SAND2017-12356PE

National Infrastructure Simulation and Analysis Center (NISAC)

American Fuel & Petrochemical Manufacturers Visit

November 14, 2017

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NISAC History

- The National Infrastructure Simulation and Analysis Center (NISAC) is
  - A program of the DHS Office of Cyber Infrastructure Analysis (OCIA)
  - Established under The USA PATRIOT Act of 2001
  - A collaboration between national laboratories
    - Sandia National Laboratories
    - Los Alamos National Laboratory
    - Pacific Northwest Laboratory (added in 2015)

NISAC Modeling and Analysis Goals

Provide fundamentally new modeling and simulation capabilities for the analysis of critical infrastructures, their interdependencies, vulnerabilities, and complexities

Aiding decision makers with

- policy assessment
- mitigation planning
- education & training
- near real-time assistance to crisis response organizations

RESILIENT INFRASTRUCTURE ANALYSIS

Resilience Science at Sandia

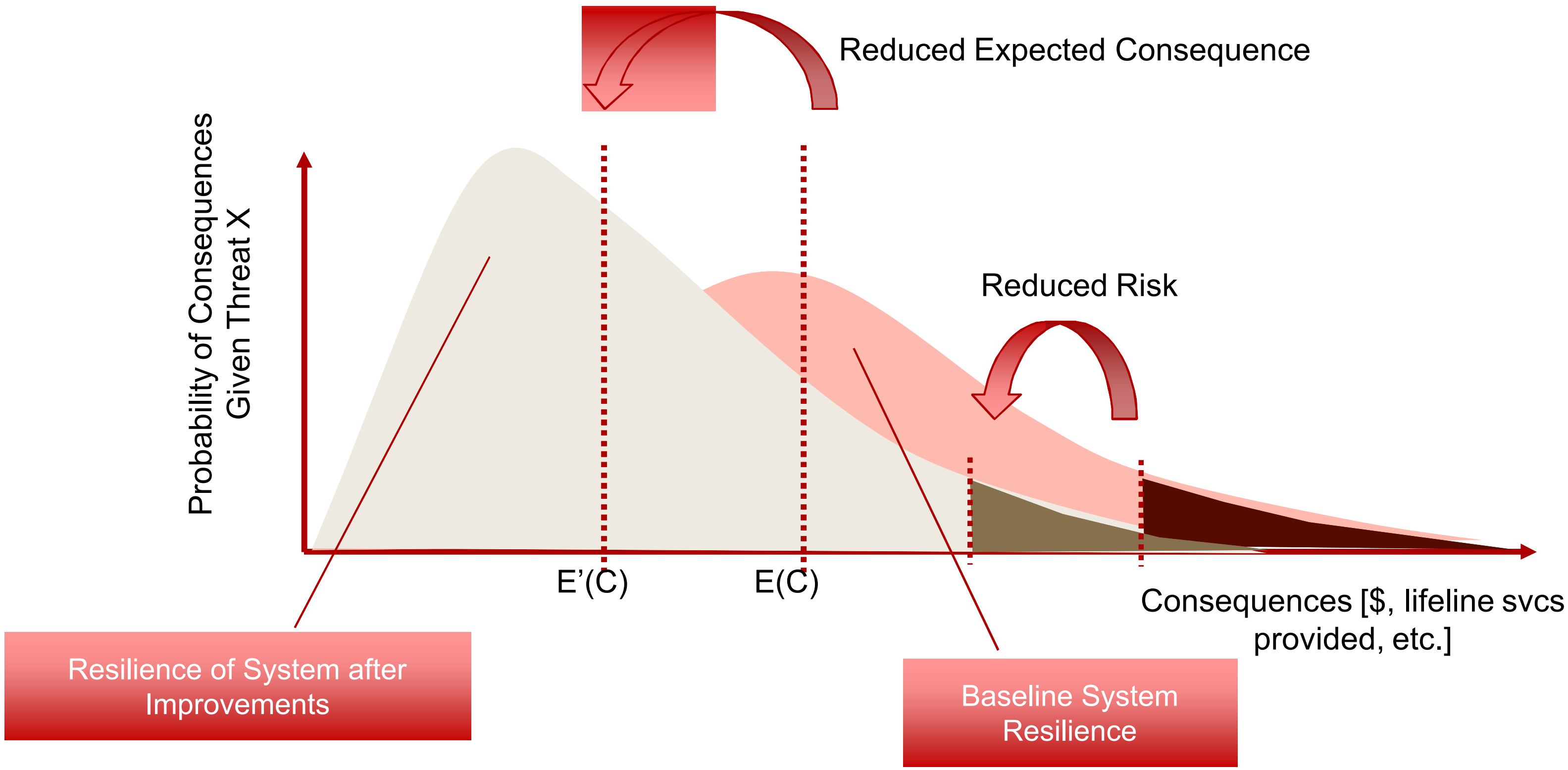
Presidential Policy Directive 21:
The term "resilience" means the ability to **prepare for** and **adapt** to changing conditions and **withstand** and **recover** rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.

Disaster Resilience A National Imperative, National Academy of Sciences:
“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…”

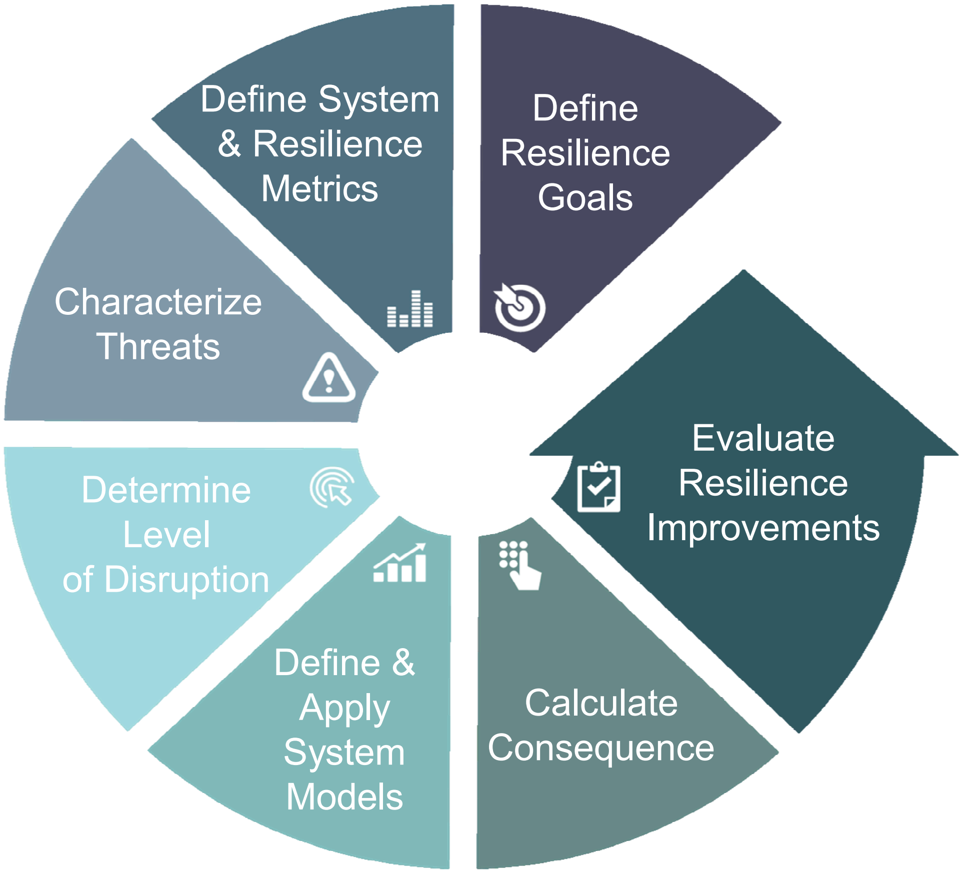
$$SI = \int_{t0}^{tf} [TSP(t) - SP(t)]\,dt. \quad TRE = \int_{t0}^{tf} [RE(t)]\,dt.$$

