Geographic Area Selection

Based on grid vulnerability criteria the following areas were chosen for more in-depth analysis:

- New York City
- Chicago
- San Francisco
- Seattle

3. Statistical Analysis Of Electric Power Outage Events: Goals

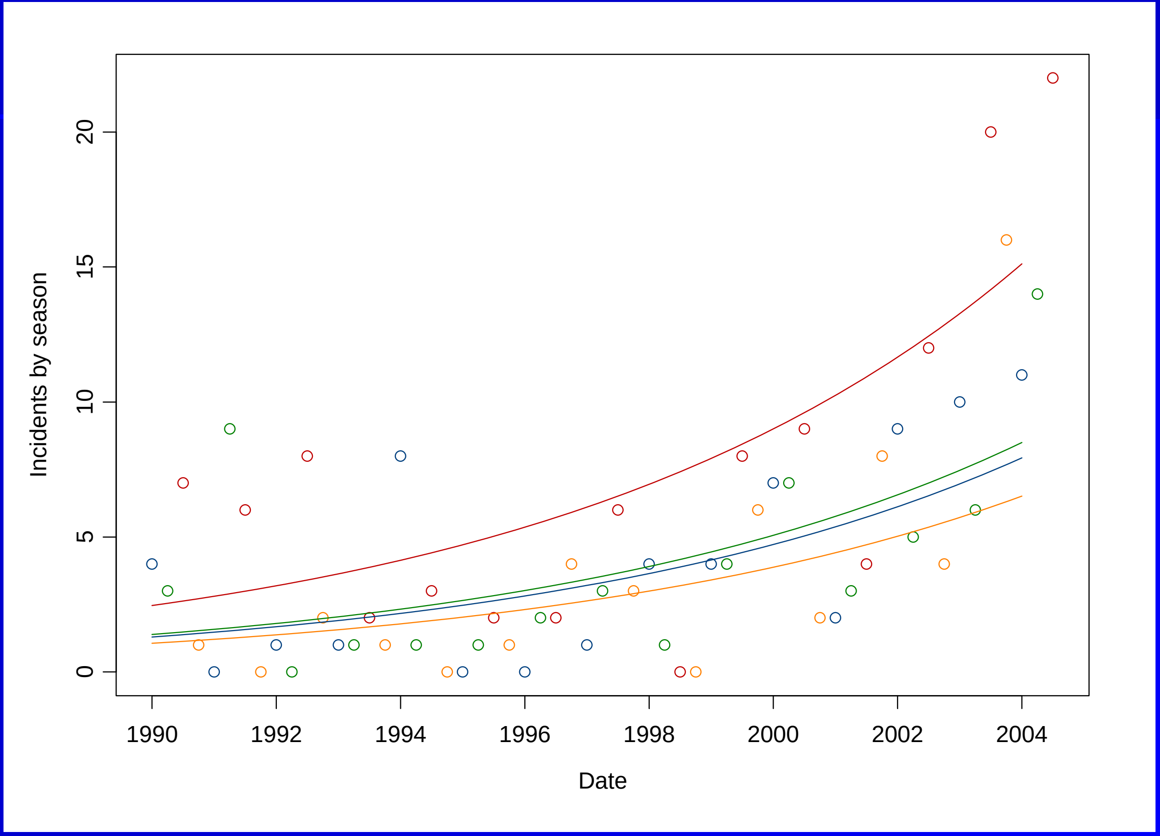
- This is a statistics-based tool to use non-terrorist data to predict the outcome of a terrorist attack
- It allows model outputs such as duration and customer loss for specific geographic areas to be used as inputs into scenarios for economic accounting

Statistical Analysis Of Electric Power Outages: Database Characteristics

- This work is based on the **Disturbance Analysis Working Group (DAWG)** database maintained by the North American Electric Reliability Council (NERC). It summarizes disturbances in United States and Canada electric utilities.
- The time period for the analysis is **January 1990 – August 2004**. It includes **400 U.S. outages**.
- Additional information about the DAWG database is found at: http://www.nerc.com/~dawg/

Electricity Outages by Season (1990-2004)

(DAWG Database)



Note: The counts of incidents per season are modeled using a negative binomial regression model, which accounts for unmodeled heterogeneity in the data. The model implies an estimated 13.8% annual increase in incident rate, and an estimated 75-135% higher rate for summer than for other seasons.

Key: The autumn points and line are in orange (bottom line); the winter points and line are in blue (second from the bottom), the spring points and line are in green (third from the bottom), the summer points and line are in red (highest).

Modeling the duration and customers lost of an outage

Available incident data are used to separately model the expected (logged) duration of an outage and customer loss using regression models based on the following predictors:

Predictors for Duration:

1. (Logged) population density
2. (Logged) number of customers serviced by the utility
3. Primary cause of the outage
4. Season
5. Time index (days since 1990)

Predictors for Customers Lost:

