Overview of the DHS/SNL National Transportation Fuel Model

The US Department of Homeland Security sponsored Sandia National Laboratories through the National Infrastructure Simulation and Analysis Center (NISAC) to develop a network-based model of US transportation fuel infrastructure. This model is to be used to inform analyses of the availability of transportation fuel in the event that the fuel supply chain is disrupted.[1,2] The portion of the fuel supply system represented by the network model spans from oil fields to fuel distribution terminals. Different components of this system (e.g., crude oil import terminals, refineries, transmission pipelines, and tank farms) can be disrupted, and these disruptions can quickly cascade through the system. Estimating the locations, timing, and severity of these impacts depends on properly simulating the capability of the fuel system to respond dynamically to disruptions.

The model network consists of the locations and capacities of tank farms, refineries, and terminals (the nodes of the network), and the pipelines that connect the nodes (the links of the network). Figure 1 shows the actual network of crude oil and refined product pipelines and refineries in the United States. Figure 2 shows how the Sandia model represents the actual network as a network of nodes and links.

Comparing the two figures shows that the actual network is simplified, or aggregated, in the model network only slightly. Links in the model network represent either a single transmission pipeline, or where multiple pipelines follow the same path, a bundle of several pipelines. (Note that model links are shown as straight lines connecting nodes, so the links only approximately overlay the actual pathways of the pipelines.) In a similar way, a model node representing refining capacity consists of either a single refinery or a group of several refineries if they are located near each other and connected to the same pipelines. Sources of crude oil to the network are nodes that represent either collections of oil fields (called geologic basins) or water terminals for receiving imports of crude oil. This close correspondence of the elements of the actual and model networks allows damages to the network, and the resulting fuel availability impacts to be simulated at a reasonably high level of spatial resolution.

Model algorithms are used to calculate flows of crude oil and refined products on the network links. If demand for crude oil or fuels exceeds what the damaged supply system can provide, the algorithms must also allocate the limited supplies to individual refineries and distribution terminals. Each distribution terminal is associated with a service area in which tanker trucks deliver fuel supplies to retail outlets.

Typically a single allocation algorithm is not well suited for all types of system disruptions. The Sandia transportation fuel model, therefore, allows an analyst to select from several algorithms. For example, one of the options currently implemented is a maximum flow algorithm standard in

