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Electric Power Systems Resilience

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Today's Discussion

- Introduction
- Defining Resilience
- Resilience Metrics
- Resilience Analysis and Improvements
- Microgrid Designs for Resilience

Where Is New Mexico?

- 5^{th} largest state in the US
- Population: 2.1 million
- New Mexico is known for its beautiful landscape, rich culture, high tech industry, plentiful wind and solar resources

Defining Resilience

Presidential Policy Directive (PPD) 21

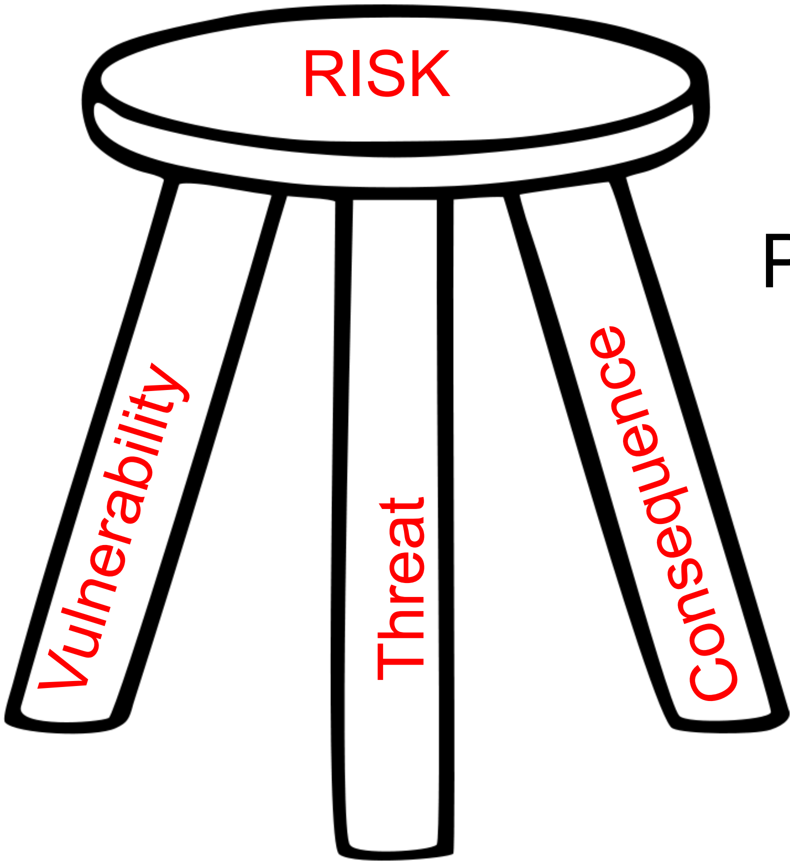
1. "[preserve] infrastructure that are vital to the **public confidence** and the Nation's **safety**, **prosperity**, and **well-being**."
2. "[prevent] debilitating impact on the national **security**, **economic** stability, **public health** and **safety**, or any combination thereof"
3. "…analyze *threats* to, *vulnerabilities* of, and potential *consequences* from all hazards on critical infrastructures".

-PPD-21: Critical Infrastructure Security and Resilience

"without some numerical basis for assessing resilience, it would be impossible to monitor changes or show that community resilience has improved. At present, no consistent basis for such measurement exists…"

-Disaster Resilience: A National Imperative, National Academy of Sciences

Resilience: A Risk-Based Approach



Probability of Consequences =

f(vulnerability, threat)

Resilience Metrics and Their Gaps

- **Attribute based metrics** are primarily used today (e.g. number of critical spare transformers)
  - They don't quantify resilience
  - They don't indicate certainty about effectiveness
- **Performance based metrics**:
  - Are quantitative and denote uncertainty
  - Allow optimal allocation of resources in system planning and operations
  - Provide an ability to differentiate resilience among systems
  - Inform development of policy goals and the assessment of their effectiveness
  - Achieve **utility** in exchange for **complexity**