Resilience Quantification Incorporating Uncertainty

The following framework was developed for the Quadrennial Energy Review and supports decision making to obtain demonstrable resilience improvements



Resilience Analysis



With stakeholders at the core, Sandia is using a multidisciplinary, science-based approach to quantify and improve resilience across infrastructures.

Case Study

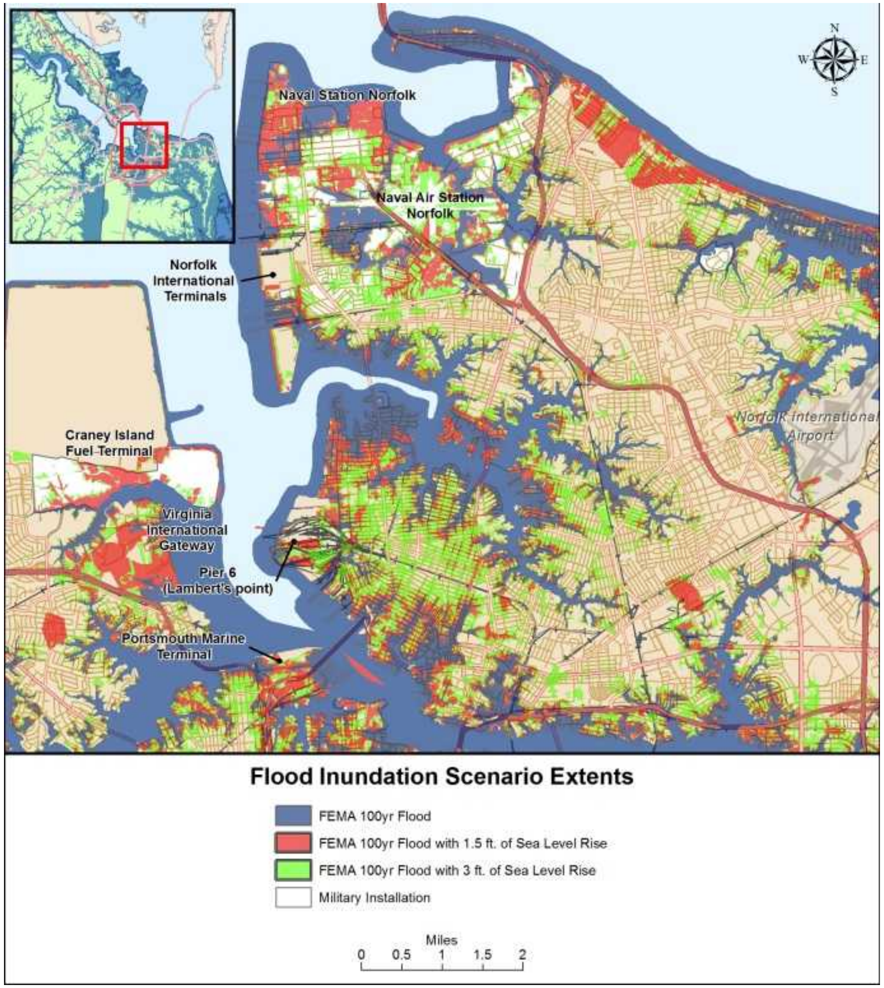
NORFOLK, VA

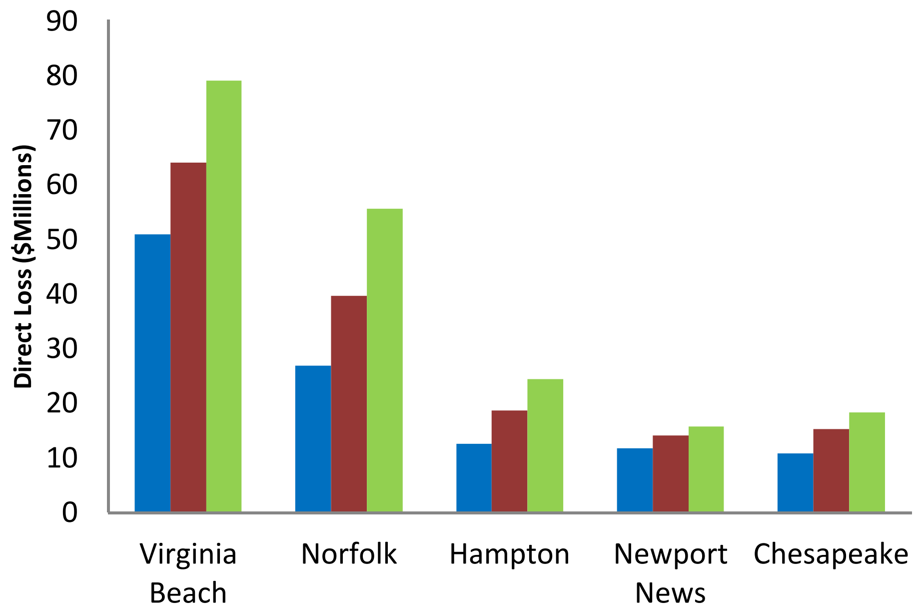
Case Study: Norfolk, VA

- What will the flood of the future look like in Norfolk?
- When Norfolk floods, who feels it?

Shock/Stress	Flood with net sea level rise
Key Infrastructures	Electric Power, Transportation, Fuel, Communications
Data and Methods	Geospatial modeling, Network tools, All-source data collection, Economic modeling
Infrastructure Performance	Availability of service to key globally-relevant assets
Resilience Metrics	Municipal, Regional, and Global economic production

Case Study: Norfolk, VA





Summary of four day direct and indirect losses for three flooding scenarios

	100yr+0ft	100yr+1.5ft	100yr+3.0ft
Annual Direct Losses	$135 M	$182 M	$231 M
Annual Indirect Losses	$219 M	$296 M	$375 M
Total	$354 M	$478 M	$606 M

Sandia quantified the economic consequences of increased flooding due to net sea level rise for Norfolk, VA.

