Analyzing Infrastructure Vulnerabilities to Multiple Hazards

Rae Zimmerman

Professor of Planning and Public Administration, Wagner School

with

Carlos E. Restrepo, Ph.D; Zvia S. Naphtali, Ph.D; Professor Jeffrey S. Simonoff (NYU-Stern)

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NYU Wagner

Robert F. Wagner Graduate School of Public Service

I. Selected patterns and trends in hazards to infrastructure

- Natural Hazards: Federally declared disasters have been increasing steadily since the 1950s with consequences for infrastructure
- Multiple Hazards: Electric power outages and the duration of outages as a result of a combination of hazards have been increasing from 1990-2004
- Accidents: Nationwide, equipment failure is a key cause of hazardous liquid oil pipeline outages and electric power transmission outages, but in the case of electricity, it appears to be decreasing in importance relative to weather-related causes
- Terrorism: Terrorist attacks on infrastructure seem to pose a significant threat internationally

(1) Natural Hazards

- Since 1953, federally declared disasters increased 2.7% per year (Simonoff, Restrepo, Zimmerman and Napthali 2007)
- The Elderly (65 years old or older) in the U.S. are disproportionately located in high hazard areas prone to hurricanes, particularly in counties that had more than 10 hurricanes between 1995 and 2005 (Zimmerman, Restrepo and Naphtali 2007)
- During the Gulf coast hurricanes, electric power outages were substantial, and the locations of the most severe outages within the State of Louisiana (as indicated by the U.S. DOE) were different for Hurricane Katrina and Hurricane Rita.

(2) Multiple Hazards, including Accidents: (a) Electricity Outages

- Fitting a negative binomial model to U.S. outages between 1990 and 2004, taking into account season, the annual increase in incidents from all causes has been 9.7%, and is statistically significant (Simonoff, Restrepo, and Zimmerman, 2007, p. 551).
- "A regression of logged duration on time alone implies an estimated 11.6% annual increase in duration" with the period from 1998-2001 showing a rate of growth between 10-20% and from 2002-2005 a growth rate of 30-40% (Simonoff, Restrepo, and Zimmerman, 2007, pp. 560-561). These changes are likely due to the increase in weather-related incidents relative to equipment-related incidents over the later time period.
- Using estimates from various sources and inputs from weighted least squares and logistic regression modeling, the estimated cost of a 19.6 hour outage in the New York City region based on estimated business losses, premature death, and transportation public service interruptions, is over $1.2 million (Zimmerman, Restrepo, Simonoff, and Lave 2007, p. 286).

Selected Causes of Electric Power Outages, 1990-2004

Primary Causes (NERC, DAWG database) (Simonoff, Restrepo, and Zimmerman, 2007, p. 549):

- "Capacity shortage
- Crime
- Demand reduction
- Equipment failure*
- Fire
- Human error
- Operational error
- Natural disaster
- System protection
- Third party
- Unknown
- Weather*"

*Weather accounted for 48% of the incidents and equipment failure accounted for 28% of the incidents in the U.S. between 1990-2004.

(2) Multiple Hazards, e.g., Accidents: (b) Oil and Natural Gas Pipeline Outages

- Oil and natural gas infrastructures are vulnerable to accidental disruptions from natural and human causes. Disruption data are available for three types of pipelines – hazardous liquid pipelines, natural gas transmission and natural gas distribution pipelines – from the Office of Pipeline Safety (OPS).
- For all three types of incidents (see Simonoff, Restrepo, Zimmerman and Naphtali 2007 for details):
  - State-to-state variation in incident rates exists, suggesting context-specific risks that should be investigated. For each type of incident certain states have higher than expected incidents per 10,000 miles of pipeline.
  - Important temporal patterns exist in incident trends.
- These failures can have serious consequences in the form of loss of product, damage to properties and the cost of cleanup and recovery. Loss of life and injuries have generally been on the decline.

