SAND 2011-4587C
SAND2011-4587C

Chemical Supply Chain and Resilience Project

FY 2010 Seminar

The N-ABLE™

Chemical Supply Chain Model

Mark A. Ehlen, Ph.D.
Sandia National Laboratories
maehlen@sandia.gov
(505) 284-4568

July 12, 2011

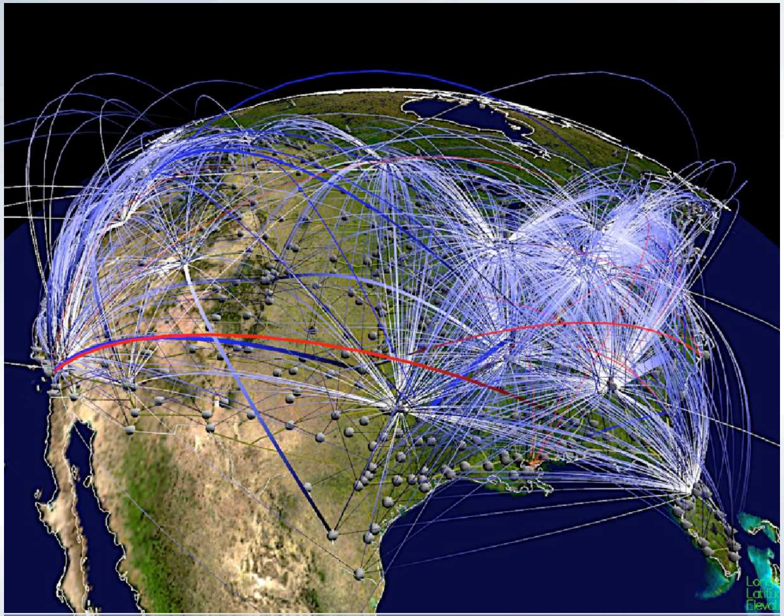
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

U.S. Department of Homeland Security
Science and Technology Directorate

Sandia National Laboratories

Outline

- Overview
  - The general problem
  - The technical approach
  - What the N-ABLE™ model is
- Chemical supply chain modeling requirements
  - Chemical plants and production units
  - Chemical and non-chemical markets
  - Critical infrastructure
  - Imports/exports
  - Disruptions



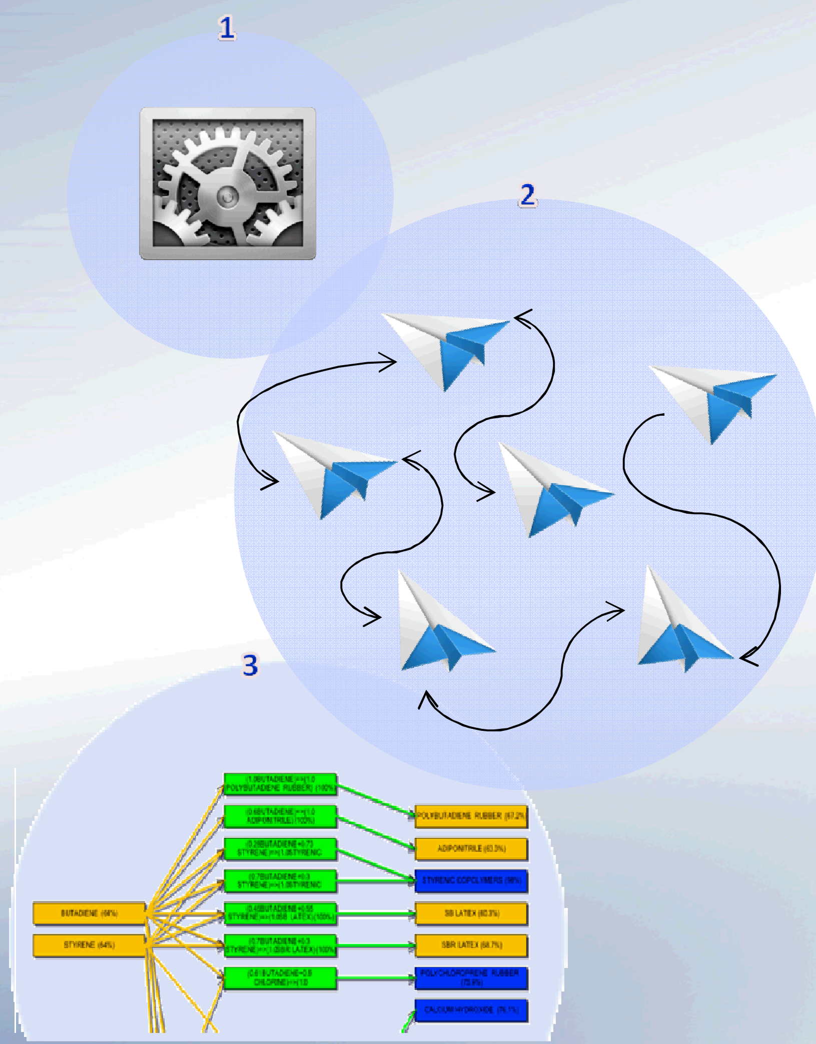
What the Problem Is

- Chemical plants and firms are enterprises that attempt to
  - **Run a business** (cash flow; internal operations; supplier/buyer relations)
  - **Compete** in the market place;
  - Add a value link to a long **value chain**;
  - Use **critical infrastructure** efficiently; and
  - Be resilient to short-term **operational** disruptions (wear and tear), medium-term **extreme** events (man-made and natural disasters); and long-term **evolutionary** change.