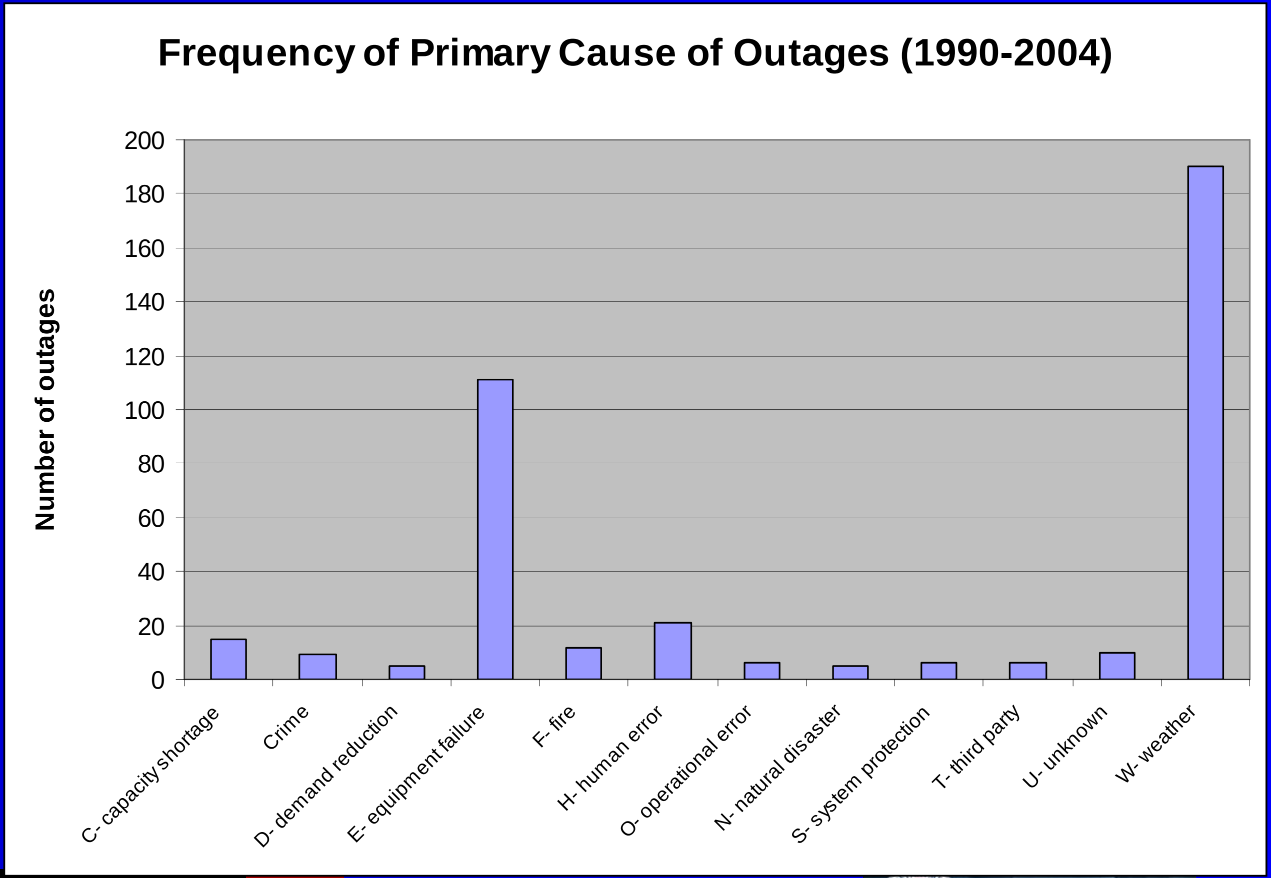
1-5 above plus logged duration

Since variability of durations is very different, depending on the cause of the outage, *weighted least squares* (WLS) is used to fit the model. The number of customers lost is also modeled using *weighted least squares*.

Causes of Outages (1990-2000)

Primary Causes:

- C- capacity shortage
- Crime
- D- demand reduction
- E- equipment failure
- F- fire
- H- human error
- O- operational error
- N- natural disaster
- S- system protection
- T- third party
- U- unknown
- W- weather



Results of modeling the duration of an outage

1. The model implies that a 1% increase in population density is associated with a 0.33% increase in duration holding all else fixed.
2. Outages are shortest during the summer, being 39% longer during the autumn, 46% longer during the spring, and 125% longer during the winter on average, holding all else fixed.
3. Incidents caused by human error, natural disaster, demand reduction, and equipment failure tend to be shorter, while those caused by system protection, third party, weather, and unknown causes tend to be longer, holding all else fixed. More than ¾ of the events are caused by either equipment failure or weather, so contrasting the two is particularly important (events caused by weather are expected to last more than five times longer than those caused by equipment failure).

Results of modeling <u>customers lost</u> during an outage

1. The model implies that a 1% increase in duration is associated with an estimated 0.12% increase in customers lost, holding all else fixed.
2. A 1% increase in total customers served is associated with an estimated 0.18% increase in customers lost, holding all else fixed. For example, if one utility serves twice as many customers as another, it is only expected to lose 13.3% more customers than the other utility given all of the other characteristics.
3. Customer losses are higher for natural disaster, crime, unknown causes, and third party cause, and lower for capacity shortage, demand reduction, and equipment failure. Note that the largest customer losses are coming from causes that are beyond the control of the utility, while the smallest losses are coming from causes that are internal to the utility.

Does an incident have zero customer loss?