Resilience versus Reliability

Differentiating reliability and resilience is important

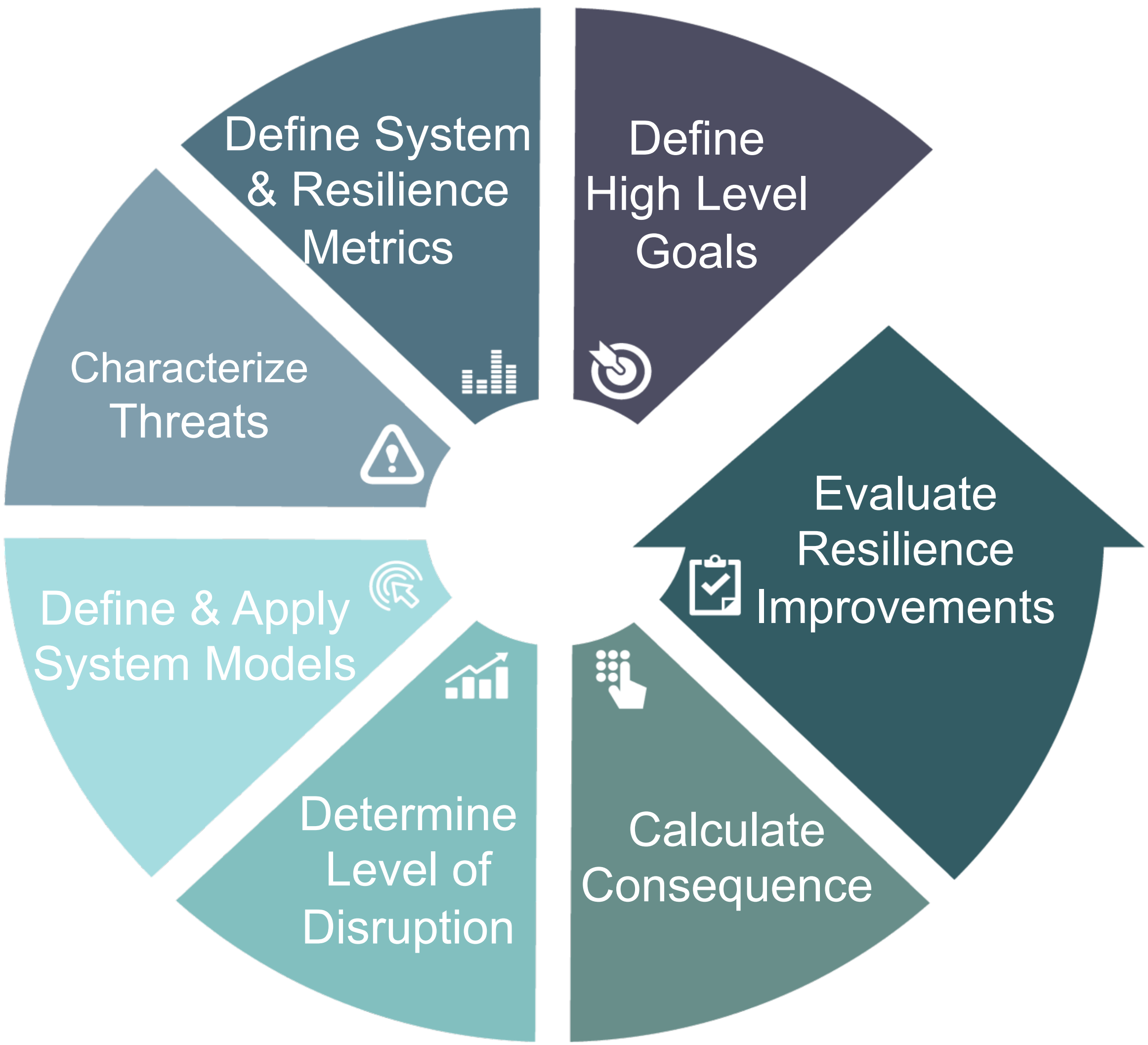
- Reliability is compulsory
- Reliability is related to rate recovery
- Adoption of resilience metrics will be easier if reliability definitions remain as-is

Reliability	Resilience
High Probability, Low Consequence (SAIDI/SAIFI exclude storm data)	Low Probability, High Consequence
Not risk based	Risk Based, includes: Threat (you are resilient to something) System Vulnerability (~reliability) Consequence (beyond the system)
Operationally, You are reliable, or you are not [0 1]. Confidence is unspecified	Resilience is a continuum, confidence is specified
Focus is on the measuring impact to the system	Focus is on measuring impact to humans

Reliability versus Resilience

- Is it possible to have two systems with identical reliability but different resilience?
  - Yes
- Why? Because reliability focuses on the system and resilience focuses on the social impact (via the system).

