Complex Adaptive System of Systems (CASoS) Engineering Initiative
http://www.sandia.gov/CasosEngineering/

Simulating the U.S. Transportation Fuels Network: From Oil Fields to Consumers

Thomas F. Corbet

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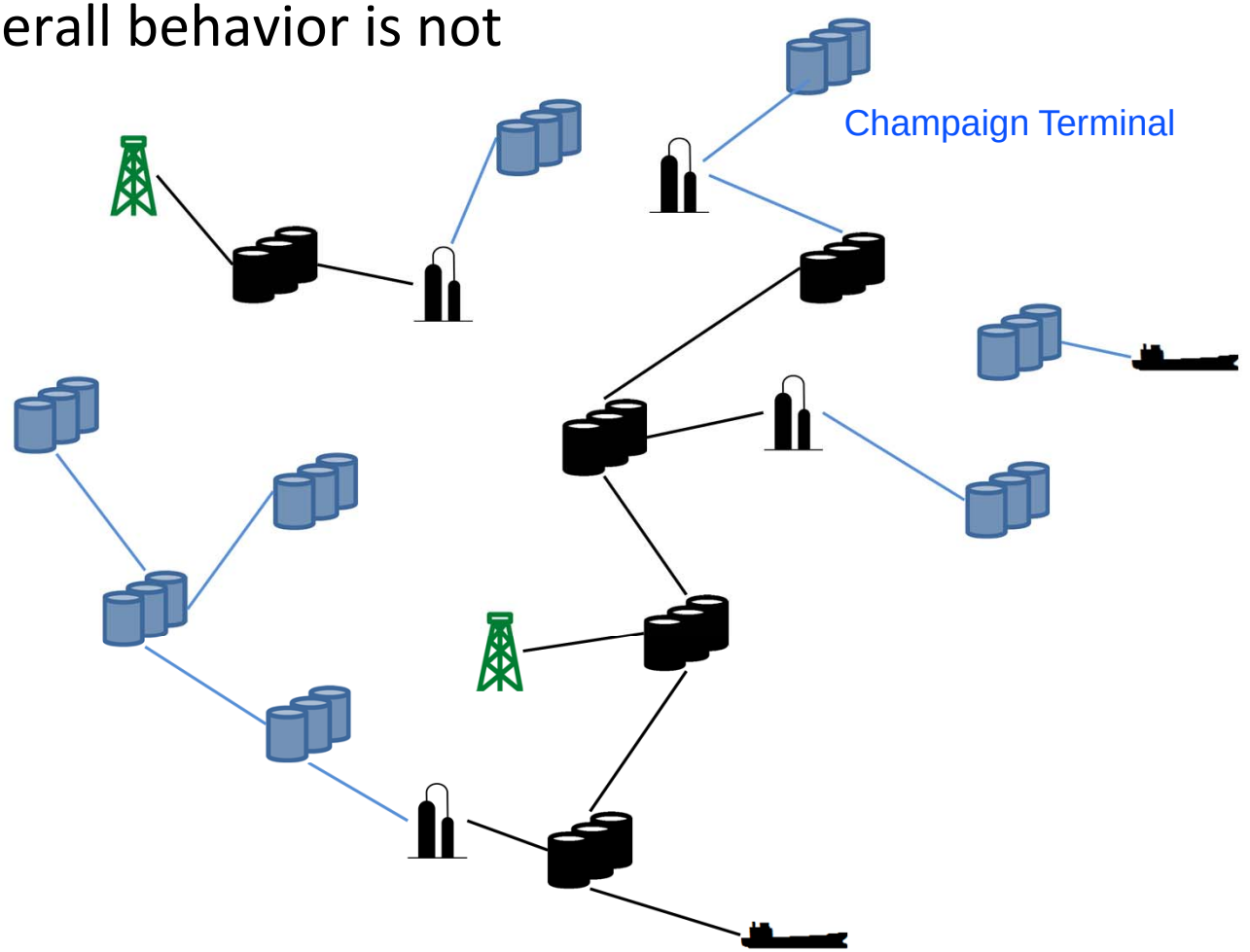
Petroleum Network Modeling

- Model domain is a network of controlled, engineered systems, but overall behavior is not



Petroleum Network Modeling

- Intent is to inform analyses for government decision makers
  - How much should I worry about …?
  - What would be the consequence of …?
  - What is the best response to mitigate …?
- Disrupted conditions
  - Focus is on robustness rather than reliability or efficiency
- Analyses informed by model results, rather than the model results themselves, are the desired product

NISAC performs this modeling using a CASoS Engineering Approach

- The National Infrastructure Simulation and Analysis Center (NISAC) is a modeling, simulation, and analysis program within the Department of Homeland Security Office of Infrastructure Protection
  - Personnel in the Washington, D.C. area, Sandia National Laboratories, and Los Alamos National Laboratory
- NISAC performs analyses of critical infrastructure, including their interdependencies, vulnerabilities, consequences, and other complexities
  - http://www.sandia.gov/nisac/
- Complex System of Systems Engineering (CASoS) methodology was used for network modeling
  - http://www.sandia.gov/CasosEngineering/