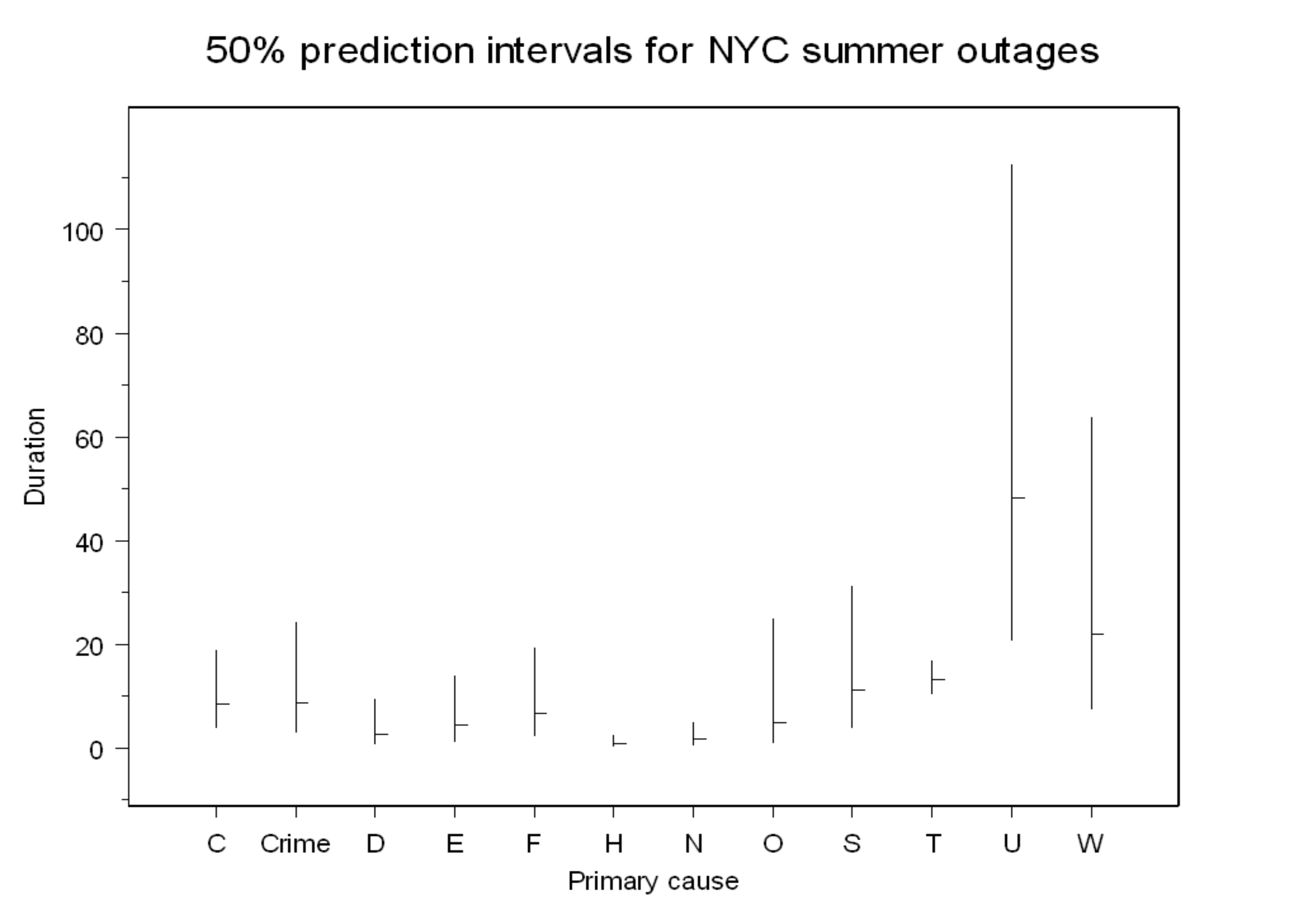
1. A 1% increase in the state population density is associated with an estimated 0.6% decrease in the odds that an incident will have zero customer loss, holding all else fixed.
2. Zero customer loss incidents are becoming rarer, as there is an estimated 11.3% annual decrease in the odds that an incident has zero customer loss, holding all else fixed.
3. The model implies that a 1% increase in the duration of an incident is associated with an estimated 0.3% decrease in the odds that an incident will have zero customer loss, holding all else fixed.
4. Given the other predictors, crime, demand reduction, and third party cause are strongly associated with zero customer loss, while operational error, system protection, and weather are strongly associated with nonzero customer loss.

