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

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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
- Complex System of Systems Engineering (CASoS) methodology was used for network modeling
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
Model Network Representing Crude Oil Pipelines and Refineries
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

- **Develop algorithms**
  - code multiple flow algorithms
  - represent physical flows and human behavior
  - test / verify
  - run on test networks
  - 20%

- **Collect data**
  - 5%

- **Build model-ready network**
  - assemble nodes and links
  - compile and represent system knowledge
  - document assumptions/knowledge
  - assign parameter values
  - 55%

- **Refine/calibrate network**
  - run algorithms
  - mass balance
  - calibrate to current conditions
  - 15%

- **Consequence analysis**
  - run one or more algorithms on scenario
  - inform analysis
  - 5%

- **Future consequence analyses**
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 to 10 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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Simulated Fuel Shortages Due to a New Madrid Earthquake
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![Map showing simulated fuel shortages due to a New Madrid Earthquake.](image)
Simulated Fuel Shortages Due to a New Madrid Earthquake
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