Interdependent, Multi-regional Impacts of Inoperability at Inland Waterway Ports and Network

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Maritime Risk Symposium 2011
Piscataway, New Jersey
November 7-9, 2011

Research questions

- How can we measure disruptive flows in a waterway network?
- How can be quantify interdependent effects of disruptions?

Extension of

Pant, R., K. Barker, F.H. Grant, and T.L. Landers. 2011. Interdependent Impacts of Inoperability at Multi-modal Transportation Container Terminals. *Transportation Research Part E: Logistics and Transportation,* **47**(5): 722-737.

The Motivation

Dock-specific Disruptions

Waterway Accidents

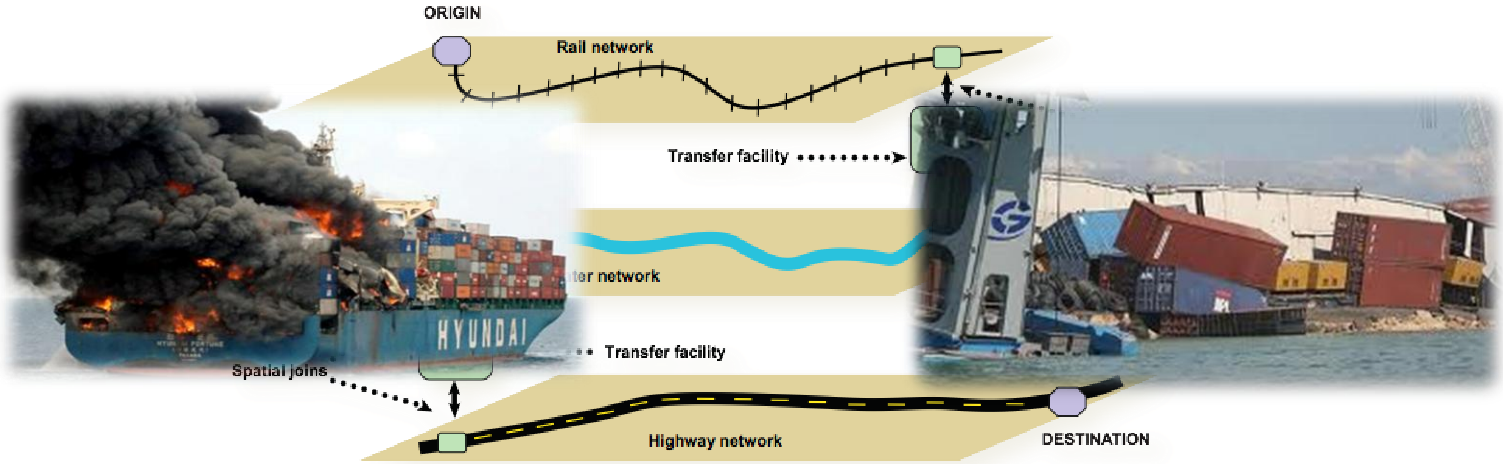
The Conclusions

Motivation

- Attacks on CI/KR
  - ...could significantly disrupt the functioning of government and business alike and produce cascading effects far beyond the targeted sector and physical location of the incident...
  - ...could produce catastrophic losses in terms of human casualties, property destruction, and economic effects, as well as profound damage to public morale and confidence [DHS 2009]
- Include, among others: agriculture/food, critical manufacturing, TRANSPORTATION

Inland ports as critical infrastructure

- US inland waterway ports move 2.5 billion tons of commerce via water annually



  - As US traffic congestion increases, growth of inland waterways will only increase
  - Containerized freight safety important homeland security issue

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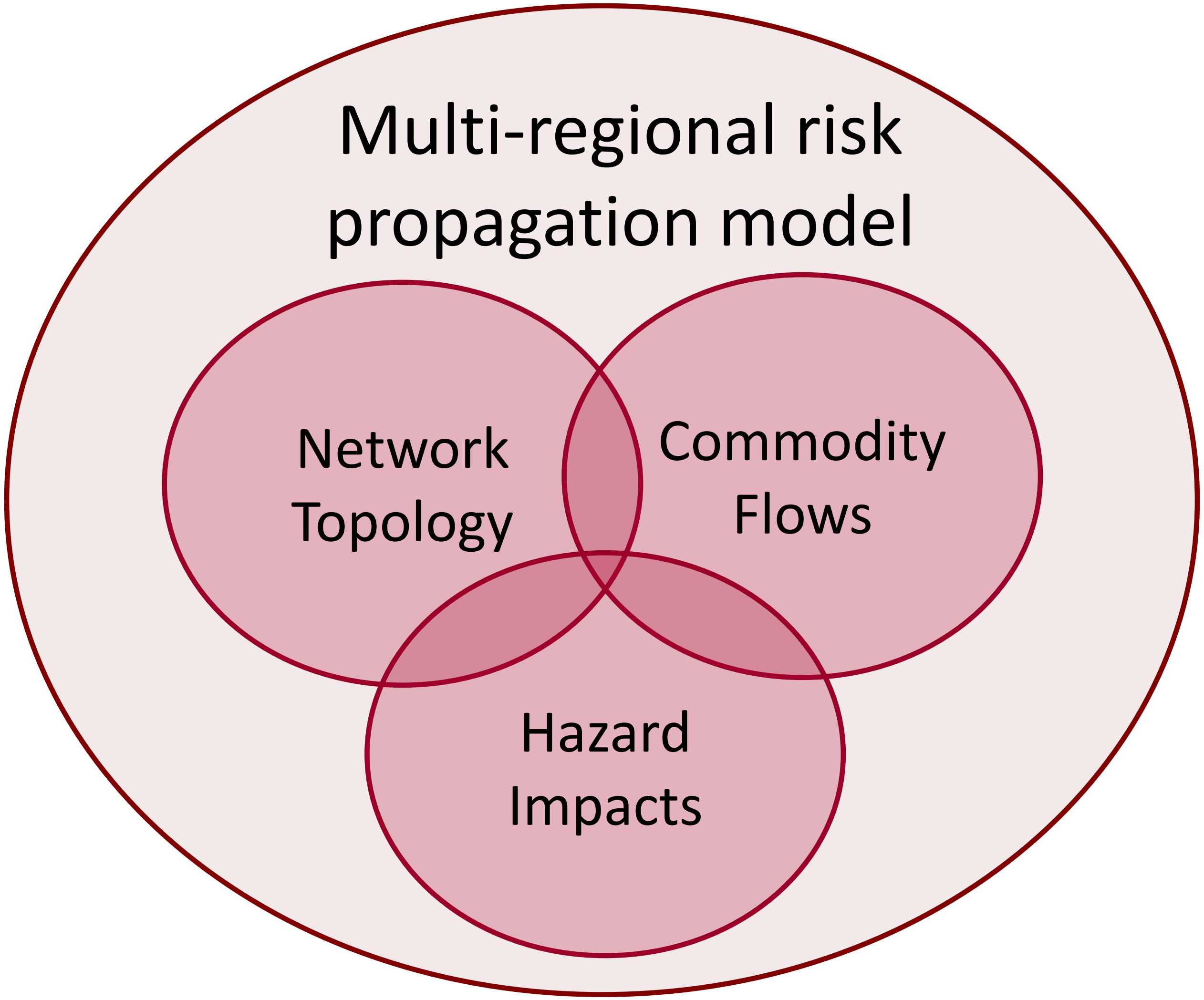
Waterway Accidents