Using the models for scenario prediction for specific geographic areas

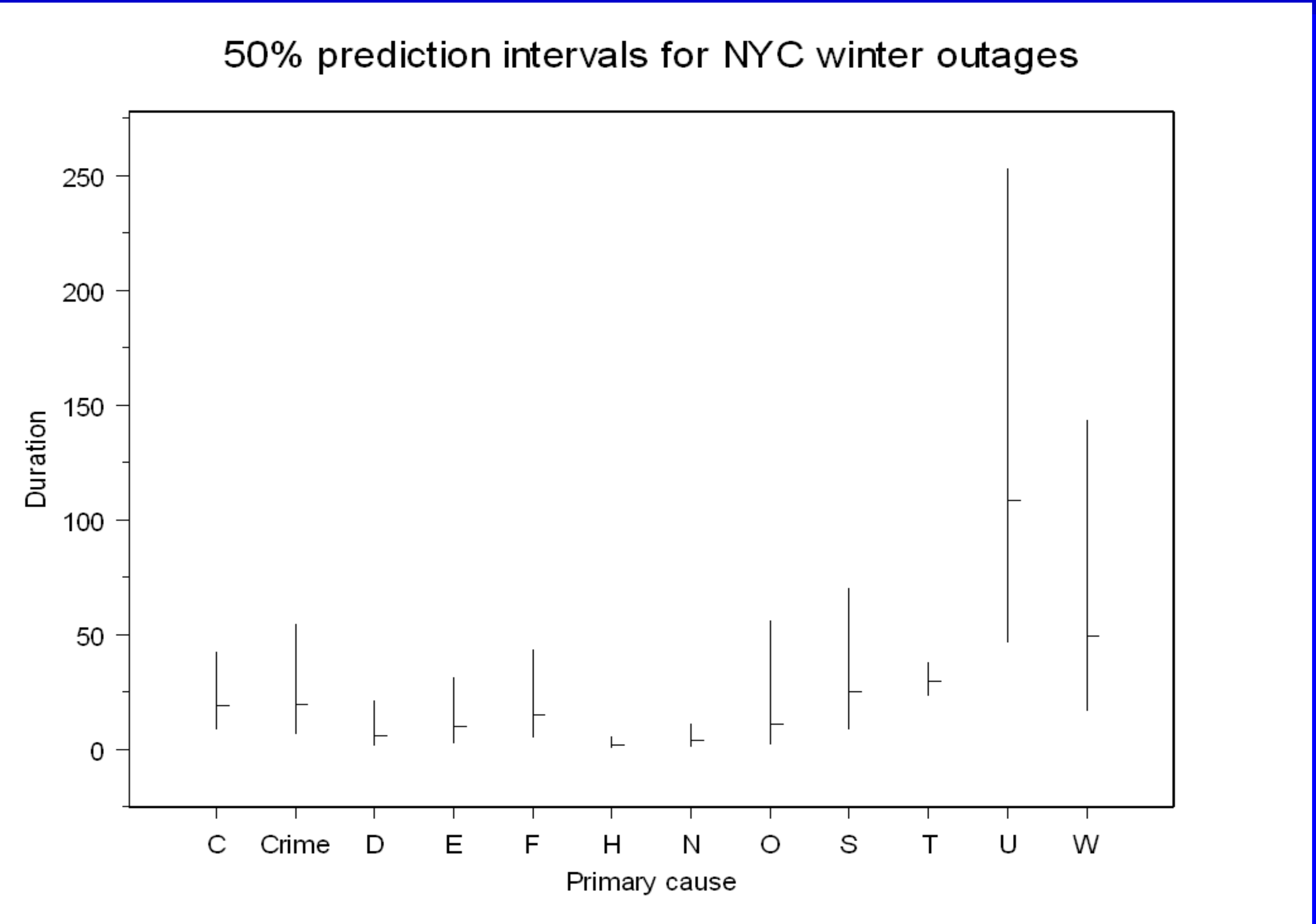
These models provide useful information about the factors related to the seriousness of a power outage, but they also can be used to construct predictions for outage outcomes based on different scenarios. By examining predicted duration and customer loss under different conditions, it is possible to map out possible outage outcomes in the event of a terrorist attack (for which there is virtually no data).

We look at scenarios for four different cities: New York, Chicago, San Francisco, and Seattle. We construct 50% prediction intervals for duration for each cause for summer and winter in each city (the central range within which there is 50% chance of duration falling). Finally, we construct 50% prediction intervals for customers lost.

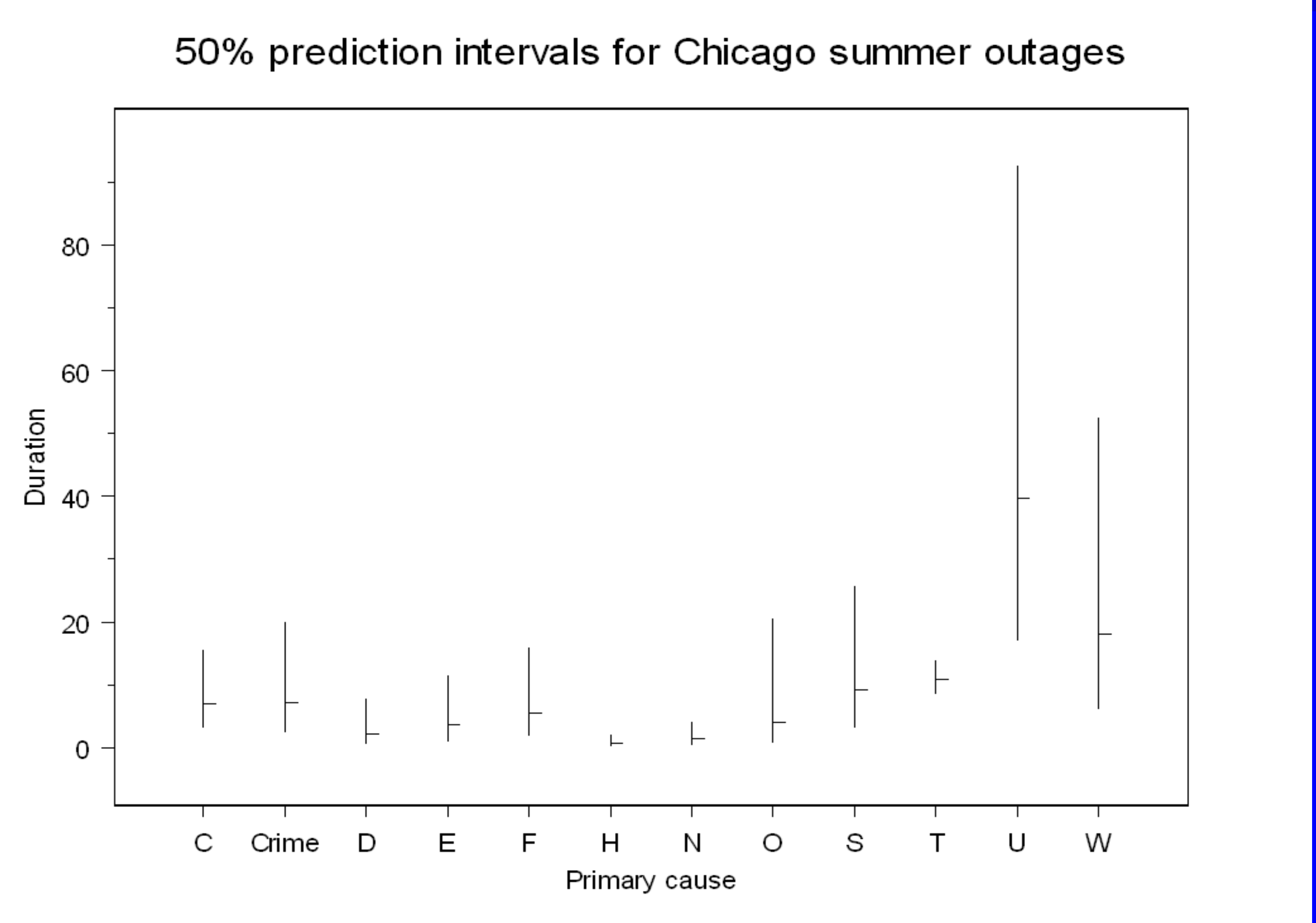
Using the models for scenario prediction for duration (hours): NYC (summer)