Moving Forward with Resilience Analysis

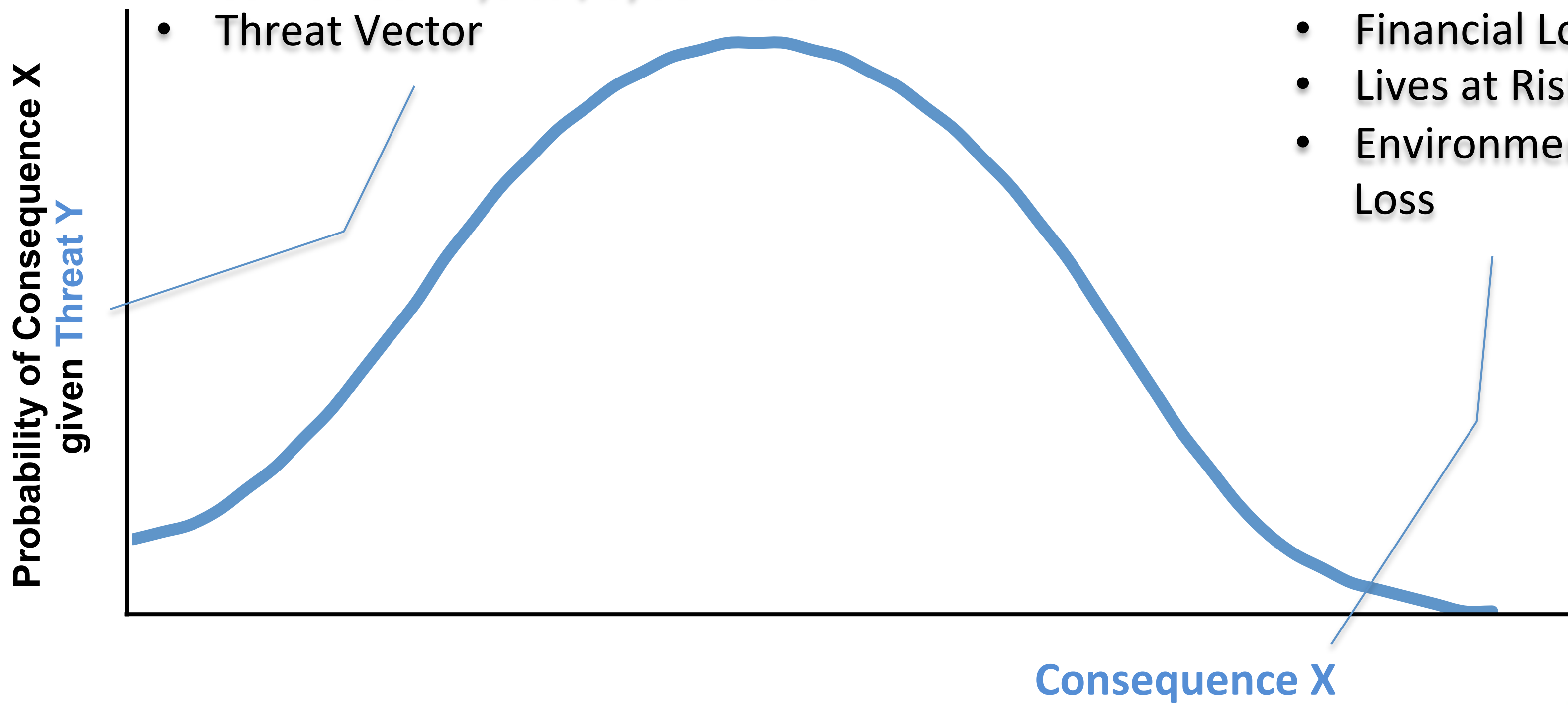


Resilience Metrics

Probability of Consequence X, Given Threat Y

- Category 5 Hurricane
- Flood, Ice Storm
- Geo-Magnetic Disturbance
- Combined Physical/Cyber Attack
- Threat Vector

