OPTIMIZATION MODEL AND RISK ANALYSIS FOR GLOBAL SUPPLY CHAIN IN CONTAINER SHIPMENTS: IMPORTS TO THE UNITED STATES

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Outline

- Introduction and Motivation
- Model Outline
- Data and Assumptions
- Results and Discussion
- Summary
Introduction and Motivation

In recent years, 67-70% of the container trade is for imports, and 75-80% in the major gateways, and peak volume in 2006 are:

- West Coast: 10 million TEUs (Twenty-foot Equivalent Units).
- East Coast ports: 7 million TEUs.
- Gulf Coast: 0.7 million TEUs.

Source: U.S. Maritime Administration 2008
Introduction and Motivation

- The top five U.S. containerized cargo trading partners in 2007 were all from Northeast Asia.
- The trade between Europe and United States is small and has been growing slow.

Introduction and Motivation

- The top 10 U.S. container ports accounted for 90% percent of U.S.
Motivation

- Results in pressure on the transportation network and escalates congestion.
- One of the most critical transportation issues facing USA in this first decade of the new century is congestion (Transportation Research Record 2006).
- Impacts of volatility on supply chain and transportation, e.g. 7.6% lower in 2008 than 2007 (Lloyd's List, 2008).
Previous study

- Studies on container shipments have been an active area especially in recent couple of decades.
- Few studies quantify and incorporate congestion and stochastic optimization on container activities.
- While developments of Prince Rupert and the Panama Canal have been discussed in the popular media, no studies have analyzed the details and quantify inter-port route competitiveness.
Objective

- Analyze containerized imports flows from NE Asia and Europe to the United States.
- Develop an optimization model that integrates international and North America inland transport networks.
- Provide quantitative insights on the behavior of container flows under environment of congestion and uncertainty.
- Quantify prospective impacts of the new container ports and expanded routes on container flows and port competition.
Model outline --- U.S. container markets

Account for 98% total import volume in year 2006.

Business Economic Areas for containerized imports consumption by origin from Europe.
Water Gateways

- There are 28 container ports, eight seaports in Pacific Coast, three in Gulf, and 17 in Atlantic Coast, including five Canadian container ports.
- U.S. ports account for 97% of total import TEU

(U.S. Maritime Administration 2008)
International trade lane

- Transpacific–West Coast North America.
- Transpacific-Panama Canal-Gulf/East Coast

- Transatlantic trade lane
Rail networks for container imports

- ArcGIS Network Analyst to generate route of primary railways
- U.S. railways: BNSF, UP, CSX, and NS
- Canadian railways: CN and CP
Methodology:

- Determine the optimal networks flows, based on criteria of minimized total costs.
- Choose the ship route(string) and size, import port, and rail route to the final market.
- Account for congestion and uncertainty.
Subject to constraints below

- Container ship
- Port water depth
- Panama Canal
- North American seaports and at border crossing
- Rail corridors
- Container demand
- Shipping time
General linear programming vs. Network flows formulation

- Network linear programs are efficient and easy to solve.
- The formulation is specified in terms *node* and *arc*, which take the place of the *subject to* and *variable* declarations.
- The joint capacity constraints disrupt pure network structure.
- The problem is presented as a linear programming formulation in this study.
Data and parameters assumption

- Markets size: *Business Economic Areas (BEAs)*
- Demand estimation: *The Journal of Commerce, U.S. Maritime Administration, and the Surface Transportation Board Carload Waybill Sample*
- Ocean shipping cost: *Analytical model (ACE)*
- Rail shipping cost: *Waybill/econometrics model*
- Port configurations: *Ports and terminals guide; ports website*
- Base GIS map: *National Transportation Atlas Databases NTAD*
Vessel cost and congestion functions at seaports

Daily vessel cost = \( f(\text{ship size, speed, charter rate, and daily bunkerage cost (at sea and in port)}) \)

- vessel at sea
- vessel in port, and
- congestion cost at queue, general distributed G/G/m queuing system
Railway shipping rate

Railway shipping rate model structure

\[ R_{ijy} = f(Distance_{ijy}, O_i, T_j, Year, Raillines, other factors) \]

The annual data set is from years 1996 to 2006.
The double log model specifies log (rate) and log (distance).
\[ R^2 \quad 0.804 \]
Adjusted \( R^2 \quad 0.797 \)
Number of Observations 1347
Port and railroads throughput capacity

Port
- general distributed $G/G/m$ queuing system
- import throughput equals total capacity less non import volume

Railroads
- uses estimates from Cambridge Systematics, Inc. (2007) for railway capacity as an important input.
Constraint Assumptions

- Ten container vessel type (Handy to Superpost Panamax)
- 4,400 TEUs ship size for Panama Canal (including Panama fee)
- Current observed flows over inland railroad corridors
- Queue theory for port throughput capacity
- Relaxing constraint for vessel number via Panama Canal
Stochastic variables

- Demand for containerized imports
- Vessel costs
- Port and railroad throughput
Stochastic Demand

- Time series to forecast demand volume for future
- The error term is a measure of risk and prediction interval provides stochastic range for demand.
Stochastic Demand

Random walk series

in the absence of impulse impact or structure change

in presence of impulse impact or structure change
Stochastic variables of vessel cost

Daily vessel cost = f (ship size, speed, charter rate, and daily HOV and MDO cost (at sea and in port))
Uncertainty of throughput at port and over railroads

Railway capacity for containerized imports within the range of ±10 per cent around volume from a uniform distribution.
Strategy for optimization with nonlinear

Piecewise-linear function for congestion cost at container port
Strategy for optimization with stochastic parameters (variables)

it may be impossible to meet certain realization of the uncertain parameters, two approaches applied to deal with potential infeasibility

- elastic or unanticipated variables, or
- “soft” constraints in place of ‘hard” constraints
- additional penalty cost terms in objective function
- penalty costs are not set infinite.
Model implementation and calibration (2006)

![Graph showing import TEU (1000) for U.S. Ports, comparing actual import volume TEU and computational results TEU.]

