From Tower Failure to Power Loss: A Fragility-Based Hurricane Resilience Assessment of a Transmission Network

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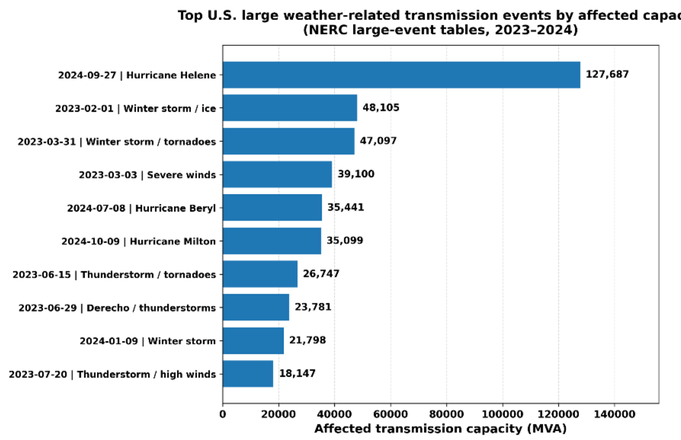
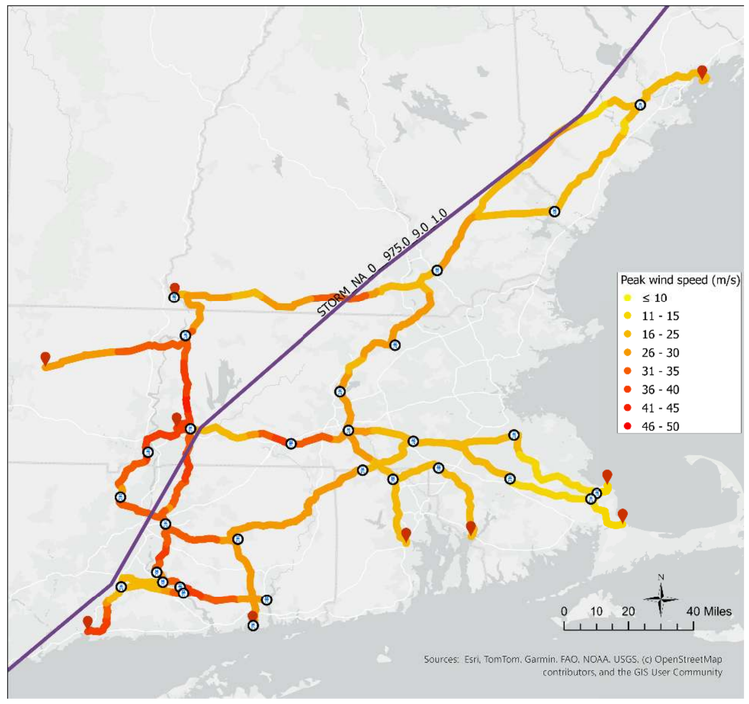
Why this matters

- **Physical damage is only the starting point.**
  Hurricane winds can fail towers, conductors, or line segments, but the larger consequence depends on how those failures affect the connected transmission network.
- **Outages can propagate beyond the damaged corridor.**
  Once key lines are lost, power flows redistribute through the remaining network, which can trigger secondary outages and increase service disruption.
- **Power loss is not experienced equally.**
  The same outage can create different recovery burdens depending on community vulnerability, including income, age, disability, vehicle access, housing conditions, and language barriers.
- **This project connects physical grid damage, service loss, and community vulnerability to support resilience planning.**



Hazard-to-grid exposure

A benchmark transmission network is exposed to stochastic hurricane wind fields, with spatially varying wind demands mapped to towers and line segments to identify the locations most susceptible to physical damage.



Representative hurricane wind exposure across a benchmark transmission network.

Damage propagation model

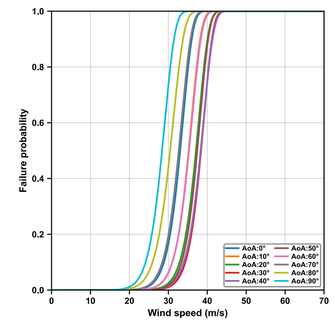
Wind Demand
Peak hurricane wind speed at each tower and line segment

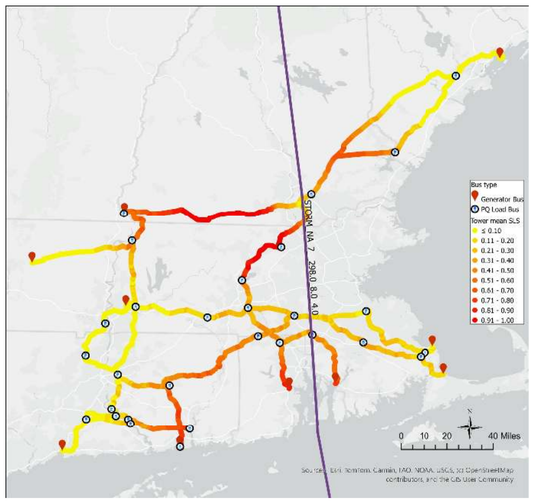
Failure Probability
Fragility curves convert wind demand into damage likelihood

Initial Outages
Structurally damaged lines are removed from the power network

Cascade Simulation
Power flows redistribute and may trigger secondary outages

Demand Survivability
Fraction of total demand still served after cascading outages