The Conclusions

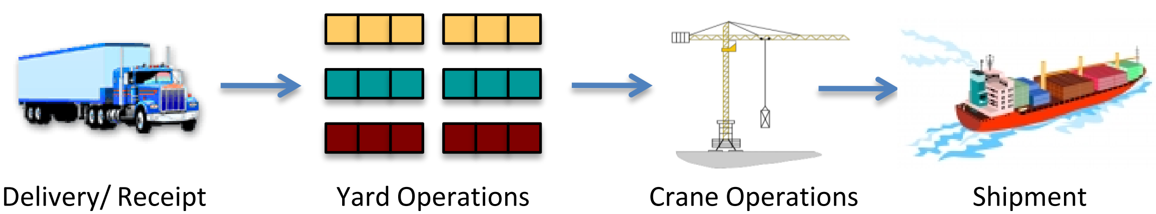
Research components



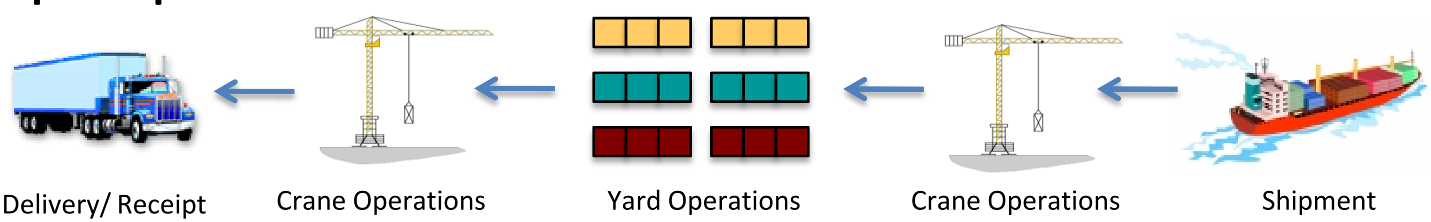
Modeling port operations

- Discrete event simulation model
  - Inputs: arrival schedules, crane and yard capacities
  - Models number of tons at each stage of the queue over time

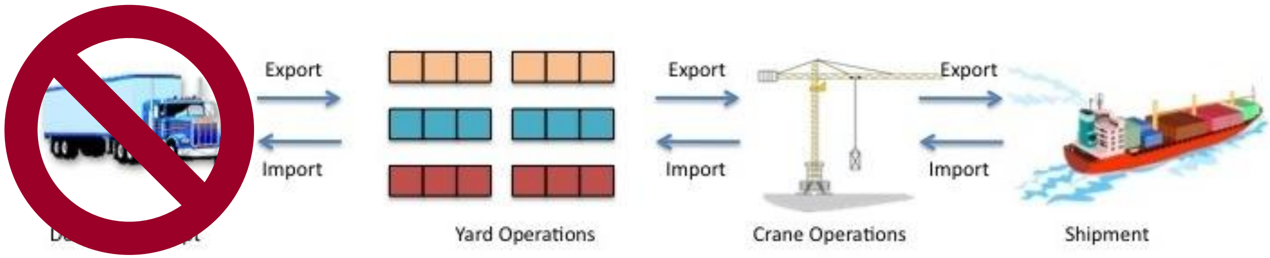
Port export operations



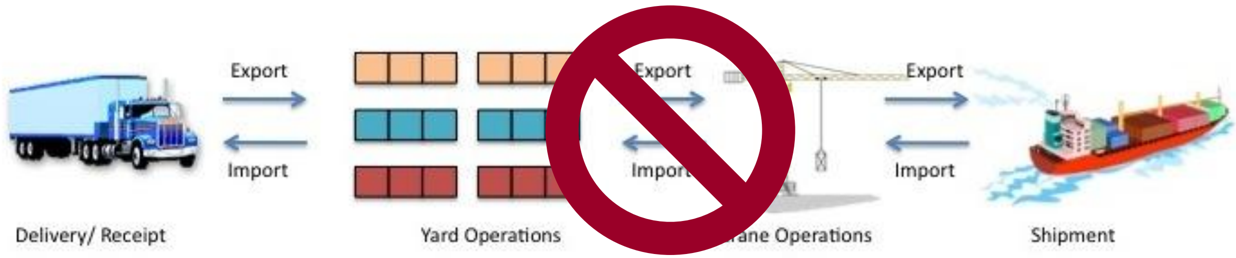
Port import operations



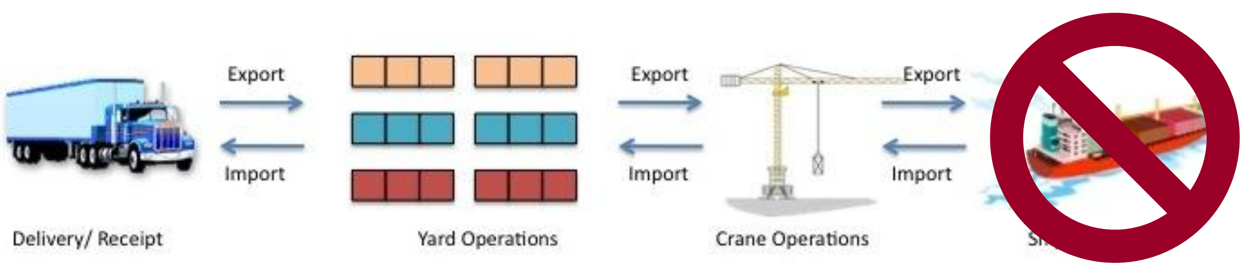
Disruptions in port operations



Disruption of transport to facility



Breakdown at facility



Disruptions downstream

Quantifying port operations

Model inputs

- Duration of disruption
- Impact of disruption
  - Reduced arrivals
  - Reduced crane capacity
  - Reduced departures

Model results

Tonnage of exports-imports flowing on the network during the disruption

Loss estimation

Difference in tonnage between as-planned and disruptive scenarios

Economic losses

Interdependent impacts of tonnage disruptions

Multi-regional inoperability

- Consequences can be expressed in terms of the losses in output and demand normalized by the as-planned sector output