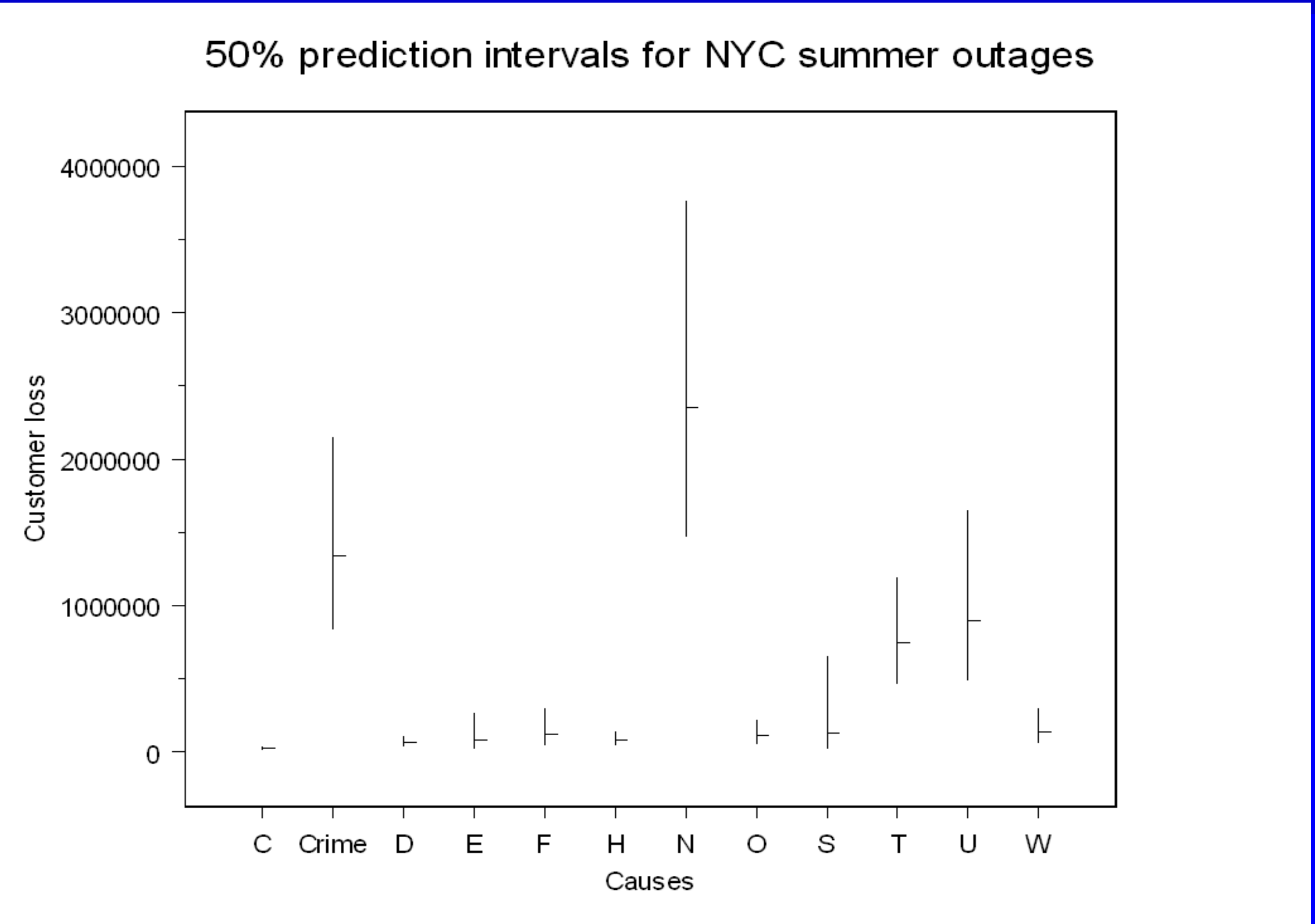
Using the models for scenario prediction for duration (hours): NYC (winter)