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many types of network models. This class of algorithms can be used to calculate the maximum total flow that can pass through a damaged network.
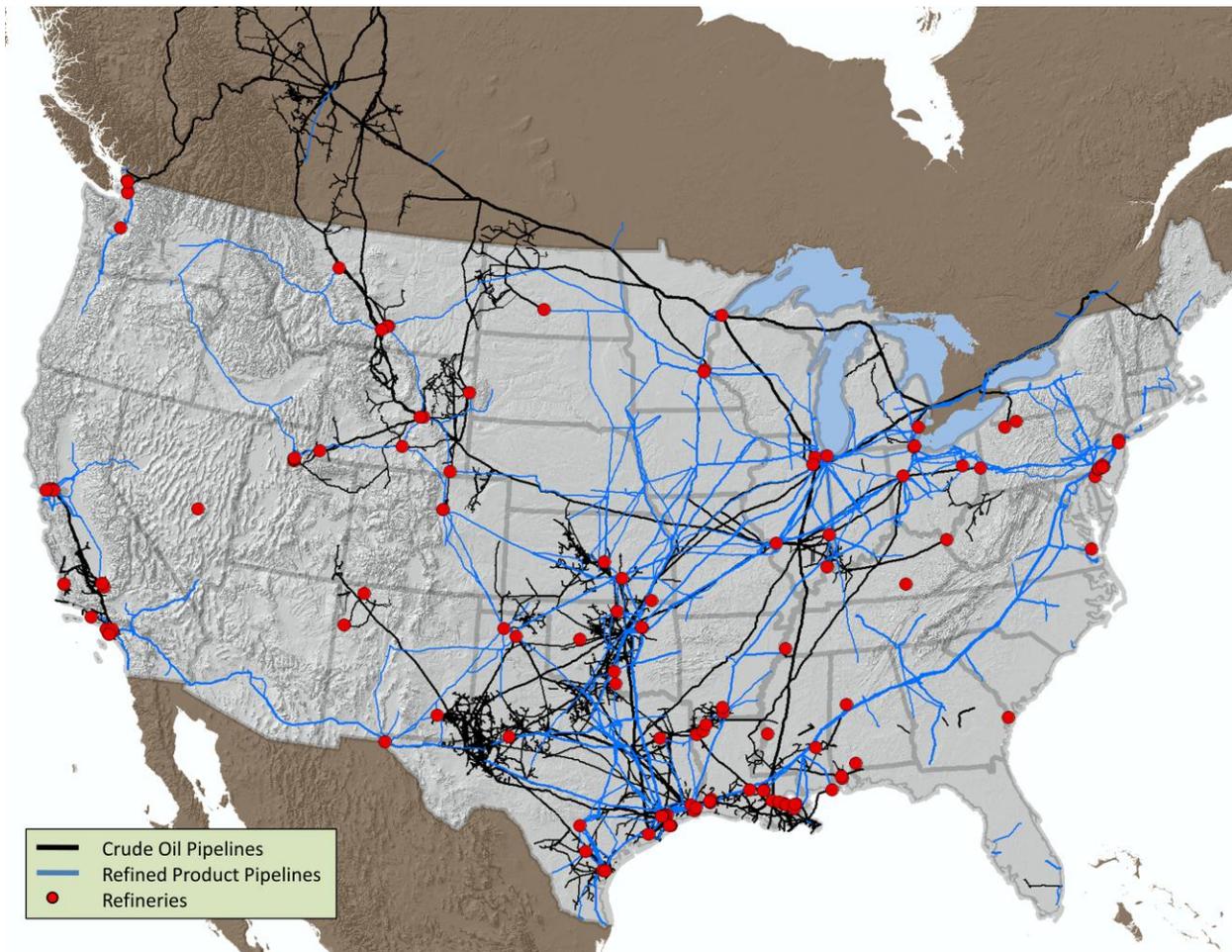
The local inventory control algorithm is the primary allocation algorithm in use, and, was developed specifically for the Sandia transportation fuel model. Its name refers to the fact that each node in the network strives both to meet the demands of consumers and to maintain sufficient stocks of crude or products. This algorithm differs from the maximum flow algorithms in two major ways. First, each node has knowledge only of the amount of oil or fuel desired, or offered, by its nearest-neighbor nodes. Second, the algorithm includes dynamic behavior by allowing each node to make use of its oil or fuel in storage. Flows of crude oil or refined products toward regions experiencing shortages occur by a diffusion-type process in which knowledge of the shortage propagates throughout the network over time.

Developing the model-ready set of data to represent the national transportation fuel network required a team of analysts to research multiple sources of data and system information. The structure and attributes of the fuel system, as well as the sources and assumptions used by the analysts is documented in a central database. This database allows multiple analysts to simultaneously view and edit attributes of the network. Storing information in a central database integrates two critical aspects of this capability development: building networks for models and knowledge management.

