SAND2009-5643C

Freight Flow Data, U.S. Import/Export Container Flow Modeling and Disruption Analysis

Dean A. Jones, Julie L. Farkas, Orr Y. Bernstein, Chad E. Davis, Adam L. Turk
Sandia National Laboratories
Albuquerque, NM

Mark A. Turnquist, Linda K. Nozick, Brian S. Levine, Carmen G. Rawls
Cornell University
Ithaca, NY

Scott D. Ostrowski
U.S. Coast Guard Academy
New London, CT

William J. Sawaya
Texas A&M University
College Station, TX

Abstract

We describe a global network model of container flows for U.S. imports and exports. The model includes 46 foreign countries, 14 major North American port areas and 84 U.S. analysis zones. Between ports and domestic zones, the model includes both rail and truck connections, reflecting the modal choice made by shippers for the domestic part of international container shipments. The modeling effort has included careful use of available (but not always consistent) data on container movements, estimation of origin-destination (O-D) matrices for international container flows entering or leaving the U.S., and development of a network model to represent container movements both internationally and domestically. Our focus in this paper is on the use of available data to estimate important model inputs and to calibrate the model parameters in order to make it usable for policy and disruption scenario analyses.

1. Introduction and Model Summary

International containerized freight movement is a vital part of the supply chain for many companies and a critical element of moving consumer goods to points of retail sale within the U.S. Containerized imports also present a clear security concern. The purpose of the effort described here is to create a model (for use by the U.S. Department of Homeland Security) to represent container flows and the potential changes in those flows under a variety of conditions (port disruptions, extensive security-related delays, etc.).

The global network model, denoted SIERRA (System for Import/Export Routing and Recovery Analysis), represents the major supply-chain links serving manufacturers and consumers in the U.S., as well as export flow patterns for U.S. shippers serving worldwide markets. A basic premise of the model is that path choices in this network (including which port of entry is used and whether rail or truck is used for the domestic portion of the movement) are based on total logistics costs, including both freight transport costs and the costs of in-transit inventory for the goods being moved. Various parts of this network, particularly the ports and land access to them within the U.S., are subject to capacity limits and congestion delays. Disruptions of various types can reduce the capacity (or cause complete unavailability) of some facilities (ports, rail connections, highways, etc.) and result in adjustment of the flow patterns and increased overall costs. Diversions of flows and changes in costs are the prime drivers of economic impacts associated with the disruption to the supply-chain. The model includes U.S. exports as well as imports, because port facilities must process both imports and exports simultaneously and because domestic disruptions (for example, of rail access to/from a particular port) would affect both imports and exports.

Foreign origins and destinations include 46 countries that account for approximately 96% of containers imported by the U.S. through seaports and approximately 93% of U.S. seaborne exports. The set of foreign origins and destinations does not include Canada and Mexico. While these two countries are among the U.S.'s largest trading partners, nearly all of the import/export movement is via overland border crossings, not through seaports. The U.S./Canadian and U.S./Mexican border crossings are not included in this analysis.

More than 90% of total containerized traffic entering or leaving the U.S. (measured in twenty-foot equivalent units [TEUs]) moves through 14 large ports. In addition, Vancouver and Prince Rupert in Canada and Lazaro Cardenas in Mexico are ports on the Pacific Coast that are entry points for containers that subsequently enter the U.S. via land crossings. The SIERRA model includes these three locations, and thus focuses on important "North American" ports that are used for U.S. imports and exports.

Inside the U.S., shipment origins and destinations are aggregated into 84 Transportation Analysis Zones (TAZs). Each TAZ represents a collection of counties and is represented by a major city. Domestic origins/destinations in Alaska and Hawaii are not represented in the SIERRA model.

For each O-D pair (foreign country to U.S. TAZ, or vice versa), the SIERRA model considers many different possible paths for a shipment. A path includes the choice of port as well as the choice of rail or truck for the U.S. domestic part of the movement. The overall model is a network equilibrium model, predicting flows between foreign countries and North American ports, the total volumes handled (import and export) by each port, the modal volumes (truck and rail) into and out of each port, and volumes between each port and each TAZ. The principal reflection of congestion in the model is in the ports and in the capacity limits for rail connections at the ports. The model finds paths through the network for shipments based on total logistics cost, including both transportation and inventory costs.