- Homeland security stakeholders need to
  - **Anticipate/forecast** when these plants and their supply chains could be impacted significantly, and
  - **Assist** them in their planning for resilience to disruptive events.
  - Address events with models that are **asset-based**, **regional to national in scope, and dynamic**

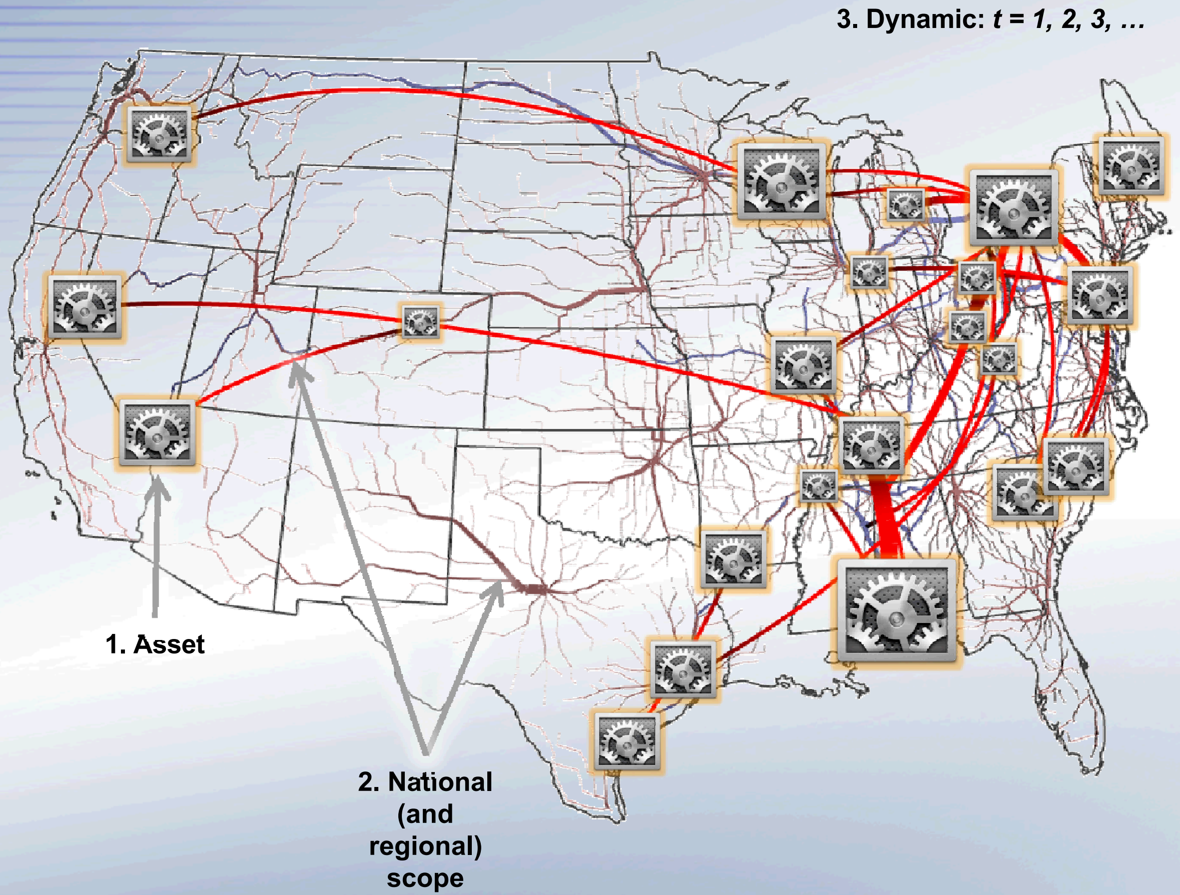
What the Problem Is

- Existing supply chain / value chain models are generally one of three types:
  1. **Enterprise supply chain models** – control theory and operations research. They focus on optimal decisions/ strategies of a single firm or small collection of firms.
  2. **Complex-adaptive system models** – representative agents ("I am a firm") making simple decisions internally but interacting with large numbers of other agents (firms) in complex ways. They focus on system performance that results from many complex interactions.
  3. **Input-output models** – macroeconomic. They focus on approximate estimates of upstream (and sometimes downstream) impacts, typically using fixed interaction values.



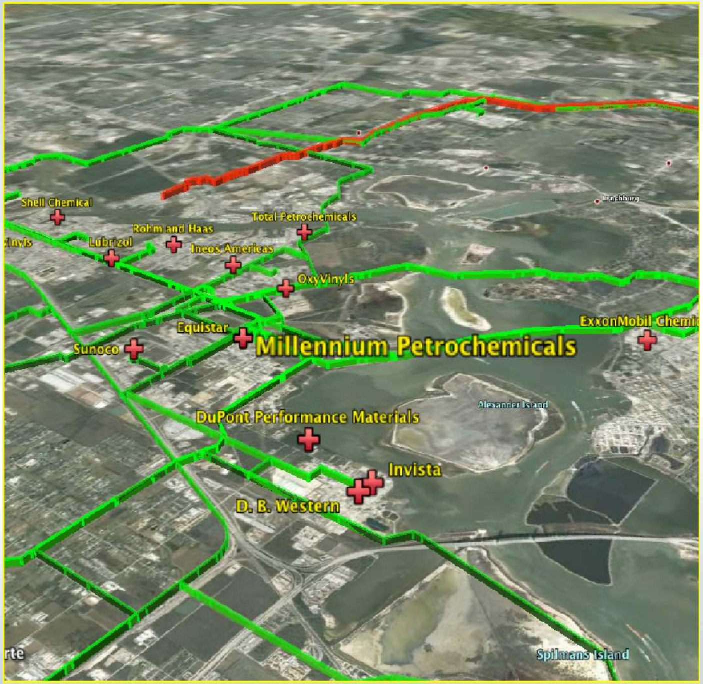
Our Technical Approach

- **N-ABLE™ is a hybrid model**: individual plants (agents) are highly structured entities that follow optimization-based business logic, and interact with other highly structured entities via (adaptive) economic markets and (adaptive) critical infrastructure.
- To meet customer needs, N-ABLE™ uses standard measures of supply chain and economic impact, that is, it abstracts away from the complex-interaction measures.