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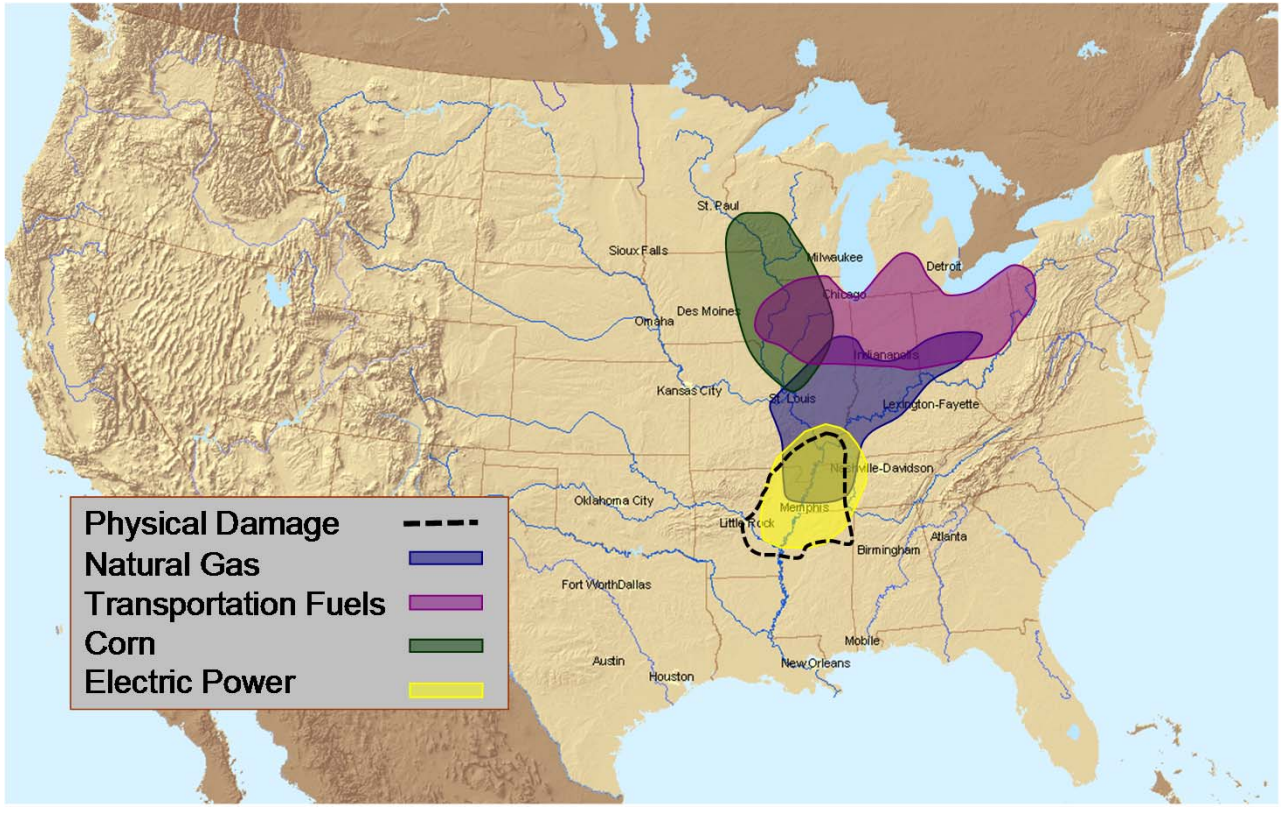
Original vision: project impacts beyond disrupted region

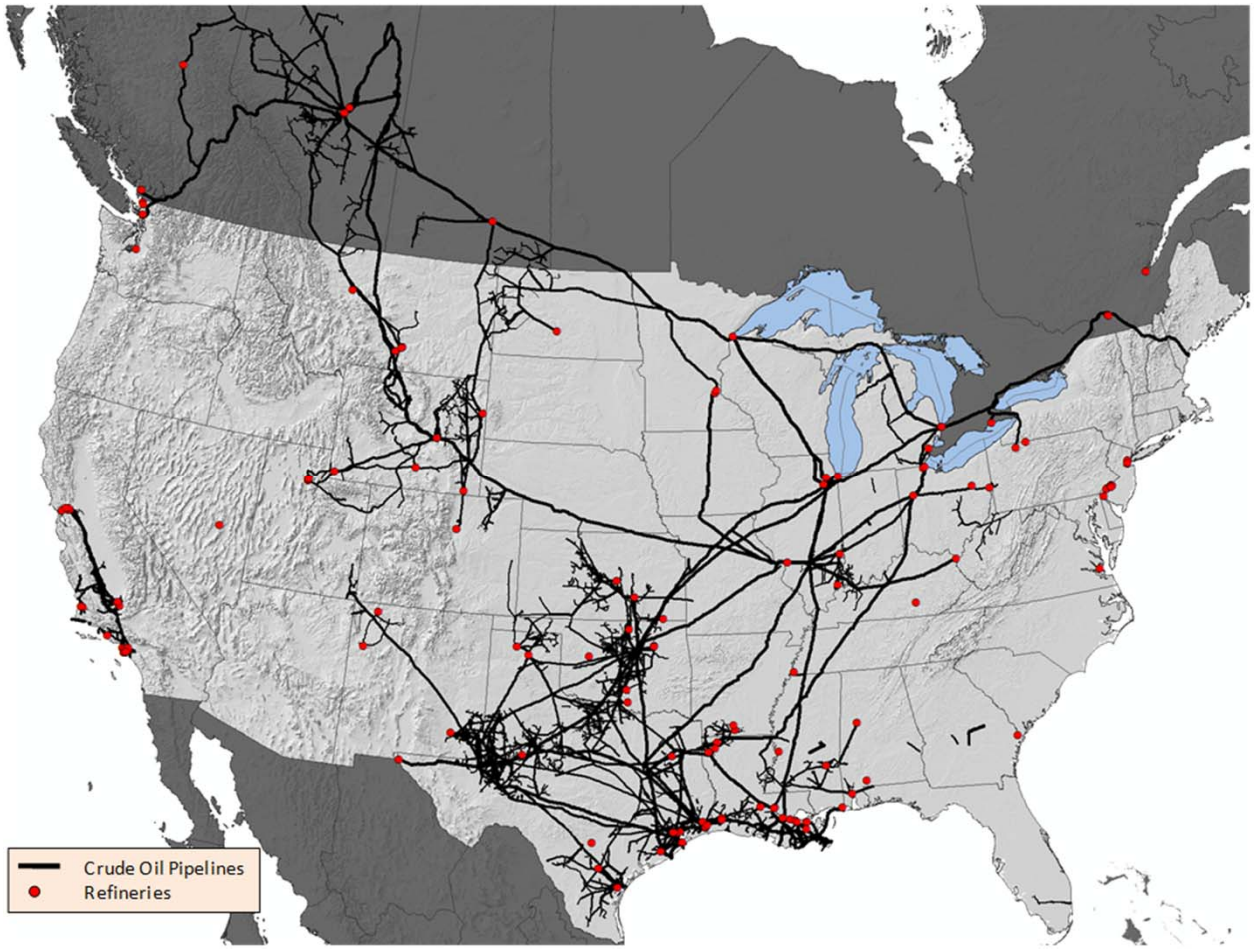


This slide pertains to damage from a scenario earthquake in the New Madrid Seismic Zone. Studies were in collaboration with the Mid-American Earthquake Center, UIUC.