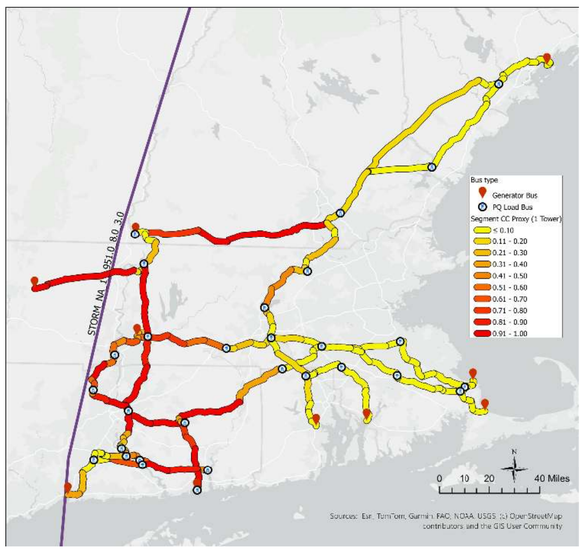




Results and Insights

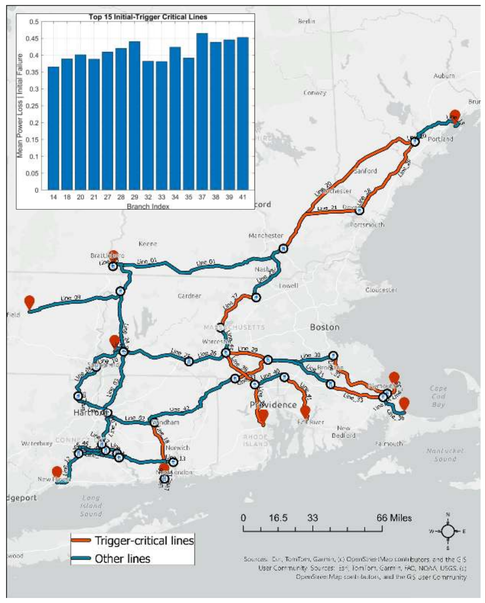
Structural damage is not the final consequence

- Hurricane damage can remove transmission lines from service, but the larger impact depends on network response.
- Power-flow redistribution can amplify local physical damage into broader service disruption.
- Consequence metrics translate failed components into demand loss, islanding, and recovery needs.



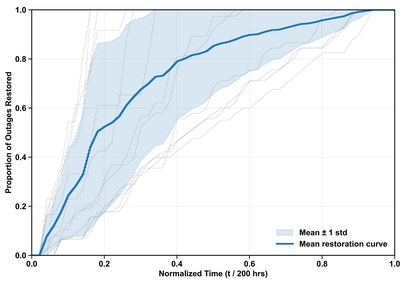
Critical lines are not all the same

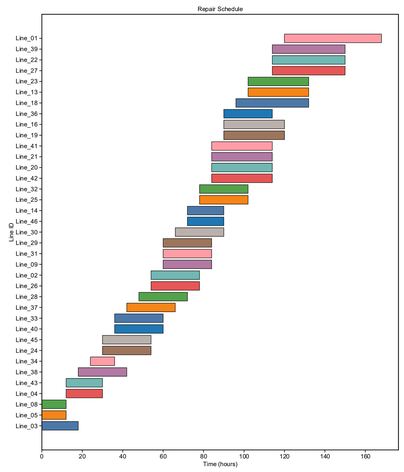
- Trigger-critical lines: directly damaged lines that initiate large service losses.
- Cascade-critical lines: lines that repeatedly fail after power-flow redistribution.
- Planning should target both hazard-exposed corridors and system-sensitive corridors.



Restoration order changes resilience

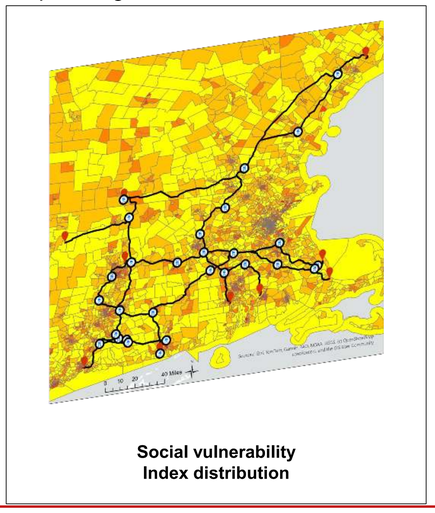
- Repair order controls when damaged network components become usable again.
- A repaired line may restore limited service if connected paths are still unavailable.
- Recovery should be evaluated using both the line restoration progress and the demand restored.
- The schedule identifies the timing of individual line repairs.
- The recovery curve summarizes how quickly the system returns toward pre-event performance.
- Comparing repair schedules helps identify which damaged lines have the highest functional restoration value for accelerating system recovery.





Applications: Social Vulnerability

- Census tracts are classified using a Social Vulnerability Index (SVI) to represent differences in community recovery capacity.
- SVI classes identify areas where power outages may create greater hardship due to socioeconomic, demographic, transportation, and housing-related constraints.
- In this framework, SVI is used as an equity-screening overlay on top of grid consequence results, not as a structural fragility input.
- Areas with both high outage consequence and high social vulnerability can be flagged as priority locations for resilience planning.



Social vulnerability Index distribution

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