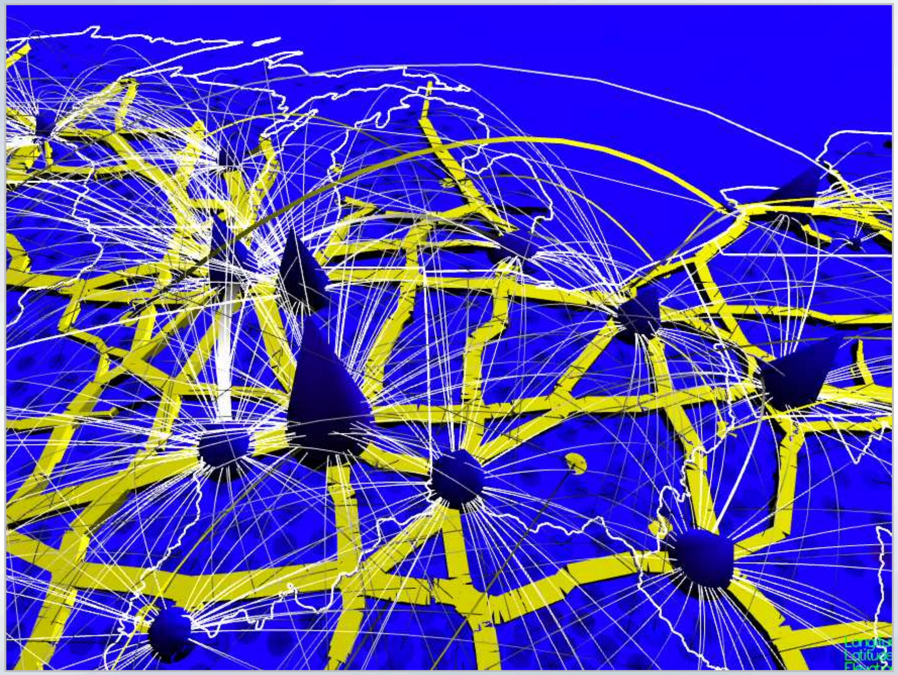
The N-ABLE™ Chemical Supply Chain Model: What it Is

- **A model** of how individual chemical plants, markets, and supporting infrastructure (rail, road, water, pipeline) operate together as a connected chemical supply chain.
- **A framework** for interpreting, reconciling, and normalizing disparate chemical data sources into a single chemical data model (the CDM).
- **A process** for creating normalized/balanced plant-level chemical supply chain models.
- **An analytical tool** for estimating the impacts of disruptive events (man-made and natural disasters) on the Chemical Sector.
- **An analytical tool** for measuring the comparative resilience of a chemical supply chain to different disruptive events.



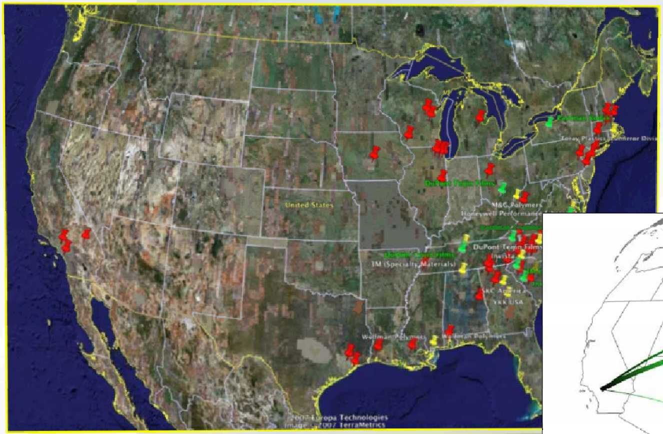
The N-ABLE™ Chemical Supply Chain Model: What it Contains

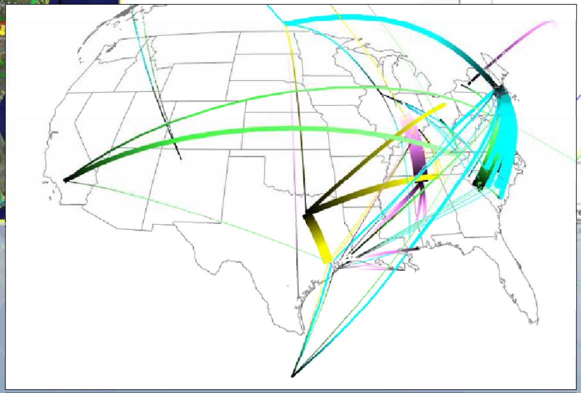
- **Enterprise models** of how individual chemical plants purchase/receive, produce, store, and price/sell/ship chemicals.
- **Linear programming models** of how a chemical plant with multiple production units produces intermediate and final chemicals.
- **Information-economics models** of how commodities are sold/purchased in merchant markets.
- **Network-theoretic transportation models** of how commodities are shipped via rail, truck, pipeline, water.