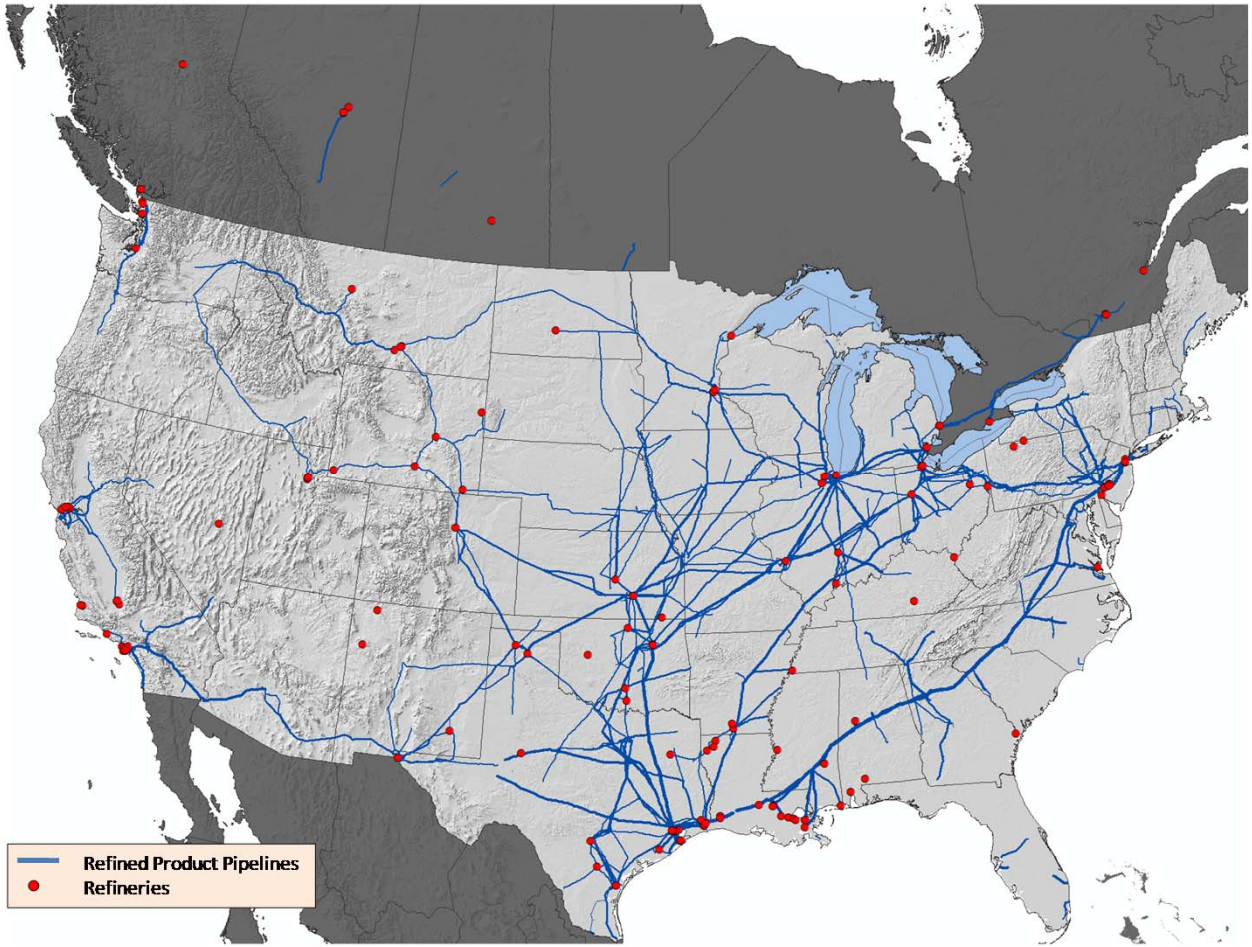
Modeling Objectives

- Estimate capacity of the petroleum network to deliver transportation fuels under stress (availability analysis) considering:
  - Network topology and dynamic routing
  - Excess capacity
  - Storage
- Include consideration of:
  - Transient, non-equilibrium behavior
  - Recovery time
  - Overall system behavior is determined by market/business decisions

