Carnegie Mellon Electricity Industry Center

Worst Case Electricity Scenarios
The Benefits & Costs of Prevention

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Carnegie Mellon Electricity Industry Center

- One of 22 Sloan Centers of Excellence in different industries
- 17 Faculty & 23 Ph.D. students at Carnegie Mellon University
- Probably the largest effort of its kind in the world focused on interdisciplinary problems of the electricity industry.
- Close cooperation with all stakeholders: Industry, regulators, government agencies, consumers, labor, national laboratories.
- Working with CREATE on Reliability & Security
- Other focal areas:
  - Market Structure & Performance
  - Distributed Energy Resources
  - Advanced Generation & Transmission Technologies
  - Environmental & Sustainability Issues

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Who Cares About Electricity?

- An electricity blackout causes us to freeze (sweat) in the dark. We find it difficult to:
  - commute (no traffic signals, no trains)
  - get up & down in buildings (no elevator)
  - work (no light, computers, copiers, faxes)
  - cook (no microwave, refrigerators, appliances, solid state ignition)
  - get entertainment (no TV, radio, VCR)

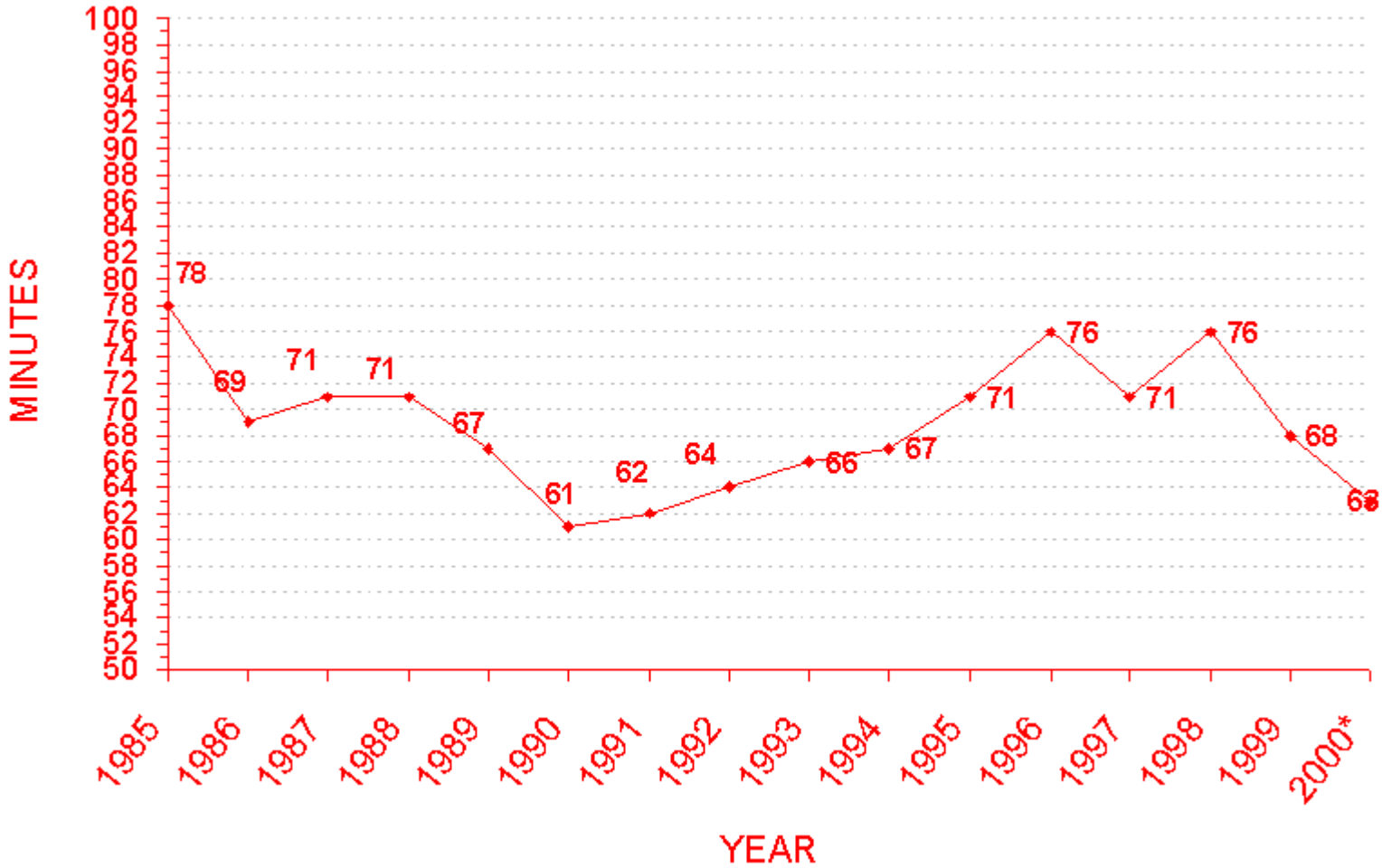
Almost all modern activities depend on electricity