- **Actual import volume TEU**
- **Computational results TEU**

**U.S. Ports**

- **West Coast**
- **East Coast**
- **Gulf Coast**

![Map of U.S. Ports with TEU data visualization for different coasts.]

Legend:
- U.S. ports
- Major ports
- Major cities

28
At ports of LA/LB, Seattle/Tacoma, and Oakland, 50%, 70%, and 30%, outbound moved by rail. Houston, 40% moved out by rail. About 90% consumed locally at New York.

The Port of Long Beach (2009) reported nearly half of all imported containers are transported directly to non-local destinations by train.
Estimate results with account congestion (2006)

<table>
<thead>
<tr>
<th>Ports</th>
<th>Traffic changes</th>
<th>Expected waiting time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA/LB</td>
<td>- 3%</td>
<td>2.5</td>
</tr>
<tr>
<td>Houston</td>
<td>+ 45%</td>
<td>4.0</td>
</tr>
<tr>
<td>New York</td>
<td>0</td>
<td>2.3</td>
</tr>
<tr>
<td>Vancouver</td>
<td>+ 21%</td>
<td>0</td>
</tr>
</tbody>
</table>
Potential Strains over Railroads (2006)

- identified using dual value theory.
- dual value or shadow price is the amount the optimal objective value is improved
- negative dual value also implies potential strains or congestion (highlight with light green color).
Impacts of Prince Rupert and Panama Canal expansion (2007)

- Demands at U.S. markets for container imports are based on projected values for 2007.
- Prince Rupert, the expansion of Panama Canal (12000TEU vessel and Canal fee), and the Bayport complex of Houston become operational simultaneously.

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<tr>
<td>LA/LB</td>
<td>- 3%</td>
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<tr>
<td>Houston</td>
<td>+ 22%</td>
</tr>
<tr>
<td>Prince Rupert</td>
<td>117,705</td>
</tr>
</tbody>
</table>
Impacts of congestion at U.S. West Coast (2007)

- controls the likelihood that average waiting time will exceed some threshold value at selected U.S. ports.
- “soft” constraint was replaced by “hard” constraint
- a Pareto optimal solution in a multi-attribute goal situation under deterministic environment
Impacts of shipping time (2007)

- Introduce shipping time constraint in the model
- Assume portion of demand to Houston less than 25 days
Impacts of shipping time (2007)

- Shipments to Memphis via Prince Rupert and Houston are 15 and 26 days respectively.

- Prince Rupert illustrated this by placing a string on the top of a globe, with one end of the string on China and the other end on Memphis. In the middle was Prince Rupert (Port of Prince Rupert, 2009).
Impacts of stochastic parameters (2007)

Two scenarios
- uniform distribution for demand only
- normal distribution for demand, normal distribution on HOV and MDO (correlation), and charter rate, and uniform distribution for port and railroads throughput capacity
- assume independent amongst stochastic variables.
- 5,000 iteration.
Container traffic at ports

- Stochastic demand (uniform)

- Stochastic demand (normal), vessel cost, and port/railroad capacity
Impacts of stochastic parameters on railway corridors

- The chance of corridor that would be operating at potential congestion situation.
Estimates network flows (most likely value of distribution)

U.S. Container Ports

U.S. Inland Railway Corridors

- Actual TEUs
- Simulated TEUs
Impacts of congestion at U.S. West Coast (2007)

- A Pareto optimal solution in a multi-attribute goal situation under stochastic environment.
Impacts of congestion at U.S. West Coast (2007)
- a Pareto optimal solution in a multi-attribute goal situation under stochastic environment

Throughput without waiting time controls at port of LA/LB

Throughput with waiting time controls at port of LA/LB
Container imports to U.S. Coasts

Estimates container traffic in year 2008 is based on the scenario in response to economic recession, i.e. assuming 10% decrease in demand for containerized import from Northeast Asia
Container traffic are highly concentrated and pose pressure on U.S. major logistics channels.
There are potential congestion at U.S. major gateways and associate corridors.
Increased volatility in the underlying economy creates risks for supply chains.
Develop a model framework that optimizes networks flows and quantifies the traffic pattern by accounting for congestion and uncertainty.
Results show inter-ports competition is intense.
Though shipments have recently declined, as the economic recovery, constraints will likely re-emerge and shippers will likely be less tolerant of logistical capacity constraints than in the past.

- Mexican container ports
- Congestion at Panama Canal
More research interesting

- Congestion at Panama Canal
- Northwest passage
- Suez Canal
- Export
Thanks and Questions