SAND2008-2022P

International Movement of Containerized Freight and Connections to the Domestic Freight Transportation System

12 January 2008

Homeland Security

National Infrastructure Simulation & Analysis Center

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List of Acronyms and Abbreviations

Acronym	Definition
AAPA	American Association of Port Authorities
AAR	Association of American Railroads
BEA	Bureau of Economic Analysis
GDP	gross domestic product
IANA	Intermodal Association of North America
ISO	International Standards Organization
LPH	lifts per hour
MARAD	U.S. Maritime Administration
NISAC	National Infrastructure Simulation and Analysis Center
NTAR	National Transportation Analysis Region
O-D	origin-destination
PMA	Pacific Maritime Association
R-NAS	Railroad Network Analysis System
STB	Surface Transportation Board
STCC	Standard Transportation Commodity Code
TAZ	Transportation Analysis Zone
TEU	twenty-foot equivalent unit

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1 Introduction

The National Infrastructure Simulation and Analysis Center (NISAC) developed a water transportation network model as part of the fiscal year (FY) 2007 capabilities development effort. This model, in connection with the Railroad Network Analysis System (R-NAS),[1] provides initial intermodal analysis capability. The water transportation model focuses on the portion of the freight transportation system that moves containerized cargo into the U.S. from foreign origins and from U.S. origins to foreign destinations. The focus of this effort has been on containers moved by sea between foreign ports and U.S. ports and on the intermodal connection of those movements to domestic movement of the containers within the U.S. NISAC has included both import flows and export flows in the analysis. However, there is substantial imbalance in containerized flows as a result of the U.S. trade deficit, particularly with Asian countries, so there is a much larger volume of loaded containers entering the U.S. via port facilities than there is leaving the U.S. Furthermore, from a security standpoint, the primary focus is on containers entering the U.S., so somewhat greater emphasis has been placed on the inbound direction. The analysis has not focused on land-based imports from (and exports to) Canada and Mexico.

About 12 million shipping containers entered the U.S. in 2006, or more than 1,300 containers every hour of every day, and the rate of import is growing at about 10 percent per year. Because containers vary in size, it is common to use the twenty-foot equivalent unit (TEU) as a standard measure of container volumes, and in 2006, the total imported volume through container ports was approximately 18.5 million TEUs.[2] Figure 1-1 shows the increasing volume of containerized imports over the last decade, in total as well as at the 4 largest U.S. container ports. In 2006, approximately 23 percent of containers entered through the port of Los Angeles, which has experienced a growth rate of about 14 percent per year over the last decade. The second largest container port is Long Beach, which handled about 20 percent of imported containers in 2006 and has been experiencing a growth rate of about 20 percent per year over the last decade.

Container traffic is highly concentrated at a small number of ports. More than 90 percent of total containerized imports (measured in TEUs) enter through 13 large ports. These ports are Los Angeles, Long Beach, Oakland, Seattle, and Tacoma on the Pacific coast; New York, Baltimore, Norfolk/Hampton Roads, Charleston, Savannah, Port Everglades, and Miami on the Atlantic coast; and Houston on the gulf coast.

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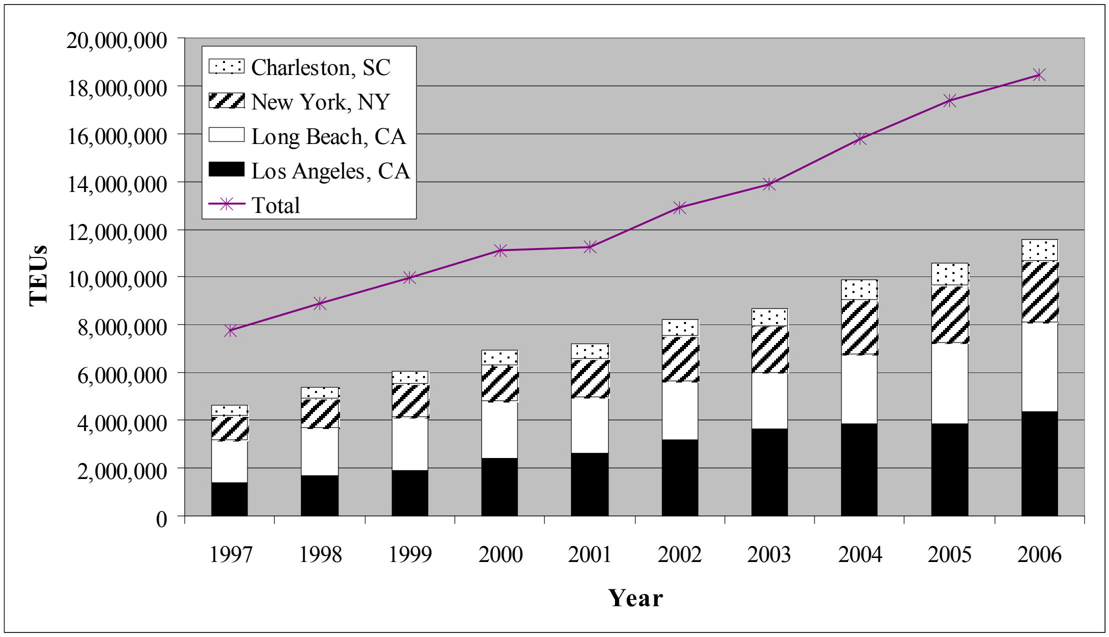
[1] Jones, Dean A. et al., 2003 "Impact Analysis of Potential Disruptions to Major Railroad Bridges in the US" (OUO), Sandia National Laboratories, NISAC, 8 August

[2] U.S. Maritime Administration, 2007a, "Data and Statistics," accessed on line at http://www.marad.dot.gov/MARAD_statistics/index.html, 24 August



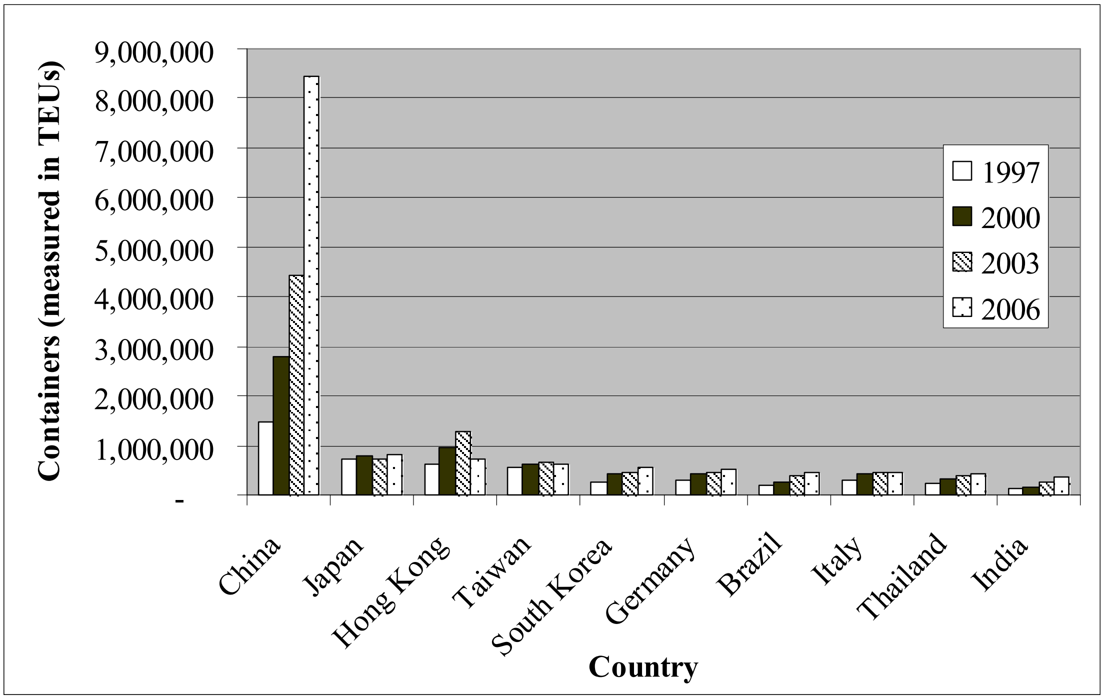
Note: TEU = twenty-foot equivalent unit

Figure 1-1: Containers (measured in twenty-foot equivalent units) imported between 1997 and 2006[3]

Figure 1-2 shows container imports to the U.S. in 1997, 2000, 2003, and 2006 from the 10 largest trading partners.[4] China is the largest, representing over 45 percent of containers imported in 2006 and experiencing more than a 20-percent annual growth rate over the last decade.

[3] U.S. Maritime Administration, 2007a, "Data and Statistics," accessed on line at http://www.marad.dot.gov/MARAD_statistics/index.html, 24 August

[4] Ibid.



Note: TEU = twenty-foot equivalent unit

Figure 1-2: Waterborne containerized imports from the 10 largest trading partners[5]

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 potential for terrorists to ship "dirty bombs," chemical or biological weapons, or even a nuclear weapon into the U.S. in a shipping container has been widely recognized.

The purpose of the project described in this report is to define a modeling approach 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 origin-destination (O-D) matrices for container flows, and development of a prototype network model to connect ports and container movements to the domestic rail network over which many of the containers move once inside the U.S. This leverages the R-NAS model, created to provide network analysis capability for the U.S. rail system.[6] R-NAS operates by flowing volumes of specific commodities over the rail network between identified geographic origins and destinations, recognizing capacity constraints and delays in the network as affecting the paths used by various commodities. Containerized movements represent one of those commodities.

By expanding the geographic origin-to-destination (zone-to-zone) structure of the R-NAS model to include waterborne imports and exports, the enhanced network model allows estimates of flow

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[5] U.S. Maritime Administration, 2007a, "Data and Statistics," accessed on line at http://www.marad.dot.gov/MARAD_statistics/index.html, 24 August

[6] Jones, Dean A. et al., 2003, "Impact Analysis of Potential Disruptions to Major Railroad Bridges in the US" (OUO), Sandia National Laboratories, NISAC, 8 August

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.

The overall structure of this report is as follows:

- Section 2 is a discussion on the analysis of available data on container movements. This forms the basis for estimating O-D tables for both imports and exports.
- Section 3 describes a model formulation to accomplish this O-D estimation
- Section 4 discusses the estimated O-D table for imports
- Section 5 discusses the comparable O-D table for exports
- Section 6 discusses the conversion of TEU flows from the estimated O-D tables into rail carload flows for use in the extended R-NAS model
- Section 7 discusses the extensions to the R-NAS model to accommodate the explicit import-export origins and destinations
- Section 8 describes specific efforts to estimate volume-delay functions for individual ports, as part of that model extension
- Section 9 presents conclusions from the overall study

2 Analysis of Container Flow Data

A major step in the project is analysis of available data on container movements. Data come from a variety of sources and are not always consistent. In this analysis, NISAC has attempted to integrate data from 8 different sources:

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

The most recent data available from these different sources are not necessarily from the same year. For example, the PIERS data are for 2004, the AAR data are for 2005, the STB Waybill Sample is from 2003, and most port authorities currently report data through 2006. In a rapidly growing market, variations of 2 to 3 years in which data were collected can result in significant inconsistencies.

Section 2.1 addresses container flows through the Pacific coast ports, and Section 2.2 addresses the Atlantic and gulf coast ports. NISAC has focused on 13 large container ports that (combined) handle more than 90 percent of container imports and exports. Section 2.3 extends the analysis to examine the foreign origins of shipments imported to the U.S., and Section 2.4 examines the data on movements of containers by rail within the U.S. This analysis sets the stage for estimation of an O-D matrix for container movements, discussed in Section 3.

2.1 Pacific Coast Ports

For 2005, Table 2-1 shows the Pacific coast ports reported TEUs handled (from individual port web sites, noted in the references).

Table 2-1: Twenty-foot equivalent units (TEUs) handled by port

Port	Import Loaded	Export Loaded	Total Empty	Total TEUs
Los Angeles[1]	3,881,326	1,171,230	2,432,068	7,484,624
Long Beach	3,346,054	1,221,419	2,142,345	6,709,818
Oakland[2]	836,258	846,579	591,153	2,273,990
Seattle[3]	846,311	484,997	414,490	1,636,261
Tacoma[4]	745,323	365,752	440,603	1,551,678

Notes: TEU = twenty-foot equivalent unit

[1] Los Angeles reports empties handled inbound (import) and outbound (export) separately: 74,727 inbound and 2,357,341 outbound. The other ports report only the total empties handled, so the values in the table show only totals.

[2] Oakland reports that 17.3 percent of total containerized movements are domestic (Hawaii and Guam) and military, but the TEUs reported are total, so the international movements are somewhat smaller than shown.

[3] Seattle reports total domestic TEUs (primarily Alaska and Hawaii) separately from international, but does not separate inbound from outbound for domestic movements. The values shown are the international movements only. Total domestic movements in 2005 were reported as 342,131 TEUs, so total port volume is 2,087,929, approximately 28 percent higher than the value shown.

[4] Tacoma reports domestic containers separately, like Seattle. The total domestic TEUs handled in 2005 were 514,769. Thus, the total port volume was 2,066,447, approximately 33 percent higher than the value shown.