- Financial Loss
- Lives at Risk
- Environmental Loss



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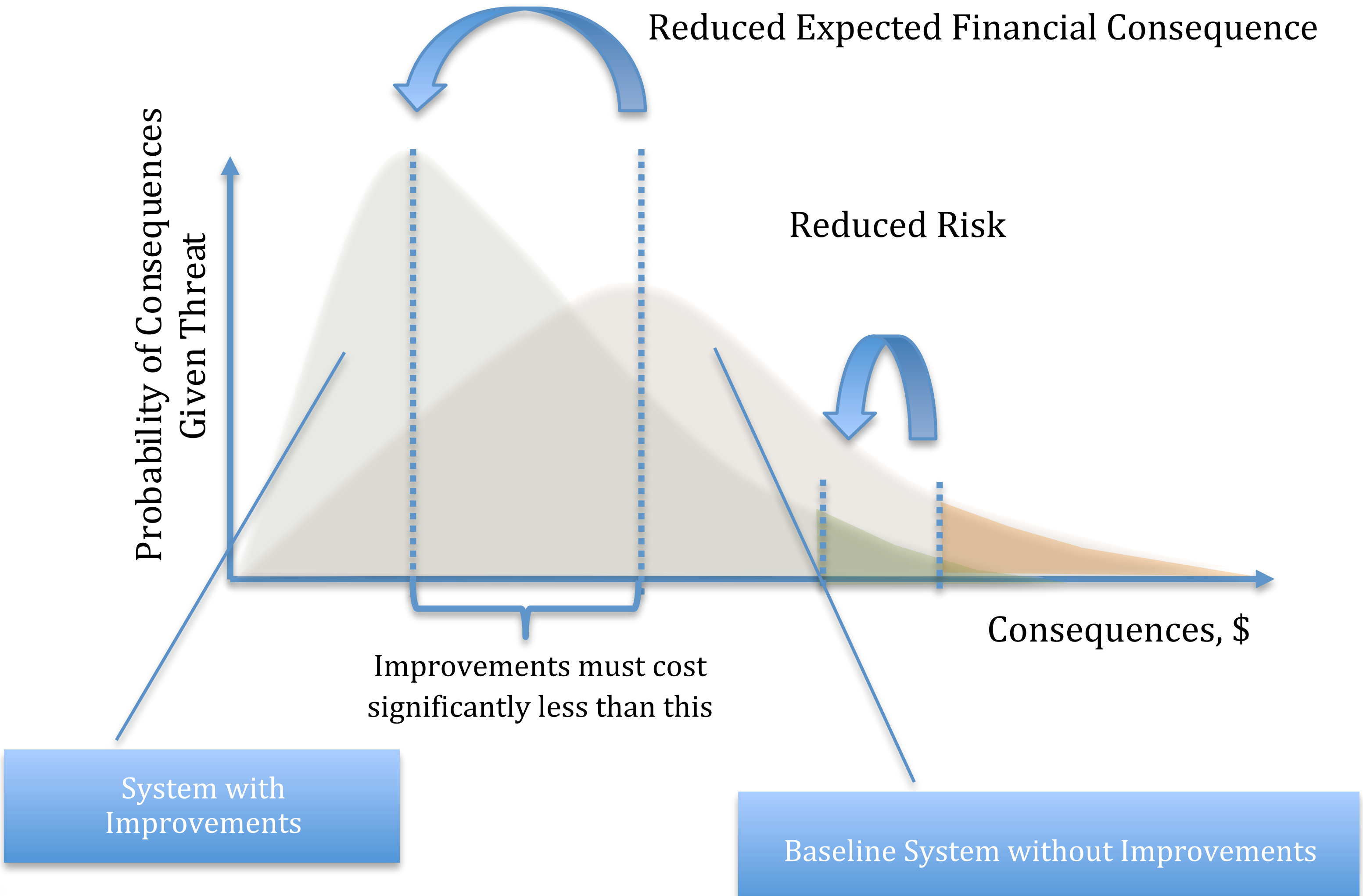
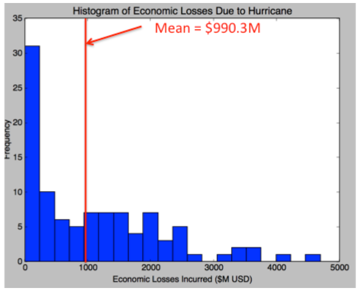
Evaluating System Improvements



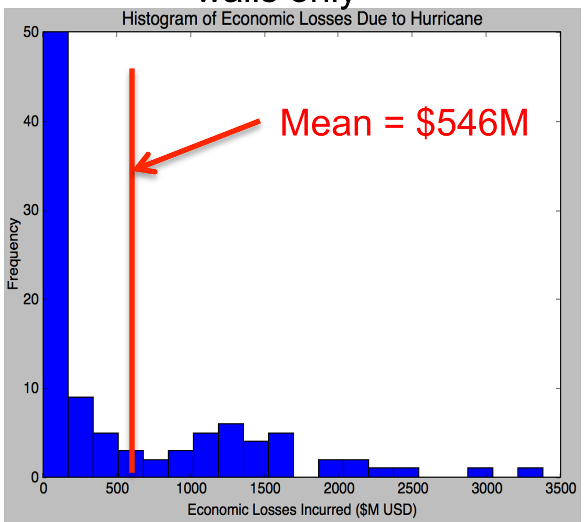
Ex: How Should We Invest $100M?



