Models to Assess Supply Chain Cost Impacts of Disruptions to Freight Transportation

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Engineering Tomorrow's Supply Chains

Georgia Tech

- Research Focus
  - Applied mathematical modeling for quantitative decision support in supply chain and logistics applications
- Food Supply Chain Research
  - Modeling to support food supply chain risk assessment
  - New *Integrated Food Chain Center*
    - Perishables and cold chains

What to Remember

- A **systems approach** to approximate cost consequences of disruption to supply chain network link
  - Optimization models predict network reconfiguration given a disruption

- Consequence vulnerability of a link depends on:
  - Pre-disruption throughput, but also
  - Availability of low-cost alternatives

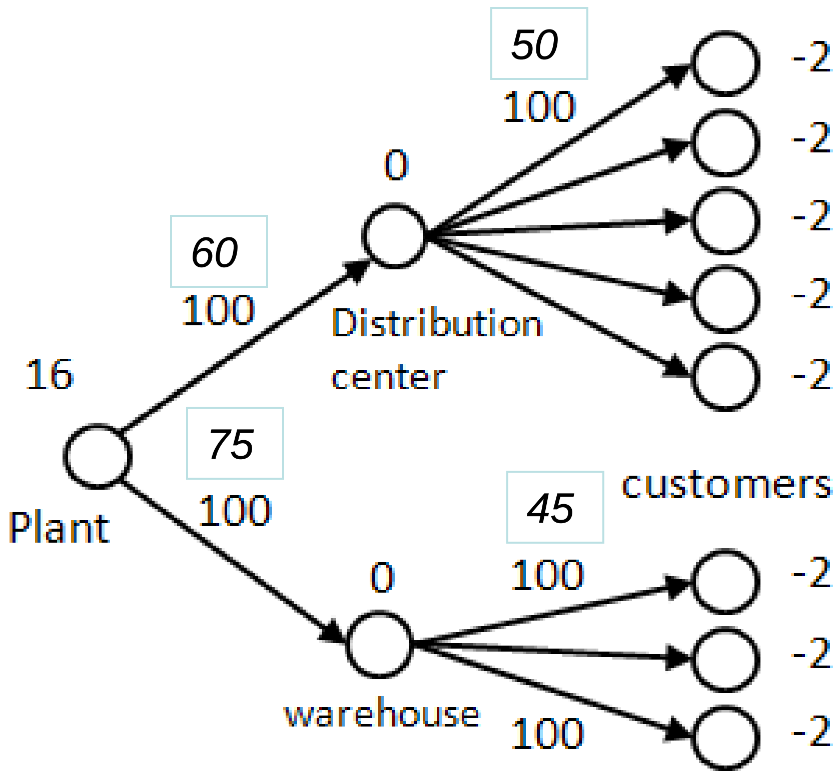
Supply chain cost consequence modeling

- Disruptions to *freight transport links* in *distribution networks*
- Supply chain costs
  - Freight transport and inventory costs, and also "costs" of inadequately serving demand
- Measuring consequences of a disruption
  - *Increase* in costs post-disruption vs. pre-disruption