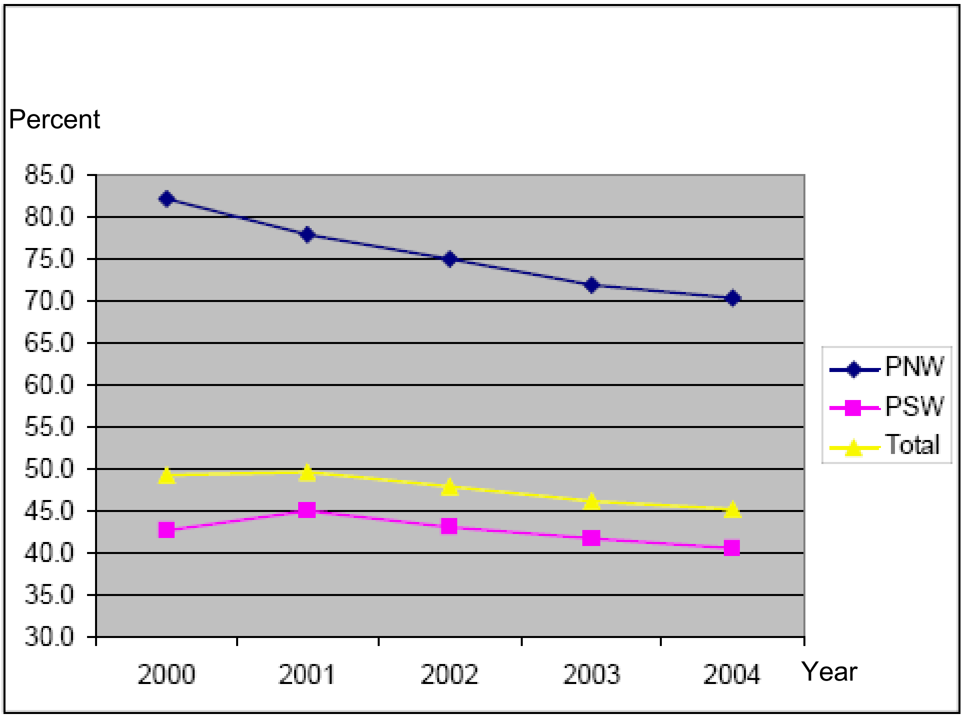
In Los Angeles (the only port that reports empty movements separately for inbound [import] and outbound [export]), the empties are overwhelmingly outbound (approximately 97 percent of the total empties handled). This is also likely to be true for Long Beach. Using the reported values of loaded inbound and empty inbound (assumed outbound) traffic at Los Angeles, the total TEUs to be moved east by land would be 3,956,053. If the inbound/outbound split of empties at Long Beach is the same as at Los Angeles, the inbound empties from Long Beach would be estimated as 65,825, and the total TEUs to be moved east by land would be 3,411,879.

The empty container situation may be a little different in Seattle, Tacoma, and Oakland, where there is more domestic container traffic to and from Alaska, Hawaii, and Guam. To estimate originating traffic that must be moved east by land from those ports (by either truck or rail), NISAC took the total TEUs handled and divided by 2. For Seattle and Tacoma, NISAC added in the separately reported domestic container movements to the international volumes to get total TEUs before doing the division. This produces the values in Table 2-2 for the 5 west coast ports.

Table 2-2: Eastbound twenty-foot equivalent units (TEUs) from the west coast ports

Port	Originating TEUs (for land movements)
Los Angeles	3,956,053
Long Beach	3,411,879
Oakland	1,136,995
Seattle	1,043,964
Tacoma	1,033,223

Robert Leachman, in his “Port and Modal Elasticity Study,” presents data on the proportion of containers moving out of the ports by rail and truck over several years, based on data assembled for a study done for the Southern California Area Governments.[7] Figure 2-1 reproduces these data, showing the rail percentage from groups of ports.



Notes: PNW = Washington/Oregon, PSW = California

Figure 2-1: Rail share of containers moving east from west coast ports[8]

The rail mode share directly out of the ports has been declining. Leachman attributes much of that to the growth of “trans-loading,” where large importers move international containers by truck a short distance inland to a warehouse facility where the contents are unloaded, sorted, and reloaded into domestic containers for movement (by either rail or truck) to actual destinations in the U.S.[9] Trans-loading allows importers to consolidate shipments from a single Asian vendor destined for several U.S. points into a single container for the Pacific voyage and then reconsolidate shipments from many different vendors destined for a single location in the U.S. into a single container for the domestic movement. In that sense, the supply network operates like the “hub-and-spoke” system so prevalent in the airlines. Furthermore, domestic containers (and truck trailers) are typically 48 or 53 feet long, rather than the typical 40-foot length of International Standards Organization (ISO) marine containers. On average, a 40-foot marine container has a capacity of about 2,500 cubic feet. A 53-foot domestic container has a capacity of about 3,900 cubic feet, and a 53-foot truck trailer has the capacity of about 4,100 cubic feet. Thus, by trans-loading into domestic containers or trailers, an importer can ship 35 to 40 percent fewer “boxes” for the overland movement.

[7] Leachman, R. C., 2005, “Final Report: Port and Modal Elasticity Study,” prepared for the Southern California Association of Governments, Los Angeles, California, September

[8] Ibid.

[9] Ibid.

From a data standpoint, the trans-loaded containers or trailers appear as "domestic" movements rather than as imports, and they do not appear to originate at the ports. However, these "domestic" movements are really shipments from the port, except that they are occurring in larger domestic boxes. This produces intermodal trainloads that look like on the trainload shown in Figure 2-2. The 53-foot domestic containers don't fit into the "well" of the double-stack railcars, but they will fit on top, so the train is loaded with 40-foot (or two 20-foot) ISO containers in the bottom positions and 53-foot domestic containers in many of the top positions.

Figure 2-2: Intermodal train with a mix of International Standards Organization (ISO) and domestic containers

The fact that port and international container flows are nearly always measured in TEUs and domestic rail movement data is in "lifts" (number of containers loaded or unloaded) and "carloads" (which as shown in Figure 2-2 as 2 or 3 containers of varying sizes), creates the need for a variety of conversion factors. The PMA (which is concerned with labor relations in the west coast ports) publishes data on actual containers handled ("box counts") by size and port for purposes of measuring labor productivity.[10] These data are not separated by import and export or by loaded and empty, but they do allow estimation of an average "actual containers per TEU" for each port.

International containers are nearly all 20-foot, 40-foot, or 45-foot lengths. The PMA data are grouped into categories (20–24, 35–40, 45, and 48–50) so that occasional "odd-length" containers (such as 24-foot or 35-foot) can be counted. The data for 2005 at the Port of Los Angeles indicate that 21 percent of containers handled were in the 20–24 foot category, 72 percent were in the 35–40 foot category, and 7 percent were in the 2 larger categories combined. By assuming that most of these containers are 20, 40 or 45 feet long, corresponding to 1, 2, and 2.25 TEUs per container, analysts can compute that at Los Angeles an average container handled is 1.8 TEUs. Thus, the

[10] PMA (Pacific Maritime Association), 2007," 2005 Annual Report: Statistical Information," accessed online at www.pmanet.org on 27 July

3,956,053 originating TEUs at Los Angeles can be converted into 2.2 million actual containers to be moved east, either by truck or rail.

Table 2-3 shows the parallel values for "TEU/container" and the resulting originating containers at all the west coast ports, based on the PMA data.

Table 2-3: Converting twenty-foot equivalent units (TEUs) into originating containers

Port	Average TEU/ Container	Originating Containers
Los Angeles	1.8	2,200,000
Long Beach	1.78	1,920,000
Oakland	1.74	650,000
Seattle	1.78	590,000
Tacoma	1.82	570,000

An estimate of the loading of containers per carload is needed to convert containers to carloads. The railroads report annual intermodal carloadings through the AAR (a total of 8.15 million for the industry in 2005).[11] This includes cars carrying trailers as well as containers. The AAR also reports that the industry loaded 2.6 million trailers in 2005. The flatcars that carry trailers generally have capacity for two trailers, and if we assume that, on average, the load was 1.5 trailers, the total trailer loadings would require 1.73 million carloads. Subtracting that from the 8.15 million reported, we get an estimate of 6.42 million carloads of containers.

The IANA reports annual statistics on total container and trailer moves and reported a total of 11.05 million container moves by rail in 2005.[12] If these moved on 6.42 million carloads, the average containers per carload would be 1.7. This seems to be a plausible number, and we will use that as the conversion factor for containers to carloads.

NISAC estimated O-D patterns for containers using TEUs. To connect those volume estimates to the R-NAS model for rail carloadings, NISAC used the "TEU/container" and "containers/carload" conversion factors before estimating the rail network movement patterns.

2.1.1 Terminations at West Coast Ports

At Seattle, Tacoma, and Oakland, NISAC estimated eastbound container flows by taking total TEUs handled and dividing by 2. This implies that westbound flows (terminations) will be the same numbers, although with a much higher proportion of empty containers. The conversion from TEUs to containers and from containers to railcars is based on averages that are not directional. NISAC used Robert Leachman's analysis of the share of eastbound containers that move by rail to estimate originating carloads.[13] If the westbound share is the same, the terminations for the rail system should be identical to the origins, with the caveat that some of those terminating containers are domestic containers that do not actually go into the port, but are delivered to the trans-loading warehouses just inland.

[11] AAR (Association of American Railroads), 2006, *Railroad Fact Book*, Washington, DC

[12] IANA (Intermodal Association of North America), 2007, "Intermodal Industry Statistics," accessed online at http://www.intermodal.org/statistics_files/stats5.shtml, 3 August

[13] Leachman, R. C., 2005, "Final Report: Port and Modal Elasticity Study," prepared for the Southern California Association of Governments, Los Angeles, California, September

Specific data are available on export loaded and empty TEUs at Los Angeles, as shown in Table 2-1. There is a modest overall imbalance; that is, 53 percent of TEUs are eastbound (imports) and 47 percent are westbound (exports). Long Beach doesn't report empties separately by direction, but their operations are likely to be similar to those in Los Angeles. For NISAC's purposes, these imbalances do not seem large enough to be very important; therefore, the assumption that the terminations at the ports are equal to the originations is likely acceptable.

2.2 Atlantic and Gulf Coast Ports

The Atlantic and gulf coast ports do not report container traffic in as much detail as the Pacific coast ports, but based on a combination of reports from some individual ports, from the AAPA and from the MARAD, NISAC has constructed the estimates of TEUs handled in 2005 (Table 2-4). The Port Authority of New York and New Jersey reports loaded TEUs imported and exported as well as total TEUs handled. From those 3 values, the empty TEUs handled can be obtained by subtraction. For the other ports listed in Table 2-4, MARAD reports loaded imports and exports (to the nearest thousand), and the AAPA reports total TEUs handled, so these sources have been combined and the empties determined by subtraction. None of these numbers should be considered more accurate than to the nearest thousand.

Table 2-4: Estimated twenty-foot equivalent units (TEUs) handled at Atlantic and gulf coast ports in 2005

Port	Import Loaded	Export Loaded	Total Empty	Total TEUs
New York[a]	2,408,121	976,882	1,400,315	4,785,318
Baltimore	244,000	137,000	221,475	602,475
Norfolk[b]	779,000	540,000	662,955	1,981,955
Charleston	894,000	615,000	477,586	1,986,586
Savannah	800,000	670,000	431,520	1,901,520
Port Everglades[c]	276,000	302,000	219,238	797,238
Miami	448,000	324,000	282,462	1,054,462
Houston	623,000	599,000	372,366	1,594,366

Notes:
[a]The port facilities are actually in New Jersey and are operated by the Port Authority of New York and New Jersey. In some data sets, this is referred to as New York/New Jersey.
[b]In some data sets, Norfolk is referred to as Hampton Roads.
[c]Port Everglades is located in Ft. Lauderdale, Florida.

None of the Atlantic and gulf ports report empty movements separately for inbound (import) and outbound (export). As on the Pacific coast, the empties are likely to be mostly outbound, given the generally higher volumes of imports than exports. In the absence of any better information, analysts can estimate originating traffic that must be moved inland from those ports (by either truck or rail) by taking total TEUs handled and dividing by 2. For New York, this value is approximately 2,392,700. This is slightly less than the reported inbound loaded TEUs, so analysts will use the larger number as total inbound. Table 2-5 shows the resulting values for all 8 ports (rounded to the nearest thousand TEUs).

Table 2-5: Estimated originating twenty-foot equivalent units (TEUs) from ports

Port	Originating TEUs (for land movements)
New York	2,408,000
Baltimore	301,000
Norfolk	991,000
Charleston	993,000
Savannah	951,000
Port Everglades	399,000
Miami	527,000
Houston	797,000

The AAPA reports the number of actual containers handled at each port as well as the TEUs handled, so analysts can compute an average "actual containers per TEU" for each port. Table 2-6 summarizes these values. The values for the Atlantic and gulf coast ports vary much more than the values on the Pacific coast, where the averages are all between 1.74 and 1.82. Table 2-6 also shows the resulting conversion of inbound TEUs from each port into an estimate of inbound containers.