***np* x 1 vector of industry inoperability in different regions**

$$\mathbf{q} = \mathbf{T}\mathbf{A}^{*}\mathbf{q} + \mathbf{T}\mathbf{c}^{*}$$

***np* x 1 vector of industry demand perturbations in different regions**

***np* x *np* normalized inter-regional commodity flow matrix based on BEA data**

***np* x *np* normalized intra-regional interdependency matrix based on CFS data**

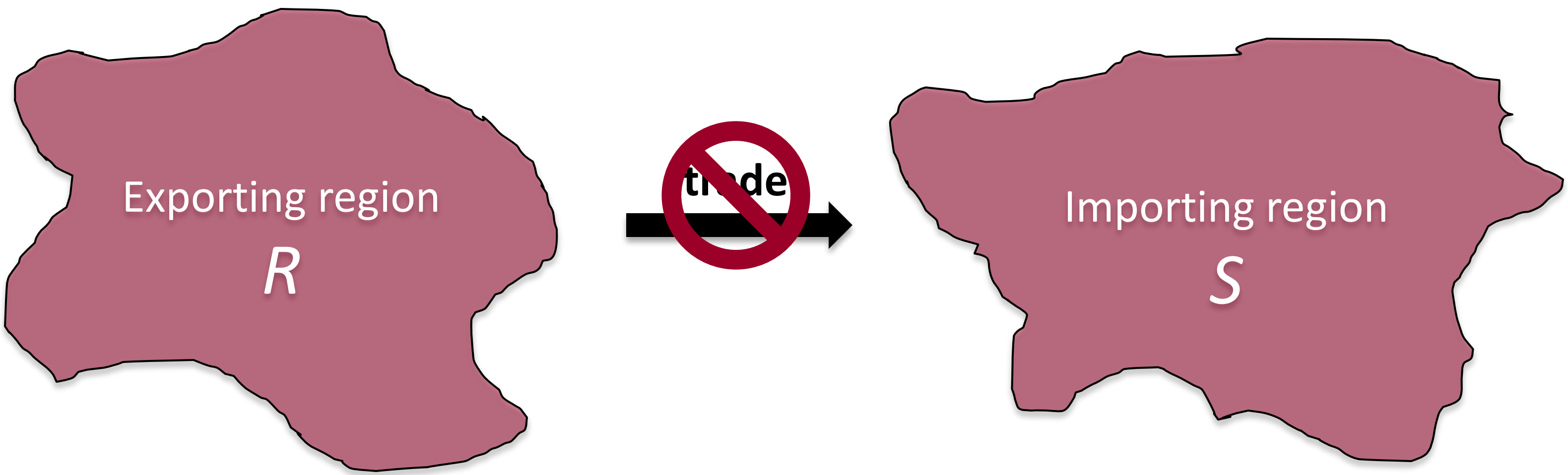
For *n* commodities across *p* regions

$$\text{Inoperability } (q_i) = \frac{\text{As-planned output } (x_{i,0}) - \text{Perturbed output}(x_i)}{\text{As-planned output } (x_{i,0})}$$

$$\text{Demand perturbation } (c_i^{*}) = \frac{\text{Exogenous demand loss}}{\text{As-planned output } (x_{i,0})}$$

Transportation inoperability

- When a transportation inoperability occurs, a loss of trade results
  - Disruption in port operations
  - Disruption in waterway operations



Demand loss (c_R^*)　　Output loss (q_s) + Demand loss (c_s^*)

Illustration: Inland waterway port

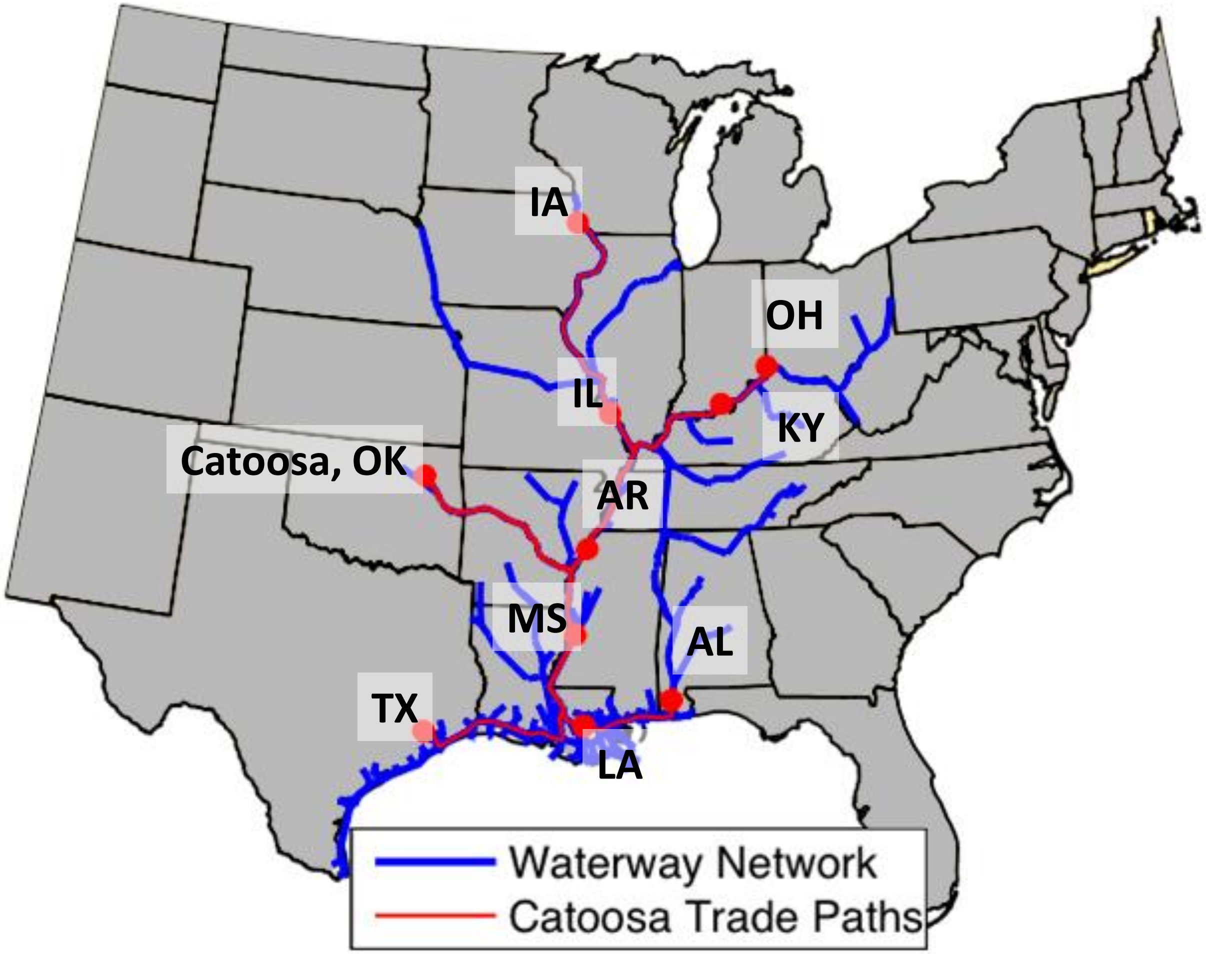
Port of Catoosa
Tulsa, Oklahoma

McClellan-Kerr
Arkansas River

Mississippi River System

- Largest in area in the US
- 2 mil tons annually

Illustration: Waterway network



Data Sources:
US Army Corps of Engineers, National Database Center

Illustration: Dock-specific commerce

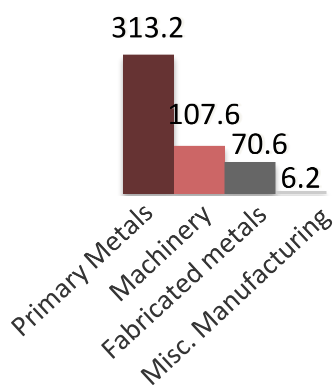
- Estimated annual amount of export-import through Catoosa in 2007 ($M), Total = $937 million