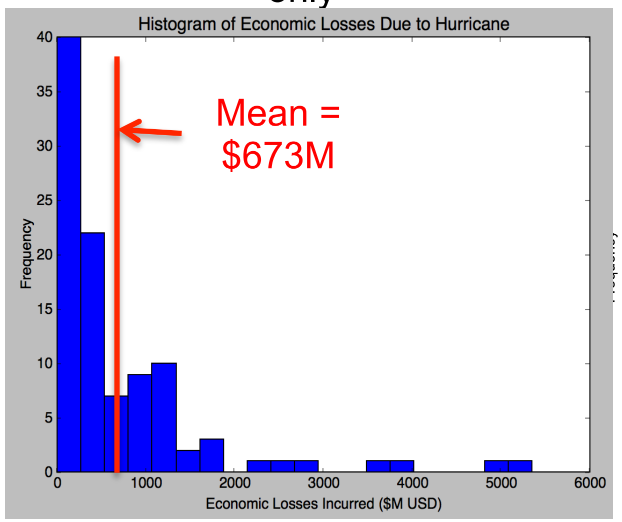
Baseline mean was $990M

Invest the same $100M in both flood walls and burying cables

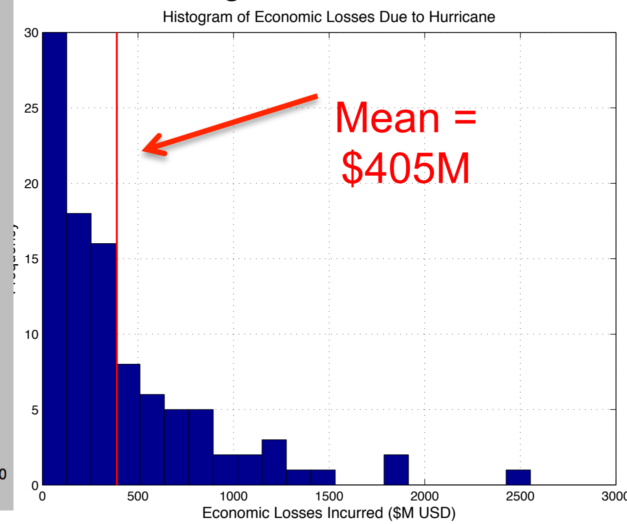
$100M of generator flood walls only



$100M of burying lines only



$100M of burying lines and generator flood walls



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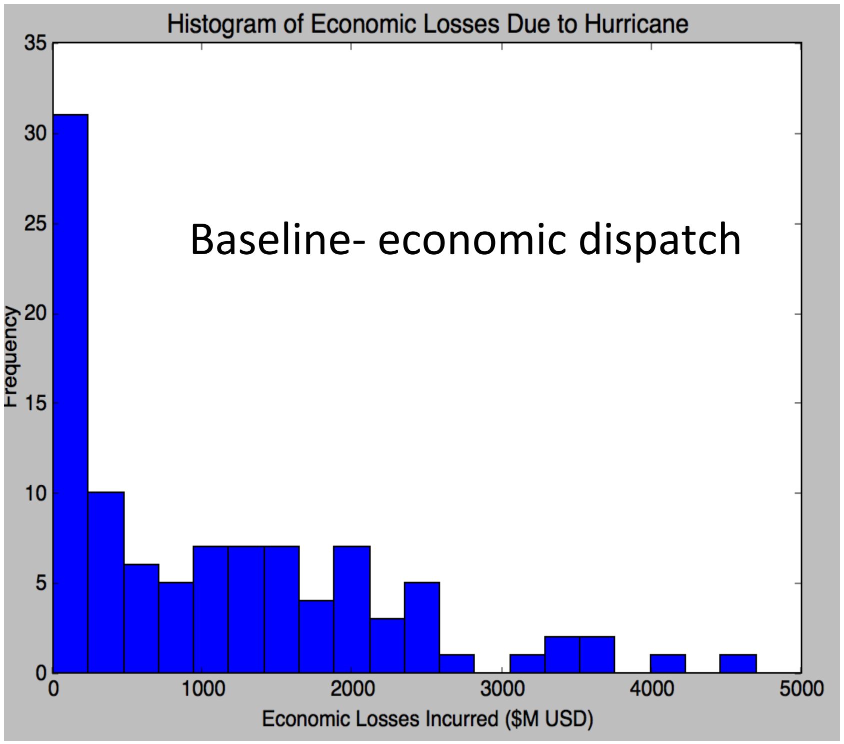
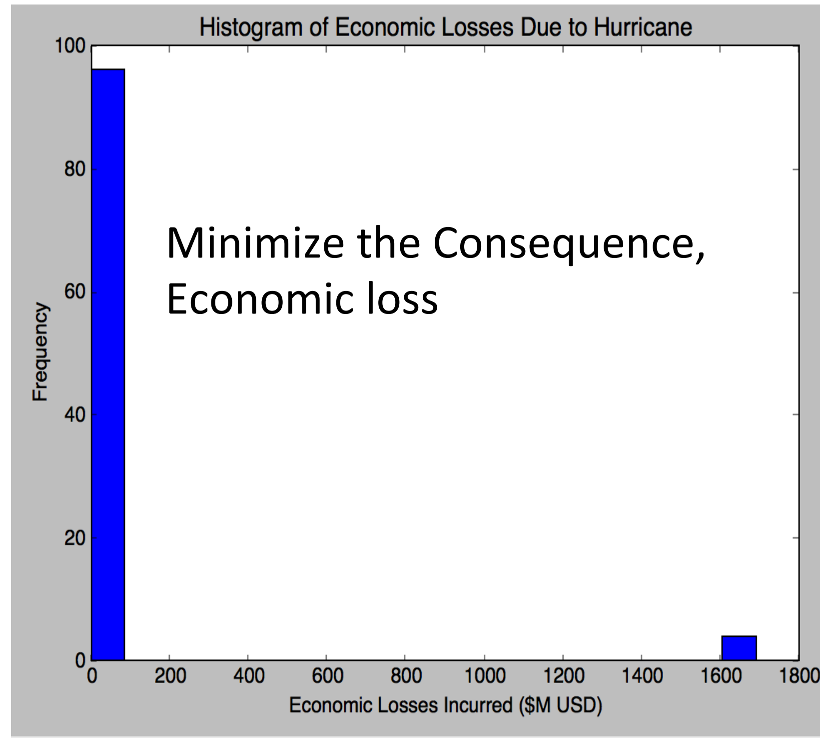
Change the Dispatch Objective