Table 2-6: Average twenty-foot equivalent units (TEUs) per container and net originating containers for Atlantic and gulf ports

Port	Average TEU/ Container	Originating Containers
New York	1.71	1,408,000
Baltimore	1.54	195,000
Norfolk	1.73	573,000
Charleston	1.75	567,000
Savannah	1.78	534,000
Port Everglades	1.75	228,000
Miami	1.66	317,000
Houston	1.63	489,000

2.2.1 Terminations at Atlantic and Gulf Coast Ports

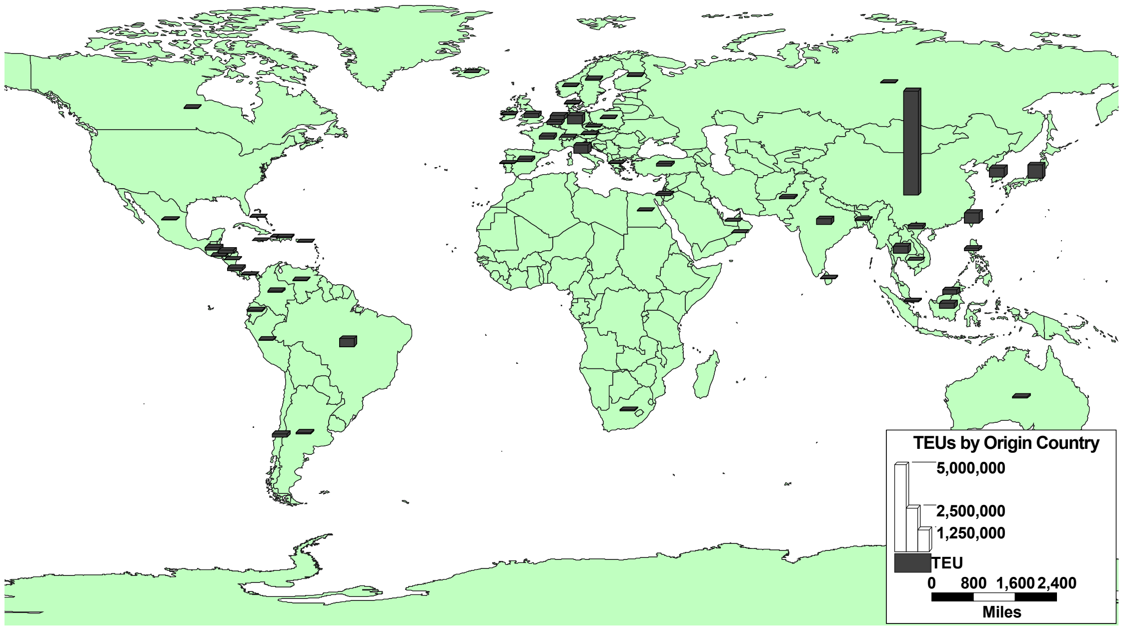
At each of the ports, terminating container flows are the difference between total TEUs handled and the estimate of originating TEUs. At all ports except New York, this is the same as the originations because originations were estimated as one-half of the total TEUs handled.

2.3 Foreign Origins of U.S. Imports

Figure 2-3 presents a map of the 67 countries that NISAC considers as container origins and a graphical representation of the number of containers they export to the U.S. These 67 countries represent about 98 percent of the containers that entered the U.S. in 2004, according to the PIERS data.[14] In Figure 2-3, the container volumes for China and Hong Kong have been grouped together. Separately, they represent approximately 39 percent and 7 percent of TEUs imported in 2004,

[14] Port Import Export Reporting Service (PIERS) accessed data under license from Global Intelligence Solutions (2005).

respectively. From this map, it is clear that the largest exporting countries to the U.S. can be grouped into 3 distinct regions: Asia, Europe, and Central and South America. Asia represents 72 percent of U.S. imports with almost 11 million TEUs; Europe represents 16.9 percent with approximately 2.5 million TEUs; and Central and South America represent 11.1 percent with 1.67 million TEUs.



Note: TEU = twenty-foot equivalent unit

Figure 2-3: Origin countries and volumes of U.S. container imports[15]

The PIERS data are very useful for understanding the routes that containers follow from an origin country, through a foreign port, and through a U.S. port. For example, Figure 2-4 illustrates 2 sample routes for a shipment from Germany to Houston, Texas. The first route goes through the port of Lisbon in Portugal and then the port of New York/New Jersey, while the second route goes through the port of Bremerhaven in Germany and then the port of New York/New Jersey. The data include a distinction between origin country $\boldsymbol{o}$ and "departure country" $\boldsymbol{o'}$, the country where the cargo is loaded onto a ship destined for the U.S. The data provide observations of flow from origin country to departure port (that is, links of type 1 in Figure 2-4), and from departure port to entry port in the U.S. (that is, links of type 2 in Figure 2-4).

[15] Ibid.

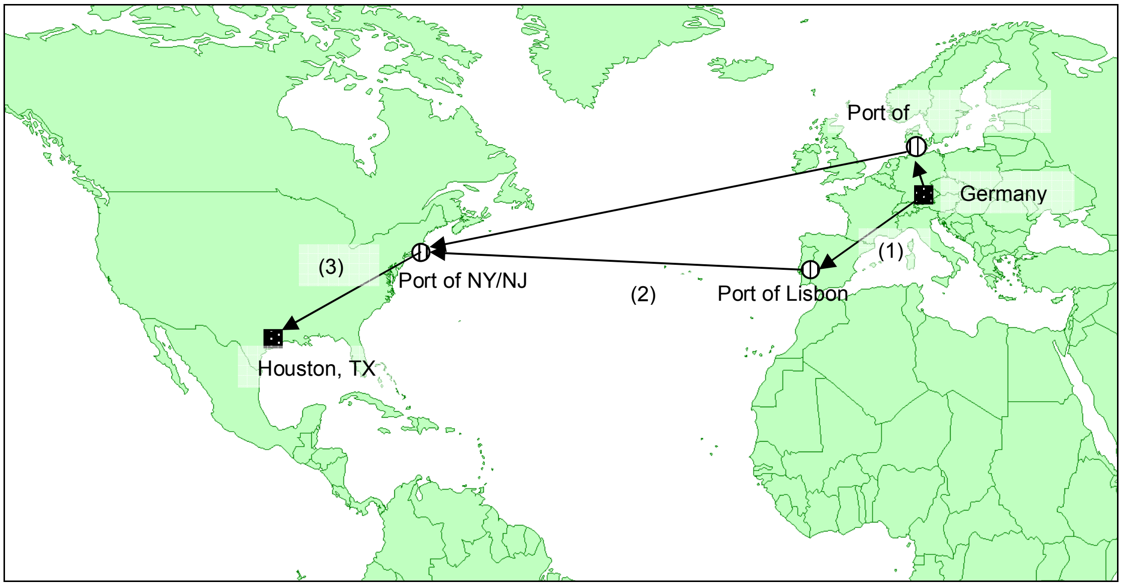


Figure 2-4: Import flows from foreign origin countries to U.S. destinations

The PIERS data do not include information on the U.S. domestic movement (link 3 in Figure 2-4). PIERS records movements (in TEUs) from origins to U.S. ports, and 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.

One source of data on the domestic leg of container movements is the Rail Waybill Sample collected by the STB. This is a sample of records of rail car movements between Bureau of Economic Analysis (BEA) areas within the U.S. that includes the commodity moved and other data. BEA areas (used for aggregating actual origins and destinations of shipments) are defined by the U.S. Department of Commerce. They are geographic regions, composed of a collection of counties, which represent centers of regional economic activity. There are 177 of these areas covering the "lower 48" states, as shown in Figure 2-5. BEA areas are also defined for Alaska and Hawaii, but for NISAC's current purposes, these are not of direct interest.

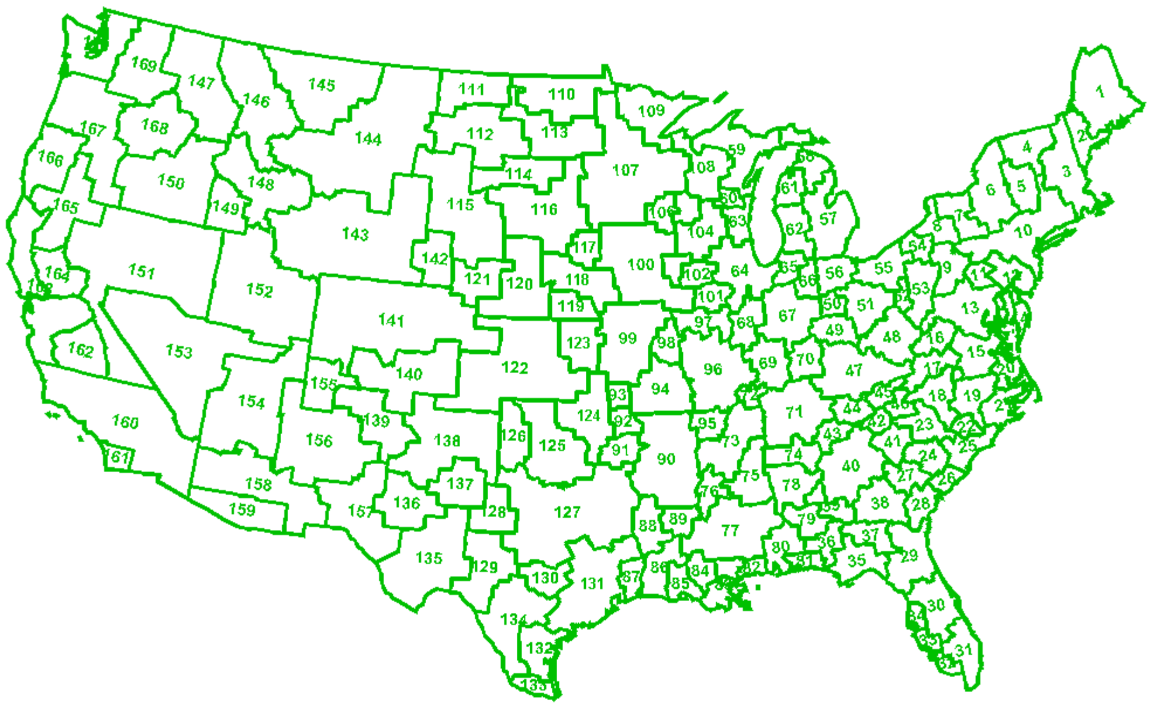


Figure 2-5: Bureau of Economic Analysis geographic regions

To make the domestic movement portion of container moves consistent with the existing structure of R-NAS, NISAC further aggregated the BEA areas into a set of 84 Transportation Analysis Zones (TAZs), as shown in Figure 2-6. Each TAZ is represented by a zone centroid; that is, a major city within that zone that serves as the modeled origin or destination for commodity movements for the entire zone. Volumes of different commodities to be moved in R-NAS are summarized in a series of 84 by 84 tables (referred to as O-D, tables), one for each commodity.

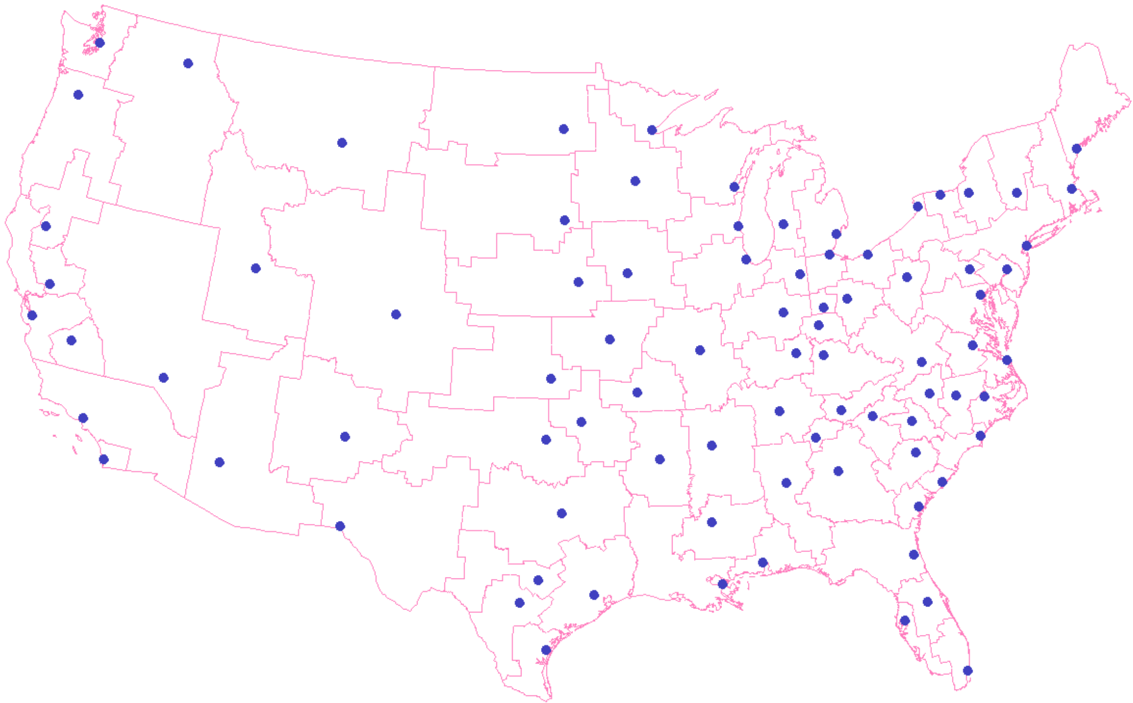


Figure 2-6: Transportation Analysis Zones (TAZs) and centroids

One commodity group in R-NAS corresponds to Standard Transportation Commodity Code (STCC) 46. This is the coding used in the rail industry for intermodal shipments (that is, shipments in containers). To extend R-NAS container movements to include foreign origins of import containers and ports of entry to the U.S., NISAC posed a problem of estimating a 67 by 84 O-D matrix (foreign origin country to U.S. destination TAZ) that is consistent with the PIERS data on foreign origins, observed U.S. port volumes and observed domestic rail movements (from the STB Waybill Sample). For domestic flow analysis, the actual origins of these shipments were "collapsed" to the port of entry and the set of 13 large container ports was separated from the 84 domestic TAZs, creating a 13 by 84 set of rail container volumes for imports. For exports, the reverse is done.

NISAC has little direct data on domestic truck movements of international container shipments. The O-D table estimation process is sensitive to the presence of truck movements, but the available O-D data are all on the rail side, and that forms the basis for model validation. NISAC then determined the truck movements by subtraction. Section 3 describes the model used for this O-D table estimation process.

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3 A Model for Estimation of Origin-Destination Tables

Estimation of the 67 by 84 O-D table for U.S. imports (and the comparable 84 by 67 table for U.S. exports) uses an optimization model based on the PIERS data and the STB Waybill data. This section describes this model. Section 4 discusses the estimation results for imports, and Section 5 discuses the comparable results for exports.