Crude Oil Pipelines and Refineries



Refineries and Refined Product Pipelines



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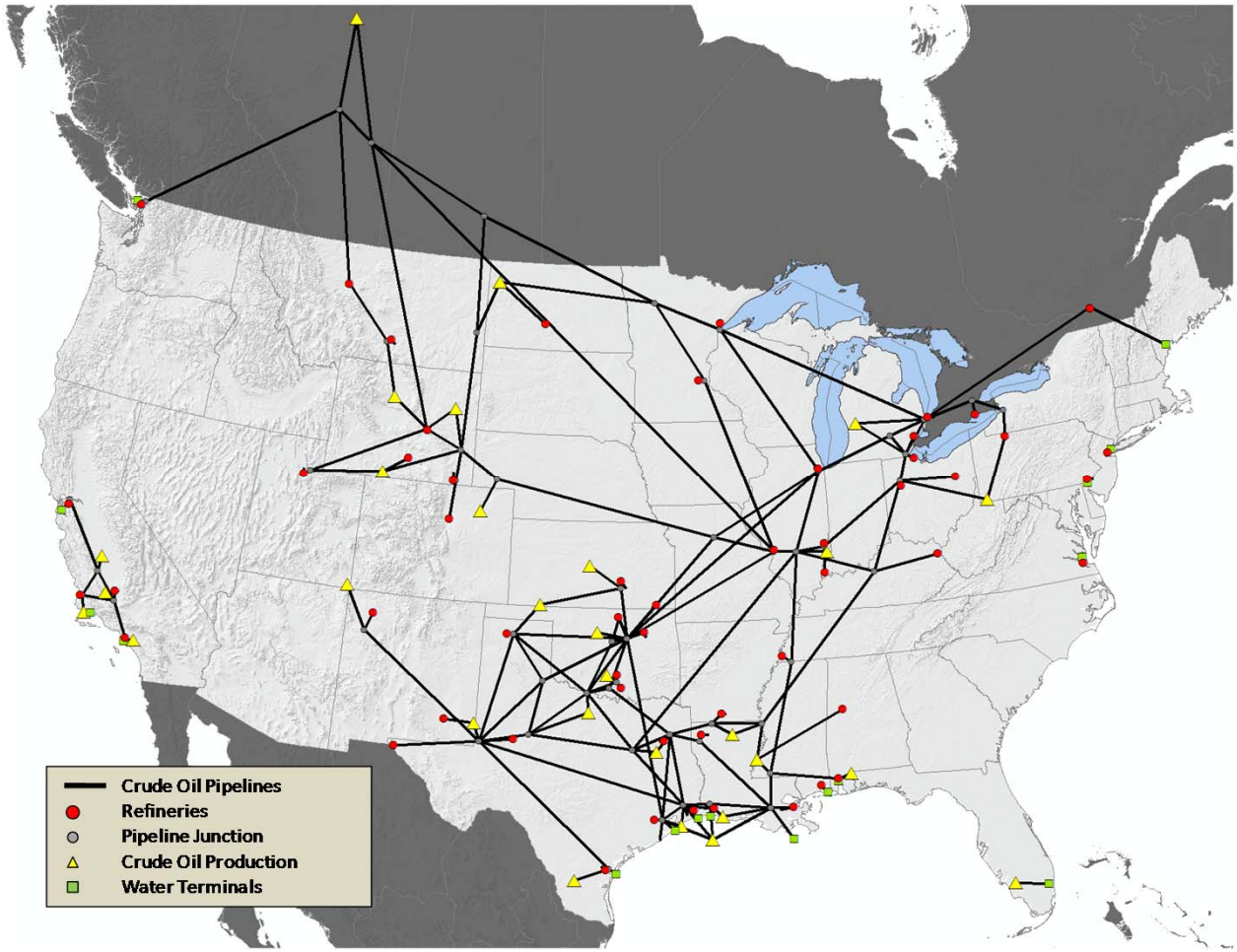
Model Network Representing Crude Oil Pipelines and Refineries



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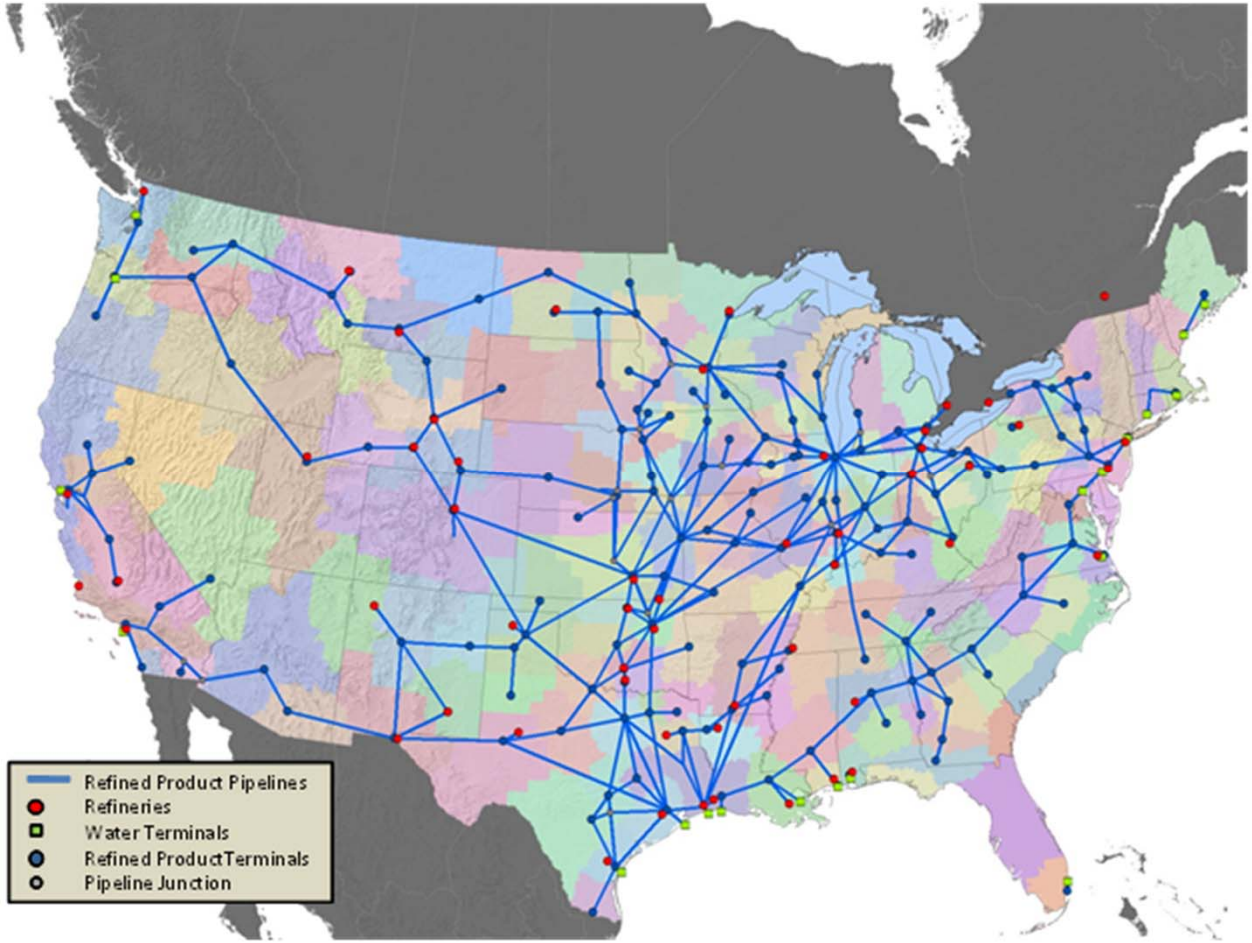
Model Network Representing Refineries and Refined Product Pipelines