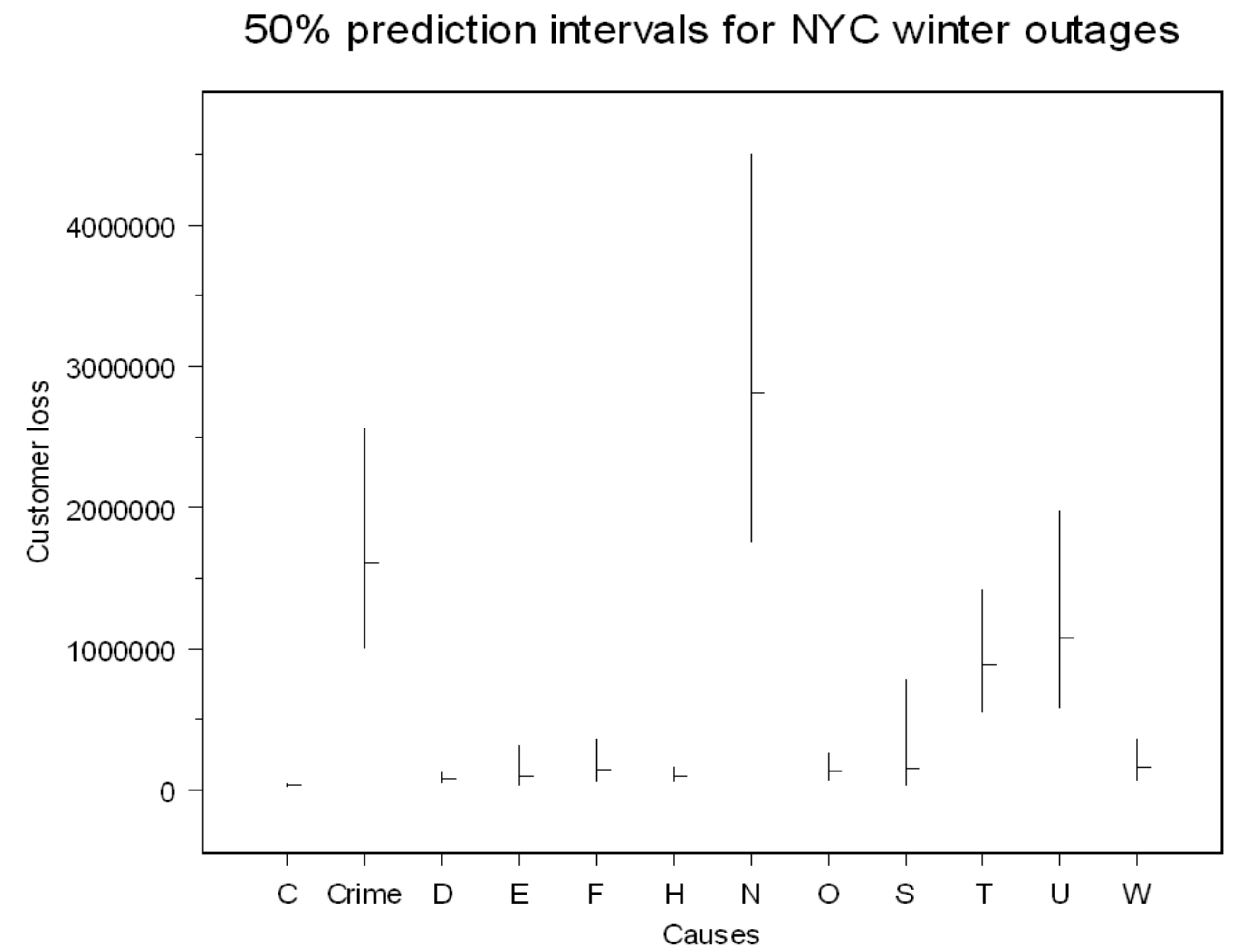
Using the models for scenario prediction for duration (hours): Chicago (summer)



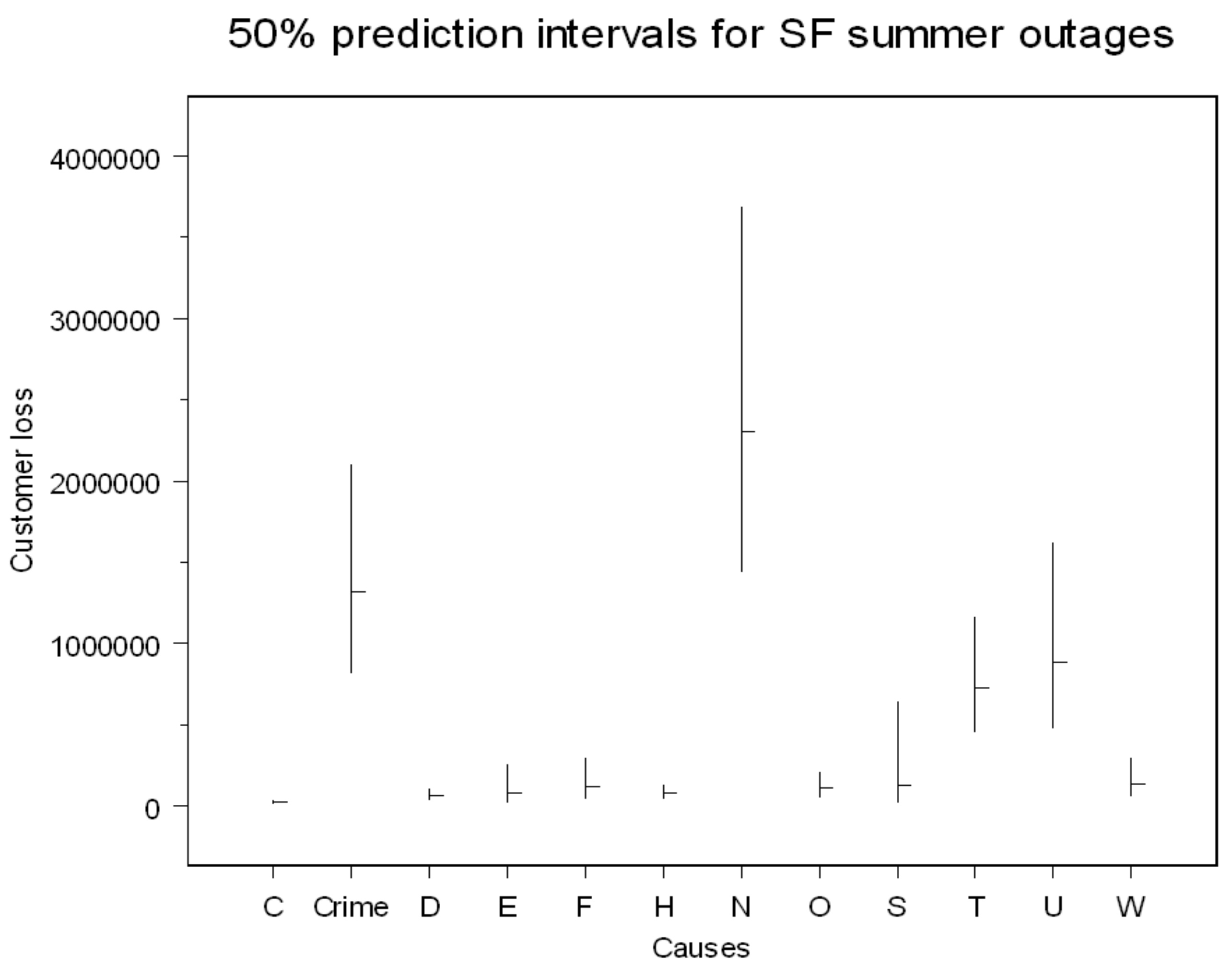
Using the models for scenario prediction for customer loss: NYC (summer)