The model estimates the O-D table by determining route flows, denoted by f_r. For U.S. imports, this flow is the number of TEUs that travel on a route from a specific origin country to a specific destination TAZ in the U.S. A route r consists of an origin country o, foreign departure port p', U.S. port p, and destination TAZ d. NISAC considered a network in which the nodes are origin countries, foreign ports, U.S. ports and TAZs. The model uses (i,j) to denote a link in the network, where i is the origin node of the link and j is its destination node. Let

- r be an index over the set of all routes
- p be an index over the set of all U.S. ports and p' be an index over the set of all foreign ports
- $p'(r)$ be the set of all routes that use foreign port p'
- Rij be the set of all routes that include link (i,j)
- $R(p)$ be the set of all routes that include U.S. port p
- R_{od} be the set of all routes connecting origin o with destination d.

The route flows f_r can then be translated into an origin destination table by summing the route flows that have the same origin country and destination TAZ. The route flow variables are constrained to be non-negative.

The PIERS dataset specifies the number of TEUs that travel along each link from origin o to foreign port p', $t_{op'}$.

- The first term on the left hand side of Equation (1) is the sum of the route flows that use both origin o and foreign port p'
- The next 2 terms are variables that represent the amount by which the route flows are lower or greater than implied by the PIERS data:
  - $u^{+}_{op'}$ is constrained to be non-negative
  - $u^{-}_{op'}$ is constrained to be non-positive

Therefore the constraint given in Equation (1) attempts to identify route flows that are as consistent as possible with the number of TEUs shipped from each origin country to each foreign port of export.

$$\sum_{r \in R_{ij} | i=o, j=p'} f_r + u^{+}_{op'} + u^{-}_{op'} = t_{op'} \qquad \forall o, p'$$

Equation (1)

The PIERS dataset also records the total number of TEUs that are shipped from each foreign port p' to each U.S. port p, $l_{p'p}$.

- The first term on the left hand side of Equation (2) is the sum of the route flows that use both foreign port p' and domestic port p
- The next two terms are variables that represent the amount by which the route flows are lower or greater than implied by the PIERS data
  - $g^{+}_{pp'}$ is constrained to be non-negative
  - $g^{-}_{p'p}$ is constrained to be non-positive

Therefore, the constraint (Equation 2) attempts to identify route flows that are as consistent as possible with the number of TEUs shipped from each foreign port to each U.S. port.

$$\sum_{r \in R_{ij} | i=p', j=p} f_r + g^{+}_{pp'} + g^{-}_{p'p} = l_{p'p} \quad \forall p', p$$

Equation (2)

Given the link flow observations $l_{p'p}$ from the PIERS data, it is possible to compute the total number of TEUs that depart each foreign port p', bp'. The constraint given in Equation (3) attempts to identify values for the route flows, f_r, that match the PIERS data for the number of containers that pass through each foreign port. However, deviations are allowed.

- $e^{+}_{p'}$ is a variable that represents the amount by which the flows, f_r, are smaller than that expected based on the PIERS data
- $e^{-}_{p'}$ is a variable that represents the amount by which the flows, f_r, are larger than expected
- $e^{+}_{p'}$ is constrained to be non-negative
- $e^{-}_{p'}$ is constrained to be non-positive

$$\sum_{r \in R(p')} f_r + e^{+}_{p'} + e^{-}_{p'} = b_{p'} \quad \forall p'$$

Equation (3)

The total number of TEUs that enter each U.S. port, m_p, is reported by the ports themselves (as described in Section 2) and is also reported in the PIERS data. These two data sources are generally quite consistent. Constraint (Equation 4) encourages solutions that match the container volumes entering each U.S. port (as shown in Tables 2 and 5 in Section 2), but deviations are allowed.

- h^{+}_{p} is a variable represents the amount by which the flows, f_r, are smaller than expected
- h^{-}_{p} is a variable that represents the amount by which the flows, f_r, are larger than expected
- h^{+}_{p} is constrained to be non-negative
- h^{-}_{p} is constrained to be non-positive

$$\sum_{r \in R(p)} f_r + h^{+}_{p} + h^{-}_{p} = m_p \quad \forall p$$

Equation (4)

Constraint (Equation 5) incorporates observations of container flows from the 2003 STB Waybill data. Each observation in the waybill applies to a group of links *(i,j)* starting from a U.S. port and ending at a TAZ or group of TAZs. The total freight shipped across those links must be at least as large as that implied by the 2003 STB Waybill data, $n_{p\tilde{d}}$, where p is the port and $\tilde{d}$ is the set of TAZ destinations to which the observation pertains. The set $\tilde{d}$ may be composed of a single destination TAZ or a collection of destination TAZs. The observations in the STB Waybill are lower limits on the link flows for 2 reasons. First, the observations only include rail movements from the ports, and therefore exclude those shipped by truck. Second, NISAC analysts are using the 2003 STB Waybill rather than the 2004 dataset, and because containerized import traffic has been growing at about 10 percent per year, the 2004 values for the flows from the Waybill are generally expected to be greater than those in the 2003 STB Waybill.[16]

- The first term on the left side of Equation (5) is the sum of the route flows that use U.S. port p and terminate at a TAZ in the set $\tilde{d}$.
- The right side is the total number of TEU containers indicated by the 2003 STB Waybill data that enter a port p and terminate at one of the TAZs in the set $\tilde{d}$.
  - k^{+}_{pd} is a variable that represents the amount by which the flows, f_r, are smaller than suggested by the STB Waybill
  - k^{+}_{pd} is constrained to be non-negative

$$\sum_{r \in R_{ij} | i=p, j \in \tilde{d}} f_r + k^{+}_{p\tilde{d}} \geq n_{p\tilde{d}} \qquad \forall p, \tilde{d} \qquad \text{Equation (5)}$$

The STB Rail Waybill Sample contains several peculiarities, as described by Wolfe and Linde.[17] For NISAC's analysis, the most troublesome of these is the practice of "re-billing" shipments as they are transferred between western and eastern railroads, usually at either Chicago or Memphis. The implication of this rebilling is that for a shipment that originates in the western U.S., there are very few recorded destinations east of Chicago or Memphis. When the shipments arrive at one of those cities and are transferred to an eastern railroad, a new waybill is created, listing Chicago or Memphis as the origin. Thus, it is very difficult to connect actual origins and destinations for shipments that pass through either Chicago or Memphis.

For all TAZs, except the ones that include Chicago and Memphis, the observations in the STB Waybill pertain to a single destination TAZ. NISAC did not write a lower limit for the TAZ that includes Chicago or the TAZ that includes Memphis separately from each port. Rather, if the port is on the west coast, NISAC wrote a lower limit constraint that pertains to all TAZs to the east of the Mississippi River. If the port is on the east coast, NISAC wrote a lower limit that pertains to all TAZs west of the Mississippi River plus the TAZs that include Chicago and Memphis. The model then computed this lower limit by summing the flows given in the Waybill from that particular port

[16] IANA (Intermodal Association of North America), 2007, "Intermodal Industry Statistics," accessed online at http://www.intermodal.org/statistics_files/stats5.shtml, 3 August

[17] Wolfe, K. E., and W. P. Linde, 1997, "The Carload Waybill Statistics: Usefulness for Economic Analysis," *Journal of the Transportation Research Forum*, **36**:2, 26–41

to each of the TAZs to which the constraint pertains. This allows the model to redistribute the containers that the Waybill associates with Memphis and Chicago to other TAZs in the appropriate group from each port.

NISAC also created upper bounds on the flows from the ports to some of the TAZs using the 2003 STB Waybill data. It is reasonable to assume that containers entering the U.S. through west coast ports would primarily move by rail if the destination TAZ is in the east. Similarly, it is reasonable to assume that containers entering the U.S. through east coast ports move primarily by rail if the destination is a TAZ is in the west. NISAC used the Mississippi River as the geographic boundary of the east with the caveat that the TAZs that include Chicago and Memphis are assumed to be on the "rail only" side. For west coast ports, this is consistent with the geographic boundary of the Mississippi. For east coast ports, this assumes that the TAZs that include Chicago and Memphis are grouped with the TAZs to the west of the Mississippi River. Let

- δ_p be the set of all TAZs d that are considered to be serviced only by rail from U.S. port *p*
- x_p be the number of TEUs that originate at port *p* and terminate at TAZs that are exclusively served by rail, as given in the 2003 STB Waybill
- y_p^- be a variable that indicates the amount by which the flows are larger than that suggested by the upper limits derived from the waybill sample
- y_p^- be constrained to be non-positive

$$\sum_{r \in R_{ij} | i=p, j \in \delta_p} f_r + y_p^- \leq \gamma_p x_p \qquad \forall p$$

Equation (6)

Where:

γp is an inflation factor

The model can use the inflation factor to represent the amount above the values in the STB Waybill for which deviations are considered acceptable. The model can also use it to compensate for the growth that has occurred between the time of the PIERS international trade data and the STB Waybill data. NISAC used the growth that occurred between 2003 and 2004 at each of the ports as estimated by the U.S. Maritime Administration.[18] Thus, constraint (Equation 6) states that for each U.S. port *p*, the sum of the route flows to all destinations serviced only by rail must be, at most, the observation value in the STB waybill, increased by some inflation factor.

The PIERS data set provides relatively detailed information on flows from foreign origins to U.S. ports, but it does not indicate anything about the ultimate destination of shipments in the U.S. The rail waybill data set indicates (with some limitations, noted above) rail flows of containers from the BEA areas that include ports to other TAZs in the U.S., but it does not indicate anything about where those containers actually originated (outside the U.S.). It also does not distinguish between containers loaded at the ports and domestic containers loaded in the same BEA area. Thus, the data contain a fundamental disconnect between movements outside the U.S. and movements inside the U.S. To give the O-D estimation model additional guidance as to how to determine route flows all

[18] U.S. Maritime Administration, 2007a, "Data and Statistics," accessed on line at http://www.marad.dot.gov/MARAD_statistics/index.html, 24 August

the way from foreign origins to U.S. destinations, NISAC incorporated a gravity model into the mathematical formulation. Constraint (Equation 7) is a gravity model for the movement of seaborne containerized freight imports from origin country *o* to TAZ *d*.

$$B_{od} = K_o G_o G_d d_{od}^{-\lambda} \quad \forall o, d$$ Equation (7)

Where:

B_{od} is the number of TEUs shipped from origin country *o* to TAZ *d*

G_o = the gross domestic product (GDP) of origin country *o*[19]

G_d = the earnings of residents in TAZ *d*[20]

d_{od} = the distance *o* to *d*

K_o = a country-specific variable (commonly referred to as a K-factor in the freight demand modeling literature)

Equation (7) can be simplified because K_o and G_o can be grouped, because they are constant for a particular origin. If we then assume that d_{od} is the shortest route from *o* to *d* (measured in travel time), and that λ is a constant, then $d_{od}^{-\lambda}$ is a constant for each O-D pair. The simplification is given as Equation (8), where $\hat{K}_o$ and B_{od} are the two decision variables, both of which are constrained to be non-negative.

$$B_{od} = \hat{K}_o G_d d_{od}^{-\lambda} \quad \forall o, d$$ Equation (8)

This equation implies that the number of containers that flow from origin country *o* to destination TAZ *d* is proportional to both the earnings in the destination TAZ *d* and the distance from country *o* to TAZ *d*. These are reasonable assumptions for two reasons. First, much of what is transported in waterborne containers is retail goods and the consumption of these goods is reasonably assumed proportional to economic activity and wealth at the destination. Second, distance has a negative impact on the demand for transportation. It is also important to realize that the PIERS international trade data provides substantial information on the total number of TEUs imported from each country. Hence, there is substantial information on the sum of the B_{od} variables for a given *o*. The model integrates this information through Equation (1).

Ashtakala and Murthy use a similar gravity model for land-based freight transportation and find that the value of λ varies from 0.25 to 1.0 depending on the commodity.[21] Ashtakala and Murthy also observe that higher exponent values are associated with the transportation of lower value goods.[22]

[19] World Bank, 2007, "Data and Statistics," accessed on line at http://web.worldbank.org/ on 27 August

[20] U.S. Department of Commerce, Bureau of Economic Analysis (2004). Regional Economic Accounts, accessed on-line at http://www.bea.gov/bea/regional/reis/ on 8/27/07

[21] Ashtakala, B., and A. S. N. Murthy, 1988, "Optimized gravity models for commodity transportation," *Journal of Transportation Engineering*, 114, 393–408; Ashtakala, B., and A .S. N. Murthy, 1993, "Sequential models to determine intercity commodity transportation demand," *Transportation Research,* Part A, 27, 373–382

[22] Ashtakala, B., and A. S. N. Murthy, 1988, "Optimized gravity models for commodity transportation," *Journal of Transportation Engineering*, 114, 393–408

They refer to 2 other studies that draw the same conclusion.[23] Because this model focuses on international waterborne shipments and the associated domestic land movement, the appropriate value of the exponent λ is less clear. NISAC's strategy to address this issue was to select the λ value that appears to fit the data best; that is, the value that minimizes the discrepancies with the data in the PIERS international trade dataset, the STB Waybill, and the resultant gravity model.

Constraint (Equation 9) allows the model to select route flows that deviate from the gravity model given in Equation (8). This is done by attempting to match the route flows from a given country *o* to a TAZ *d* to the gravity model estimate for the sum of those route flows, B_{od}. Again, NISAC included error terms to allow for deviations.