This Essential System is Highly Vulnerable

- Central generation creates high value targets
  - & long, vulnerable transmission lines
  - & unique high voltage transformers
  - & vulnerable substations

System is disrupted frequently by natural hazards, human error, & human attack

Long Island Power Authority
Customer Average Interruption Duration



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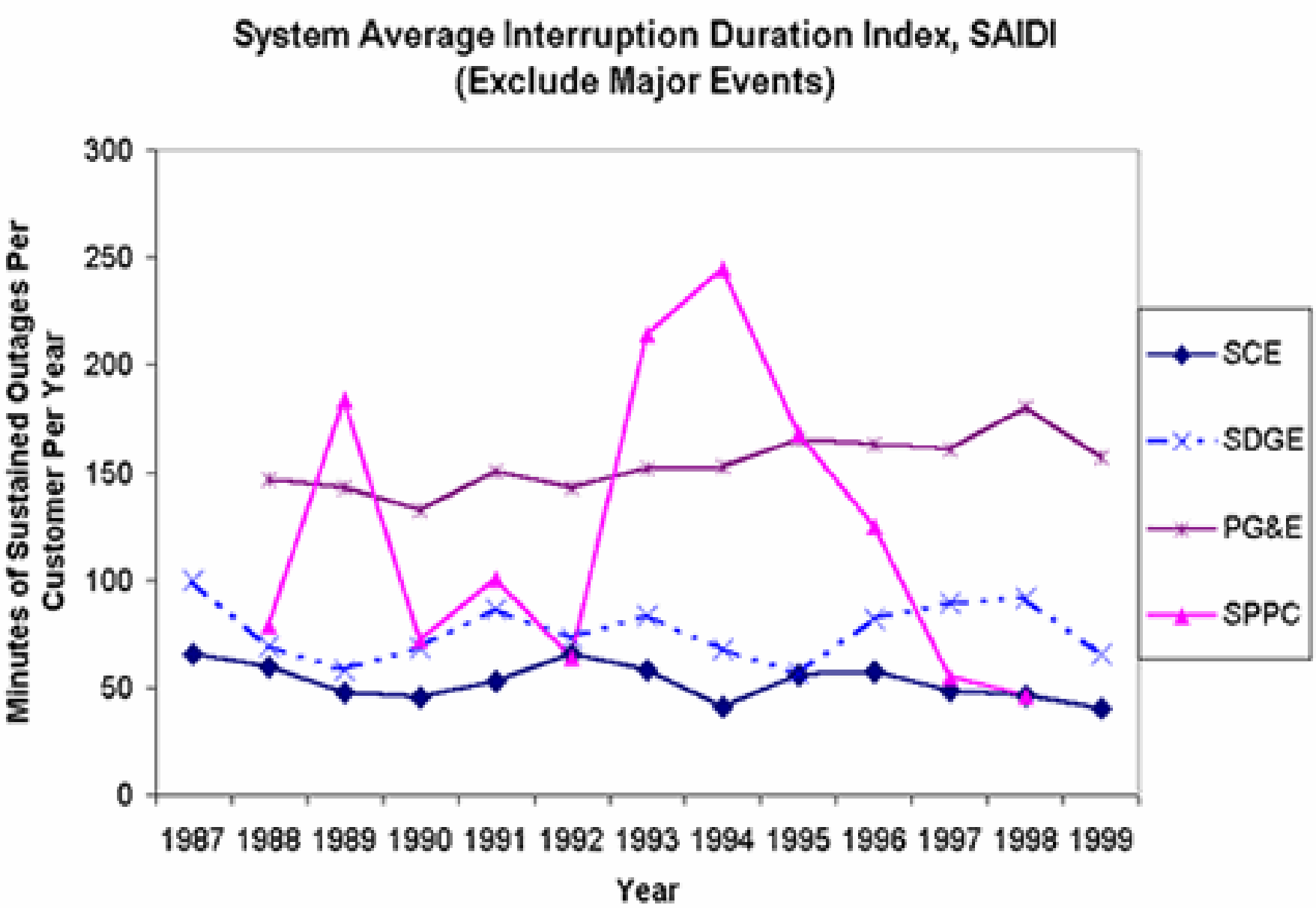