Using the models for scenario prediction for customer loss: NYC (winter)



Using the models for scenario prediction for customer loss: San Francisco (summer)



Use and challenges of these models

The statistical modeling techniques described here can be used to understand the factors related to the seriousness of power outage incidents, and to make predictions under different hypothesized scenarios. Given the lack of data on terrorist attacks on the power grid in the United States, the predictions for these different scenarios provide the opportunity to understand and prepare for power emergencies while knowing likely outcomes for similar non-terrorist threats.

Improvements to the models are possible. More detailed data on outages would allow for more accurate predictions (and narrower prediction limits). For instance, these models could be enriched to allow for more local information (e.g., ambient temperature, rather than just season). More complex models are also possible; for example, ones that do not allow the upper limit of the customer loss prediction interval to be greater than the total number of customers served.

4. Economic Accounting: Sample Formulation for Business Losses

Business Losses are estimated as follows:

- **Business Loss = $112 GDP/person/day X Number of people affected X Duration/24 hours**
- **The regression models used in the statistical analyses provide estimates for duration and customers affected under different conditions (see first row of table below), and business loss estimates can be computed for such scenarios (note that 3 people per customer is assumed):**

Ex.: $112 x 887,028 x 3 x 19.6/24 = $245,225,986

Economic Accounting: Estimated Business Losses from Predicted Duration and Customers Lost

City	Cause of Outage	Season	Predicted duration (hours)	Predicted # of customers lost	Expected Business Loss ($)
NYC	Crime	Winter	19.6	887,028	245,225,986
NYC	Weather	Summer	21.8	134,935	41,491,028
San Francisco	Natural disaster	Fall	5.6	132,135	10,437,079
San Francisco	Fire	Spring	8.0	180,631	20,382,402
Chicago	Human error	Summer	0.7	72,048	711,365
Seattle	Equipment failure	Winter	5.8	44,661	3,653,671

5. Economic Accounting: Sample Formulation for Premature Death

$$C(D,I) = P_1\,(D) + P_2\,(I)$$

where

C(D,I)=total cost of deaths and injuries (spatially and temporally specified)

D = per capita estimate of the cost of deaths based on value of life estimates (e.g., $5.8 million)

I = per capita estimate of the cost of injury by type of injury

P_1=total population at risk of dying

P_2=total population at risk of being injured

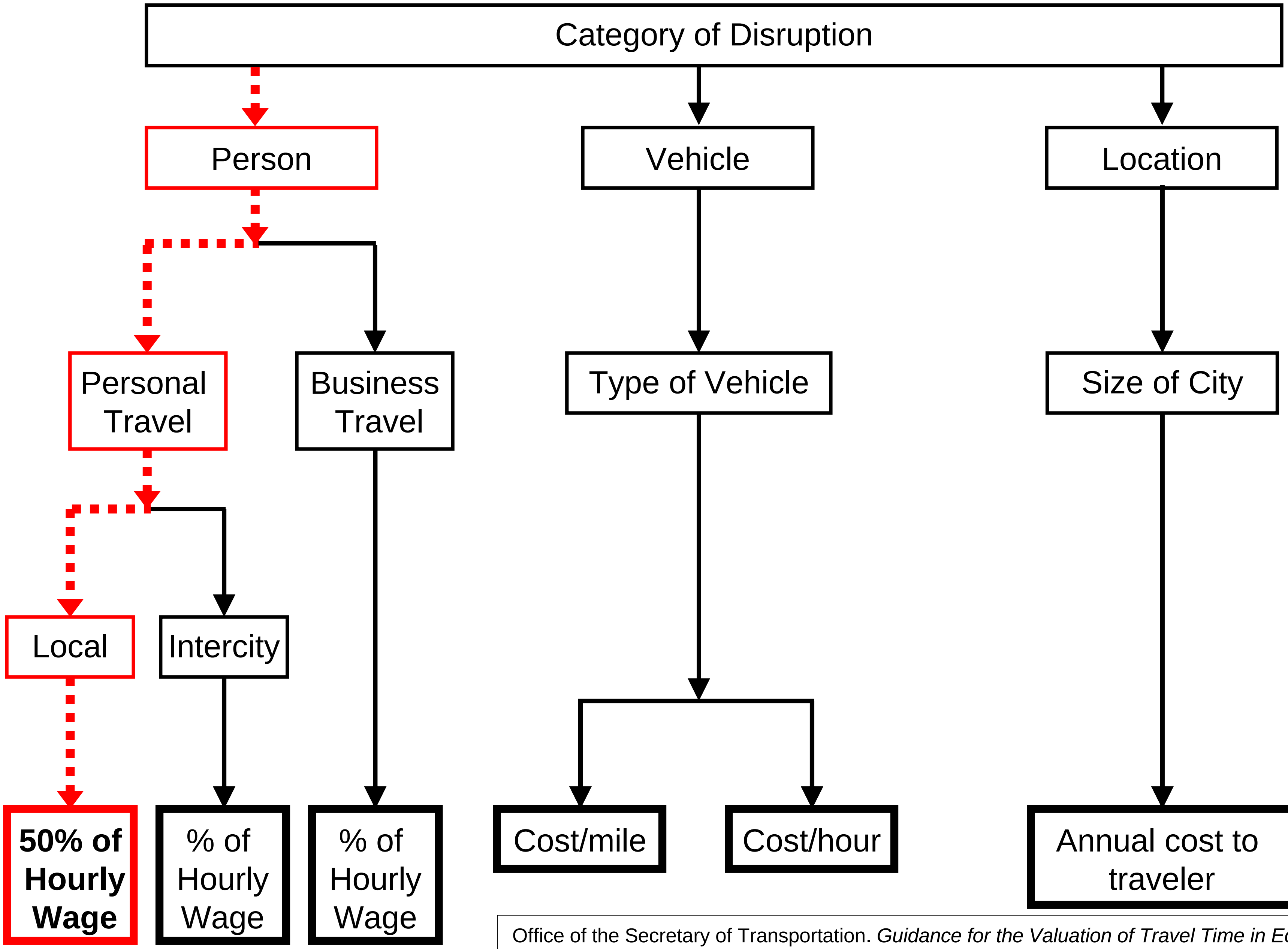
6. Economic Accounting: Sample Formulation For Cost Of Congestion