- q^{+}_{od} is a variable that represents the amount by which the flows, f_r, are smaller than that expected based on the gravity model
- q^{-}_{od} is a variable that represents the amount by which the flows, f_r, are larger than expected
- q^{+}_{od} is constrained to be non-negative and q^{-}_{od} is constrained to be non-positive

$$\sum_{r \in R_{od}} f_r + q^{+}_{od} + q^{-}_{od} = B_{od} \quad \forall o,d \qquad \text{Equation (9)}$$

The goal of this formulation is to identify route flows for containerized international freight traffic that enters the U.S. through seaports, which are as consistent as possible with:

- Observations of flows from each foreign origin country to each foreign port of export
- Observations of flows from each foreign port to each U.S. port
- The total freight leaving each foreign seaport that is destined for the U.S.
- The total freight entering each U.S. port
- The number of containers shipped by rail from the largest U.S. seaports to each TAZ or group of TAZs
- The number of TEU containers from each port destined for the TAZs that are served by rail only
- A gravity model between origin country *o* and TAZ *d* based on GDP for each foreign country, earnings for each TAZ, and the distance between them

Equation (10) gives the objective function for the optimization. The first 7 terms in the objective penalize the various deviations from data estimates that have been described in constraint Equations (1) through (9). The final term in the objective minimizes the total distance represented by all of the route flows, where D_r is the distance of the r^{th} route. NISAC included this term to encourage the use of shorter routes, when possible, because this will produce a more reasonable solution. The model uses the rail distance to compute the land portion of the route distance, because if substantial travel is required on land, it is more likely to be done by rail than by truck.

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[23] Chisholm, M., and P. O'Sullivan, 1973, "Freight flows and spatial aspects of the British economy," Cambridge University Press, London; Black, W. R., 1971, "The utility of the gravity model and estimates of its parameters in commodity flow studies," Proceedings of the Association of American Geographers, 3, 28–32

$$\text{Min} \sum_{(p',p)} \alpha_0 \left(u^+_{op'} - u^-_{op'}\right) + \sum_{(p',p)} \alpha_1 \left(g^+_{p'p} - g^-_{p'p}\right) + \sum_{p'} \alpha_2 \left(e^+_{p'} - e^-_{p'}\right) + \sum_{p} \alpha_3 \left(h^+_p - h^-_p\right) + \alpha_4 \sum_{p\tilde{d}} k^+_{p\tilde{d}} - \alpha_5 \sum_{p} y^-_p + \sum_{(o,d)} \alpha_6 \left(q^+_{od} - q^-_{od}\right) + \beta \sum_r f_r D_r \quad \text{Equation (10)}$$

Where:

α_o, α_1, α_2, α_3, α_4, α_5 and α_6 = coefficients that reflect the relative importance of deviations from each set of constraints

β = a per TEU-mile penalty for travel distance

Because generally it is more important to match the total volumes at each port than it is to match the flows of containers between specific ports, the model penalized separately

- Deviations from expected total port container volumes at foreign ports and U.S. ports
- Deviations from the observations of flows from individual foreign countries to individual foreign ports
- Deviations from the observations of flows from individual foreign ports to individual U.S. ports

It is also likely that the observations of total volumes at ports are more reliable than observations on individual foreign port to U.S. port movements. By setting the coefficients α_2 and α_3 higher than α_0 and α_1, this can be achieved quite easily when there are inconsistencies with other data or the gravity model. Because the data that support the first 4 terms are derived from the PIERS international trade data and those data are internally consistent, the tradeoff in the objective is really between the first 4 terms; the 5th and 6th terms, which come from the 2003 STB Waybill; and the distance term. However, if violations are to occur with the PEIRS data, it is preferable that these violations are more heavily focused on the link observations rather than the port volume observations. The distance term has the lowest penalty because it is simply used to choose between alternative solutions that match the various data elements equally well.

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4 Estimation of an Origin-Destination Table for U.S. Imports

Merger of the data from PIERS and the STB waybill sample for actual O-D table estimation requires 3 major manipulations. PIERS records data in TEUs while the STB waybill records data in carloads; therefore, NISAC had to establish a conversion to make units of flow consistent. Second, the waybill data do not distinguish between containers originating at ports and domestic containers loaded in the same geographic areas, so NISAC had to find a way to estimate the number of imported containers that are loaded on the rail system for the domestic portion of their movement. Third, the PIERS data and port container statistics do not distinguish between import containers that leave the port by truck and those that leave by rail, and NISAC had not found any independent estimate of volumes leaving by truck. This complicates the resolution of the second issue, related to the waybill data. To resolve these issues, NISAC sought additional information and made a series of assumptions about how to extend partial information to the entire system.

In 2003, the U.S. imported approximately 6 million TEUs through the ports of Los Angeles and Long Beach. As described in Section 2, rail has about a 40-percent share of eastbound container traffic from the ports of Los Angeles and Long Beach. Leachman estimates that another 5 percent of containers from these 2 ports are trans-loaded near the port into 53-foot containers for rail shipment.[24] Therefore, analysts can infer that about 2.7 million imported TEUs move by rail from the ports of Los Angeles and Long Beach. Because the ports of Los Angeles and Long Beach are both in Los Angeles County, for the purposes of extracting flows of rail cars from the 2003 STB Waybill, NISAC considered these ports together. According to the 2003 STB Waybill, 1,886,000 rail carloads of STCC 46 originated in Los Angeles County. Assuming that there are about 1.7 containers per railcar (as described in Section 2) and there are about 1.79 TEUs per container handled at these 2 ports,[25] NISAC can infer that the total container volume that originates in Los Angeles County is about 5.7 million TEUs, of which about 2.7 million TEUs originate at the ports.

Table 3-1 gives estimates of the number of containers (measured in TEUs and rounded to the nearest thousand) moved by rail from 12 of the largest ports. Miami is not included because the 2003 STB Waybill reports no rail carloads of STCC 46 originating in Miami-Dade County. It is not clear why this is the case. Leachman also provides estimates for the rail share from the ports of Oakland, Seattle, and Tacoma.[26] NISAC has also incorporated these estimates into the estimates of the number of containers moved by rail from each of these ports in Table 4-1. For the remainder of the ports, NISAC has no data to indicate what the share of rail might be. However, the number of TEU container originations implied by the rail carload originations in the counties in which the ports are located is less than the number of containers handled at the ports, so it is reasonable to assume that all of the rail carloads originate at the ports themselves.

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[24] Leachman, R. C., 2005, “Final Report: Port and Modal Elasticity Study,” prepared for the Southern California Association of Governments, Los Angeles, California, September

[25] PMA (Pacific Maritime Association), 2007, “2005 Annual Report: Statistical Information,” accessed online at www.pmanet.org on 27 July

[26] Leachman, R. C., 2005, “Final Report: Port and Modal Elasticity Study,” prepared for the Southern California Association of Governments, Los Angeles, California, September

Table 4-1: Estimated container origins by port

Port	Counties	Containers (TEUs) Moved by Rail
Los Angeles/Long Beach	Los Angeles	2,700,000
Oakland	Alameda/Contra Costa/ San Joaquin	365,000
Seattle/Tacoma	King/Peirce	864,000
New York	Hudson, Union, Bergen, Essex	843,000
Baltimore	Baltimore	101,000
Norfolk	Norfolk, Portsmouth	296,000
Charleston	Charleston	160,000
Savannah	Savannah	140,000
Port Everglades	Broward	66,000
Houston	Harris	450,000

Note: TEU = twenty-foot equivalent unit

Using this information, analysts can estimate the spatial distribution of trips originating at each port. The model can apply the fraction of the total number of TEUs estimated to originate by rail in each county (or counties) associated with a given port to each observation in the STB waybill data originating in the county (or counties). This gives an estimate of how many TEUs travel between a port and each TAZ. Figure 3-1 gives these estimates for the ports of Los Angeles and Long Beach (combined) and the Port of New York. For example, this process implies that 370,000 TEUs are bound for the Dallas area from the ports of Los Angeles and Long Beach. It is useful to notice the large number of containers that the model estimates as bound for Chicago and, to a lesser extent, for Memphis. These are likely a result of the practice of "rebilling" on transcontinental rail movements, as discussed by Wolfe and Linde (1997).[27] To account for the practice of rebilling, NISAC assumed that for ports on the east coast, observations of TEUs into the TAZs that include Chicago and Memphis really reflect the flow of TEUs bound for those TAZs as well as TAZs to the west. Similarly, for ports on the west coast, NISAC assumed TEU flows observed for the TAZs that include Chicago and Memphis were bound for those TAZs as well the TAZs to the east.

[27] Wolfe, K. E., and W. P. Linde, 1997, "The Carload Waybill Statistics: Usefulness for Economic Analysis," *Journal of the Transportation Research Forum*, **36**:2, 26–41

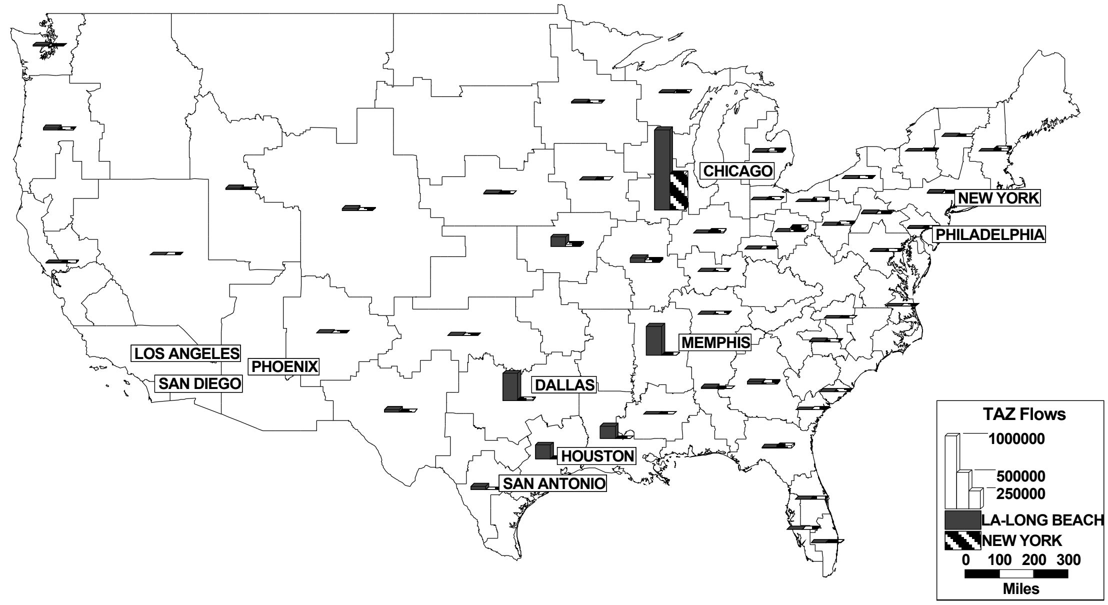


Figure 4-1: Twenty-foot equivalent unit (TEU) flows from the ports of Los Angeles/Long Beach and the Port of New York to each Transportation Analysis Zone (TAZ) based on the 2003 Surface Transportation Board (STB) waybill data

The lower bound constraints generated by Equation (5) and the upper bound constraints generated by Equation (6) for container movements from the ports of Los Angeles and Long Beach to TAZs east of the Mississippi River use the data shown in Table 4-2. The second column in Table 4-2 gives the number of TEUs estimated to move by rail on links from the ports of Los Angeles and Long Beach to each TAZ east of the Mississippi River, based on the 2003 STB waybill sample. The third column gives an upper limit for the TEU containers on these links, assuming that the ports of Los Angeles and Long Beach only serve these TAZs by rail. To get this estimate, NISAC used the growth rate at the ports of Los Angeles and Long Beach from 2003 to 2004, which was about 14 percent,[28] and the estimate based on the 2003 STB waybill data. Therefore, the model assumed γp for these 2 ports to be 1.14. Again, notice the large values for the TAZ that includes Chicago and the TAZ that includes Memphis.

[28] U.S. Maritime Administration, 2007a, "Data and Statistics," accessed on line at http://www.marad.dot.gov/MARAD_statistics/index.html, 24 August

Table 4-2: Waybill flows from the ports of Los Angeles/Long Beach to each Transportation Analysis Zone (TAZ)

Destination TAZ	TEU Containers	TEU Containers Scaled by Inflation Factor
Portland, ME	120	130
Boston-Worcester-Lawrence-Lowell-Brockton, MA-NH-RI-VT	2,700	3,080
Albany-Schenectady-Troy, NY	2,640	3,010
Syracuse, NY-PA	1,000	1,140
Buffalo-Niagara Falls, NY-PA	290	330
New York-No. New Jersey-Long Island, NYNJ-CT-PA-MA-VT	12,780	14,570
Pittsburgh, PA-WV	470	540
Harrisburg-Lebanon-Carlisle, PA	8,790	10,020
Philadelphia-Wilmington-Atlantic City, PANJ-DE-MD	2,930	3,340
Washington-Baltimore, DC-MD-VA-WV-PA	3,340	3,810
Norfolk-Virginia Beach-Newport News, VANC	1,170	1,340
Greensboro-Winston-Salem-High Point, NCVA	820	940
Charlotte-Gastonia-Rock Hill, NC-SC	8,790	10,020
Charleston-North Charleston, SC	1,290	1,470
Atlanta, GA-AL-NC	33,180	37,830
Savannah, GA-SC	290	330
Jacksonville, FL-GA	7,330	8,350
Orlando, FL	60	70
Miami-Fort Lauderdale, FL	2,110	2,410
Tampa-St. Petersburg-Clearwater, FL	410	470
Mobile, AL	60	70
Birmingham, AL	22,100	25,190
Louisville, KY-IN	180	200
Cleveland-Akron, OH-PA	60	70
Columbus, OH	470	540
Cincinnati-Hamilton, OH-KY-IN	230	270
Detroit-Ann Arbor-Flint, MI	8,620	9,820
Memphis, TN-AR-MS-KY	396,980	452,560
Chicago-Gary-Kenosha, IL-IN-WI	1,093,340	1,246,410
TOTAL	1,612,550	1,838,310

Note: TEU = twenty-foot equivalent unit

There are two classes of lower bound constraints generated by Equation (5). The first type has only one TAZ in the set $\tilde{d}$ and the other includes all of the TAZs east of the Mississippi River (as listed in Table 4-2) in the set $\tilde{d}$. Each link, excluding the TAZ that includes Chicago and the TAZ that includes Memphis, has its own lower bound constraint. For example, for the Jacksonville TAZ, the lower bound constraint says that the number of TEUs from the ports of Los Angeles and Long Beach to Jacksonville should be at least 7,330. Equation 5 also allows the creation of a lower limit constraint on the flow of TEU containers from the ports of Los Angeles and Long Beach to all TAZs east of the Mississippi River (implying that the set $\tilde{d}$ includes all TAZs in Table 4-2). This constraint states that this flow should be greater than or equal to 1.6 million.