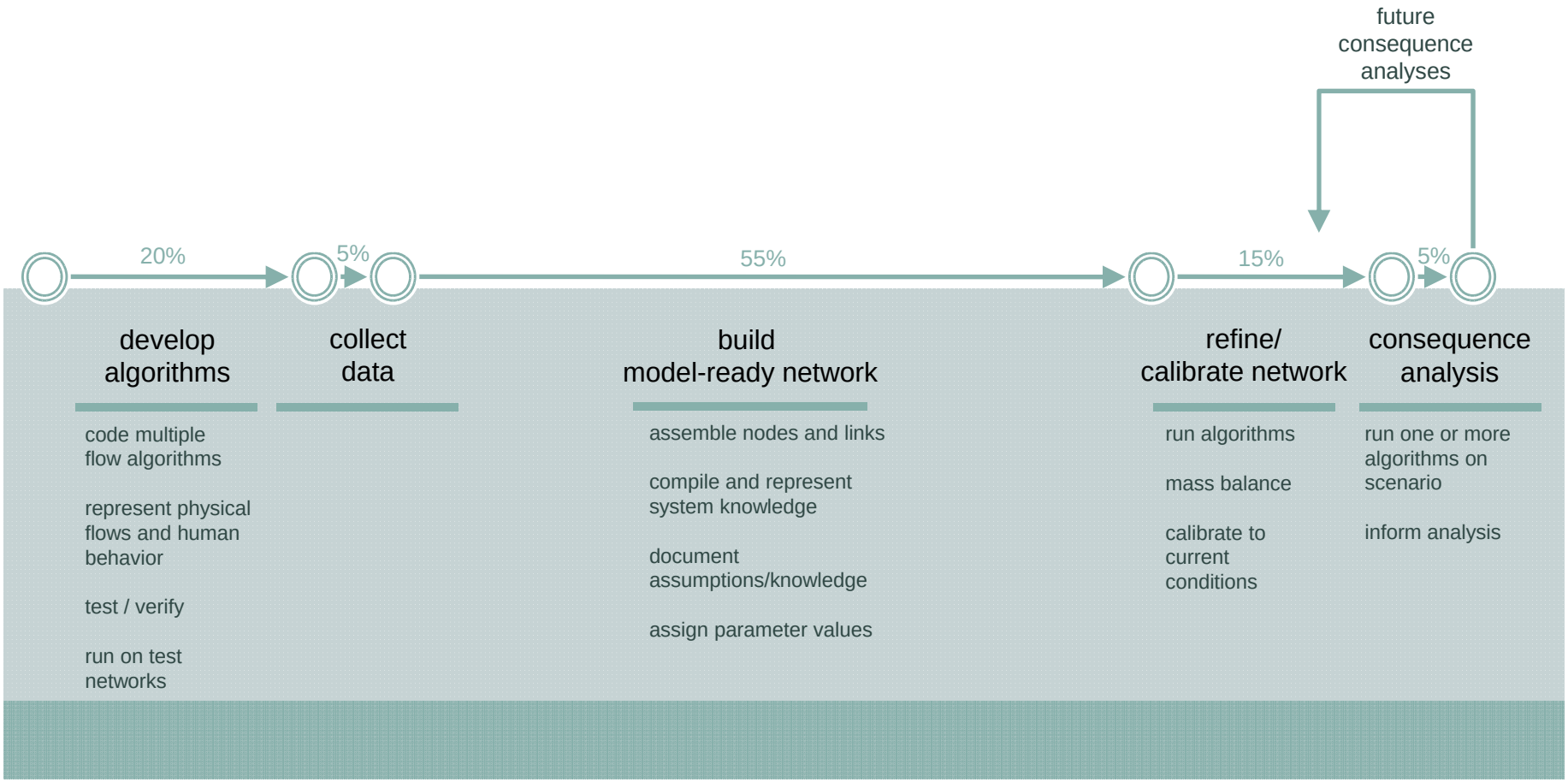
How to approach the problem … Lessons learned the hard way

- Not by linking physics-based engineering models
  - Not practical to build models of large networks because the engineering details of system components are not available
  - Such a model would be overly complicated and expensive
  - An engineering model would have to be "operated" by an analyst or an algorithm
- Not by predicting market behavior
  - It's too hard, and not necessary for the model to be useful

Approach

- Demand-driven capacity-constrained
- Assume best plausible outcome
  - Can't provide fuel to a particular region because …
  - Can supply fuel to a particular region because ….
- Multiple allocation algorithms
  - Market with dynamic network (economic/operations research approach)
  - Local Inventory control (supply chain management approach)
  - Diffusion equation for defined potential field (hydraulic approach)

Level of Modeling Effort



Example: New Madrid Earthquake

- The New Madrid Seismic Zone (NMSZ) stretches along the Mississippi River Valley from southern Illinois to Memphis
- A cluster of very powerful earthquakes occurred during the winter of 1811–1812.
- The U.S. Geological Survey estimates a 7 to10 percent chance of earthquakes with magnitudes equivalent to the 1811–1812 quakes occurring in any 50-year period *
- A similar cluster of earthquakes occurring today would cause extensive damage to oil and gas transmission pipelines

*(USGS, Center for Earthquake Research and Information Fact Sheet 2006-3125).