Consequence modeling approach

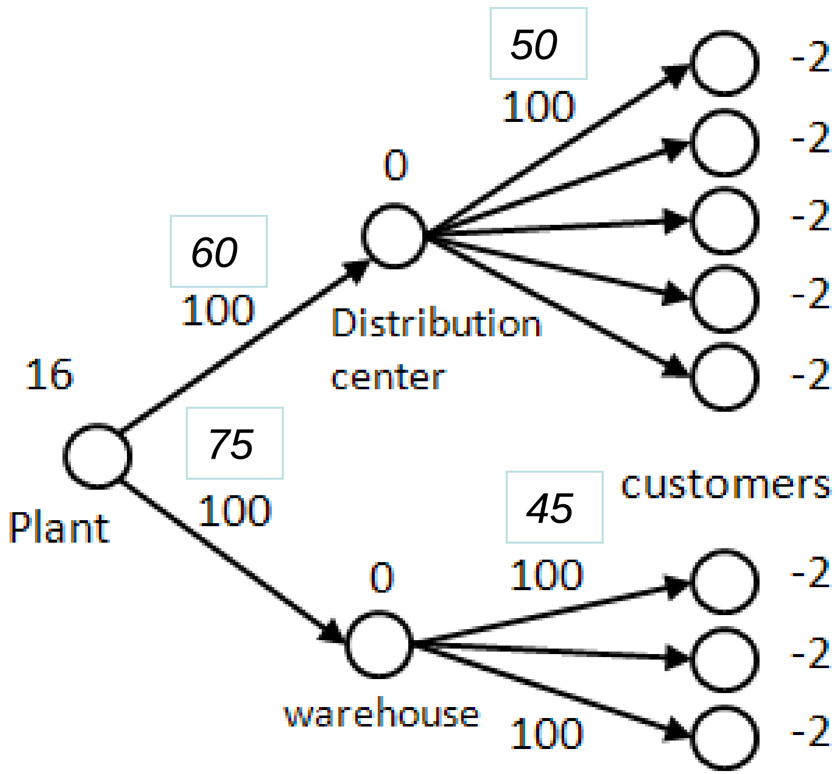
- Build calibrated model of distribution network
  - Assume network is configured to *optimize* supply chain costs to meet service requirements
- Linear minimum cost network flow models
  - Can be optimized *efficiently (computationally)*
  - Can be re-optimized quickly post-disruption

Linear network flow model of distribution



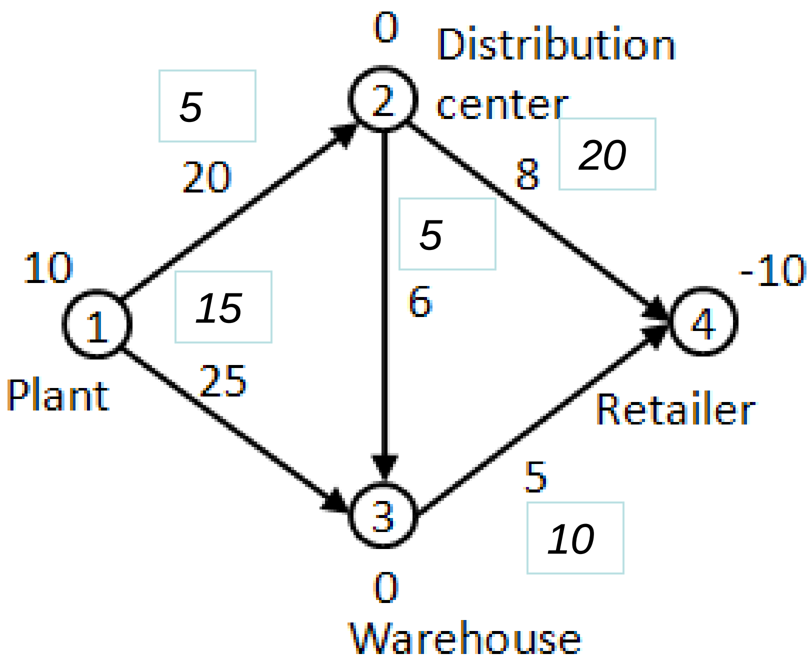
- Flow
  - units of commodity
- Nodes
  - decision points
  - flow sources/sinks
- Arcs
  - connections between decision points