There is only 1 upper bound constraint written for the TAZs in Table 8 from the combined ports of Los Angeles and Long Beach. There are no upper limits for individual TAZs based on these data, because containers can travel either direct or through an intermediate point such as Chicago or Memphis. For TAZs east of the Mississippi River, Equation (6) says that the total number of TEU containers on all the links connecting the ports of Los Angeles and Long Beach to each of the destinations east of the Mississippi River should be no greater than the sum of all the values in the third column of Table 4-2. Therefore, for the ports of Los Angeles and Long Beach, the total estimated sent TEUs to all these destinations should be no greater than 1,838,300. Of course, the model allows violations of this upper limit at a penalty.

To identify an effective value for the exponent λ of the distance term in the gravity model (Equation 8), the model ran optimization for values of λ from 0 to 9 in increments of 0.2. Figure 4-2 shows a graph of a measure of the error as a function of λ. The measure used is the ratio of the value of the objective function (excluding the last term) and the sum of the entries in the resultant O-D table, expressed as a percentage. Figure 4-2 shows that values of λ, which are associated with very small errors, are between 1.2 and 3.2. For each of these values, the total percent error is less than 2 percent and the estimated solutions are very similar. Therefore, NISAC chose to use a λ of 1.2. That value is close to what other studies have estimated for λ.

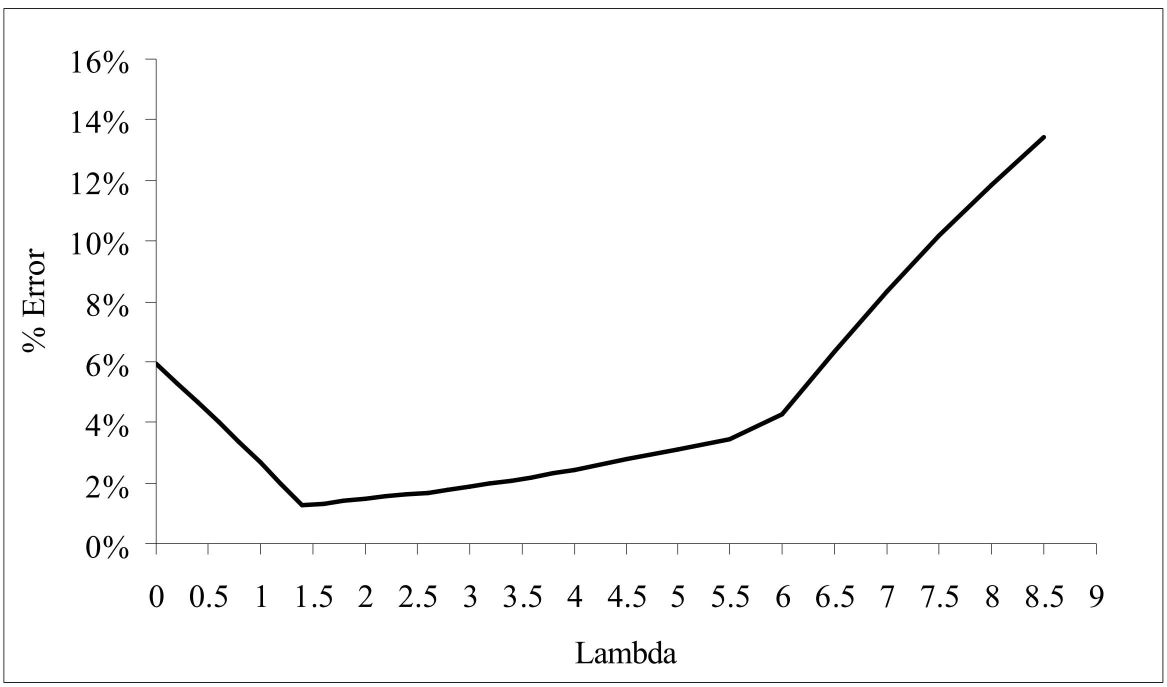


Figure 4-2: Percent error of model results as compared to origin-destination (O-D) table for various values of λ

When $\lambda = 1.2$, the estimated O-D table is consistent with both the 2004 PIERS international trade data for containerized imports and the gravity model. Appendix A shows the estimated O-D table in detail. However, there is 1 inconsistency with the observations in the 2003 STB waybill sample that were used to generate lower bound constraints (Equation 5), and 1 inconsistency with the observations that were used to generate upper bound constraints (Equation 6). Table 4-3 shows these discrepancies. The only discrepancy of significant magnitude is that from the Port of Houston to Los Angeles. The estimated route flows from the model imply that about 190,000 TEUs enter at the Port of Houston and are bound for the Los Angeles area. The 2003 STB waybill data imply that there are about 347,000 TEUs shipped from the Port of Houston to the Los Angeles area by rail. Hence, there is a discrepancy of about 157,000 TEUs. The 347,000 TEUs reported in the waybill sample represent about 77 percent of all container rail movements from the Port of Houston. While there is no direct evidence to discount this observation in the waybill sample, the magnitude of the observation is somewhat inconsistent with the remainder of the traffic at the Port of Houston (which is local).

Table 4-3: Discrepancies between the estimated origin-destination (O-D) table and the 2003 Surface Transportation Board (STB) waybill data

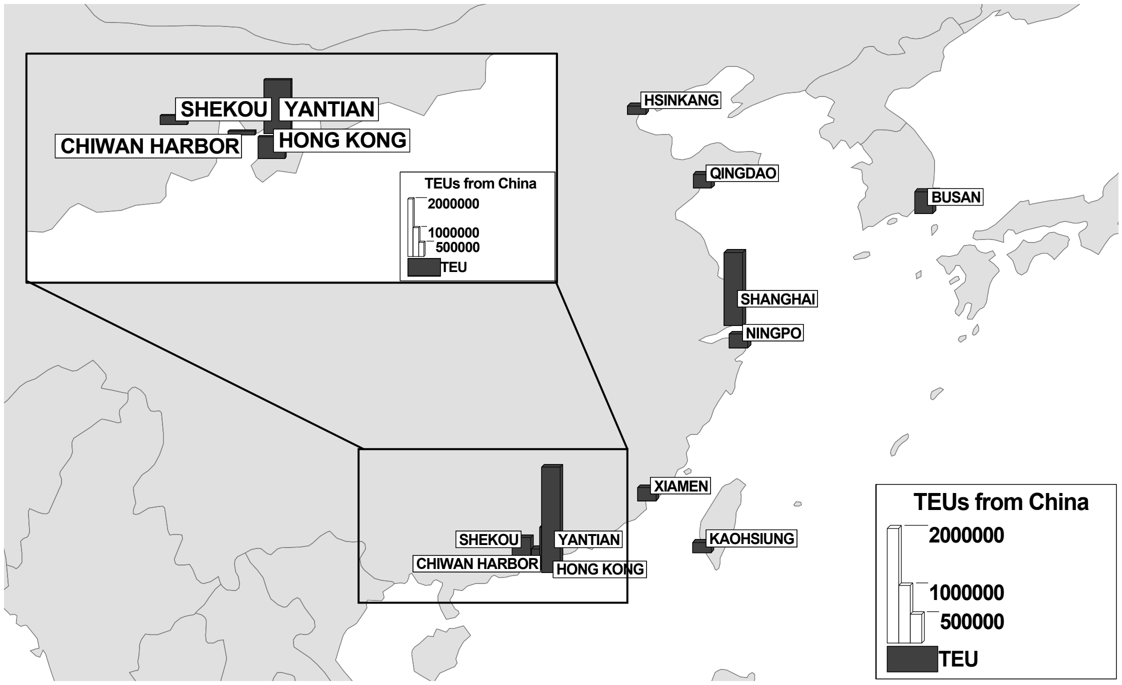
Origin-Destination	Constraint	Error
Houston to Los Angeles TAZ	Lower Bound, Equation (5)	157,000
Ports of Los Angeles and Long Beach to TAZs east of Mississippi	Upper Bound, Equation (6)	- 62,000

Note: TAZ = Transportation Analysis Zone

The other discrepancy shown in Table 4-3 arises from a violation of the upper bound constraint. The 2003 STB waybill data and the growth rate at the ports of Los Angeles and Long Beach from 2003 to 2004 implies that about 1.8 million TEUs travel from the ports of Los Angeles and Long Beach to all TAZs east of the Mississippi River, whereas the model estimates that this number is low by about 62,000 TEUs. However, this represents an error of only about 3.5 percent.

From the route flow variables in the model, analysts can track the flow of TEUs through the network. Considering the traffic originating in China, about 95 percent of TEUs exported from mainland China are shipped through 8 Chinese ports; the Port of Hong Kong; the Port in Busan, South Korea; and the Port of Kaohsiung, Taiwan. Figure 4-3 illustrates these ports and the TEUs imported. The concentration of activity at the Shanghai and Hong Kong port areas is notable. The region from Shanghai to Hong Kong is a special economic zone with substantial financial incentives spurring tremendous growth. Historically, Hong Kong has been the dominant port, second only to Singapore. However, with the rapid growth in this special economic zone in China, the ports of Yantian and Shanghai have attracted substantial traffic. Today, Shanghai is the second largest port in the world next to Singapore,[29] with Hong Kong third.

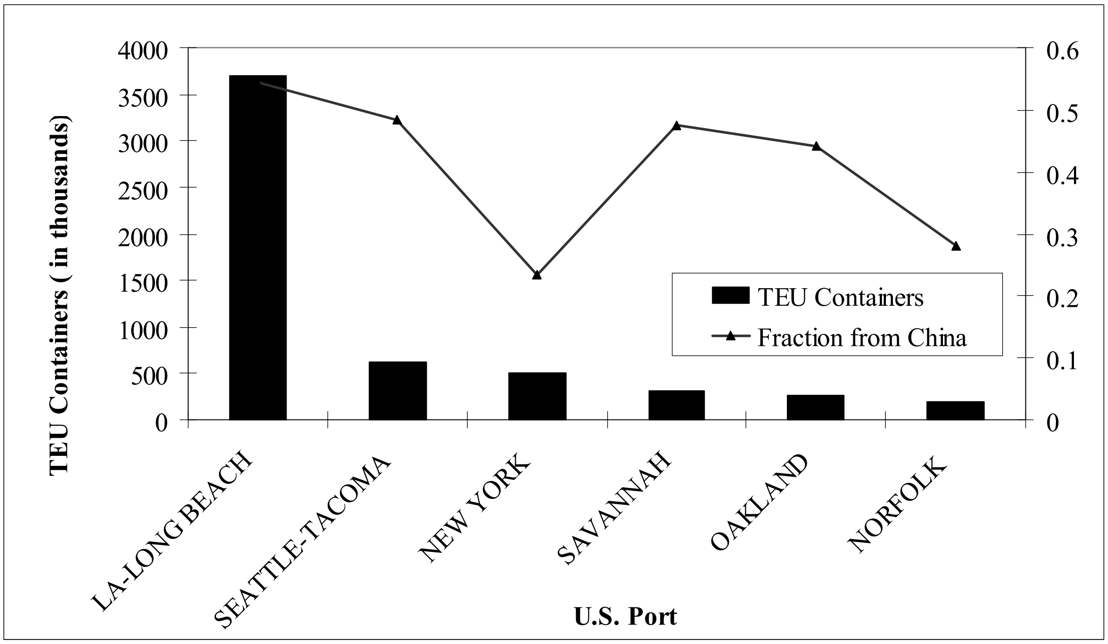
[29] Asian Economic News, 2007, "Hong Kong Port Throughput Slips to 3rd after Singapore, Shanghai: A Report," 23 April



Note: TEU = twenty-foot equivalent unit

Figure 4-3: Export port volumes (in twenty-foot equivalent units [TEUs]) from China

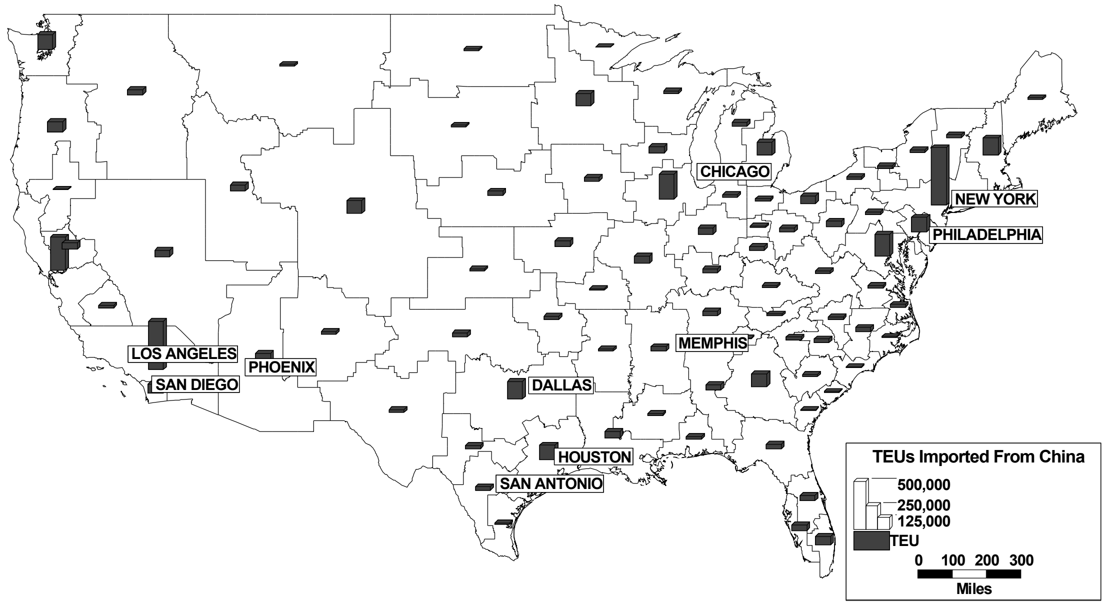
Once containers originating in China are exported through the collection of Asian ports mentioned above, they arrive at U.S. ports. Figure 4-4 gives the number of TEUs imported from China through the 6 U.S. ports with the highest volume. Together, these 6 ports represent about 94 percent of the total volume imported from China. As expected, the majority of the containers are imported through west coast ports, but it is interesting to note that about 17 percent of the total containers imported enter through the ports of New York, Savannah, and Norfolk. Figure 4-4 also shows the fraction of TEUs through each of the ports that originates in China. It is not surprising that the west coast ports have a high percentage of traffic coming from China, but perhaps it is more surprising that east coast ports, such as Savannah and Norfolk, have almost 50 percent and 30 percent of their traffic originating in China, respectively.