Visualization of networks and simulation results is critical for analysis, and an important aspect of this capability development. An analyst needs to view the ways that simulated system attributes vary temporally and spatially. For example, an analyst might want to view how the amount of fuel stored at a tank farm changes over time, or to view the pattern of flow rates in pipelines across the entire network at a single time within the simulation. Simulation results are output to commercial Graphical Information System (GIS) tools to allow efficient and flexible viewing of spatial results. Connection to GIS tools also is important for knowledge management in that an analyst can easily drill down into individual components of the network to access complete documentation and information about those components.
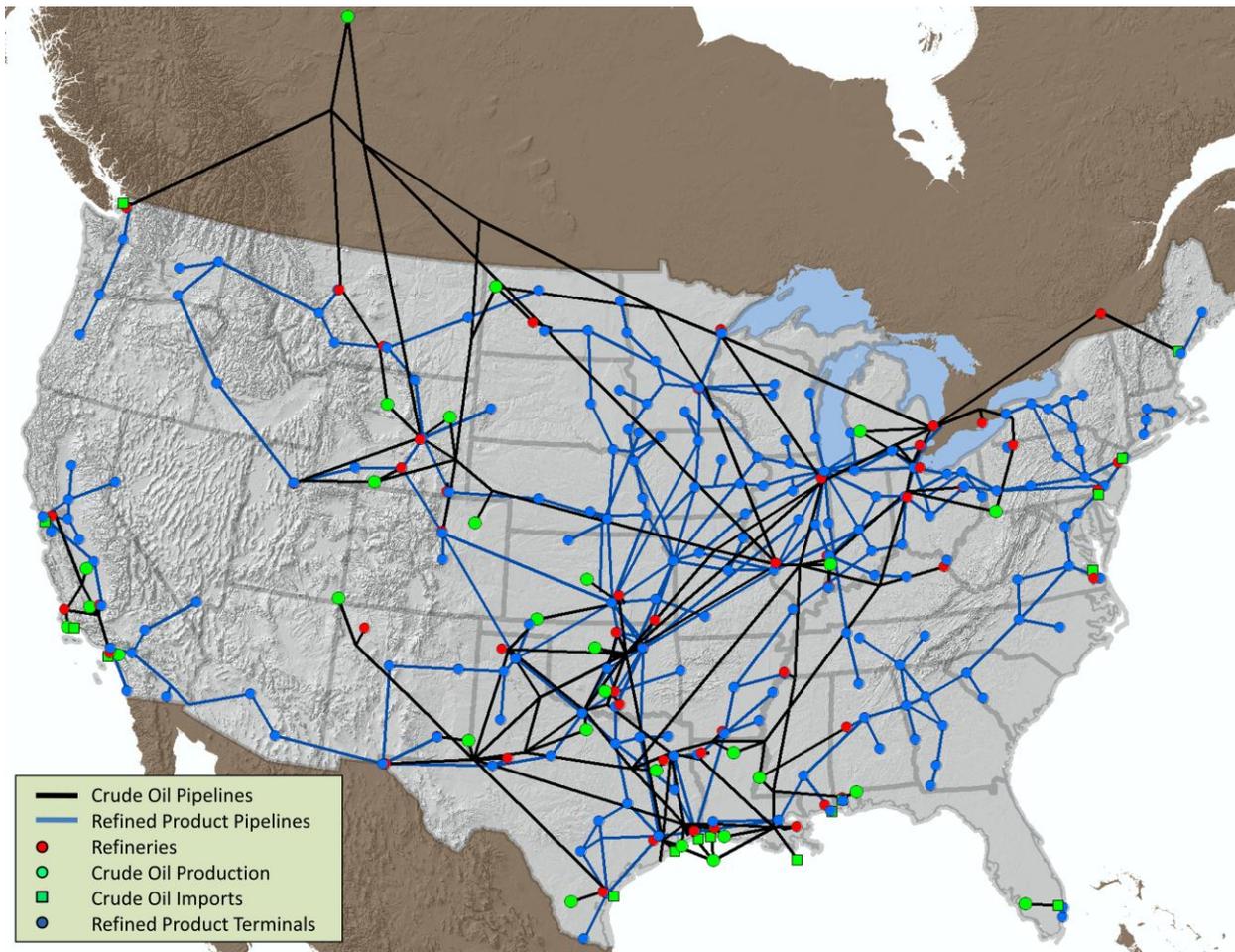
The crude oil portion of the transportation fuel model, including import terminals, oil fields, transmission pipelines, and refineries, is defined and the individual component capacity values have been vetted and tested. The ability to simulate scenario disruptions to the crude oil system and to simulate predicted shortages of crude oil to refineries is functional. The refined product portion of the model, including transmission pipelines, distributions terminals, and service areas for the terminals, is defined, however capacity values for this portion of the system have not been vetted and tested.

Figure 1. Actual national transportation fuels network.

Figure 2. NISAC model representation of the national transportation fuels network.

Legend:
- Crude Oil Pipelines
- Refined Product Pipelines
- Refineries
- Crude Oil Production
- Crude Oil Imports
- Refined Product Terminals