Linear network flow model of distribution



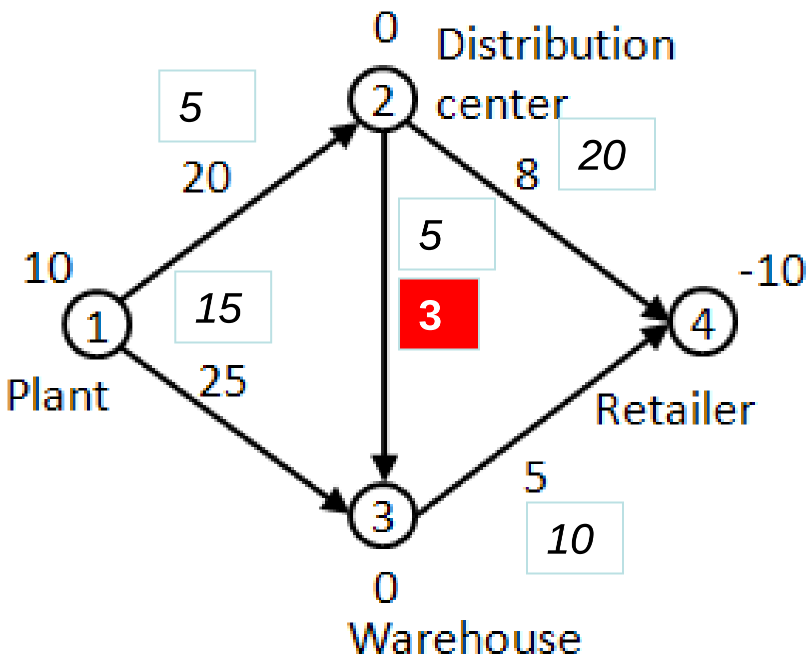
- **Arcs**
  - key to modeling
  - costs
    - linear in flow
  - capacities
    - maximum flow

Example simple network



- Example optimal flow
  - 5 units on path {1,2,3,4}, each costs 20
  - 5 units on path {1,2,4}, each costs 25

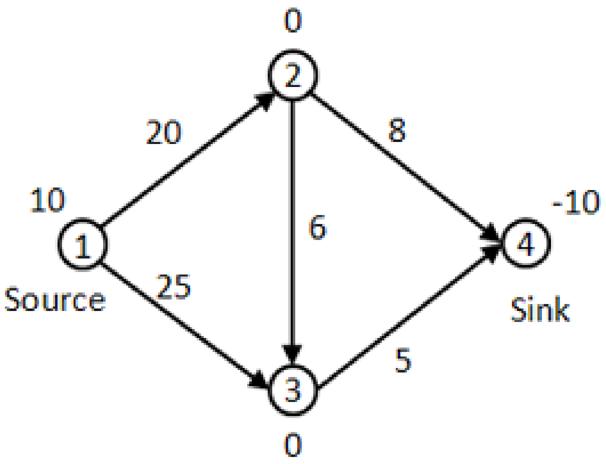
Disruption!



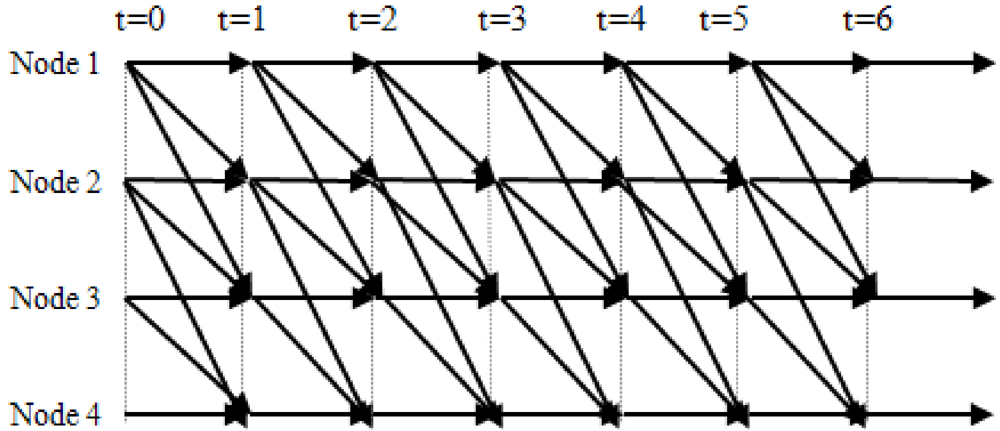
- 50% capacity reduction on arc (2,3)
- New optimal flow
  - 3 units on path {1,2,3,4}, cost 20
  - 7 units on path {1,2,4}, cost 25
  - Adds 10 (4%) to total cost!