VS

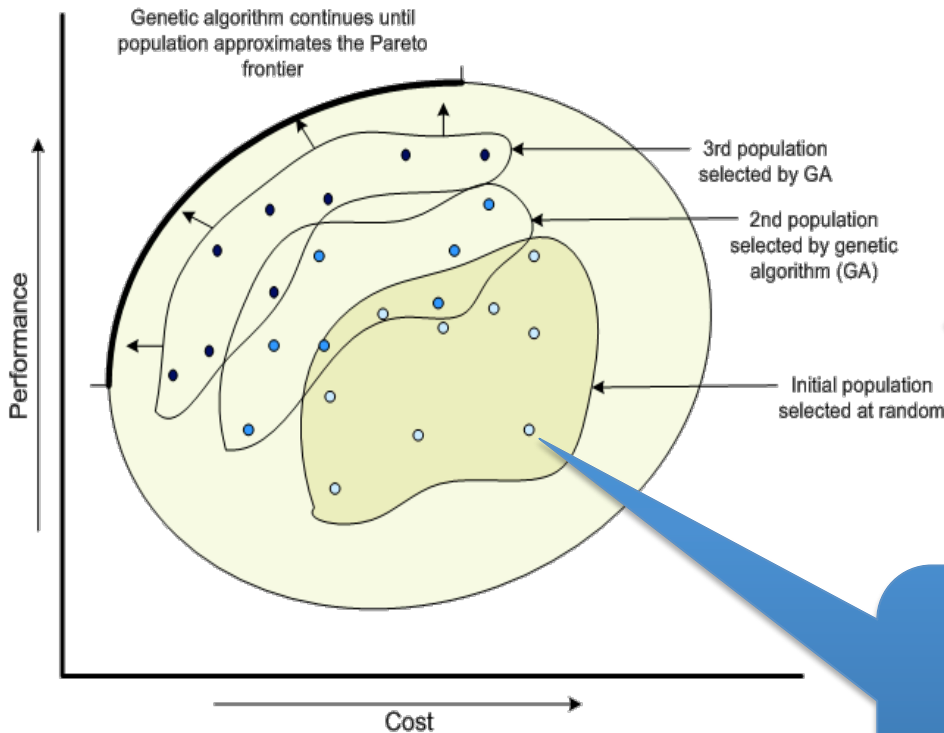


In our IEEE 118 bus resiliency example, it is possible to mitigate nearly all economic consequences of the posited hurricane

Designing Microgrids for Resilience

- Engage stakeholders
- **Establish a design basis** Define performance metrics
- Define system boundaries
- Collect system and operations info and data
- Generate feasible designs
  - **measure performance against the design basis**
  - improve the design
  - repeat