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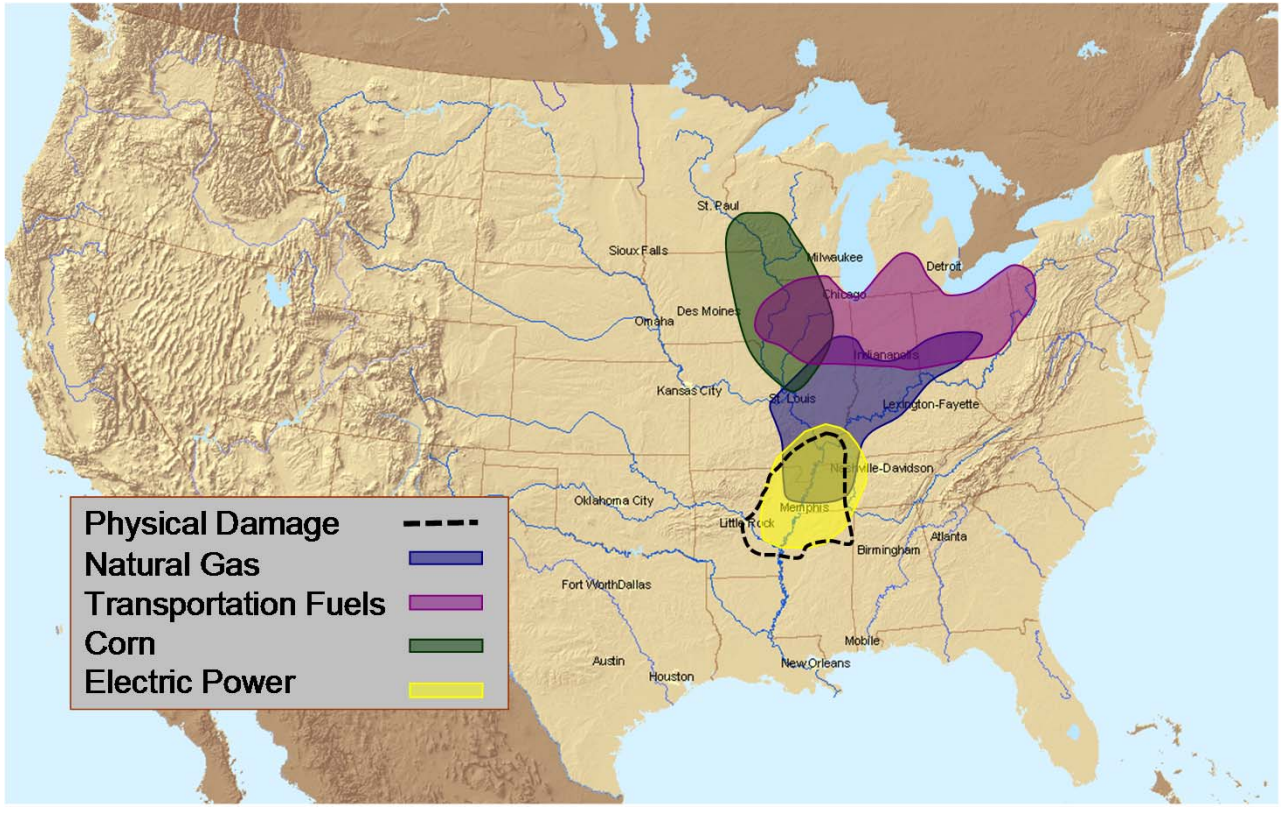

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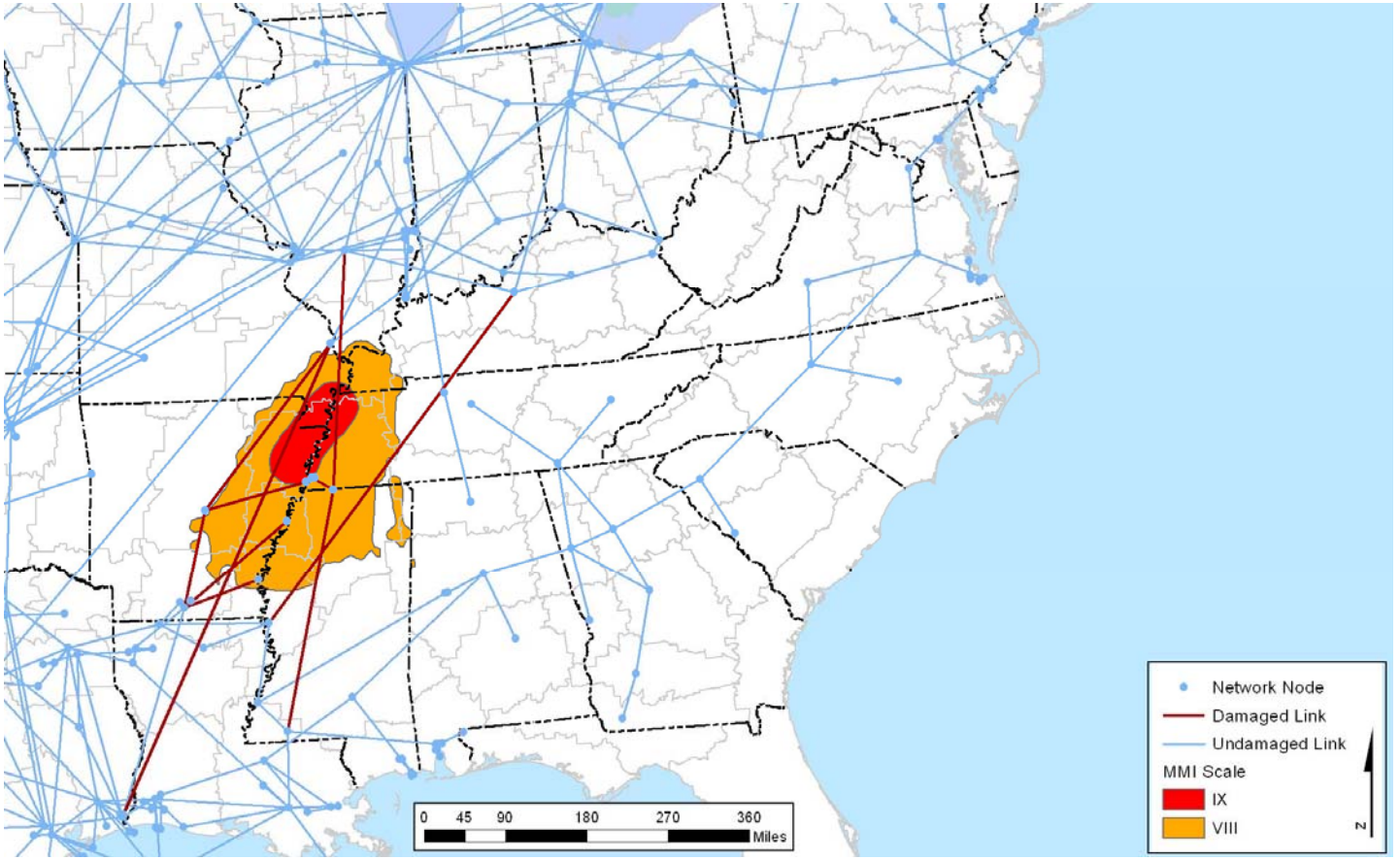
Simulated Fuel Shortages Due to a New Madrid Earthquake