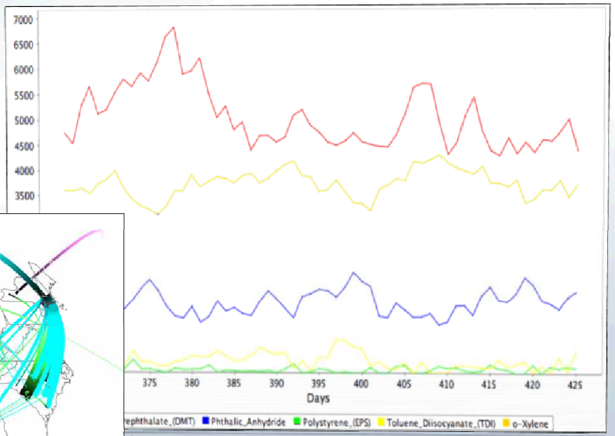


The N-ABLE™ Chemical Supply Chain Model: What it Functionally Does

- Assists subject-matter experts in answering questions like those during the NISAC pre-landfall analysis of Hurricane Ike:
  - Which chlorine plants are in the surge zone of the Houston Ship Channel?
  - Which of these plants produce for themselves and which for merchant markets?
  - What are the potential impacts to the overall chlorine supply chain?
  - What are the potential impacts to the broader U.S. macroeconomy?
- Provides asset, network, spatial, dynamic measures of impact:



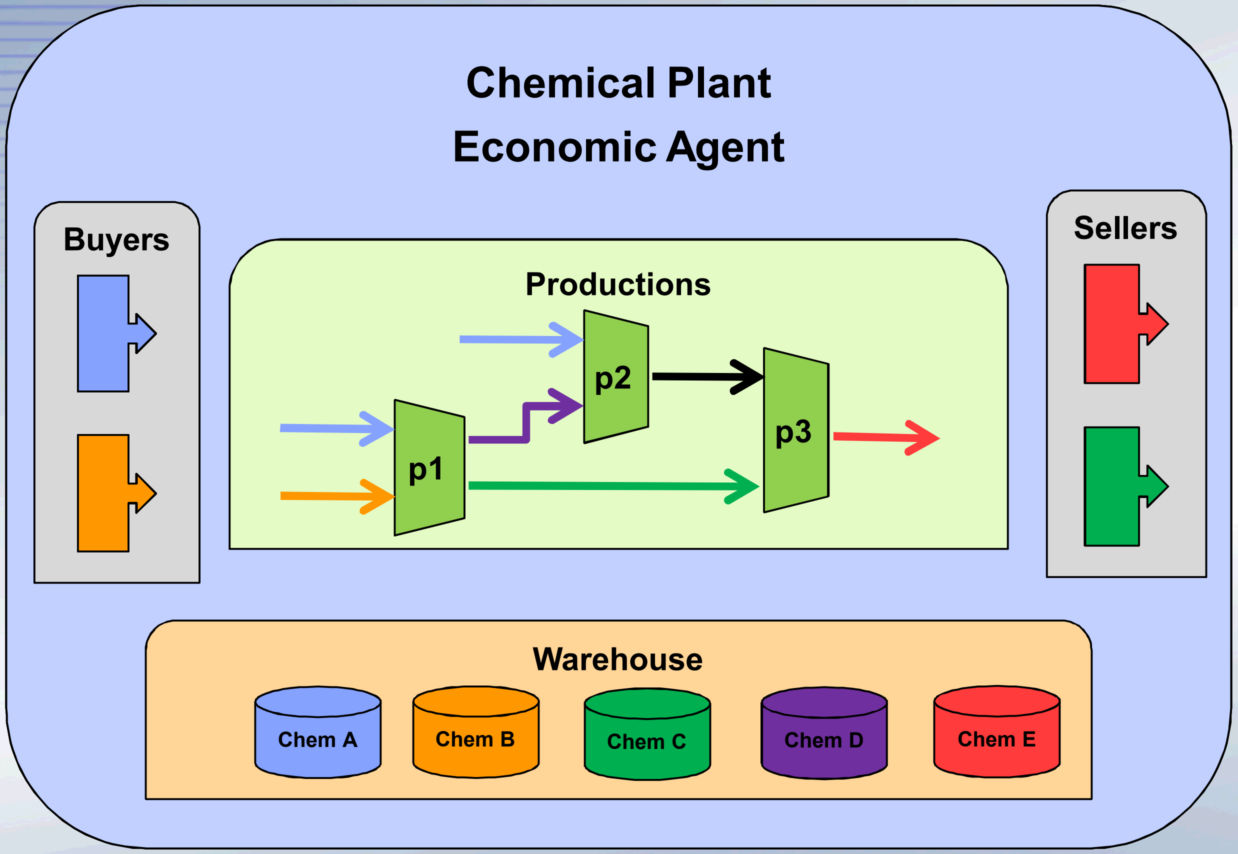




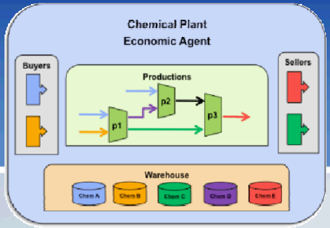
Chemical Supply Chain Modeling Requirements

- Asset Based
  - Enterprise modeling of chemical plants
- Regional/National/International in Scope
  - Markets (merchant markets)
  - Critical Infrastructure (transportation, pipelines)
  - Imports/Exports (foreign trading partners)
- Dynamic (Temporal)
  - Baseline supply chain conditions/characteristics
  - Performance during disruptive events (hurricanes, earthquakes, terrorist events)