Pareto Optimality Using Genetic Algorithms

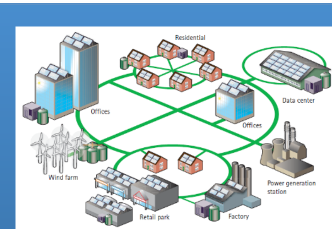


Topology

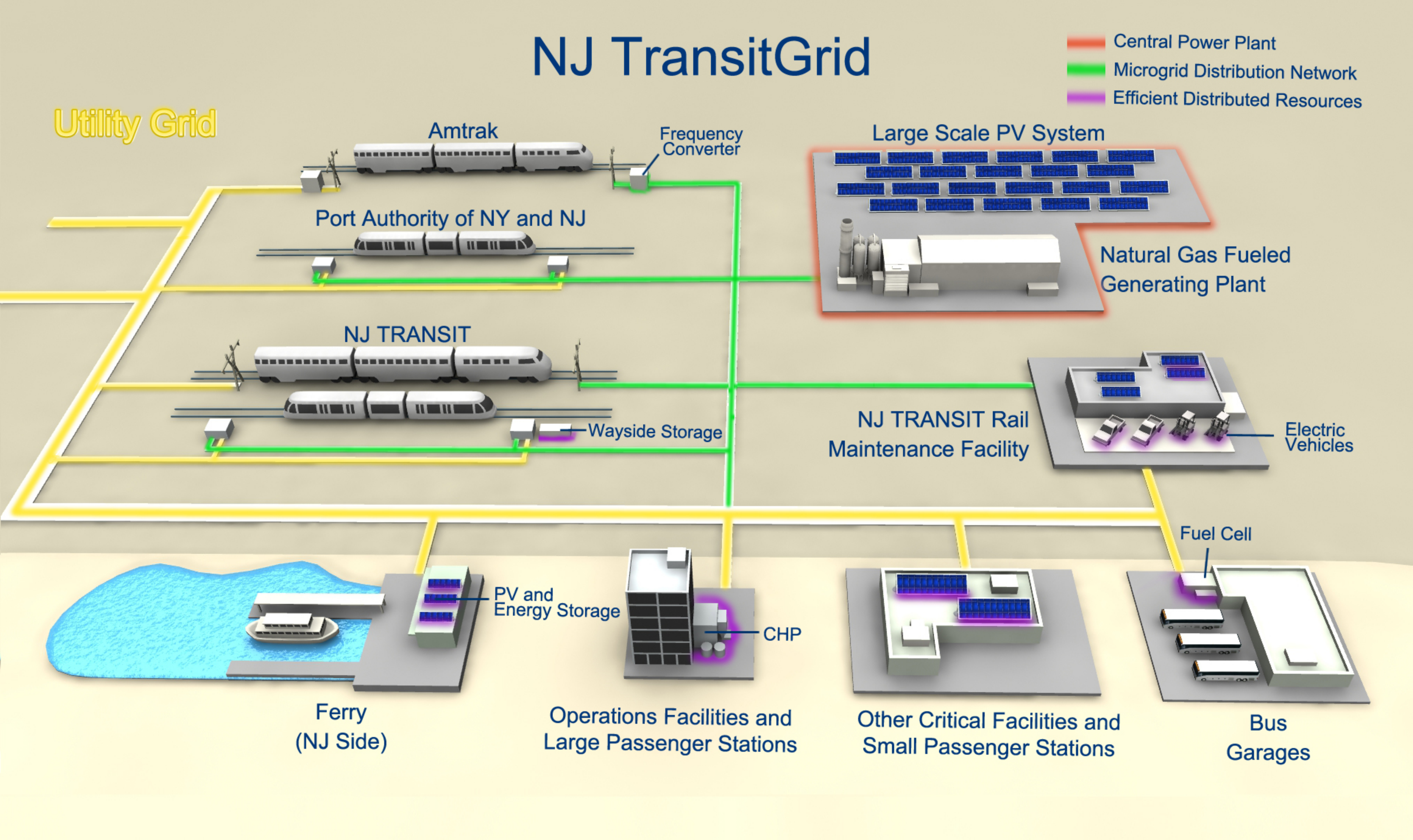
Performance

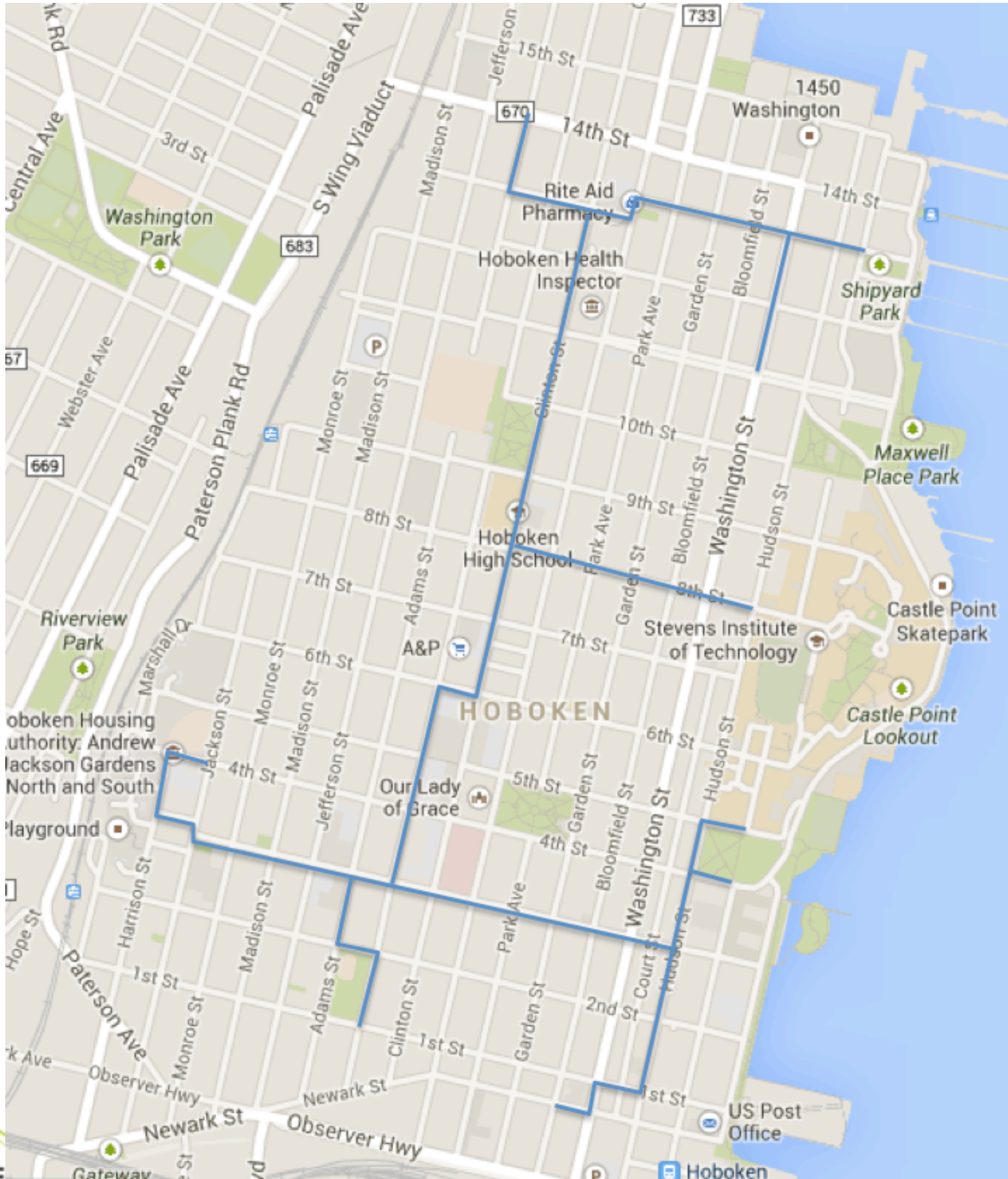
Event Driven Simulation

Monte Carlo Analysis



Each dot is a different microgrid layout


NJ TransitGrid
Central Power Plant
Microgrid Distribution Network
Efficient Distributed Resources
Utility Grid
Amtrak
Frequency Converter
Large Scale PV System
Port Authority of NY and NJ
Natural Gas Fueled Generating Plant
NJ TRANSIT
Wayside Storage
NJ TRANSIT Rail Maintenance Facility
Electric Vehicles
Fuel Cell
PV and Energy Storage
CHP
Ferry (NJ Side)
Operations Facilities and Large Passenger Stations
Other Critical Facilities and Small Passenger Stations
Bus Garages



COOPR

Mixed Integer Optimization

Early Solution Subset: Steiner Tree Problem

Objective: minimize cost

Constraints:

- Serve all loads
- $300/linear foot
- $20K for a junction

Solution: $6.7M for Trenching – with an optimality gap of 5%.

Least cost topology for a single large microgrid

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