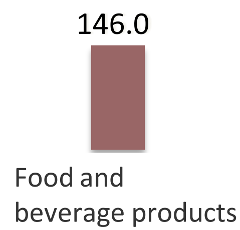
General Dry Cargo

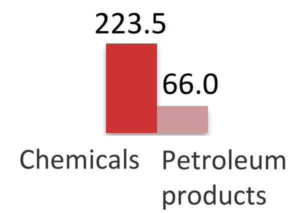
Dry Bulk

Grains

Liquid Bulk







Data Sources:
US Army Corps of Engineers, Tulsa Port of Catoosa
US Department of Transportation Research and Innovative Technology Administration

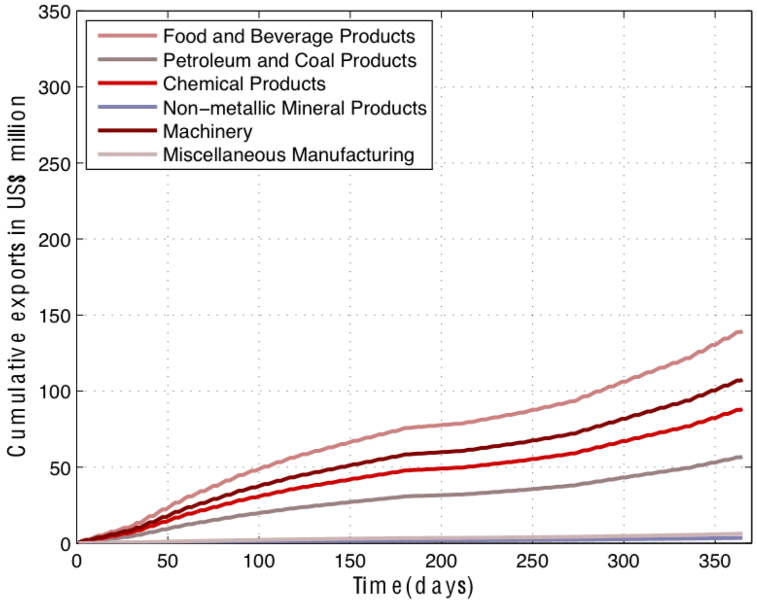
Illustration: Dock operations

- Available data for annual flow of commodities through port can be converted to daily flows
  - Also reflects seasonality
- Queueing models apply to the general dry goods, dry bulk, and grain docks
  - For liquid bulk docks, commodities arrive and are transferred to and from barges through pipes to tanks
- Daily capacities of cranes determined by the number of hours they are in operation

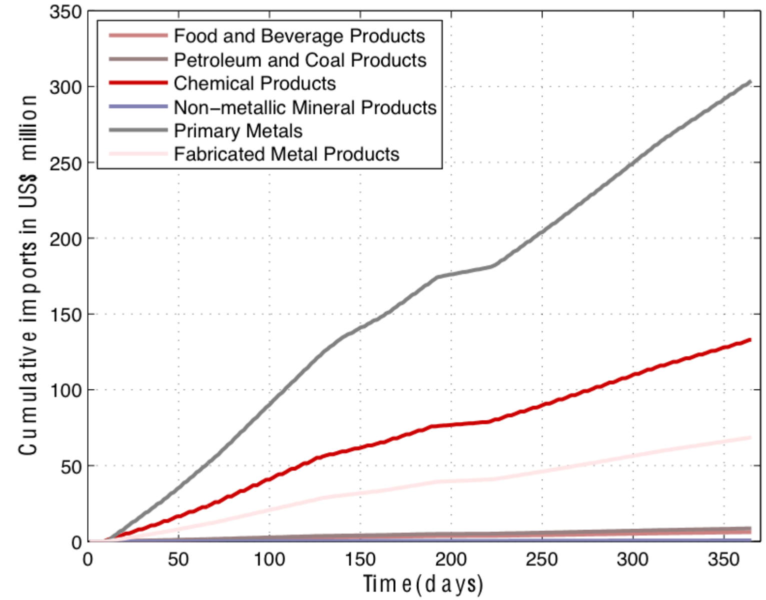
Illustration: Port commerce simulation

- Estimated annual amount of export-import through Catoosa in 2007 ($M)

Exports



Imports



Main trading states

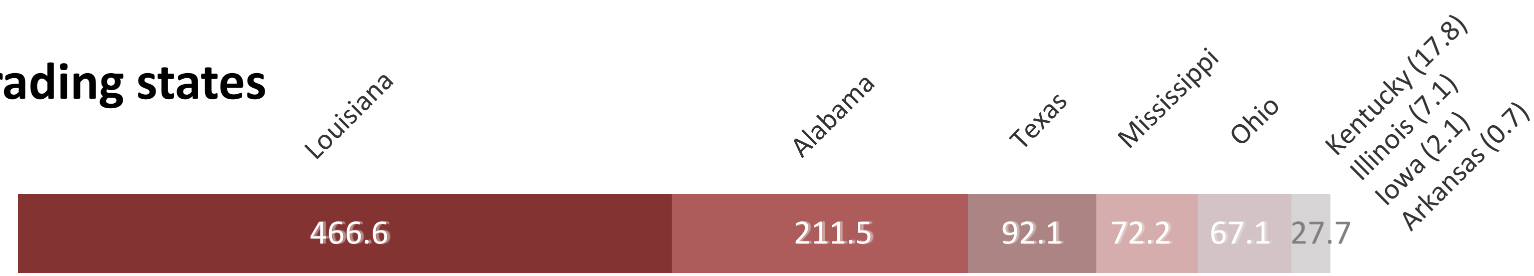


Illustration: Dock disruption

- Floods, snowstorms, (hurricanes) could disable the entire port
- Dock disruption scenarios modeled separately
  – Complete shut down of dock for duration of two workweeks