The Agent-Based Chemical Plant (the Asset)

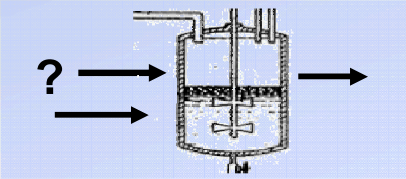


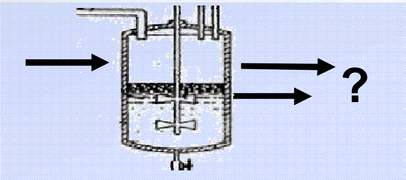
Production Scheduling



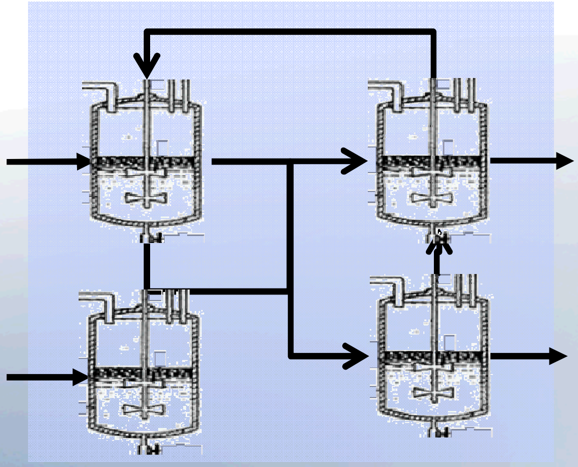
- Traditional **economic** “enterprise” models are either:
  - Multiple inputs, single output – “select input levels that minimize costs subject to output level”
  - Single input, multiple outputs – “select output levels that maximize profits subject to input cost”

  → They are solved with closed-form calculus solutions.

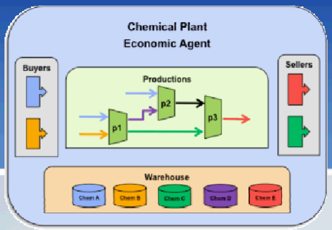




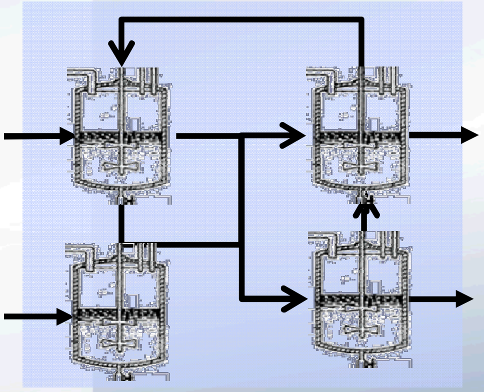
- What’s needed is
  - Multiple inputs, multiple outputs – “select output level that maximize profits subject to prices and production technologies.”
  - Logistics networks – solving the same problem **across** all of a firms’ plants. (intra-firm shipments are inventories)
  - Specification: solve the problem “maximize targeted production levels given internal production constraints and available inventory levels.”



Production Scheduling: Some Math



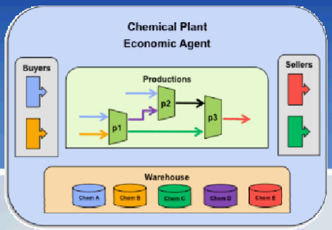
- Production scheduling algorithm solves for the internal production-unit levels that most closely reach the targeted production levels set by the firm.
- Identical algorithm is used pre-simulation to verify that agent chemical plants as constructed from data will actually produce in the designed fashion during simulation.



"Set production levels for each plant as close as possible to desired levels subject to the conditions:

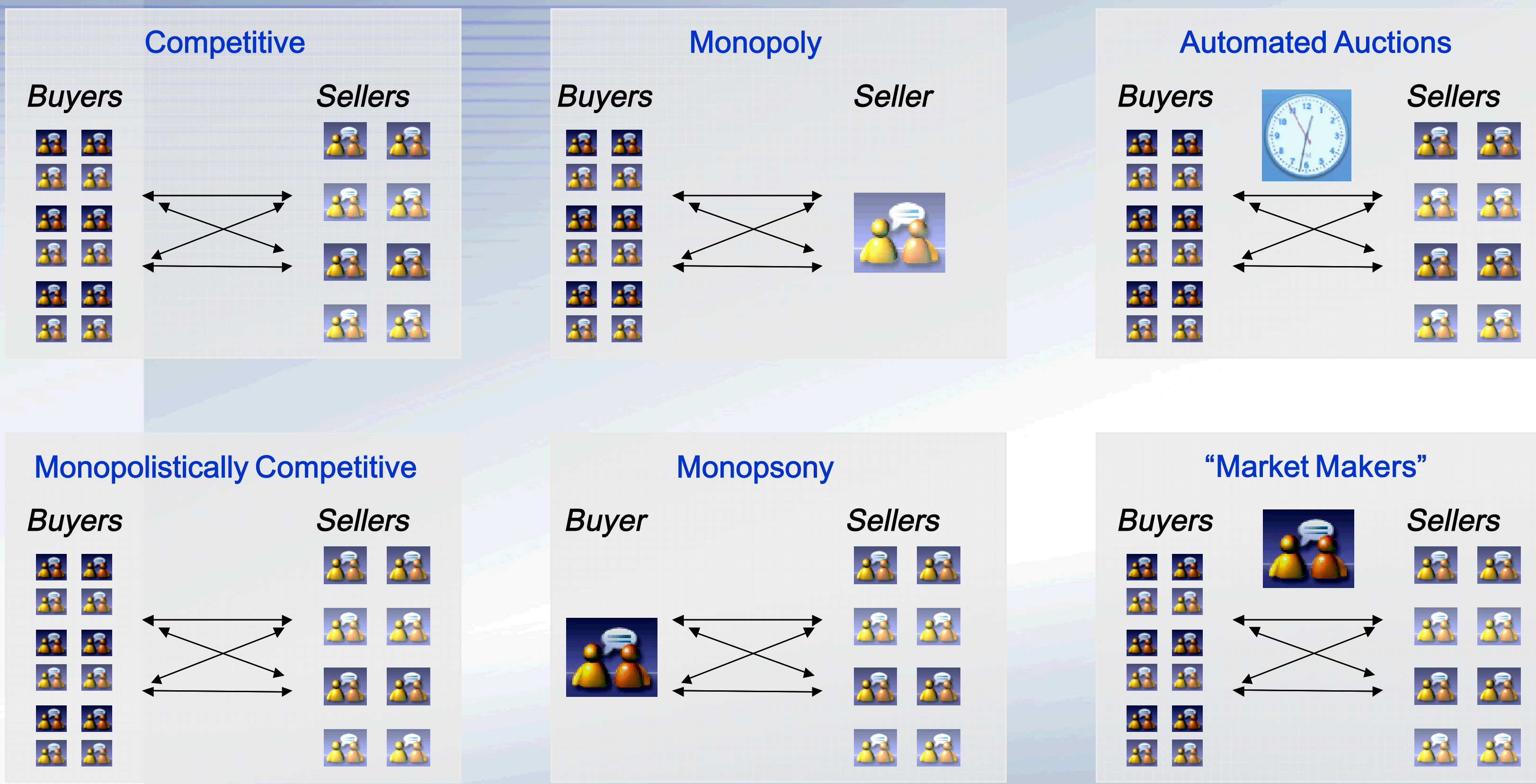
1. Each unit's production level is not more than its capacity;
2. Net increase in a chemical's inventory level can't be more than its capacity;
3. Net decrease in a chemical's inventory can't be less than its initial level;
4. Each unit's input link amounts must equal the output of its feeder production units;
5. Each units output link amounts must equal the inputs of its recipient production units; and
6. All production levels, warehouse amounts, and link flows must be non-negative."

Inventory Management



- Requirements
  - **Purchased chemicals:** maintain input material inventories that minimize inventory cost but still meet internal production needs.
  - **Sold chemicals:** maintain final product inventories that minimize inventory costs but still meet seller needs.
  - **Intermediate chemicals:** maintain sufficient inventory to minimize costs subject but still meet internal production needs.
  - **Composite chemicals: purchased/intermediate and intermediate/sold**
- Model
  - **Purchased chemicals**: Chemical buyer follows *economic order quantity approach* to determining when and at what level to purchase.
  - **Sold chemicals**: Production scheduler sets production levels of sold commodities based on existing inventories, targeted inventory levels, sales, and turned-down sales.
  - **Intermediate chemicals**: follow production scheduling linear program (LP)that attempts to hit desired production levels subject to production configuration and minimizing of intermediate chemical inventories.
  - **'Composite chemicals'**: controlled by the production scheduling LP.

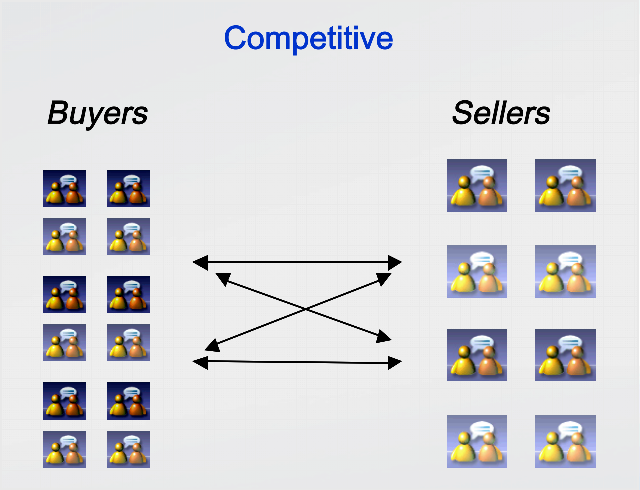
Market Modeling



Need to be able to address a range of possible market structures and pricing mechanisms