Case Study

RESILIENCE OF U.S. OIL INFRASTRUCTURE

Resilience of U.S. Oil Infrastructure

Added fuel cost (relative to undisturbed costs)

Evaluate resilience of U.S. oil infrastructure to a large earthquake in the New Madrid

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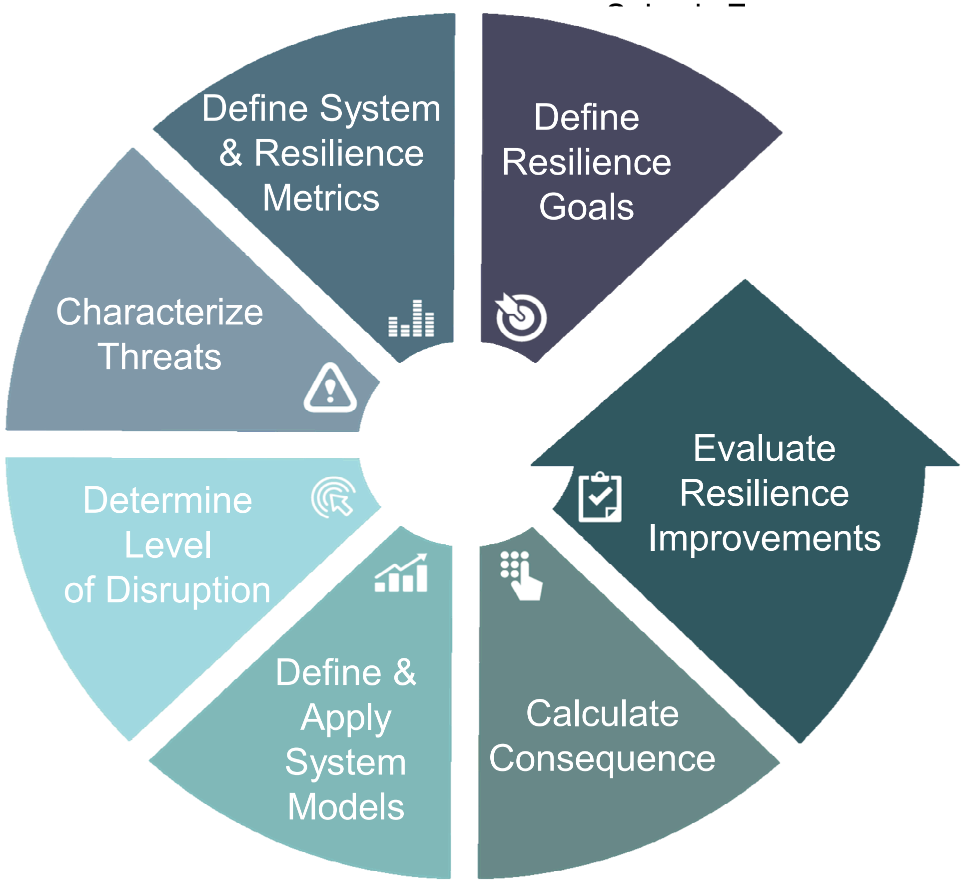

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National Transportation Fuel Model using NetFlow Dynamics

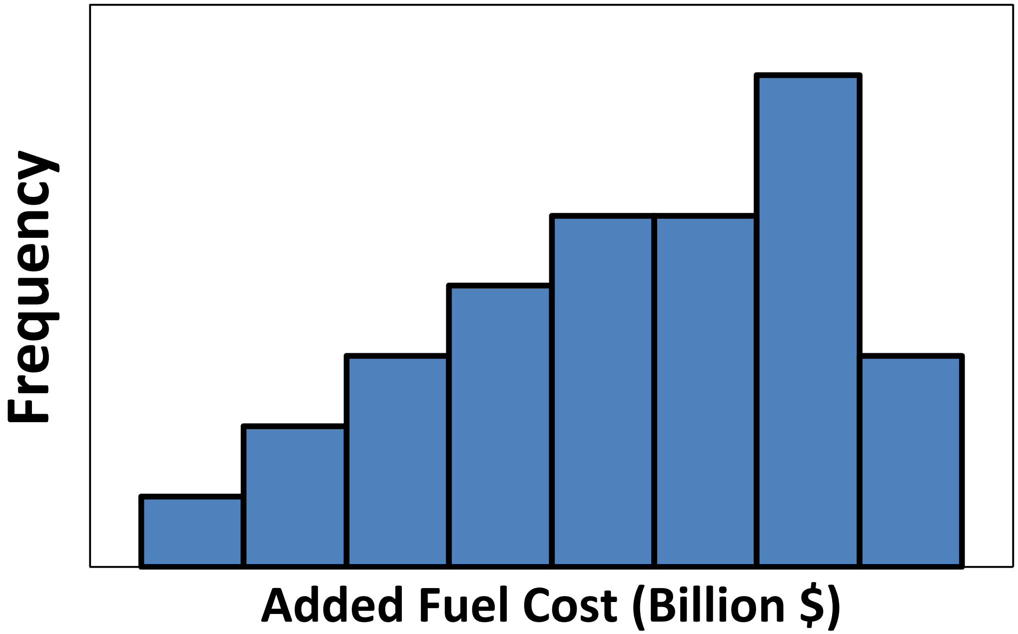
Calculate consequence

Define Resilience Goals

- Evaluate the resilience of U.S. oil infrastructure to a large earthquake in the New Madrid Seismic Zone
- Demonstrate use of the process to:
  - Identify potential actions to increase resiliency
  - Measure the increase in resilience due to implementing these options
- Specifically, we will calculate the increase in resilience gained by re-engineering two major pipelines to decrease down time after a New Madrid earthquake