$$C(T) = [\sum_{i=1}^{n} X(i)\ x\ Y(i)]\ x\ Z\ x\ T$$

where

C(T) = the total cost associated with transportation-related congestion for outage duration T
n = the number of sectors for which wages are defined
X = sector for wage category i
Y = the number of workers in wage category i
Z = a congestion factor in terms of percentage of hourly wages
T = extra commuting time in hours

PUBLIC SERVICE INTERRUPTION: Estimators for Transportation-Related Congestion



Office of the Secretary of Transportation. *Guidance for the Valuation of Travel Time in Economic Analysis*, U.S. Department of Transportation, February 2003.

Example of Economic Accounting (Using Statistical Output for Business Loss) - Assumptions

- For this scenario (from statistical output) -

City	Cause of outage	Season	Predicted duration (hours)	Predicted # of customers lost	Business loss estimate ($)
NYC	Crime	Winter	19.6	887,028	**245,225,986**

And assuming:
(1) 150 premature deaths resulting from the criminal activities associated with the blackout (i.e., explosions, etc.) and
(2) 4 hours of added congestion to the workforce of the NYC Metropolitan Area

Example of Economic Accounting (Using Statistical Output for Business Loss) - <u>Calculations</u>

Economic costs for the NY area:

- Estimated average <u>business losses</u>:

  $112.84 (GDP/person/day) X 887,028 (customers) X 3 (# people/customer) X 19.6/24 (hrs.): **$245,225,986**

- Estimated cost of <u>premature deaths</u>:

  $5.8 million X 150 deaths = **$870,000,000**

- <u>Public service disruption</u>: 10,175,935 workers X $16/hour (ave. wage) X 0.5 (cost of congestion per hourly wage) X 4 hours = **$117,088,000**

TOTAL (for a 19.6 hr. outage**) =** **<u>$1,232,313,986</u>**

Findings

- **Databases of non-terrorist outages and statistical models provide a <u>tool for identifying vulnerable grid scenarios and developing terrorism scenarios</u>.**
- **Three approaches are developed to estimat <u>economic costs</u>: premature deaths, busines loss, and public transportation disruptions.**
- **Applying these tools, civil unrest and/or another attack taking advantage of the outage, would have to accompany a 24 hou outage to produce costs equivalent to a major catastrophe, such as September 11.**

Acknowledgement and Disclaimer

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R. Zimmerman et al., "Diagnostic Tools to Estimate Consequences of Terrorism Attacks Against Critical Infrastructure," U.S. Department of Homeland Security conference, "Working Together: Research and Development Partnerships in Homeland Security," Boston, MA, April 27, 2005.

R. Zimmerman, "Decision-making and the Vulnerability of Critical Infrastructure," Proceedings of IEEE International Conference on Systems, Man and Cybernetics, edited by W. Thissen, P. Wieringa, M. Pantic, and M. Ludema. The Hague, The Netherlands: Delft University of Technology, 2004. ISBN: 0-7803-8567-5.

R. Zimmerman and C. Restrepo, "The Next Step: Quantifying Infrastructure Interdependencies to Improve Security," International Journal of Critical Infrastructures, Fall 2005. UK: Inderscience Enterprises, Ltd. www.inderscience.com.

R. Zimmerman, "Public Infrastructure Service Flexibility for Response and Recovery in the September 11th, 2001 Attacks at the World Trade Center," in Natural Hazards Research & Applications Information Center, Public Entity Risk Institute, and Institute for Civil Infrastructure Systems, Beyond September 11th: An Account of Post-Disaster Research. Special Publication #39. Boulder, CO: University of Colorado, 2003, pp. 241-268. ISBN I-877943-16-9. http://www.colorado.edu/hazards/sp/sp39/sept11book_ch9_zimmerman.pdf

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