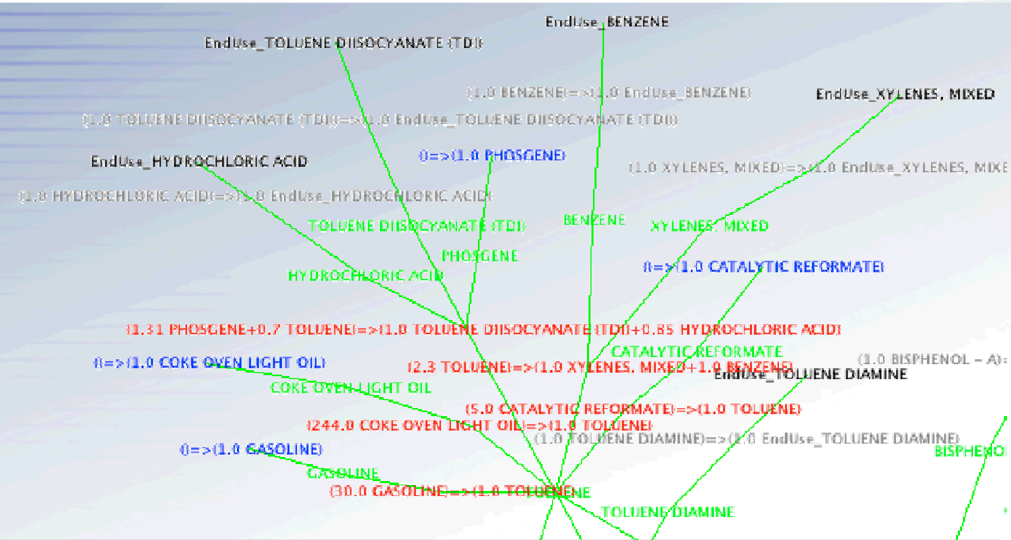
Chemical Markets

- Requirements
  - General: model the day-to-day, regional, national, and international chemical merchant markets.
  - Include ability of chemical buyers to shop for low-price chemicals in "spot" chemical market, and determine when to shop based on *economic order quantity* techniques.
  - Include ability of chemical plant to set different prices in different markets (domestic, international) and change prices based on changes in market conditions.
- Approach
  - Implement an information-economics-based approach for buyers finding the "best" seller of a commodity given firms' locations, and types and costs of transportation.
  - Buyers use *sequential search*, at a cost, which then allows for different seller prices (price dispersion).

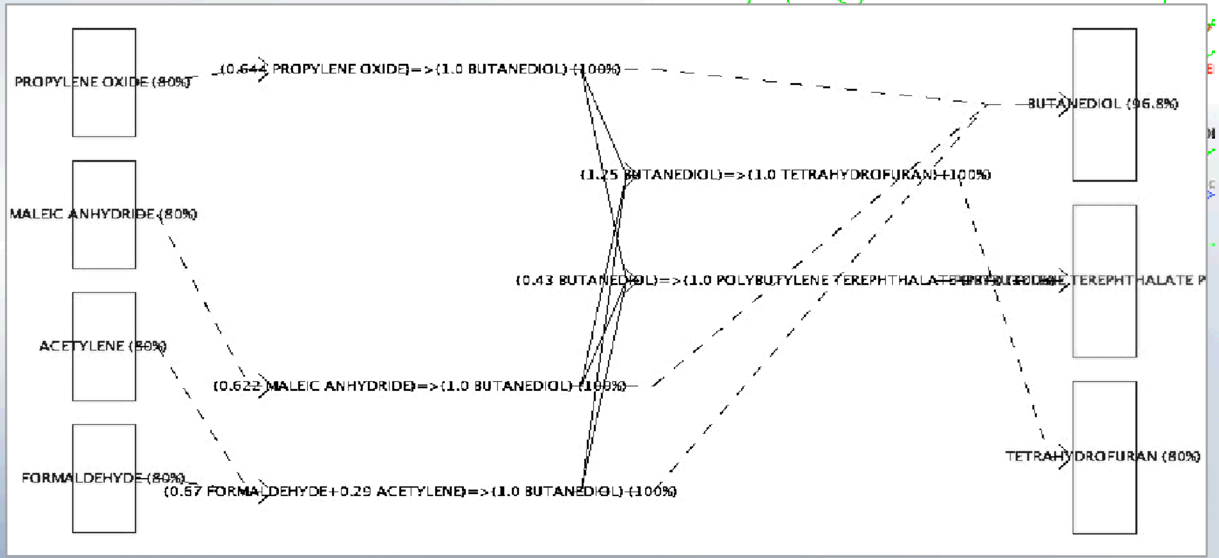


Boundary Markets

- Requirements
  - Need to capture the interactions between chemical plants from the CDM and “outside the supply chain” firms.

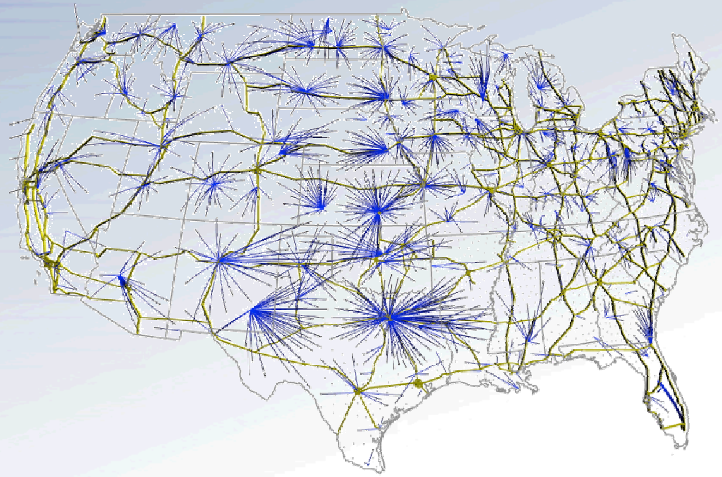


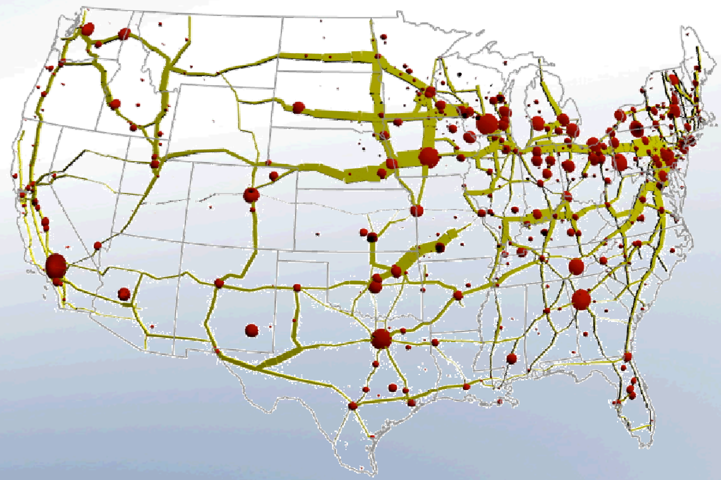
- Approach
  - Create upstream start-suppliers and downstream end-consumers to complete all chemical markets
  - Spatially distribute them to capture regional disruption effects on these markets.