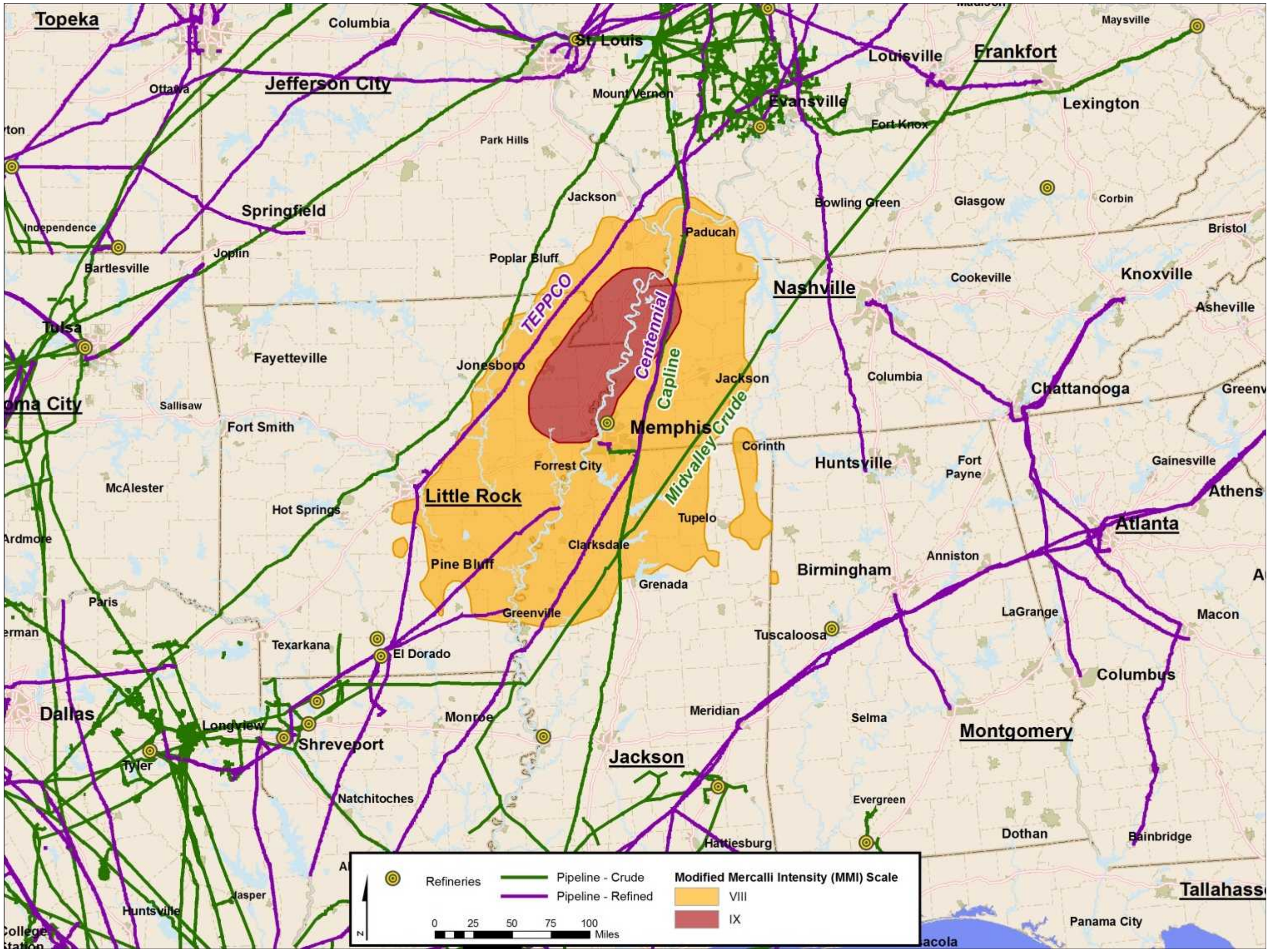
Define a Resilience Metric

- Added fuel cost to consumers (relative to undisturbed costs)
  - Amount of fuel consumed decreases, but fuel prices increase



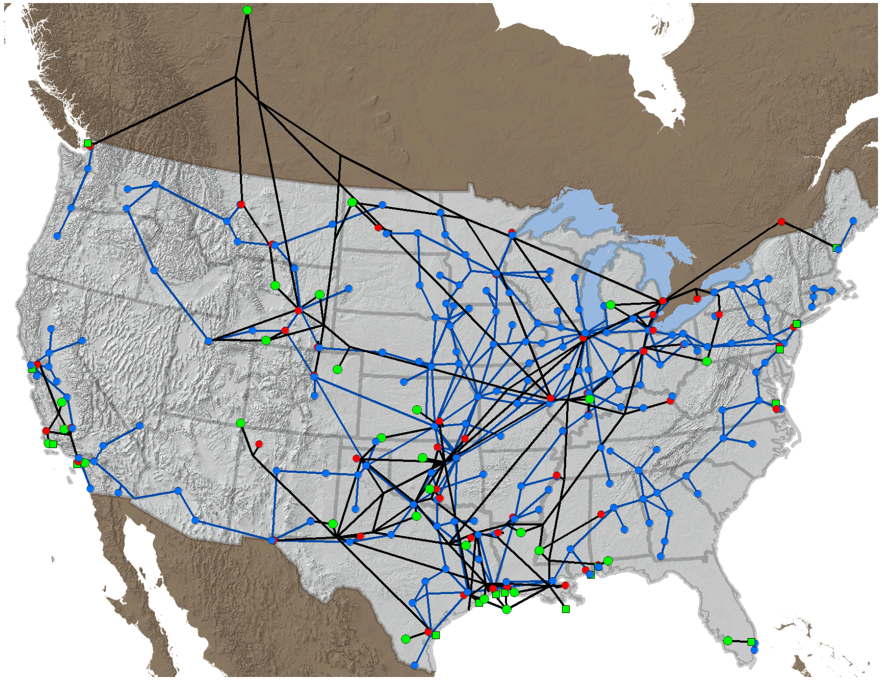
Characterize Threats / Level of Disruption

Four Transmission Pipelines could be Damaged by a New Madrid Earthquake



National Transportation Fuel Model

- Designed to answer questions of the form:
  - Which regions of the United States would experience shortages of transportation fuel after a specified disruption to one or more components of the fuel infrastructure?
  - What would be the duration and magnitude of the shortages?