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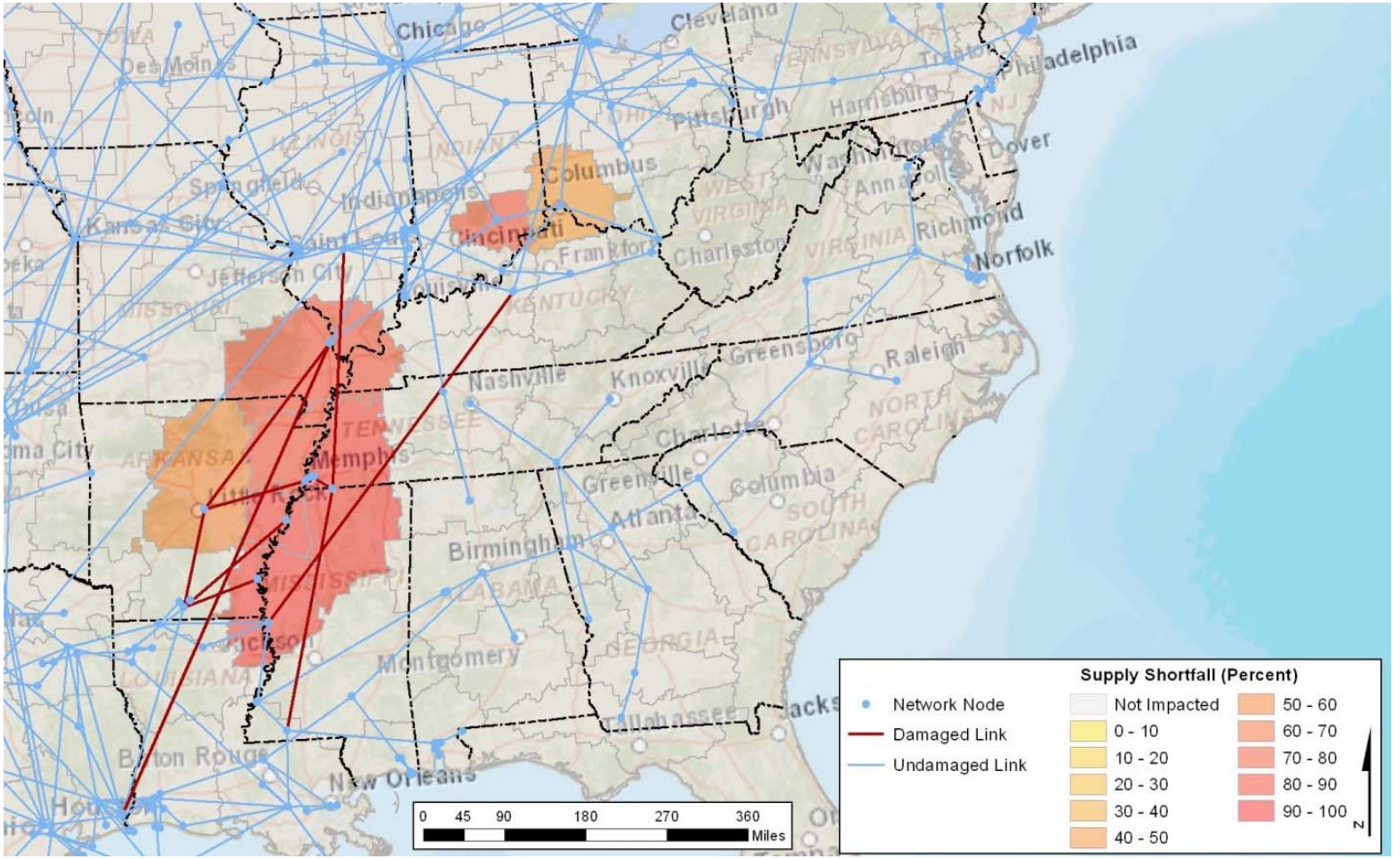