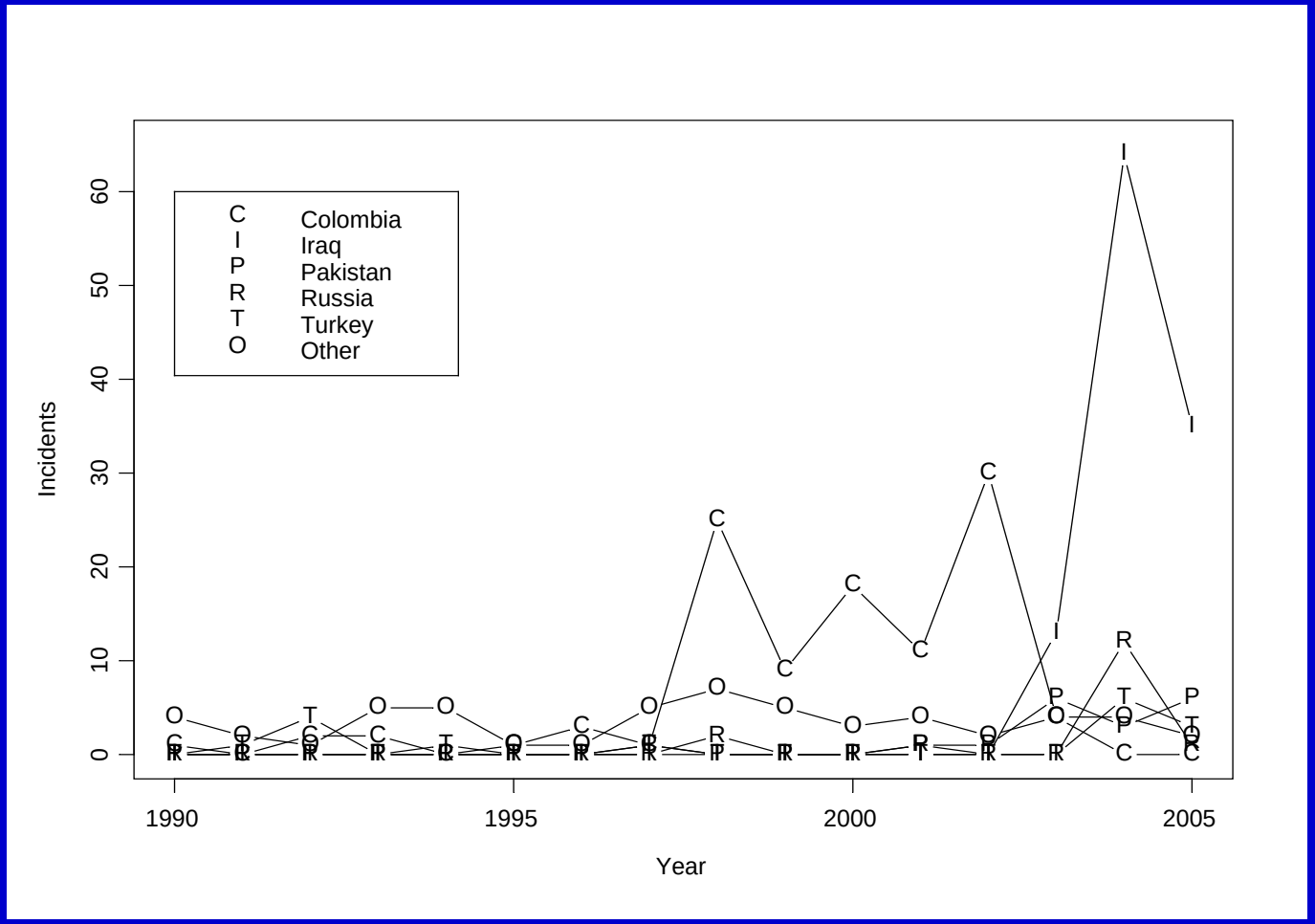
Selected Causes of Hazardous Liquid Incidents (from the OPS database)

- CORROSION, EXTERNAL
- CORROSION, INTERNAL
- EARTH MOVEMENT
- LIGHTNING
- HEAVY RAINS/FLOODS
- TEMPERATURE
- HIGH WINDS
- OPERATOR EXCAVATION DAMAGE
- THIRD PARTY EXCAVATION DAMAGE
- FIRE/EXPLOSION AS PRIMARY CAUSE
- CAR, TRUCK OR OTHER VEHICLE
- RUPTURE OF PREVIOUSLY DAMAGED PIPE
- VANDALISM
- BODY OF PIPE
- COMPONENT
- JOINT
- BUTT WELD
- FILLET WELD
- PIPE SEAM WELD
- MALFUNCTION OF CONTROL/RELIEF EQUIPMENT
- THREADS STRIPPED, BROKEN PIPE COUPLING
- RUPTURED OR LEAKING SEAL/PUMP PACKING
- INCORRECT OPERATION
- MISCELLANEOUS
- UNKNOWN