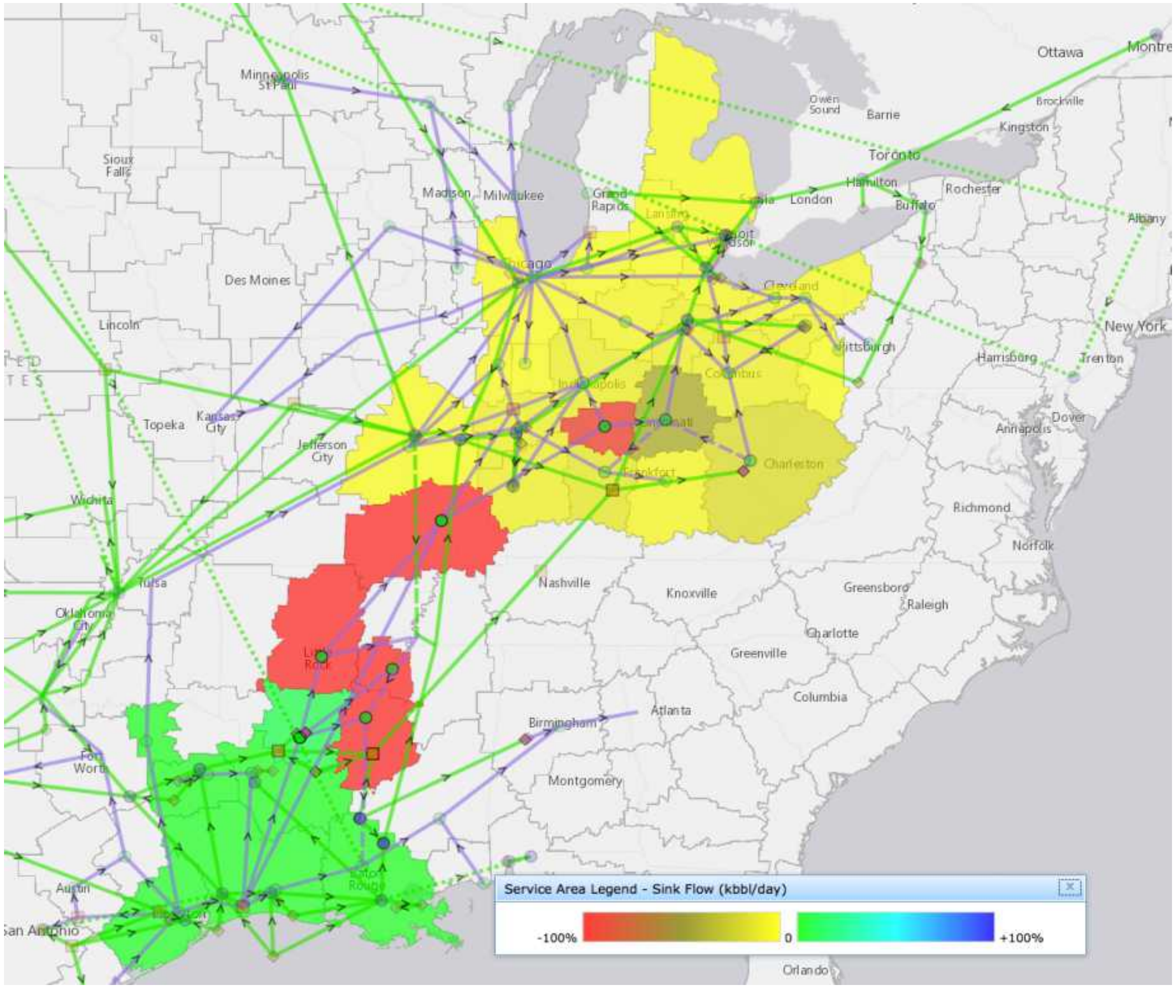
Network Model Description

- Market-driven Resilience Attributes minimize fuel shortages
  - Re-routing shipments
  - Drawdown of inventory
  - Use of surge capacity
  - Increasing imports
  - Reducing consumption
- Constrained by connectivity of the system and capacity of individual system components:
  - Pipeline flow
  - Refinery throughput
  - Tank farm storage
  - Import terminal throughput

Calculate Consequence

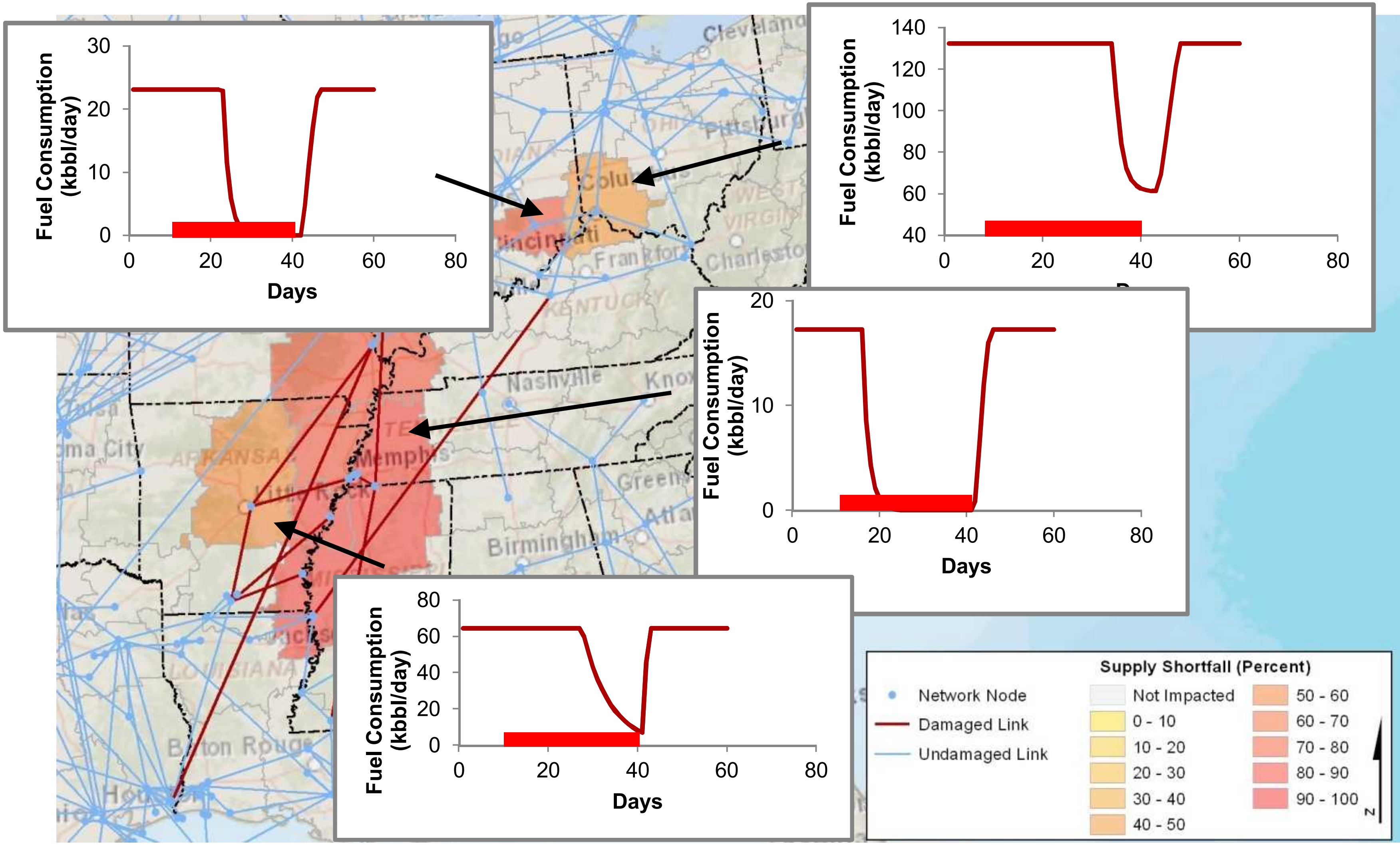
Simulated Impacts of New Madrid Earthquake on Availability of Transportation Fuels

Sandia National Laboratories



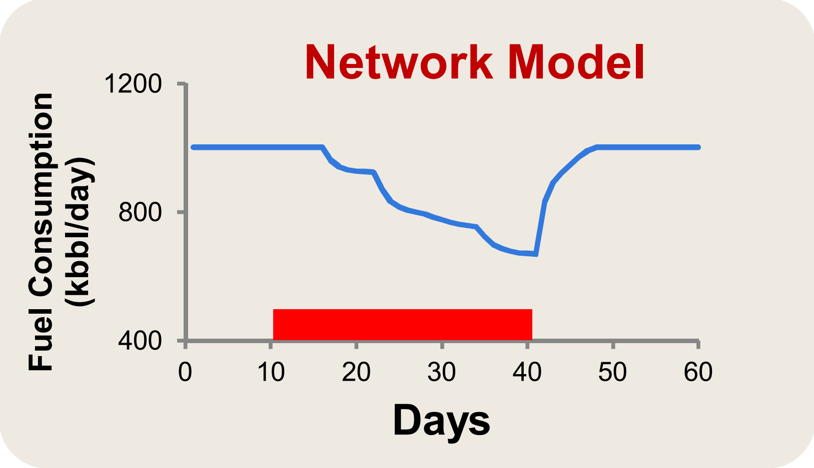
Calculate Consequence

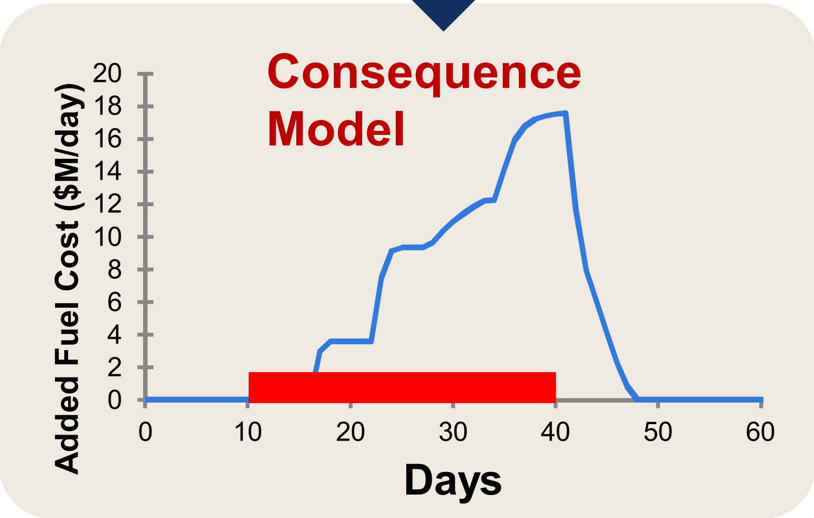
Calculated Consumption Shortfall of Fuel Due to a New Madrid Earthquake