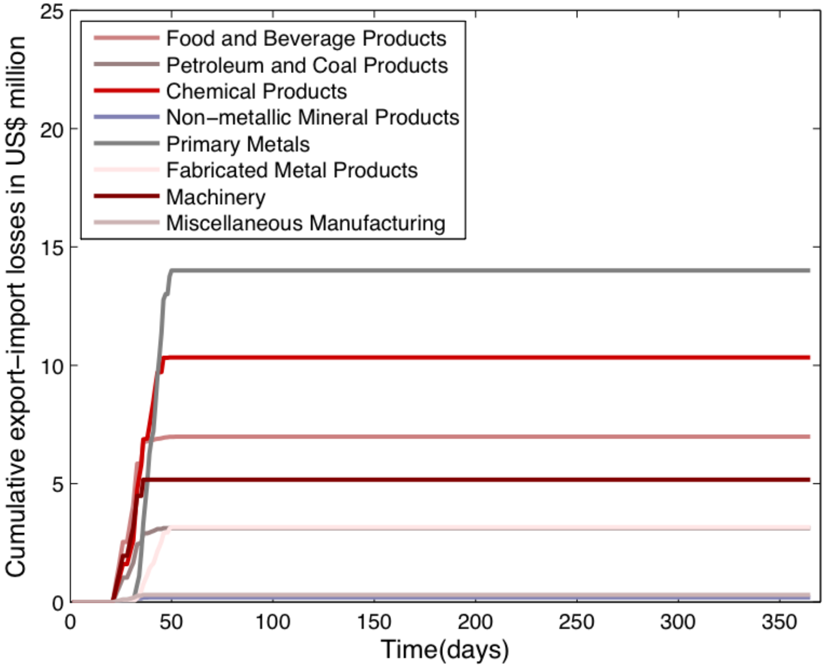
Liquid Bulk

- Spillages
  – Dock shut during cleanup
- Impact of disruption
  – No arrivals
  – No departures

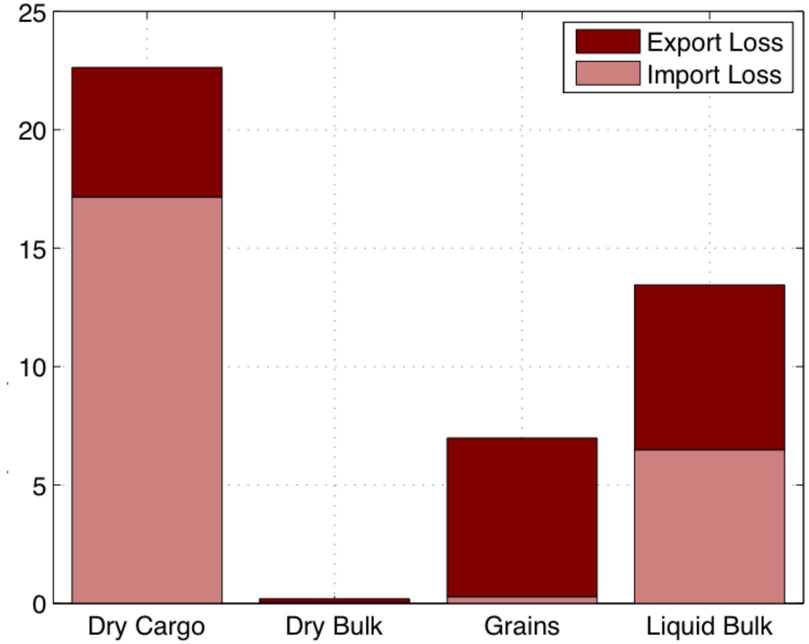
Other Docks

- Crane outages
  – Partial/total shut down
- Impact of disruption
  – Reduced crane capacity
  – Reduced departures

Illustration: Export-import losses



Sector-wise accumulation of export-import losses

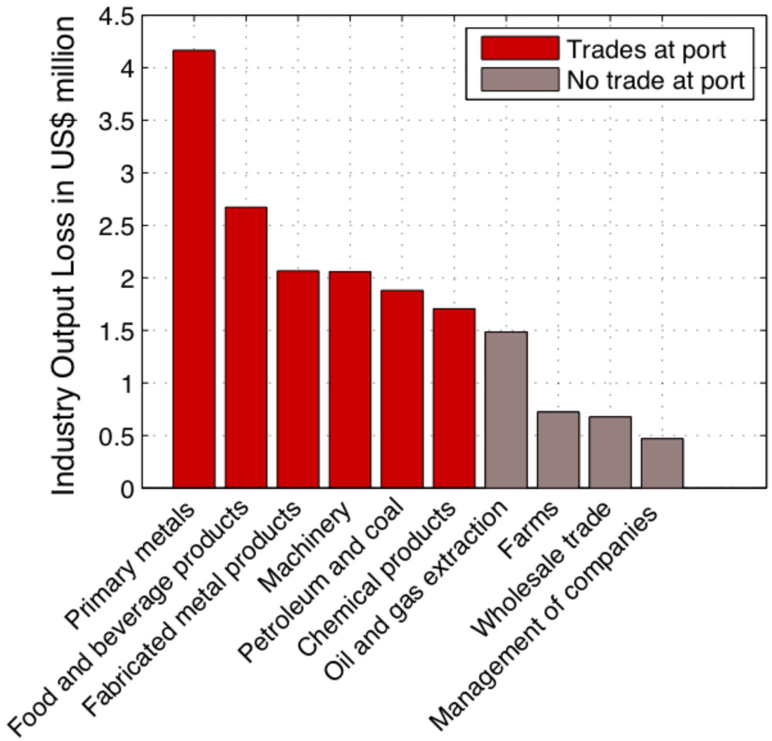


Dock specific losses

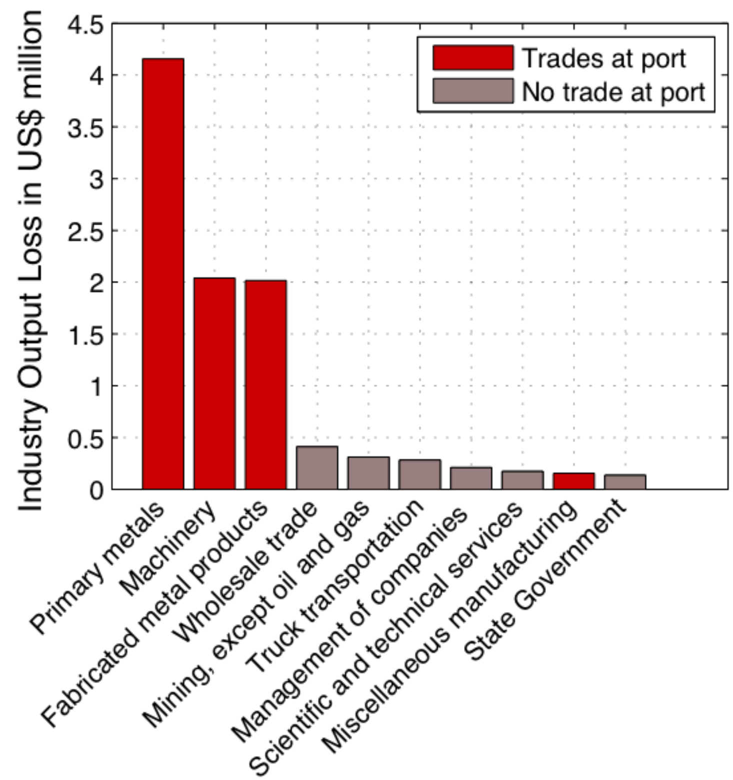
- Onset of disruption chosen arbitrarily