(3) Terrorism

- International attacks on infrastructure have persisted and in some countries are on the rise.
- The transmission and distribution systems are most commonly attacked in countries outside of the U.S. For electric power 90% of the attacks are to the transmission system (Simonoff, Restrepo and Zimmerman 2007, p. 548). For oil and gas, about 70% of the attacks are to the distribution system (primarily pipelines) (Simonoff, Restrepo and Zimmerman 2005, p. 52).

Trends in International Terrorist Attacks on Oil & Gas, selected countries, 1990-05



Source: Simonoff et al. I3P Research Report; no. 2 (November 2005) "Trends for Oil and Gas Terrorist Attacks," Hanover, NH: The I3P, Dartmouth College, Figure 12, p. 9.

II. Factors Potentially Contributing to Infrastructure Vulnerabilities

- Interdependencies among infrastructure systems (Zimmerman 2005, 2006, 2008; Zimmerman and Restrepo 2006)

- Concentration, spatial and functional, of infrastructure facilities, use and value

(1) Interdependency: Selected Metrics

- Metrics can be developed to quantify infrastructure interdependencies
- Metrics developed at NYU-Wagner/ICIS examine the ratio of the duration of an electric power outage to the duration of the cascading outage of another impacted infrastructure
- Metrics were also applied to the recovery of oil refinery outages during Hurricanes Katrina and Rita: an estimated 15% of refinery outages occurred when power outages outages occurred also.

Data Analysis of Failure Events to Portray Infrastructure Interdependencies

A preliminary set of about 100 infrastructure failures over the past ten years shows that:

- Water main failures affect other infrastructure to a greater extent than other infrastructure failures affect them
- Roads and sewer line failures affect other infrastructure slightly more than other infrastructure failures affect them
- Electric, gas, and fiber optic line failures tend to be affected by other infrastructure disruptions to a greater extent than their disruptions affect other infrastructure

Source: R. Zimmerman, "Decision-making and the Vulnerability of Critical Infrastructure," Proceedings of IEEE International Conference on Systems, Man and Cybernetics, 2004. Based on an illustrative data set of approximately 100 cases.

Infrastructure Interdependency Indicators: "Effect" Ratio

Type of Infrastructure	Ratio of # Times Infrastructure Causes Failures vs. is Affected by Failure
Water mains	3.4
Roads	1.4
Gas lines	0.5
Electric Lines	0.9
Fiber Optic/Telephone	0.5
Sewers/ sewage treatment	1.3

Source: R. Zimmerman, "Decision-making and the Vulnerability of Critical Infrastructure," Proceedings of IEEE International Conference on Systems, Man and Cybernetics, 2004. Based on an illustrative data set of approximately 100 cases.

Electricity Dependent Infrastructure: Outage Durations T(e) and Affected Infrastructure Outage Duration T(i)

Outage Durations for the August 2003 Blackout (Total Duration = 42-72 hours)

	T(i)/T(e)
Transit-electrified rail (NYC)	1.3
Traffic Signals (NYC)	2.6
Water Supply (Cleveland, OH)	2.0
Water Supply (Detroit, MI)	3.0

Source: R. Zimmerman and C. Restrepo, "The Next Step: Quantifying Infrastructure Interdependencies to Improve Security," *International Journal of Critical Infrastructures*, 2006 forthcoming. UK: Inderscience Enterprises, Ltd. www.inderscience.com Summarized from Table 3.

(2) Infrastructure Concentrations as a Potential Vulnerability (Zimmerman 2006)

- 50% of transit ridership is in two states: New York (35%) and California (15%) (Source: U.S. DOT, National Transit Database, 2003).
- 50% of enplanements are at 18 out of 570 airports
- 50% of auto ridership (annual VMT) is in 9 states; congestion is in fewer states
- 50% of electricity consumption is in 9 states
- 50% of mobile wireless subscribers are in 8 states

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