Note: TEU = twenty-foot equivalent unit

Figure 4-4: Import volumes for major U.S. ports (in twenty-foot equivalent units [TEUs]) from China.

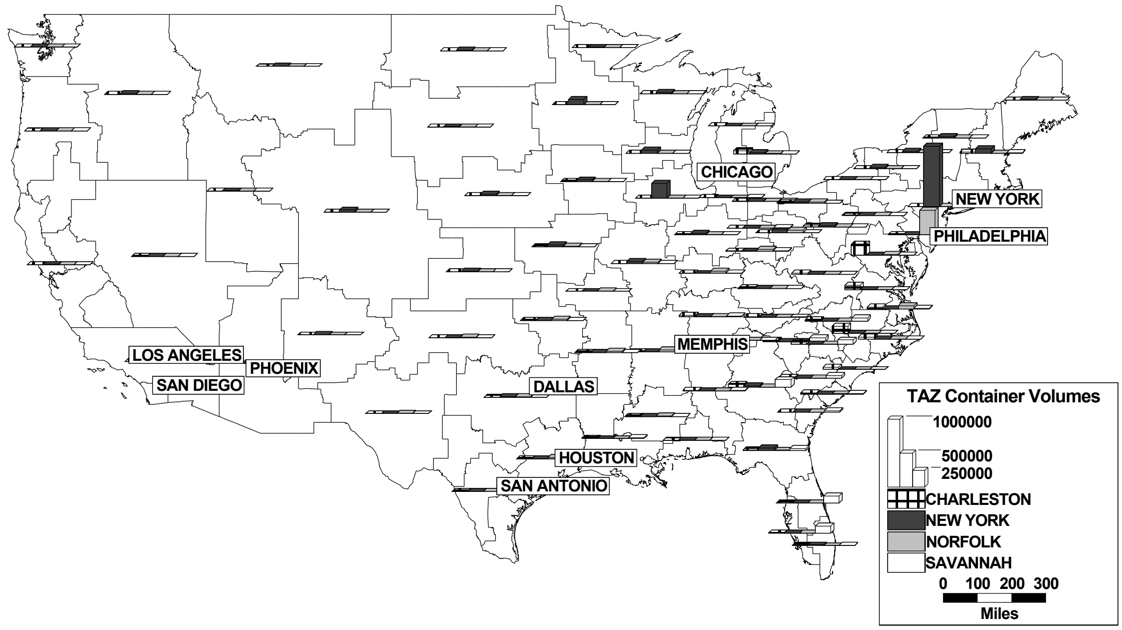
Figure 4-5 gives an estimate of the number of TEUs imported from China that are destined for each TAZ. The large economic areas in the U.S. attract a large number of TEUs. For example, there are almost 600,000 TEUs destined for the New York City TAZ from China. The model estimates that about 75 percent of these containers enter the U.S. through the Port of New York and about 25 percent through the ports of Los Angeles and Long Beach. On the other hand, shipments from China headed to the TAZs near Savannah and Norfolk enter almost exclusively through nearby ports and are served via truck. These conclusions should be used with some caution. This formulation has significantly more decision variables than equations, and linear programs tend to produce solutions that have relatively small numbers of variables that take on positive values, thereby producing “lumpy solutions.” Therefore, individual TAZs may be served by a larger number of ports than indicated in the solution, though there is a strong basis to believe that the ports indicated in the solution do provide significant service.



Note: TEU = twenty-foot equivalent unit

Figure 4-5: Estimated number of twenty-foot equivalent units (TEUs) imported from China to each Transportation Analysis Zone (TAZ)

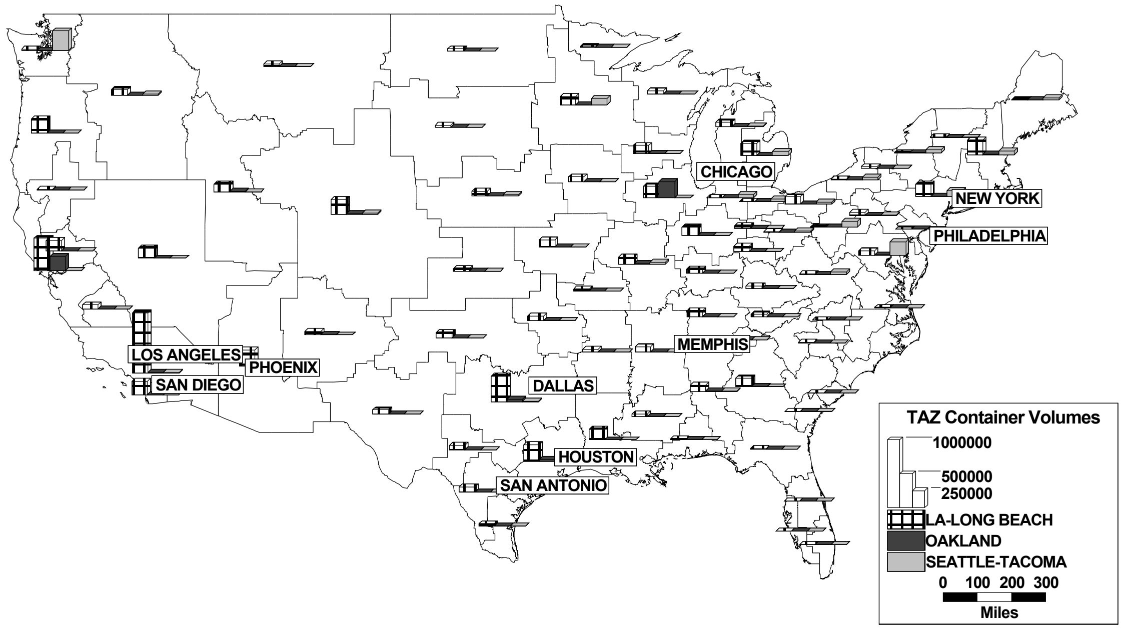
Figure 4-6 gives the estimated number of TEUs (by truck and rail) destined for each TAZ from the ports of Los Angeles and Long Beach, the Port of Oakland, and the ports of Seattle and Tacoma. Given that all but one upper bound constraint was honored in the model, analysts can also infer that all of the container volumes destined for TAZs east of the Mississippi River were achieved with rail service. The ports of Los Angeles and Long Beach are estimated to provide significant service across the U.S., with the exception of the southeast; whereas, the ports of Seattle and Tacoma provide service mainly in the north.



Note: TAZ = Transportation Analysis Zone

Figure 4-6: Flow of containers from west coast ports to Transportation Analysis Zones (TAZs)

Figure 4-7 gives the estimated number of TEU containers (by truck and rail) destined for each TAZ from the ports of New York, Charleston, Norfolk, and Savannah. The majority of containers that enter the U.S. through these ports are destined for TAZs on the east coast. Very few containers travel west of the Mississippi River. This is in contrast to the ports on the west coast, which service a large portion of the continental U.S.

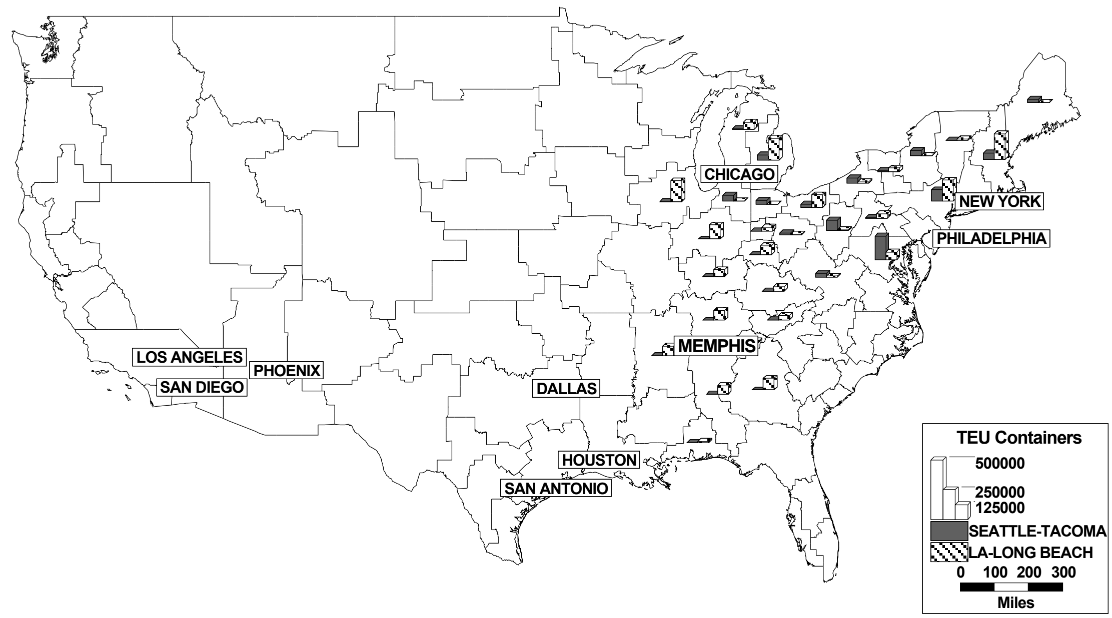


Note: TAZ = Transportation Analysis Zone

Figure 4-7: Flow of containers from major east coast ports to Transportation Analysis Zones (TAZs)

As mentioned previously, the STB waybill data indicate more containers destined for Chicago and Memphis than are likely to be correct, due to the practice of rebilling. NISAC can use the model to infer the actual destinations for the containers that are labeled as destined for Chicago or Memphis in the waybill data. When doing this, it is important to understand that these flows are generally higher than those indicated by the waybill data because they include the growth that occurred at these ports from 2003 to 2004, through Equation (6).

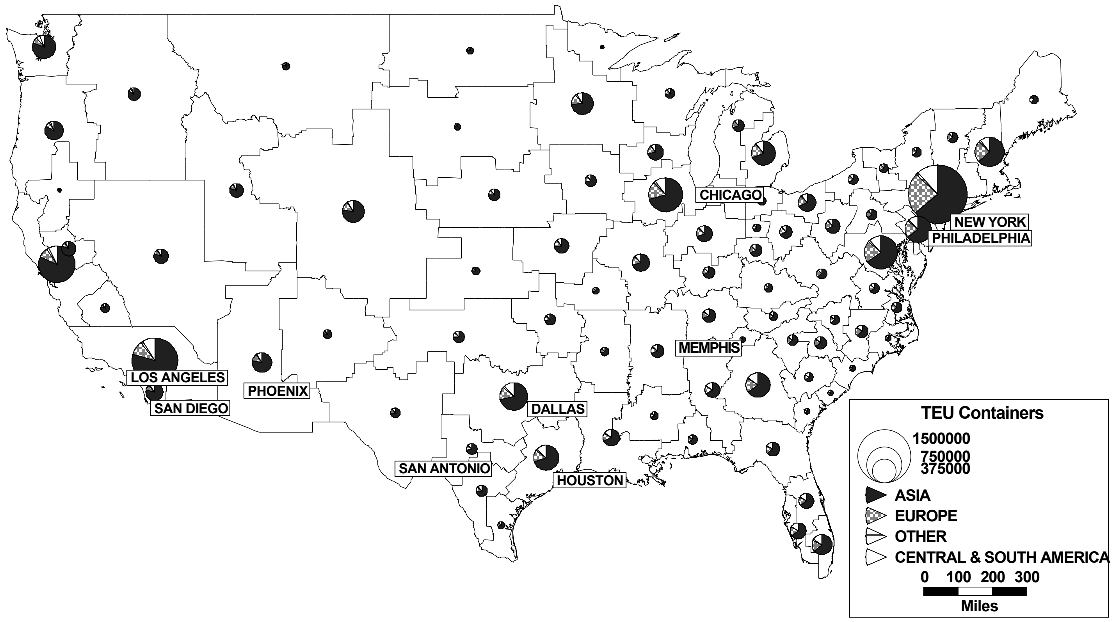
Figure 4-8 shows the estimated TEU flows from the ports of Seattle and Tacoma and the ports of Los Angeles and Long Beach to TAZs east of the Mississippi River and that were indicated as terminating at Chicago or Memphis in the waybill data. The model concludes that some of this traffic does, indeed, terminate at the TAZs that include Chicago and Memphis, but much of it is destined for other TAZs. For example, the waybill data indicate that from the ports of Seattle and Tacoma, about 600,000 TEUs are destined for the TAZ that includes Chicago and about 35,000 are destined for the TAZ that includes Memphis. The model indicates that much of this traffic is really destined for the Northeast U.S., with significant concentrations in New York City, Boston, and to a lesser extent, Michigan and Ohio. The waybill data indicate that from the ports of Los Angeles and Long Beach about 1,090,000 TEUs are destined for the TAZ that includes Chicago and about 400,000 TEUs are destined for the TAZ that includes Memphis. The model indicates that much of this traffic is really destined for other TAZs east of the Mississippi River. Given the larger role of Memphis, substantial traffic is estimated to be destined for TAZs in the South.