Some Recent Large Blackouts

• 11/9/65	Northeast	30 million people
• 6/5/67	PA-NJ-MD	4 million
• 5/17/77	Miami	1 million
• 7/13/77	NYC	9 million
• 1/1/81	Idaho-Utah-Wyoming	1.5 million
• 3/27/82	West	1 million
• 12/14/94	West	2 million
• 8/24/92	Florida	1 million
• 7/2/96	West	2 million
• 8/10/96	West	7.5 million
• Jan 98	Québec	2.3 million
• Feb-Apr 98	Auckland	1.3 million
• 12/8/98	San Francisco	½ million
• 8/14/03	Great Lakes-NYC	50 million
• 8/30/03	London	½ million
• 9/18/03	Tidewater	4 million
• 9/23/03	Denmark & Sweden	4 million
• 9/28/03	Italy	57 million
• 11/7/03	Most of Chile	15 million

Valuing Unserved KWh

- Blackouts are costly
- Purchased KWh: 10¢ - Unserved KWh: $2
- Electricity revenue: $250 billion per year
- Consumer surplus from electricity: $2.5- 5 trillion per year
- The cost to the US economy from blackouts & defensive measures (backup generation) is billions of dollars per year

Some ‘Worst Case’ Scenarios

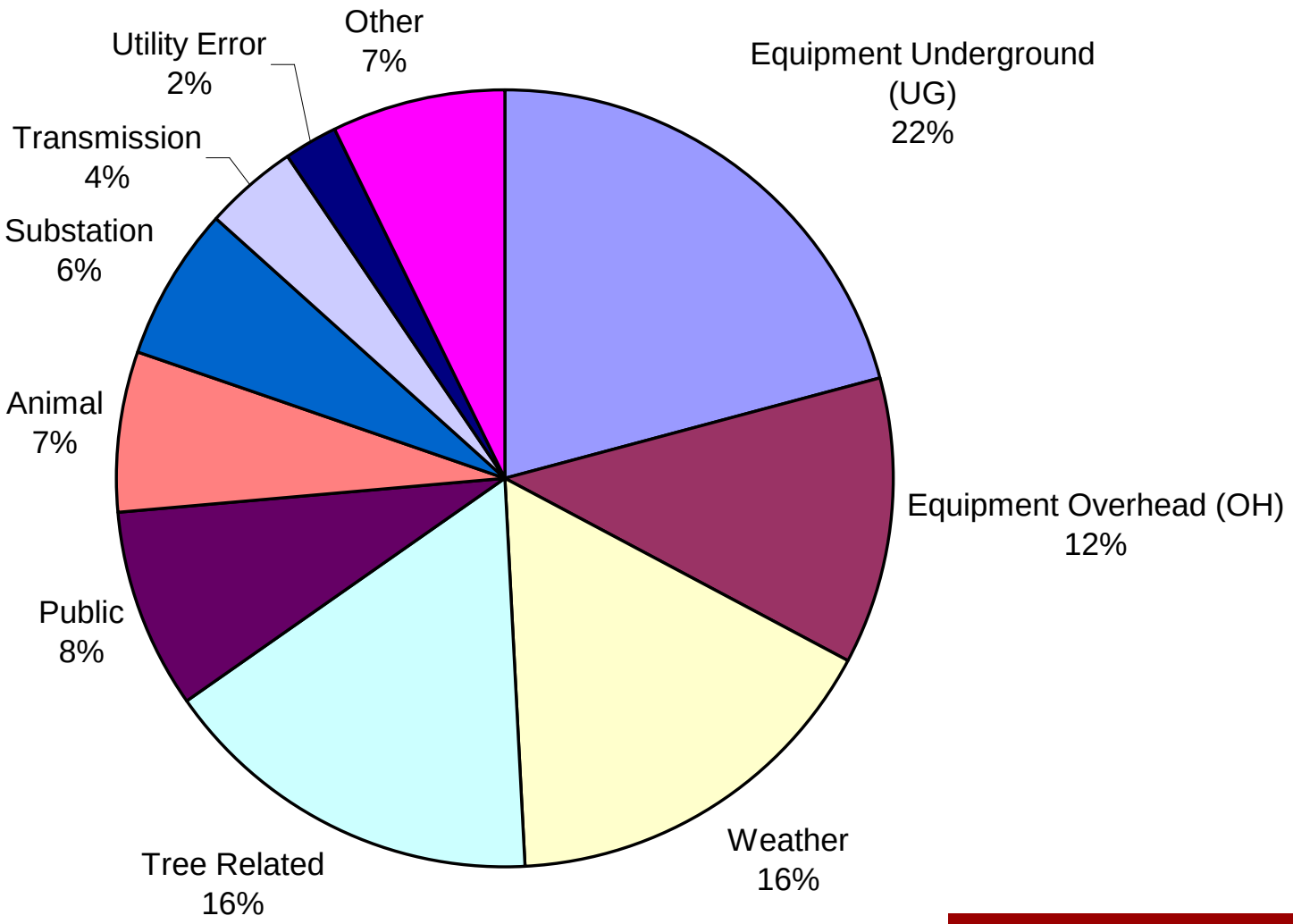
1. Ice storm downs transmission & distribution lines & almost 1,000 transmission towers
2. 3 hurricanes hit same location in 6 weeks
3. Earthquake collapses bridges & highways, taking out electrical system
4. Reactive power shortage leads to a cascade that blacks out 50 million people
5. Large hurricane floods New Orleans for weeks

‘Worst Case’ Scenarios?

1. Ice Storm: Quebec & NY in 1998
2. 3 Hurricanes: Florida in 2004
3. Earthquake: Bay area, California in 1989
4. Reactive power: NE in 2003
5. Hurricane Ivan: Almost occurred in 2004