Static versus dynamic network models

Static



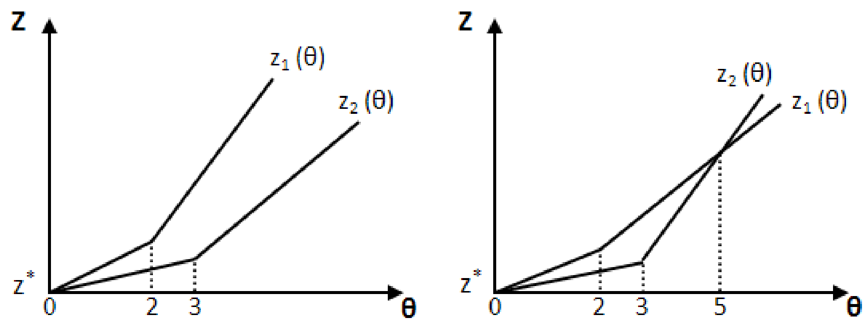
Dynamic



- Cost, capacity, supply, demand can vary over time
- "Horizontal" arcs
  - Forward: holding inventory
  - Backward: satisfying demand late

Consequence assessment algorithm

- For a set of target arcs representing potentially vulnerable infrastructure:
  - Determine **impact cost curves** to measure cost increase as a function of capacity degradation



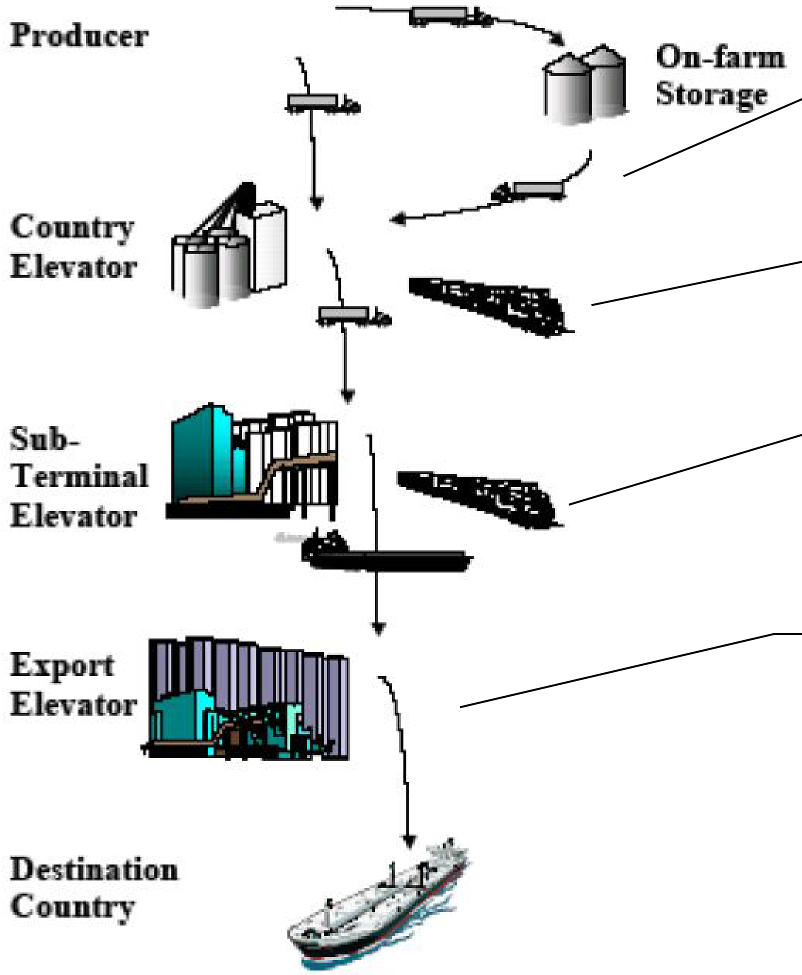
- Technical: uses ideas parametric minimum cost network flows based on dual network simplex algorithm

U.S. grain industry statistics

Crop	Annual Production	Value	Export %	U.S. Export Share %
Corn	280 mmt	$20-35 billion	20%	67%
Wheat	85 mmt	$18-20 billion	31%	41%
Soybeans	280 mmt	$7-8 billion	47%	24%