Calibration of important parameters for the port cost functions as well as "pseudo-costs" for truck-rail modal choice allows the model to accurately reflect reported port volumes and truck-rail splits for the base case (2007 total volumes). Then the model can be used as a laboratory assessing vulnerabilities and economic costs related to potential loss of capacity at specific ports or in connections from ports to the domestic freight network.

Development and implementation of SIERRA has included a careful examination of available data on container movements, estimation of origin-destination (O-D) matrices for international container flows entering or leaving the U.S., estimation of logistics cost functions that include both transportation rates and the inventory costs of time in transit, and calibration of the overall model to correctly reflect overall port volumes, rail/truck mode shares for the domestic movement of containers, etc. The methodological elements of the global network model, computing network flow patterns, etc., are discussed in detail in the complete project report. This summary paper focuses on the use of available data to estimate important model inputs and to calibrate the model parameters in order to make it usable for policy and disruption scenario analyses. A hypothetical example analysis illustrates of how the model can support assessments of the impacts of potential events.

2. Supporting Data, Origin-Destination Table Estimation and Model Calibration

A major aspect of the project is integration of available data on container movements from a variety of (not always consistent) sources. In this analysis, we have integrated data from seven major sources:

- U.S. Maritime Administration (MARAD) data on waterborne container imports and exports;
- PIERS Global Intelligence Solutions data for container imports to the U.S.;
- American Association of Port Authorities (AAPA) data on containers handled at ports;
- Association of American Railroads (AAR) data on intermodal car loadings;
- Surface Transportation Board (STB) Rail Waybill Sample data;
- Data on domestic container volumes published by the Intermodal Association of North America (IANA); and
- Data reported by individual port authorities and railroads through their websites, publications and direct contact.

The PIERS data are very useful for understanding the routes that containers imported to the U.S. follow from an origin country, through a foreign port, and into a U.S. port. The PIERS data records movements (in TEUs) from origins to U.S. ports, but do not include information on the U.S. destination. There is high consistency between the total recorded volumes of imports by U.S. port and the origin-specific data, but once the shipment has entered the U.S., there is no record of its final destination.

The rail waybill sample collected by the Surface Transportation Board (STB) is one source of data on the domestic leg of container movements, at least those moved by rail. However, these records do not distinguish between containers moving to/from ports for export/import and containers that are actual domestic movements originating or terminating in the same Bureau of Economic Analysis (BEA) area. Thus, the available data provide some important pieces of flow information, but are not sufficient to specify an O-D table directly.

An optimization model has been used to estimate O-D tables for both U.S. imports and U.S. exports of seaborne containers. This optimization and the resulting import and export estimates are described in more detail by Levine, *et al*. (2009a, 2009b). Because more than half of all containers exported through U.S. ports are empty, the export flow estimates also include flows of empty containers. The resulting import and export O-D tables are a vital input to the SIERRA model.

The SIERRA model contains parameters for a network-level calibration. This allows the model to be "tuned" to represent total port volumes and rail-truck mode split values accurately over the entire network. Calibration of the total port volumes uses a port "handling cost" parameter. Changing these values for individual ports makes those ports more or less attractive to shippers, and causes flow to adjust over the network. Through adjustments to the parameter values for all the North American ports, the model has been calibrated to reproduce observed port volumes for 2007, as shown in Figure 1.

Data on the rail access capacity at specific ports is quite limited. For a few ports (Oakland, for example) where rail access capacity is a limiting factor in port operations, there is some useful data. For many of the ports, however, some rough approximations are necessary. Only a few ports have very useful data on rail/truck splits for containers entering or leaving the port. The data that exist are often anecdotal, or based on counts of containers leaving the port property, and do not reflect operations where trucks may shuttle containers to nearby rail loading points. These containers appear to be leaving the port by truck, but are really being transported by rail to their inland destinations.