Since these happened recently, a 500 year worst case would be much, much worse

Causes of All Outages

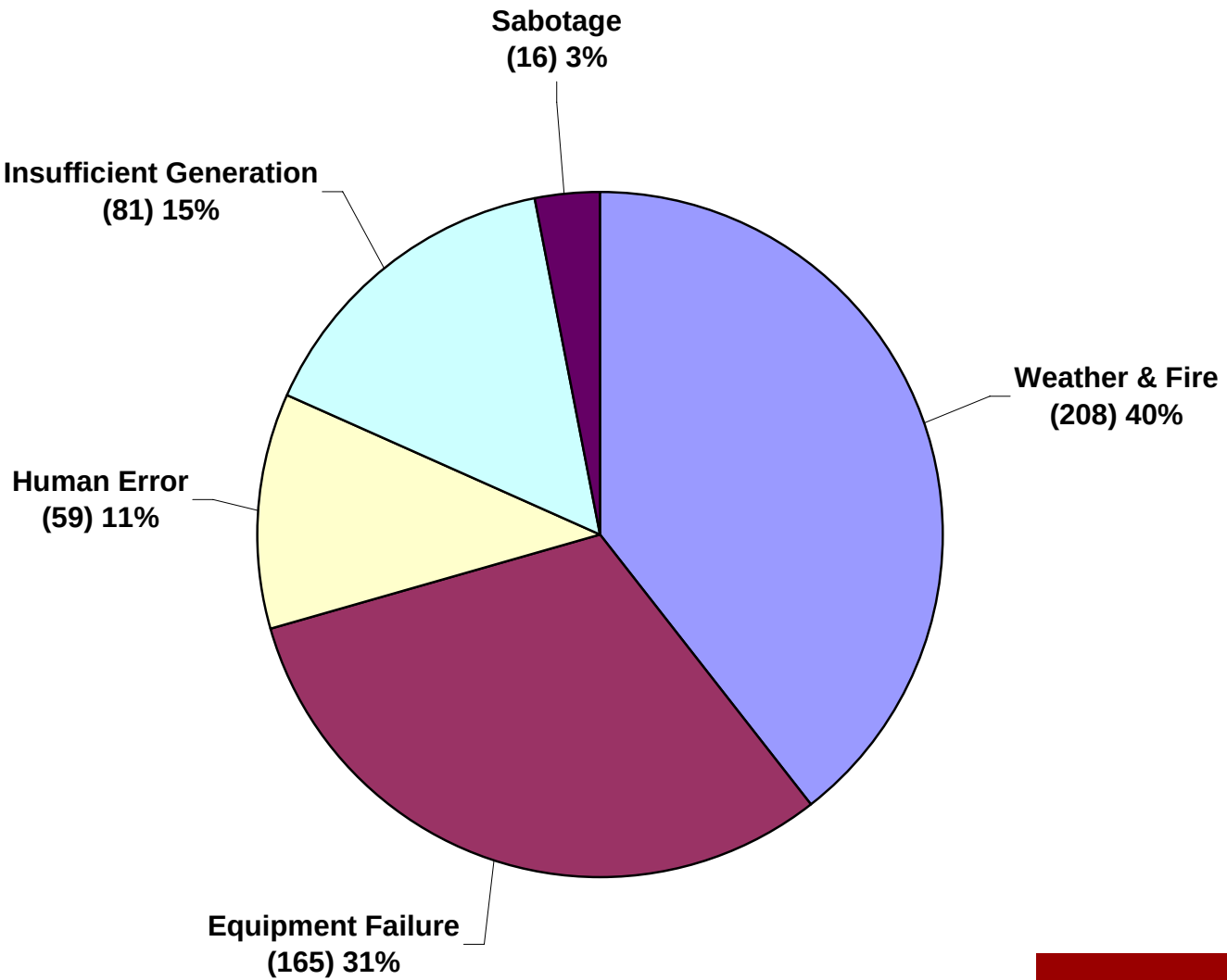


Illinois, 2000

Failure Statistics 1984-2000

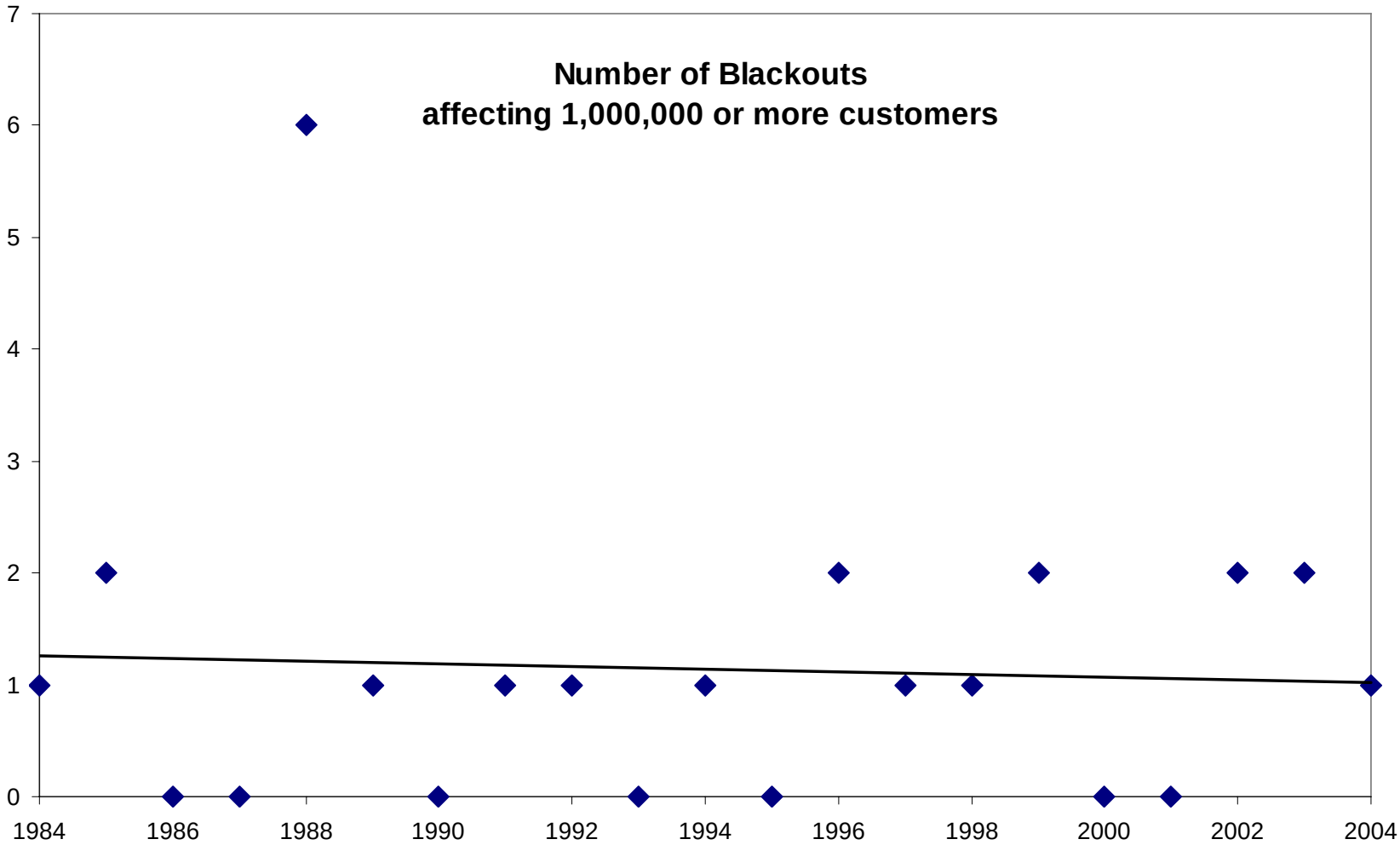
- 533 transmission or generation events
- 324 had non trivial power loss
- 46 of these (3 per year) were >1000 MW

Causes of Major Disturbances



Source: Analysis of NERC DAWG data 1984-2000 by Jay Apt

Are Blackouts Getting More Frequent?



Source: Jay Apt analysis of NERC Distribution Analysis Working Group (DAWG) Database

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Are We Adequately Backed Up?

- In Pittsburgh, 2 of 5 police are backed up
  - $48,000 total capital cost to back up all zones
- 15% of Pittsburgh customers would lose water with a 1-day power outage, 50% after 3 days.
- Detroit, Cleveland, & New York dumped untreated sewage into water bodies on 8-14.
- Many hospitals, factories, stores, etc. that thought they were backed up lost power

Other Infrastructure

- Land-line telephones have robust backups (& were functional on 8/14)
- BUT: handsets & new phone systems need electric power
- Cellular tower transmitters lose battery power in 6 hours
- Most natural gas pipelines are self-powered
- Garbage services typically do not have emergency diesel contracts

Human Attack

- Human attack could cause a blackout by taking out transmission lines during peak demand. This could be done by dynamiting transmission towers or destroying high voltage transformers.
- Worse case: At a time of peak demand, 24 terrorists drive vans filled with explosives into New York City, attacking 24 tall buildings at 4:30 PM after timed explosives take down 4 major transmission lines. The resulting blackout darkens traffic signals causing gridlocked streets. Police & firemen cannot get trucks to damaged, burning buildings. Panic ensues as commuters try to get home amidst frozen elevators, subways, & trains, as well as gridlocked streets.