USDA, 2007 statistics

Distribution network for export corn



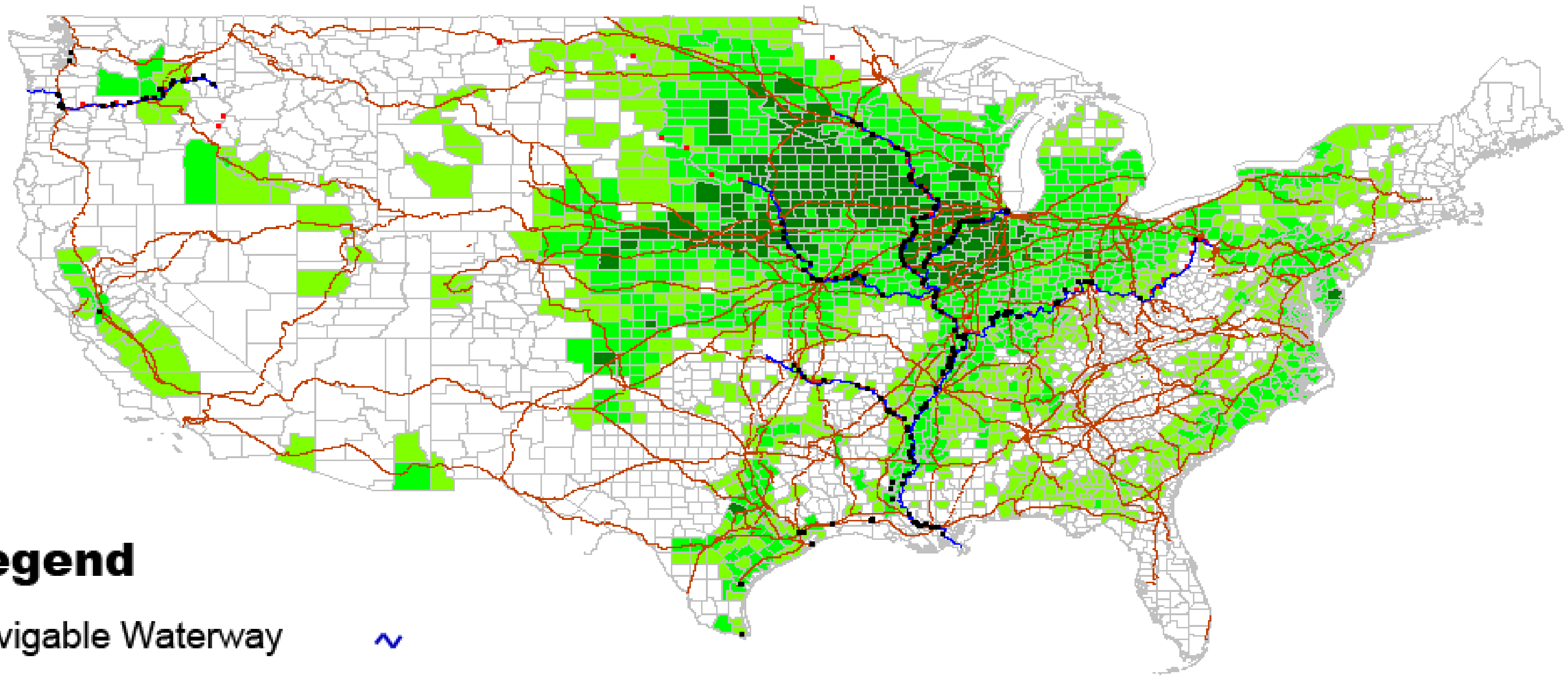
Motor freight

Rail and motor freight

Barge and rail freight

Primary export ports:
South Louisiana/NO
PNW
Houston/Galveston

Geographic scope of export corn network



Legend

Navigable Waterway	
Railroads	
Ports	
Dams	
Corn Harvest (acres)	1000 - 9999 10000 - 99999 100000 - 999999

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Building a corn export network

- Both static and dynamic networks constructed
- Based entirely on publicly-available data sources (2007)
  - USDA Grain Transportation Reports, Agriculture Stats
  - USDOT STB Railroad Public Use Waybill Sample Reports
- Nominal (undisrupted flows)
  - Supplies and demands from Grain Transportation Report (annual, and estimated seasonal for dynamic network)
  - Public Use Waybill statistics to estimate railroad flows
  - Remainder on waterway network