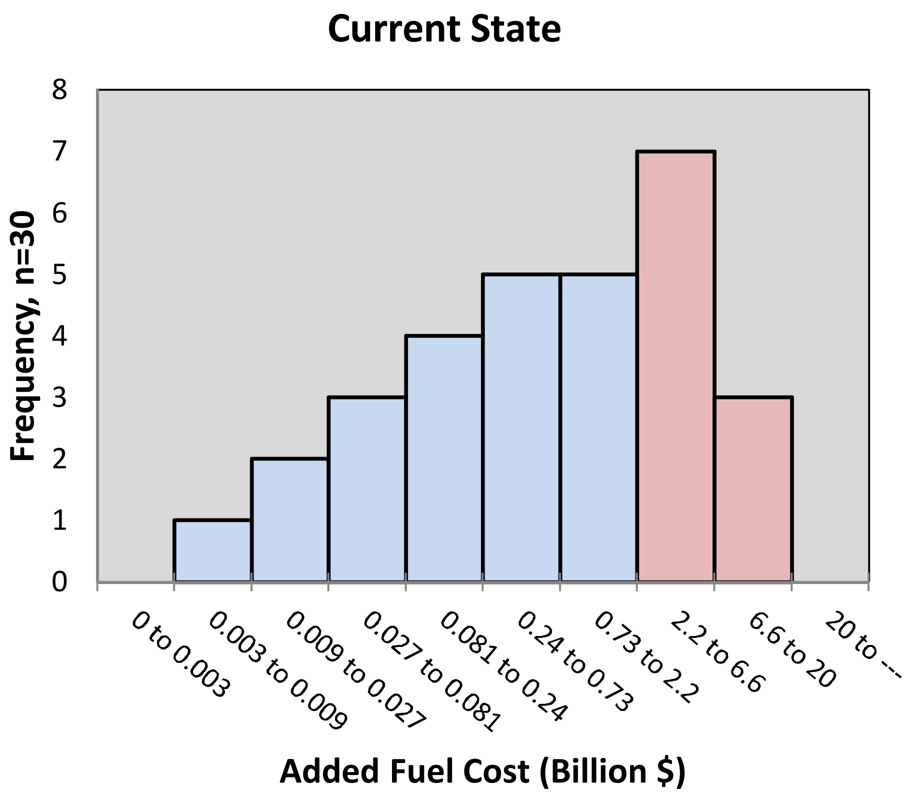
Use Models to Calculate Metric

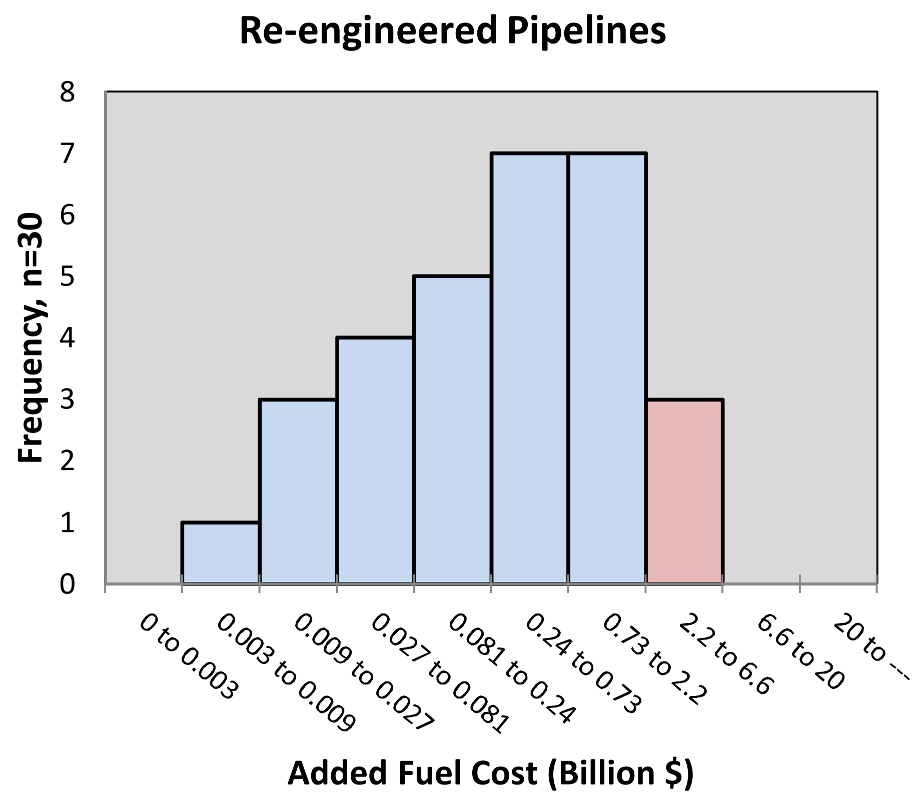
Damage Repair Duration





Evaluating Investment to Increase Resilience





Histograms show the likelihood of cost >$2.2B drops from 1/3 to 1/10

Summary

- Applied the metric development process to evaluate the resilience of U.S. oil infrastructure to a large earthquake in the New Madrid Seismic Zone
- Calculated the increase in resilience gained by re-engineering two major pipelines to decrease down time after a New Madrid earthquake

NEXT STEPS DISCUSSION

BACKUP SLIDES

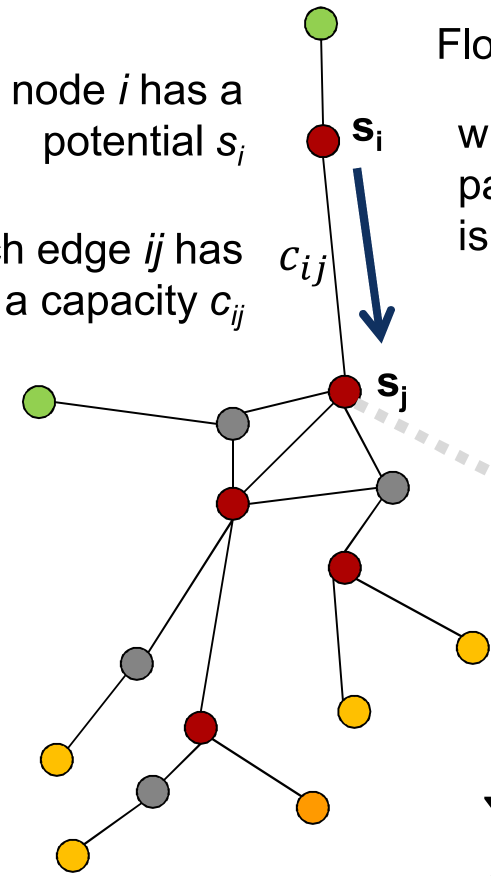
NTFM Assumptions and Limitations

- Includes transmission system (pipelines, rail, water), but not distribution (trucks)
  - For example, the model does not know that fuel can’t be delivered because roads are damaged
- Market behavior is based on fuel availability
  - No hoarding behavior (by consumers or suppliers)
  - No price increases until inventories decline