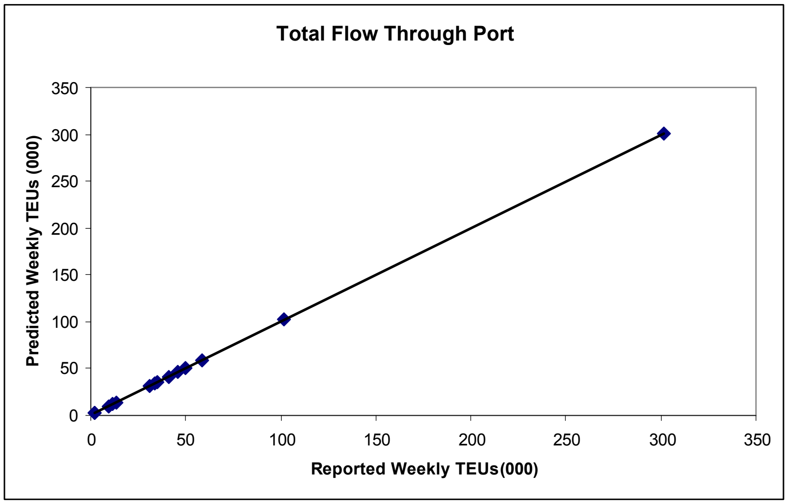

Figure 1. Comparison of predicted and actual container flow volumes through North American ports.

Some ports are clearly at the extremes of the mode split decision. For example, all containers entering the U.S. through Prince Rupert, BC or Lazaro Cardenas in Mexico are moved by rail. Truck is really not an option from those ports. At the other extreme, rail access to the South Florida port is very poor, and nearly everything entering there is moved to its destination by truck. However, for many of the ports, approximate estimates have been made, as the basis for calibration.

Figure 2 shows the comparison of the predicted mode split from the calibrated model to the reported values from the various ports. “Reported” in this case, should be interpreted somewhat loosely, because these are often estimates gleaned from news articles or other anecdotal sources, not necessarily from carefully reported data.

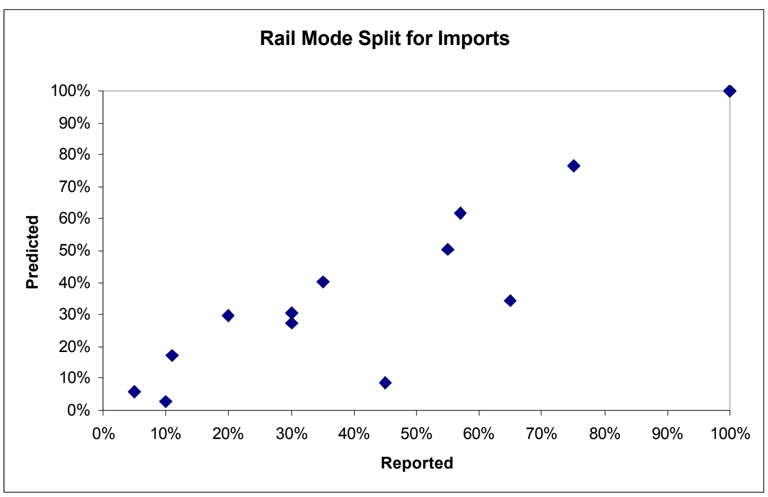

Figure 2. Comparison of predicted and reported domestic mode split for imports through North American ports.

3. An Illustrative Model Analysis: Rail Service Disruption at Los Angeles / Long Beach

In the base case, available rail capacity for handling imports through Los Angeles / Long Beach is very heavily utilized. As an example analysis, all rail traffic into and out of Los Angeles / Long Beach is interrupted. This affects approximately 73,000 TEUs/week of exports, as well as nearly 100,000 TEUs/week of imports.