Illustration: Interdependent effects

- Output losses across Oklahoma industries due to port shutdown

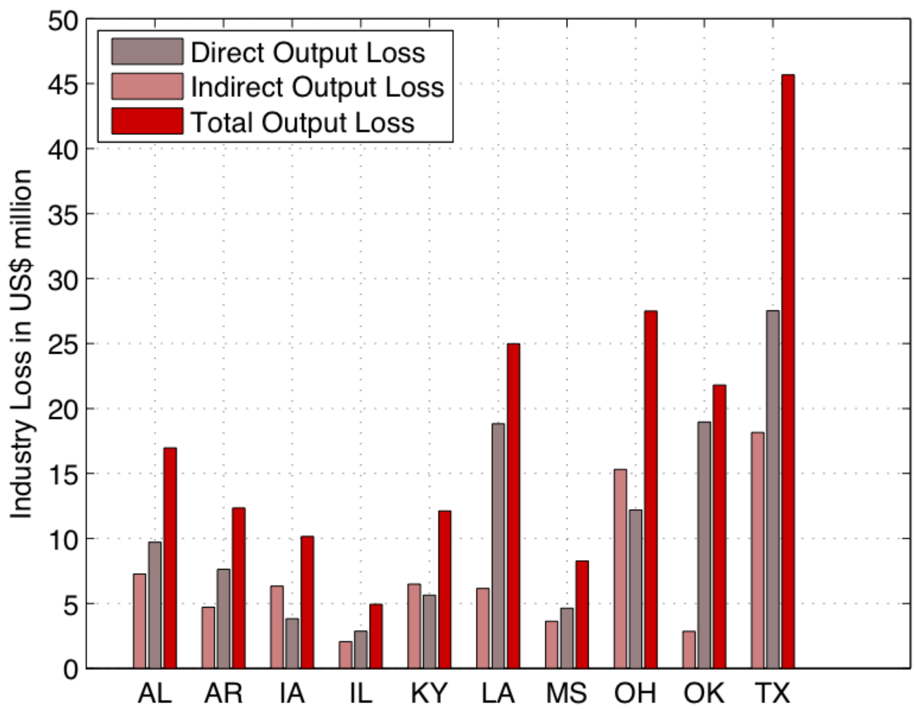


Entire port shutdown



Only general cargo dock shutdown

Illustration: Interdependent effects



Total direct losses: $72.9 million
Total indirect losses: $111.8 million
Total losses: $184.7 million

- Oklahoma has more direct loss because the port is mainly importing
- Texas has almost no direct impact but large indirect impact

Illustration: Risk management

- We use the interdependency model to measure the efficacy of risk management
  - What does extra capacity (e.g., crane) do to minimize large-scale impacts?
  - On which dock should we put most emphasis?

- The future: robust decision making framework

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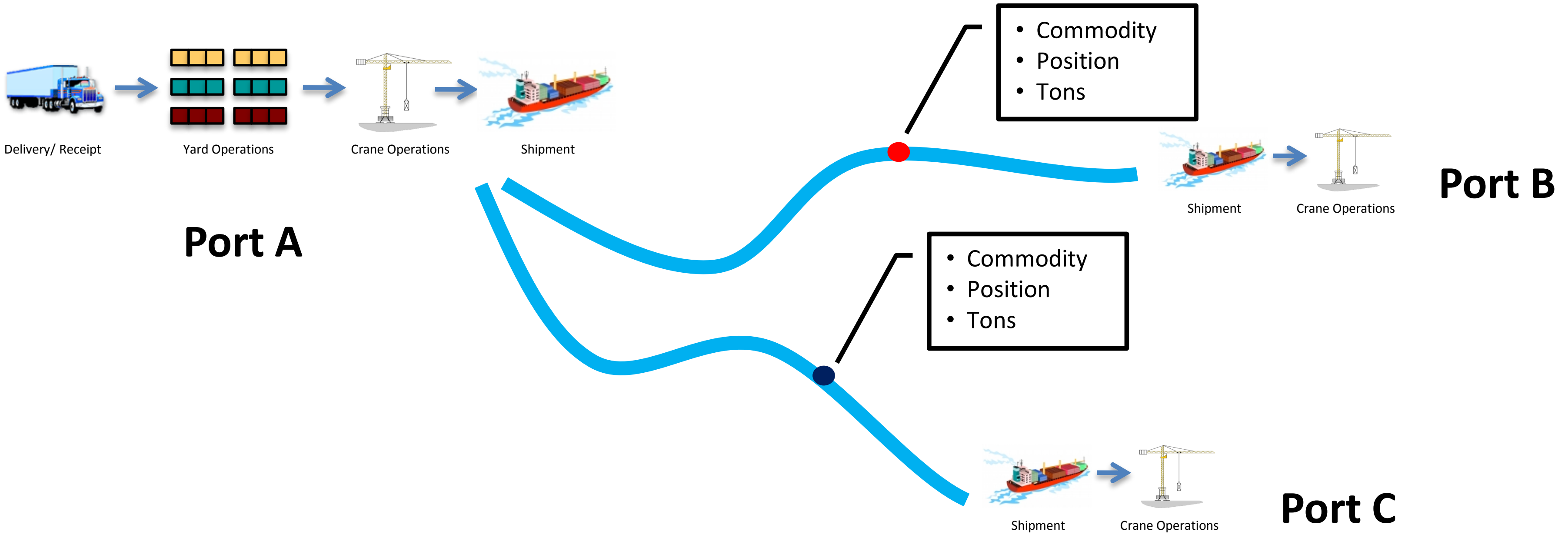
Waterway Accidents

The Conclusions

Modeling waterway operations

- Network topology model tracks the flow of freight between ports
  - Captures spatial and temporal nature of freight flow
  - Tracks commodity type, position, and tonnage at each period