Minimize shortages while balancing mass and not exceeding capacities

Each node i has a potential s_i

Each edge ij has a capacity c_{ij}

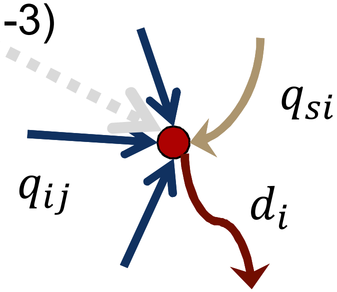


Flow rates are given by : $$q_{ij} = c_{ij}\, f\big((s_i - s_j)u_{ij}\big) \quad (1)$$

where u_{ij} is a utilization parameter and the function f(x) is: $$f(x) \equiv 1 - e^{-x} \quad (2)$$

In equilibrium, the net flow at each node i is 0: $$\sum_j q_{ji} + q_{si} - d_i = 0 \qquad \forall i \quad (3)$$

The equilibrium solution $\{\hat{s}_i\}$ is obtained by solving equations (1-3)



In the transient case, net inflow into a node results in the accumulation of stored fluid:

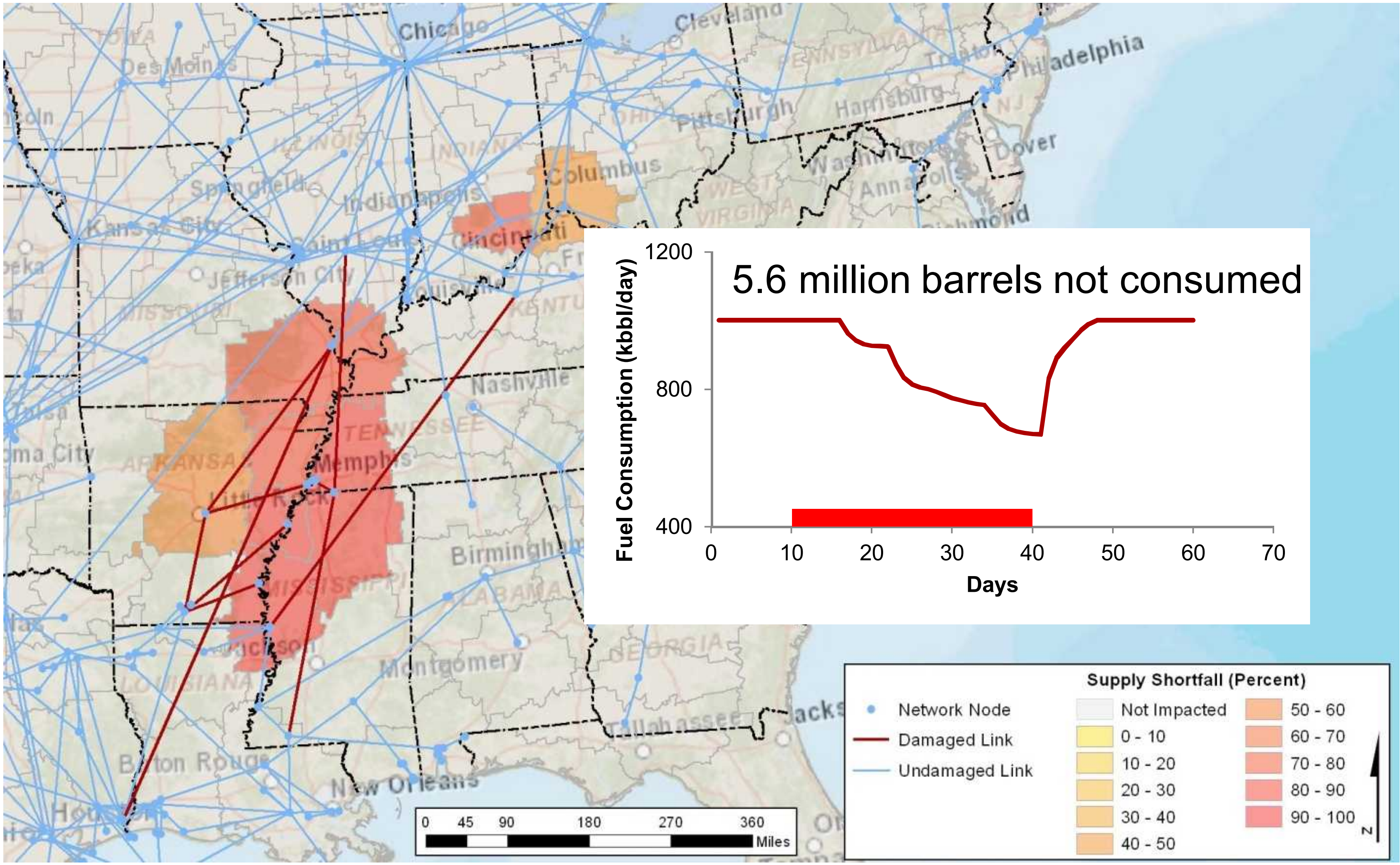
$$\sum_j q_{ji} + q_{si} - d_i = \frac{dv_i}{dt} = r_i \left[1 + \left(\frac{s_i - a_i}{b_i}\right)^2\right]^{-3/2} \frac{ds_i}{dt} \qquad \forall i$$

where r_i , a_i and b_i are storage parameters

Beyeler, Corbet, and Hobbs, 2012

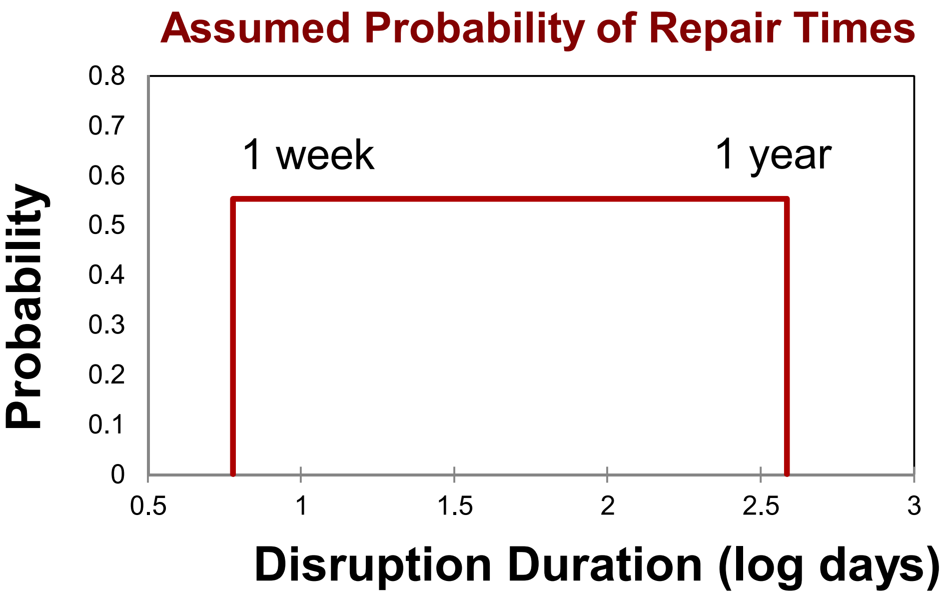
Calculated Consumption Shortfall of Fuel Due to a New Madrid Earthquake