This disruption has three major effects:

- Total volume through Los Angeles / Long Beach is reduced from approximately 298,400 TEUs/week to 184,300 TEUs/week, a 38% decrease.
- Volume at other Pacific Coast ports increases to accommodate some of that traffic, until their available rail capacity is fully utilized.
- The remaining traffic shifts to East Coast ports.

Because all volume moving through Los Angeles / Long Beach must be moved domestically by truck, the set of destinations for imports and origins for exports served through that port changes dramatically and total volume decreases. Flows into California and the western states (as far east as Texas) continue to be served through Los Angeles / Long Beach, but much of the flow into the Midwest and all of the flow into the Northeast is diverted to other ports.

At the other Pacific Coast ports, volume increases to accommodate the need to move import containers to the Midwest and Northeast. For example, the volume through Seattle /Tacoma increases from approximately 65,600 TEUs/week to 96,400 TEUs/week. The diversion to other Pacific Coast ports is limited by available rail capacity from the other U.S. ports and from Vancouver, BC, and by total port capacity at Prince Rupert, BC, and Lazaro Cardenas, Mexico. Prince Rupert and Lazaro Cardenas are both new port developments that, as yet, have relatively small capacity. Los Angeles / Long Beach is the largest port in the U.S., and the diversion of much of the container import traffic that would normally leave Los Angeles / Long Beach by rail would place severe strain on the other Pacific Coast ports. Oakland is also rail-constrained under normal circumstances, so very little of the normal Los Angeles / Long Beach rail traffic can be diverted there. In total, approximately 49,000 TEUs/week are diverted to other Pacific Coast ports, and the remainder must go to East Coast ports.

The principal changes on the East Coast are at Charleston, SC; Jacksonville, FL; and Savannah, GA. Total volume increases are approximately 14,100 TEUs/week (42%) at Charleston, 3500 TEUs/week (30%) at Jacksonville, and 31,300 TEUs/week (66%) at Savannah. The estimated port capacities at these ports are sufficient to accommodate the increased volume, but such large percentage changes would create disruptions in established patterns of operation in all three ports, as well as in the supply chain operations of many importers on the East Coast.

Such a significant diversion of container traffic from Pacific Coast ports to East Coast ports would also place strain on shipping through the Panama Canal, because the imports coming through Los Angeles / Long Beach are primarily from Asian origin points. The SIERRA model does not include explicit capacity constraints for the Panama Canal, but a major and prolonged disruption to Los Angeles / Long Beach would be likely to strain capacity there.

4. Conclusions

The purpose of the project summarized here is to create a modeling tool for looking at container flows and the potential changes in those flows under a variety of conditions (port disruptions, extensive security-related delays, and so forth). This effort has included a careful examination of available data on container movements, estimation of O-D matrices for international container flows entering or leaving the U.S., and development of a network model to represent container movements both internationally and domestically. This global network model, referred to as SIERRA (System for Import/Export Routing and Recovery Analysis), allows estimates of flow diversions between U.S. ports as a result of implementation of security initiatives or occurrence of port disruptions. This is a major advance in capability for use on behalf of the U.S. Department of Homeland Security.

The SIERRA model has been calibrated to match observed data from 2007 for total volumes through ports, and for domestic shares of container movement by rail and truck. This provides a strong basis for predictions of changes that might occur as a result of disruptions in the system.

The SIERRA model has been implemented in Java using a web interface. This means that a user of the model can access it and use it without having the model and its data installed on a local computer. The model uses a scenario management system designed to maintain data integrity of model inputs and outputs, as well as information pertaining to model run pedigree. This ensures that model runs are repeatable and well documented, which expedites follow-on analyses that often arise while studying the results of a current analysis.

References

Levine, B., Nozick, L., Jones, D. (2009a). “Estimating an Origin-Destination Table for U.S. Imports of Waterborne Containerized Freight,” *Transportation Research, Part E*, 45:4, 611-626.

Levine, B., Nozick, L., Jones, D. (2009b). "Estimating an Origin-Destination Table for U.S. Exports of Waterborne Containerized Freight," *Maritime Economics and Logistics*, 11:2, 137-156.