Disruptions on waterway network

M = Total number of trips along path

m = Number of trips that result in accident and loss of freight

L = Total length of path

d = Length of segment along which incident occurs

p = Probability of loss of cargo due to accident

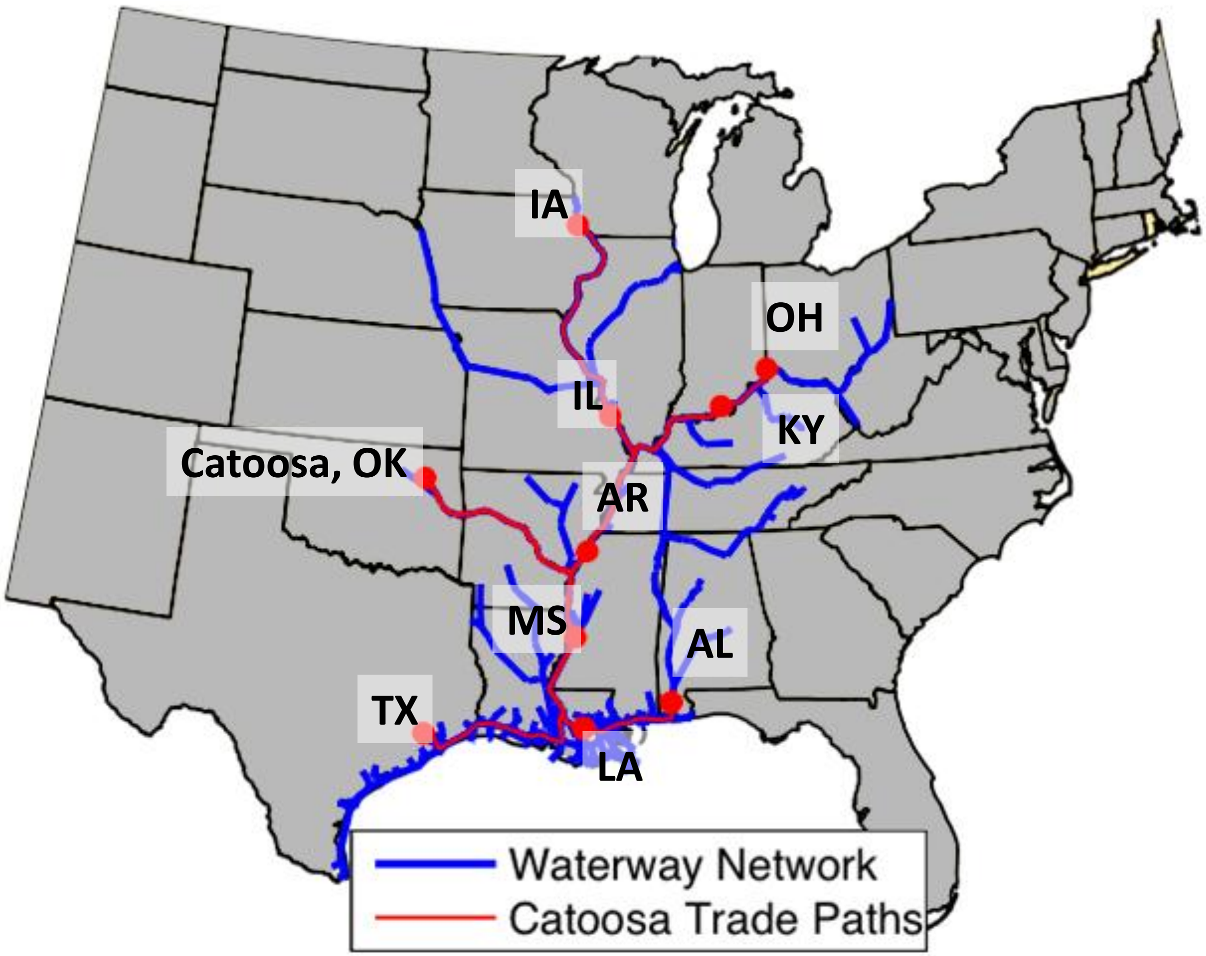
D = Amount of cargo on path

ΔD = Expected amount of loss of cargo

$$p = (d/L) \times (m/M)$$

$$\Delta D = p \times D$$

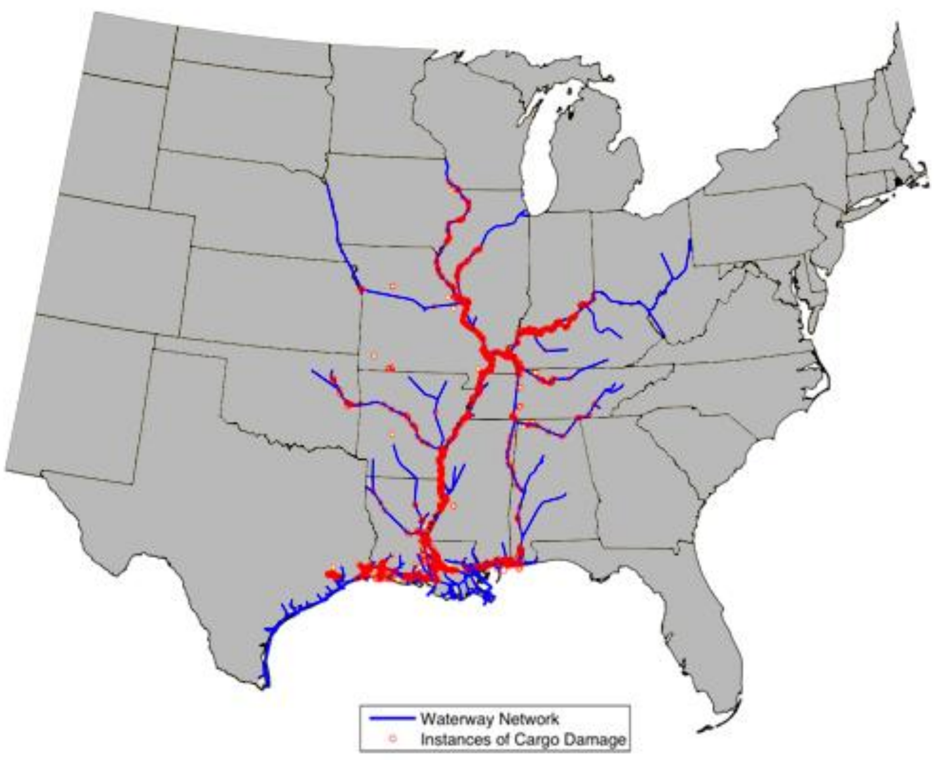
Illustration: Waterway network



Data Sources:
US Army Corps of Engineers, National Database Center

Illustration: Waterway accidents

- If it is assumed
  - Accidents are spread uniformly over topology
  - One accident accounts for one trip