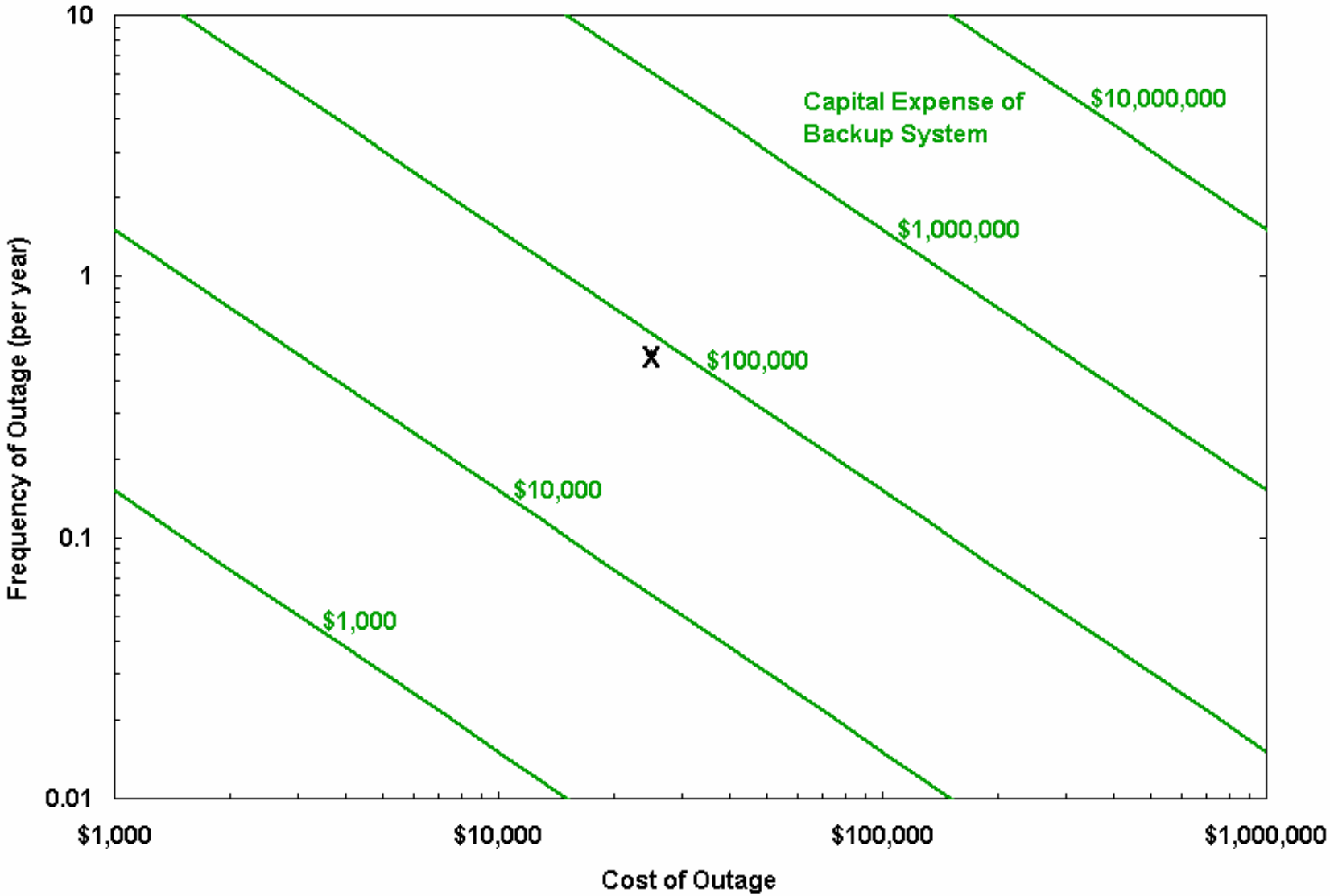
Human Attack

- Other worse case: Terrorists destroy high voltage transformers on the largest transmission lines serving New York, Boston, Philadelphia, Chicago, Los Angeles, etc. The cities lose 30-70% of their electricity supply for more than one-year.

How Much Reliability Do We Want?