Critical Infrastructure: Transportation

- Requirements
  - Capture the interactions between chemical plants caused by transportation systems, their constraints, and their disruptions.
- Approach
  - Use network-theoretic transportation models (shortest-path, max-flow), to capture how chemical plants use national-level transportation systems, during baseline and disruption conditions.





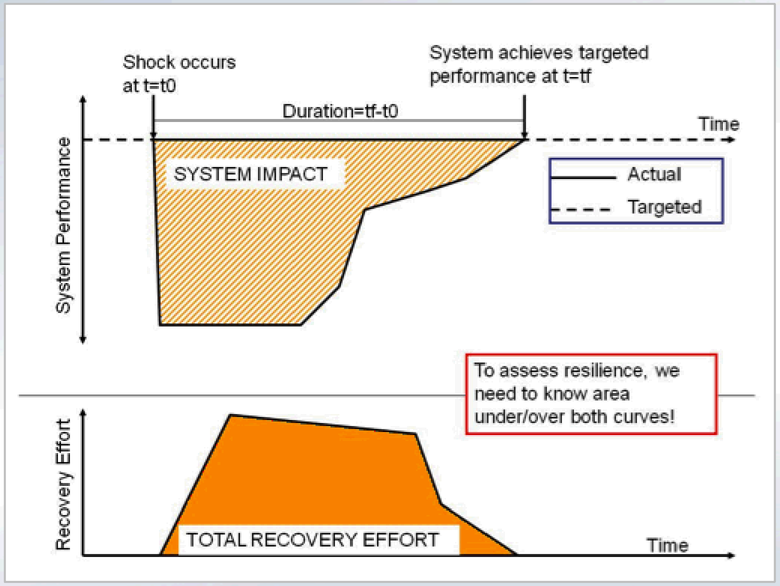
Imports/Exports Modeling

- Requirements
  - Capture the reliance of U.S. chemical plants on imports from and exports to foreign chemical facilities.
  - Capture effects of longer distance, slower international shipments on dynamic performance of U.S. chemical supply chain (baseline and disruption).

- Approach
  - Model the transportation of international chemical shipments (e.g., water)
  - Includes passage through particular ports of entry (POEs) and intermodal/multimodal use of transport (rail; truck)

Homeland Security Disruptive Events and Resilience

- Requirements
  - Capture how individual plants, markets, and infrastructure **adapt** over time to disruptive event.
  - Produce analytical metrics of the **performance** of plants (winners, losers), chemical markets, chemical shipments, and transportation requirements and use.
  - Provide supply chain statistics and analytical results that can be used to assess the **resilience** of the supply chain to the disruptive event and what supply chain characteristics give in terms of absorptive, adaptive, and restorative capacity to be resilient.



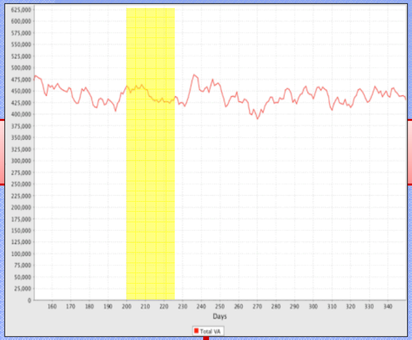
- Approach
  - Model and simulate key characteristics of plants and supply chains to provide the data needed for resilience analysis.

Homeland Security Disruptive Events and Resilience

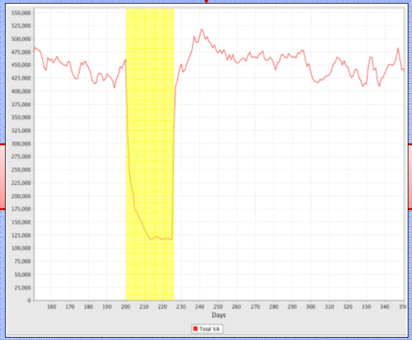
System Impact

GDP

Baseline

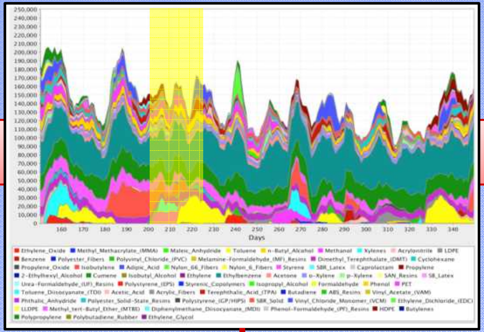


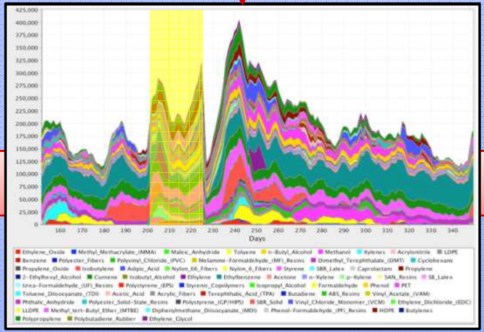
Disruption



Recovery Costs

Transportation Costs





Market Costs