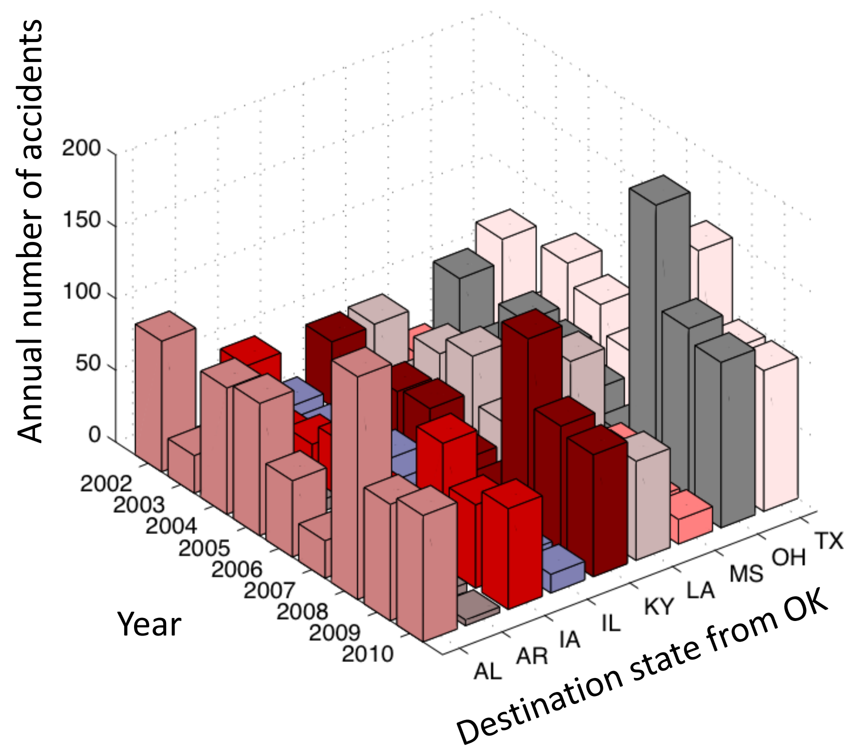
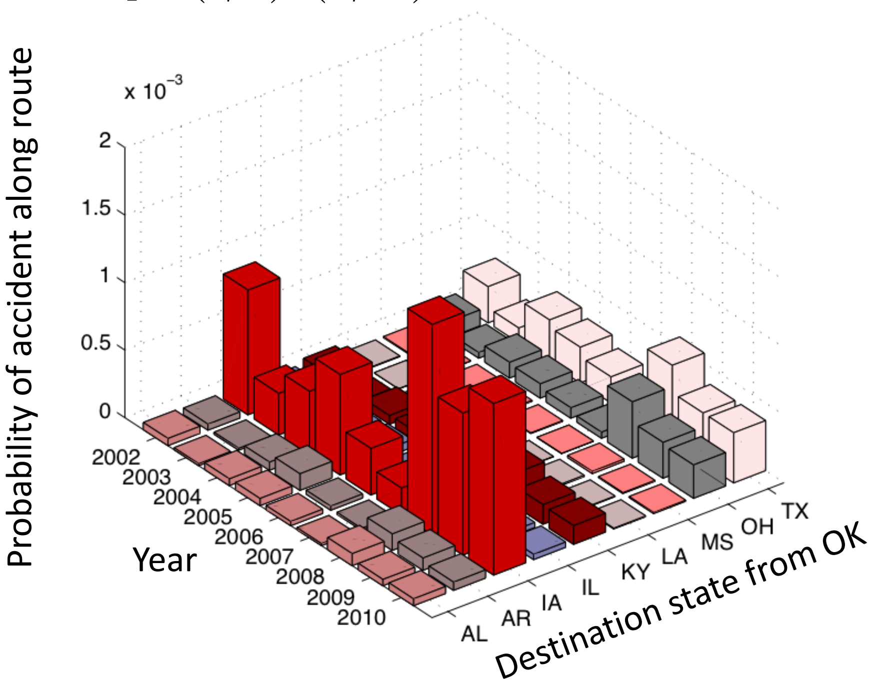
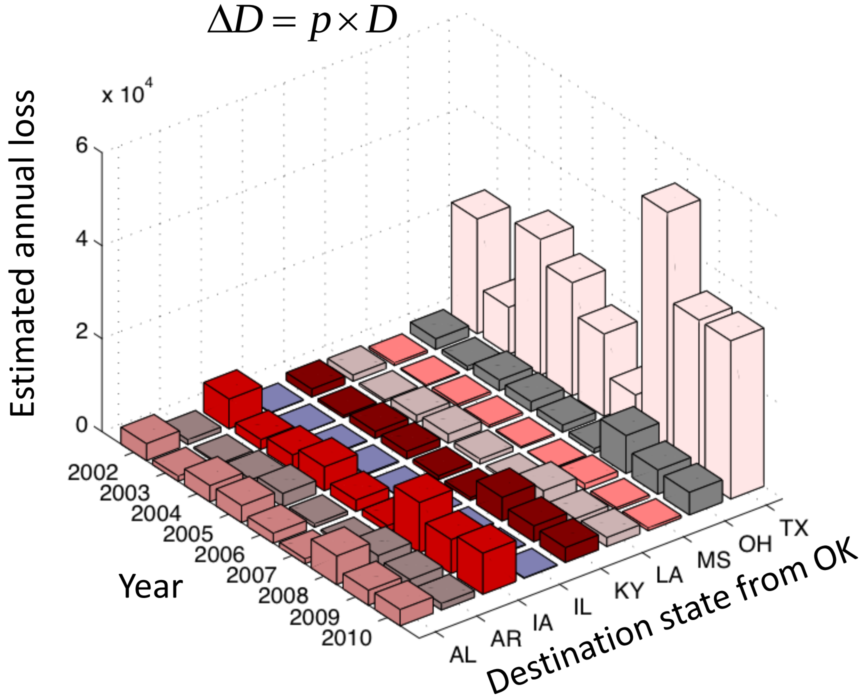


Illustration: Estimating accident losses

$p = (d/L) \times (m/M)$



$\Delta D = p \times D$



- OK-IA route has higher likelihood to result in accident due to length and fewer number of trips
- OK-TX route subject to greater losses due to higher value of cargo: liquid bulk like petroleum

Illustration: Risk management

- We can integrate with the interdependency model
  - What navigable paths lead to the largest multi-regional economic losses?

- The future: integrate with interdependency model, robust framework

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Concluding remarks

- Network analysis
  - Network topology to track the flow of freight between ports
  - Model captures spatial and temporal nature of freight flow
  - Model tracks commodity type, position, and tonnage at each period
- Interdependent disruptions
  - Direct port losses of $88 million result in $184.7 million output losses across states
  - Oklahoma has more direct loss because the port is mainly importing
  - Texas has almost no direct impact but large indirect impact

Concluding remarks

- Waterway accident risk
  - OK-IA route has higher likelihood to result in accident due to length and fewer number of trips
  - OK-TX route subject to greater losses due to higher value of cargo most of which is liquid bulk like petroleum

Appreciation

- The U.S. Federal Highway Administration under awards SAFTEA-LU 1934 and SAFTEA-LU 1702
- The National Science Foundation, Division of Civil, Mechanical, and Manufacturing Innovation, under award 0927299

- Thanks to grad students Cameron MacKenzie (current) and Zach Walchuk (former)

End of Presentation

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