- Terrorists, natural hazards, & error can all cause blackouts in similar ways.
- Many (but not all) measures to protect against one problem offer protection against all.
- US electricity system is less reliable than UK, Japan, etc.
- We choose not to spend more to increase reliability
- Economic loss for shutdown is $112 per person per day
- Additional losses from injury & death, crime, & delay
- E.g., 8-14-03 => 50 million people x $112 = $5.6 billion
- Next graph shows whether to invest in backup, given capital cost & loss if electricity fails.

Example analysis for backup systems with 12 year depreciation at 7% discount rate & annual O&M cost equal to 2.5% of capital cost



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Creating Greater Resilience: Lessen Damage from Nat Haz, Errors, & Attacks

1. Improve operator training & communication
2. Multiple transmission lines to deliver electricity
3. Diversified fuel supply & generation technology
4. On-site fuel storage
5. Decentralized generation
6. Backup generators
7. Ability to shed individual loads automatically
8. Improved, secure information & control systems
9. Inventory high voltage transformers that are portable

1. Improve Operator Training & Communication

- Regular training on simulators
- Dedicated lines to critical operators & ISO
- Real time displays about conditions throughout the system with time stamp on when data were gathered

2. Multiple Transmission Lines to Deliver Electricity

- Long transmission lines are impossible to protect & highly vulnerable
- Need multiple, redundant lines in different corridors
- Only certain solution is distributed generation

3. Diversified Fuel Supply & Generation Technology

Electricity generation has been curtailed or threatened by:

- 1975 OPEC oil embargo
- Threatened shut-down of nuclear plants after Three Mile Island
- Scarcity & high price of natural gas since 2000
- Droughts, which curtail hydro-electric generation
- Limits on carbon-dioxide & other greenhouse gases threaten fossil fuel generation

It is impossible to predict droughts or other untoward circumstances. Best to have a diversified portfolio of fuels& generation technologies.

4. On-Site Fuel Storage

- Fuel deliveries are vulnerable: Natural hazards, accidents, human error, markets, terrorists
- Nuclear & coal best, natural gas & wind worst
- Wind requires backup, but natural gas usually is not backed up. But if there is no local storage, a break in delivery could stop generation & cause a blackout
- Trend toward less coal storage is unfortunate

5. Decentralized Generation

- Eliminating “power parks” removes attractive targets
- Also reduces or eliminates transmission lines
- No spillover from other generating units (TMI-2 put TMI-1 out of operation for years)
- Moving generation closer to customer lowers exposure to natural hazards & terrorists
- Inherently greater reliability

6. Backup Generators

- Achieving perfect reliability is impossible
- Outage frequency is high enough so that high value customers find backup generation has benefits greater than costs
- On 8-14 many hospitals, factories, stores, etc. with backup generators found that they did not work; for reliability, these generators must be tested monthly under full load
- There must be sufficient onsite fuel storage to last until external supply is restored or fuel can be replenished

7. Ability to Shed Individual Loads Automatically

- At 10¢ per KWh, most electricity goes to low value uses, e.g., pool pumps, dishwashers, etc.
- If demand had to be curtailed for a few hours or even a day, there would be little inconvenience to cutting demand by 50, 70, or even 90%
- Today, shedding demand means shutting down a substation & all the customers it serves
- The ability to shed individual loads automatically would increase reliability & lower cost

8. Improved, Secure Information & Control Systems

- Many utilities have moved from dedicated SCADA systems to internet or telephone based systems
- These systems are vulnerable to disgruntled employees or hackers
- Controllers need better real time information on the state of each generator, transmission line, & substation demand

9. Inventory High Voltage Transformers & Store Portable Transformers

- High voltage transformers can take more than one-year to replace.
- Having some transformers in inventory is prudent.
- However, since these transformers are so large that they are difficult to transport without disassembly, having portable high voltage transformers is important.

Conclusion

- The US electricity system currently experiences many disruptions due to natural hazards & human error. Large, costly blackouts occur frequently.
- It is highly vulnerable to human attack. A worst case scenario would be highly destructive.
- Many investments would simultaneously improve reliability & reduce vulnerability or the amount of damage from terrorist attack
- Evaluating the reliability & security benefits together would justify many new investments