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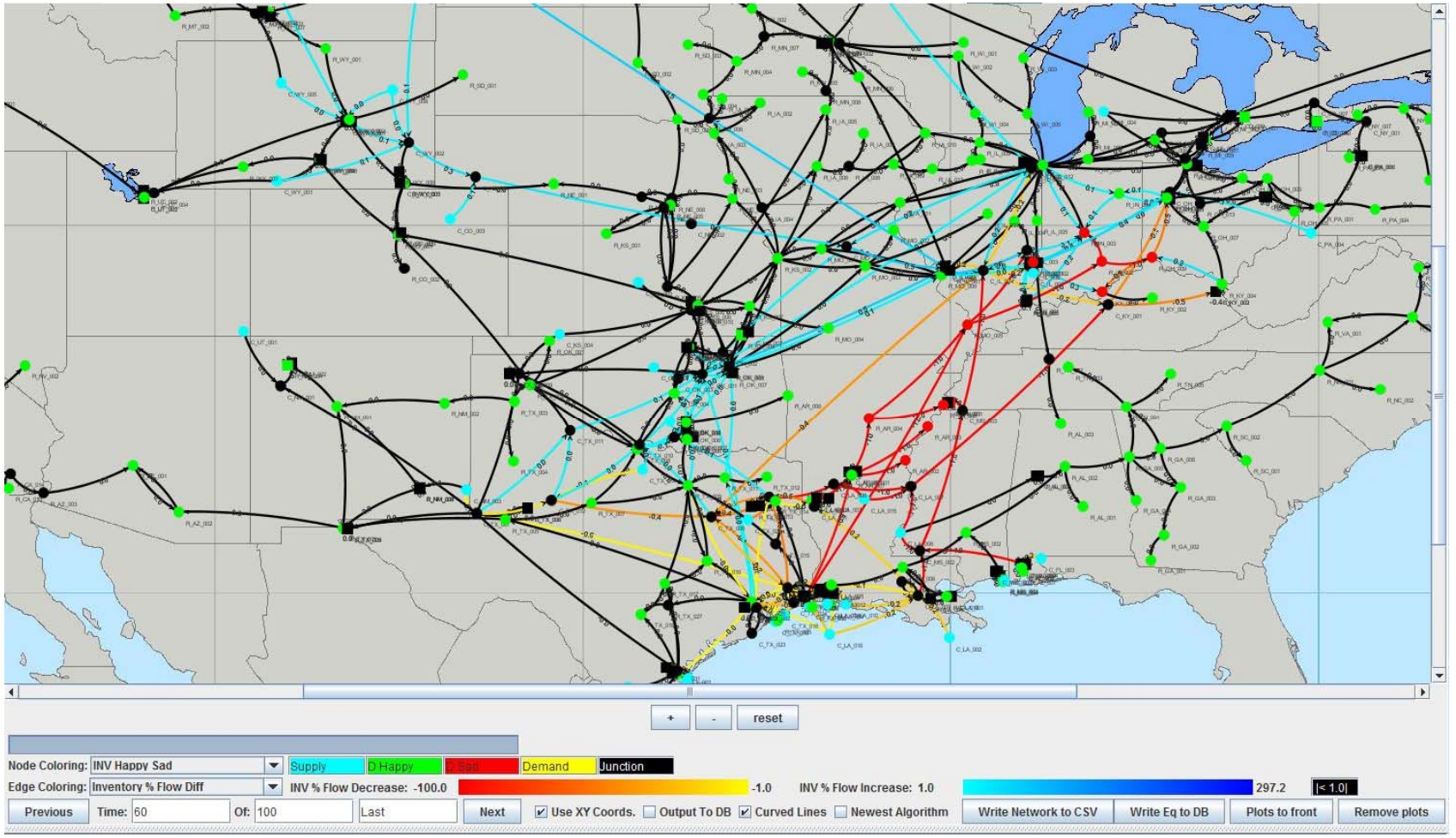

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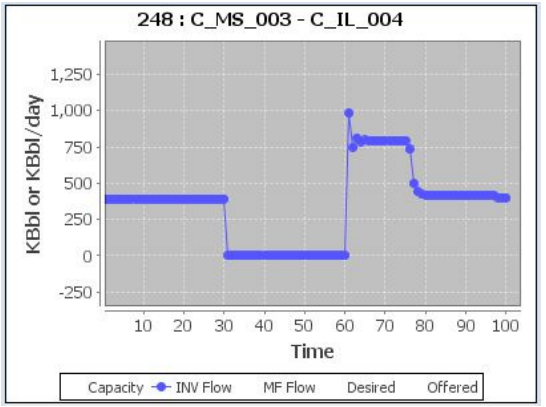
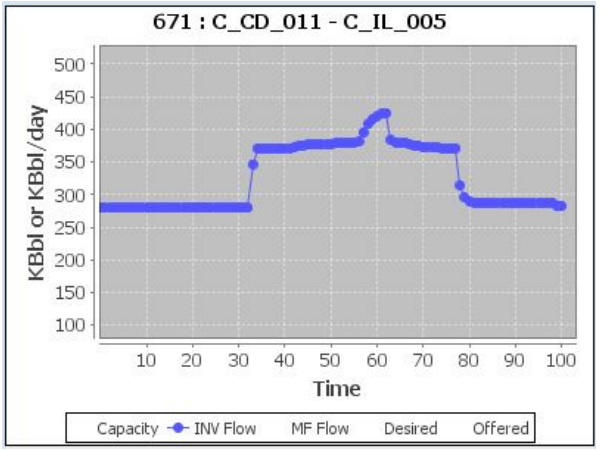
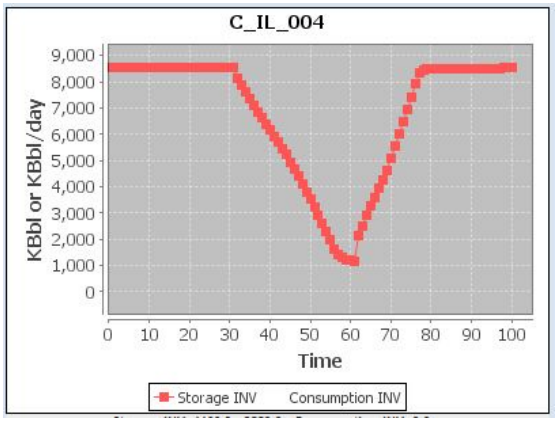
Simulated Fuel Shortages Due to a New Madrid Earthquake

Flow on the disrupted Capline Crude Pipeline

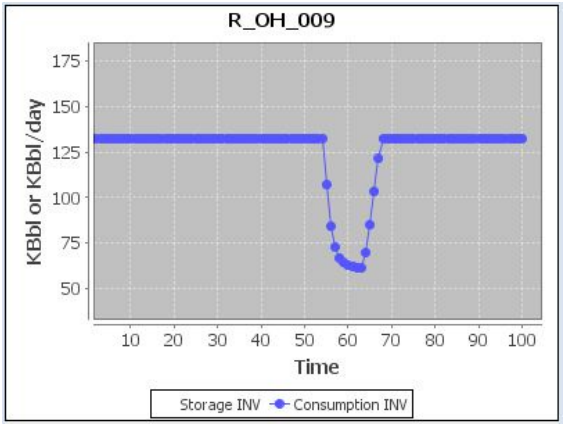


Flow on the Keystone Crude Pipeline from Canada





Crude Storage at Patoka, IL



Fuel consumption at Cincinnati, OH