Calculate Consequence

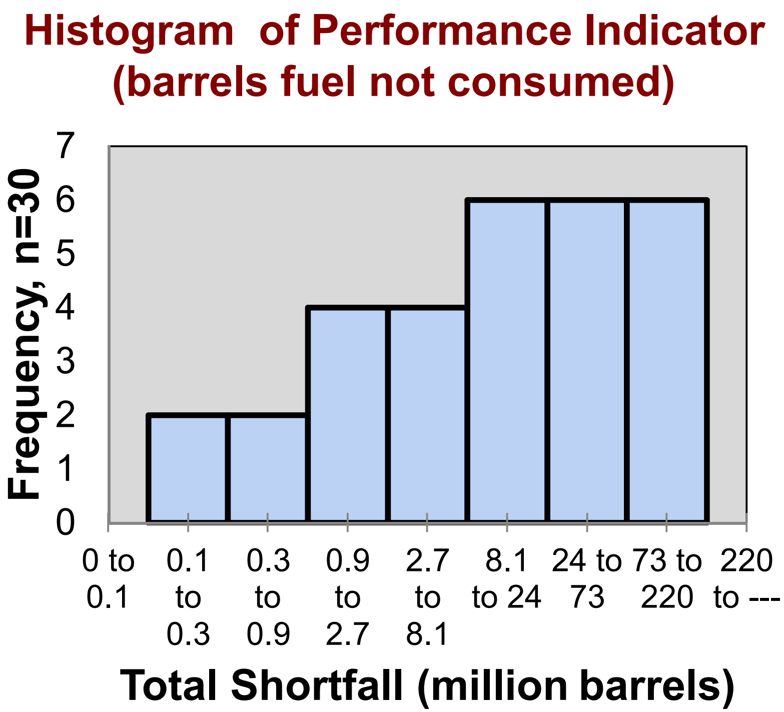


Uncertainty of Repair Time

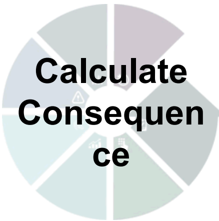
Calculate Consequence



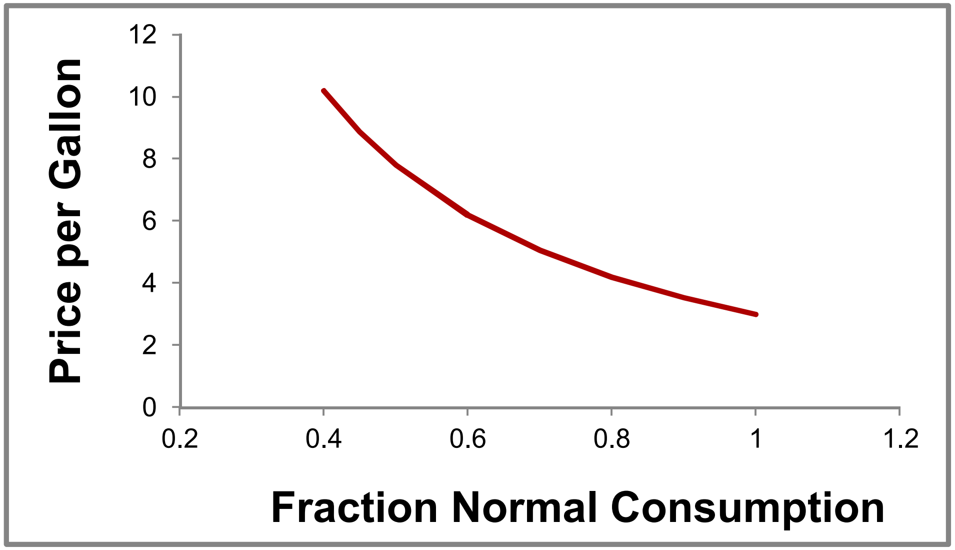
Network Model



Consequence Model



- Main Assumptions:
  - During a fuel shortage that is expected to be temporary (weeks) services, businesses, and individuals will try to maintain normal output despite fuel shortages
  - Market behaviors will act to decrease fuel consumption by raising prices



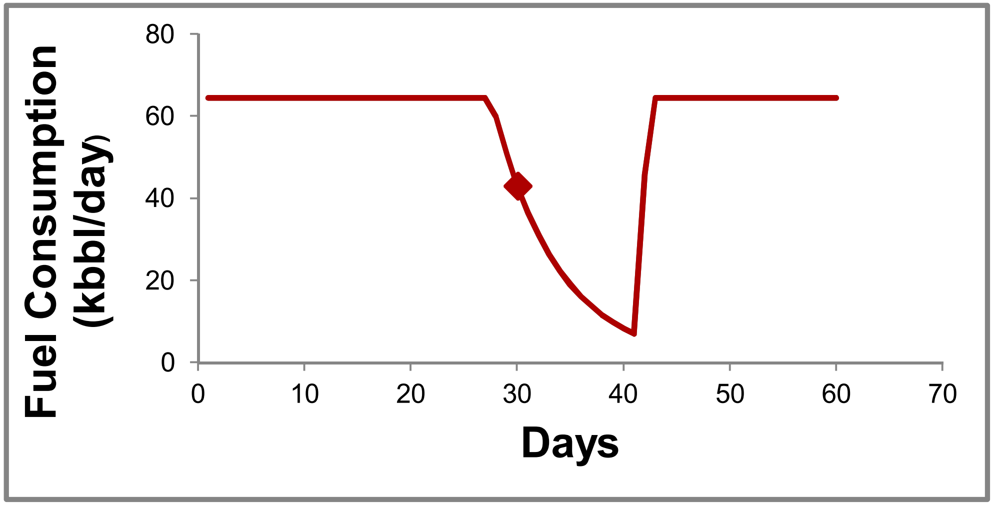
Assumed Demand Curve

Informed by price data from the 2004 Phoenix fuel disruption**

** http://www.doney.net/aroundaz/gas_lines.htm

Calculate Additional Cost of Fuel Consumed

1. For each impacted distribution terminal, calculate the daily price of fuel (using the calculated consumption fraction and the assumed demand curve)
2. Multiply the price times the amount consumed to get the daily cost of fuel
3. Subtract the undisturbed daily cost of fuel



At day 30 in Little Rock:

Consumption = 43,125 bbl/day
Consumption fraction = 0.67
Price = $5.36/gal
Cost = $9,708,300

Undisturbed:
Consumption = 46,400 bbl/day
Price = $3.00/gal
Cost = $8,114,400

Added cost = $1,593,900