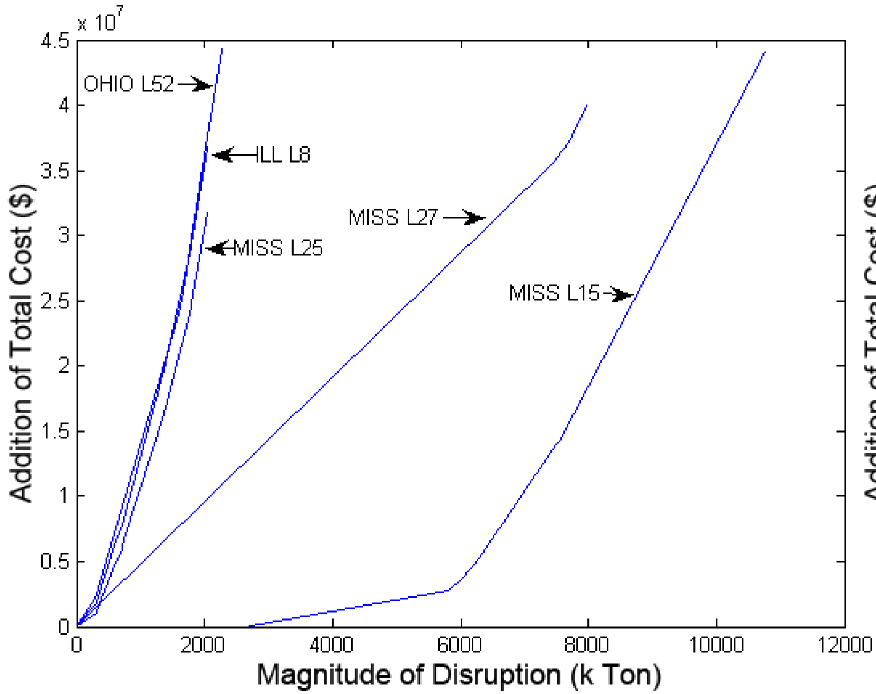
Building a corn export network

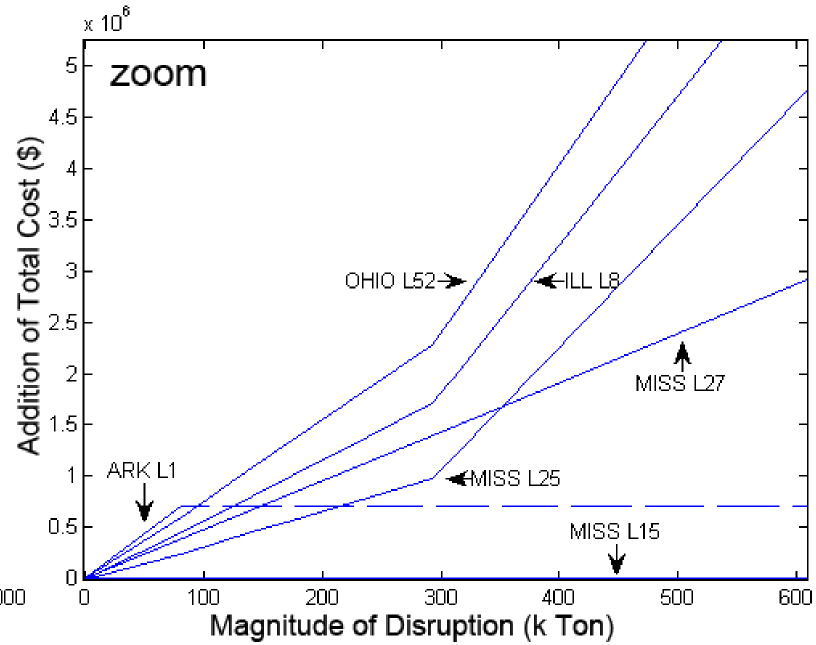
- Arc costs and capacities
  - *Critical for modeling*
  - Capacity
    - Nominal flows used as capacities for high-volume routes
    - Low-volume more costly routes given limited spare capacity
  - Costs
    - Average costs per mile for grain transportation used for railroad and waterway cost estimation
    - Inventory costs based on 20% value held annually
    - Late delivery cost penalty is four times inventory holding cost

Key freight components assessed for disruption

- Targets
  - Each is an important waterway component
  - Navigation dams and locks
  - We examined
    - Mississippi NO. 15 (Rock Island), 25 (Winfield), and 27 (Chain of Rocks)
    - Illinois NO. 8 (Aux Sable)
    - Ohio NO. 52 (Brookport, IL)
    - Arkansas NO. 1 (Norrell)

Static analysis results





- Ohio 52 and Illinois 8 are "steepest" curves, most sensitive to disruption
- Example: Capacity reduction of 300K tons/year on Ohio 52 leads to $2.25M in supply chain costs

Dynamic analysis

- Disruptions lasting one week only
- Results to date show that Ohio 52 and Illinois 8 appear to be most vulnerable
  - Large-scale disruptions that last only a single week can lead to cost losses from $2-10M
- Consequences vary significantly by time of year
  - For example, consequences of disruption to Ohio 52 peak right before peak harvest week in August

Next steps

- Technical enhancements
  - Costs, demand function of disruption level

- Explore whether results from these models can better inform risk assessment practice for key grain transportation infrastructure
  - Refined input data to our models

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Thanks!

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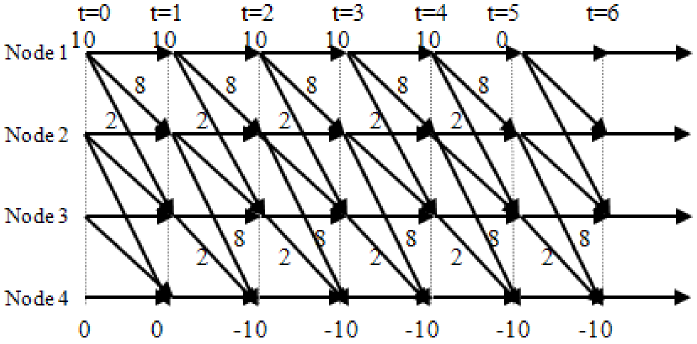
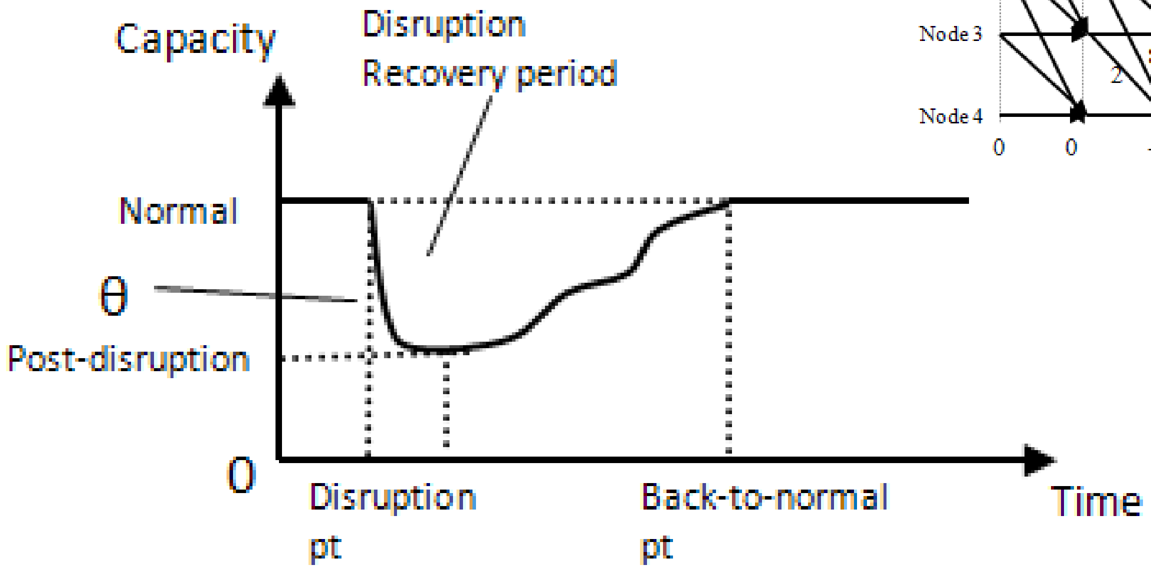
Disruptions on Dynamic Networks





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