Note: TEU = twenty-foot equivalent unit

Figure 4-8: Inferred flows from the ports of Seattle and Tacoma and the ports of Los Angeles and Long Beach that the waybill data reports as terminating in Memphis or Chicago

Figure 4-9 gives the number of containers that are destined for each TAZ by originating region of the world (Asia, Europe, Central and South America, other). Clearly, Asia is the dominant region. Perhaps the most interesting observations in this figure is how constant the balance is between the four regions of the world across the continental U.S. Certainly, there is a slight increase in the percentage from Asia in the west, Europe in the east, and Central and South America in the south and gulf coast, but these differences are quite minor. For example, the TAZs with the largest percentage share from Asia are in California, Seattle, Oregon, Montana, Utah, and Idaho (percentages in the low eighties). The TAZs with the smallest percentage share from Asia (percentages in the low sixties and among the highest from Europe) are in Maine, Florida, Georgia, South Carolina, Massachusetts, Pennsylvania, and so forth. Imports from Central and South America are relatively larger in Florida, Georgia, South Carolina, and the gulf coast region (percentages in the mid-teens).



Note: TEU = twenty-foot equivalent unit

Figure 4-9: Distribution of twenty-foot equivalent units (TEUs) by regions of origin for each Transportation Analysis Zone (TAZ)

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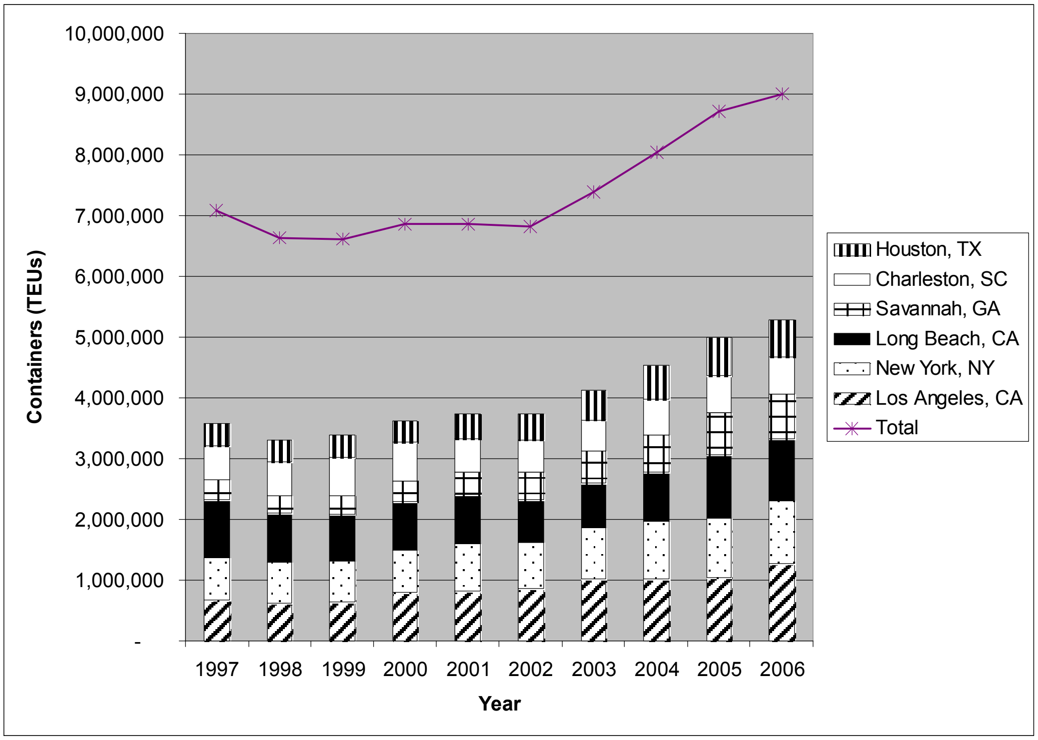
5 Estimation of an Origin-Destination Table for Exports

In 2006, almost 9 million TEUs of goods were exported from the U.S. through U.S. container seaports.[30] Since 2002, U.S. containerized exports have grown at an average rate of 7 percent per year. Figure 5-1 gives the total number of full containers (in TEUs) exported and the number that exited through the 6 largest container ports, from 1997 to 2006. These 6 ports represent about 60 percent of containerized exports (as measured in TEUs) in 2006. In 2006, about one-quarter of U.S. containerized exports exited through the ports of Los Angeles and Long Beach.

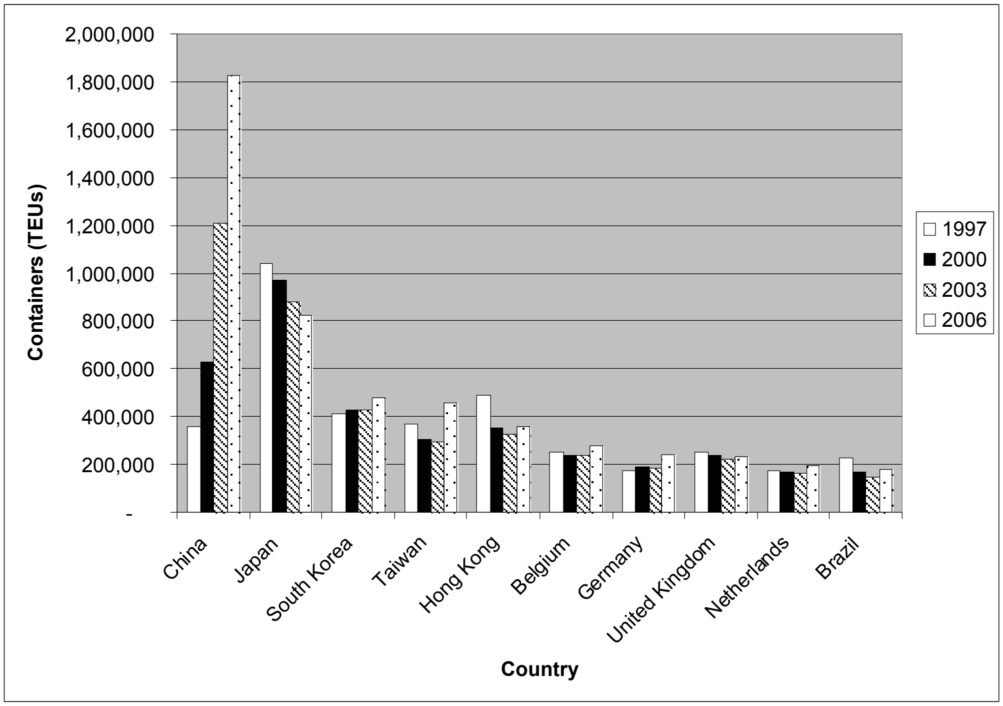


Note: TEU = twenty-foot equivalent unit

Figure 5-1: Containers (measured in twenty-foot equivalent units [TEUs]) exported from the U.S., 1997 to 2006

Figure 5-2 gives the number of containers exported from the U.S. in 1997, 2000, 2003 and 2006 to the 10 largest destination countries (U.S. Maritime Administration, 2007a). China is the largest destination, representing over 20% of containers exported in 2006 and experiencing more than a 20% annual growth rate over the last decade.

[30] U.S. Maritime Administration, 2007a, "Data and Statistics," accessed on line at http://www.marad.dot.gov/MARAD_statistics/index.html, 24 August



Note: TEU = twenty-foot equivalent unit

Figure 5-2: Waterborne containerized exports to specific countries

NISAC developed an O-D table for U.S. container exports using a model that is similar to that used in Section 4 for U.S. imports. There are 3 significant changes in the model for estimating the export O-D table. First, the analysis for U.S. exports uses MARAD data for international trade in place of data from PIERS. Because the MARAD dataset is more limited, this has a significant impact on the model formulation. Second, more than half of all containers exported through U.S. ports are empty; whereas, very few containers that are imported are empty. Because NISAC is focused on estimating an O-D table for U.S. exports that supports decision-making with respect to transportation infrastructure, it is important to consider the flow of empties; therefore, this analysis pays explicit attention to estimating an O-D table that includes the movements of empty containers. Third, because the U.S. operates with a large trade deficit, the interpretation of the STB Waybill data is different for the observations that are assumed to be U.S. exports in comparison to U.S. imports.

NISAC formulated the O-D table estimation problem as a linear program where the origins are aggregations of BEA economic areas forming 84 TAZs and the destinations are 1 of 88 countries. The 88 countries included in the O-D table represent about 99 percent of all containerized U.S. exports, including empty containers. Because the TAZs are considered the origins and the countries are the destinations, the number of containers to be moved (over some defined period of time) can be summarized by an 84 by 88 table.

As in the import O-D table estimation, the key decision variables in this model are route flows, f_r. However, in the export model, NISAC included both full and empty containers in the flow on route r. Each route in the export model is a path from an origin TAZ o, through a U.S port p, to a destination foreign country d. In contrast to the import model, NISAC is not concerned about flows through foreign ports as being distinct from foreign destinations. These route flows can then be translated into an origin destination table by summing the route flows that have the same origin TAZ and destination country. The variables are constrained to be non-negative.

The MARAD reports the total number of full TEUs, b_p^f, exported through each U.S. port in 2005.[31]

The total number of empty TEUs handled at each U.S. port in 2005, b_p^e, can be obtained from individual port websites, but empty containers handled are generally not distinguished by direction (import or export). The U.S. has a significant trade imbalance, and this imbalance is also present in waterborne containerized trade. The Port of Los Angeles reports that less than 2 percent of TEU containers imported are empty, but about 60 percent of containers exported are empty.[32] In 2005, about twice as many full containers were imported as were exported. Therefore, it is reasonable to assume that nearly all empties are flowing out of the U.S., and NISAC interprets the empty flows reported by the ports as export containers. Equation (11) is a modified version of constraint (Equation 4), encouraging solutions that match the combined loaded and empty container volumes leaving each U.S. port.

- g_p^+ is a variable that represents the amount by which the flows, f_r, are smaller than that expected
- g_p^- is a variable that represents the amount by which the flows, f_r, are larger than expected
- g_p^+ is constrained to be non-negative and g_p^- is constrained to be non-positive

$$\sum_{r \in R(p)} f_r + g_p^+ + g_p^- = b_p^e + b_p^f \qquad \forall p$$

Equation (11)

MARAD also reports the total number of full TEUs, m_d^f, entering each foreign country d in 2005.[33]

The total number of empty TEUs, m_d^e, is not reported directly by either MARAD or by the individual countries. For this analysis, NISAC allocated the total number of empty TEUs leaving U.S. ports proportionally to each foreign country d based on the difference between full TEUs exported from and full TEUs imported to country d. This creates an estimate that is consistent with the total number of empty TEUs leaving U.S. ports. For any country where this difference is positive, NISAC assumed the excess must return in the form of empty containers. If this difference is negative (that is, the country imports more than it exports), then NISAC did not allocate empties to this particular country. Constraint (Equation 12) encourages solutions that match the container volumes entering each foreign country, as a modification of constraint (Equation 3) in the import model.

- h_p^+ is a variable represents the amount by which the flows, f_r, are smaller than that expected
- h_p^- is a variable that represents the amount by which the flows, f_r, are larger than expected

[31] U.S. Maritime Administration, 2007a, "Data and Statistics," accessed on line at http://www.marad.dot.gov/MARAD_statistics/index.html, 24 August
[32] Port of Los Angeles, 2007, "2005 TEU Statistics," http://www.portoflosangeles.org/factsfigures_Annual_2005.htm, accessed 19 July
[33] U.S. Maritime Administration, 2007a, "Data and Statistics," accessed on line at http://www.marad.dot.gov/MARAD_statistics/index.html, 24 August

- h_p^+ is constrained to be non-negative and h_p^- is constrained to be non-positive

$$\sum_{r \in R(d)} f_r + h_d^+ + h_d^- = m_d^e + m_d^f \quad \forall\, d$$

Equation (12)

Because PIERS data for exports were not available, the Waterborne Databank (2004) from the U.S. Maritime Administration and the U.S. Army Corps of Engineers[34] was used to provide observations on total weight of containerized cargo (in tons) moved from each U.S. port to specific foreign countries. Although these data are in tons rather than TEUs, the model can calculate the percentage of tons at a given port destined for each foreign country and then multiply by the total number of full TEUs leaving U.S. port *p*, b_p^f, to get a lower bound on the total number of TEUs on links connecting U.S. port *p* and foreign country *d*, l_{pd}. This is a lower bound because the model only uses full containers in this computation, ignoring the empty containers. NISAC also assumed that the coefficients obtained from the 2004 Waterborne Databank are very similar to those that would be computed based on 2005 data. This process generates a small number of minor inconsistencies where the lower bound of the total number of TEUs on links entering foreign country *d* is greater than the amount estimated by the right side of Equation (12). Constraint (Equation 13) encourages solutions that match or exceed the number of full TEUs on the links, as a modification of constraint (Equation 2) in the import model.

- g_{pd}^+ is a variable that represents the amount by which the flows, f_r, are smaller than expected and is constrained to be non-negative

$$\sum_{r \in R_{ij} | i=p, j=d} f_r + g_{pd}^+ \geq l_{pd} \quad \forall\, p, d$$

Equation (13)

The 2005 STB Waybill data have observations of rail carloads for links *(i,j)* starting from a TAZ and ending at a county that is associated with a U.S. port. The STB Waybill data do not explicitly identify containers to be exported or the port of export. Rather, the data identify the number of carloads for STCC commodity code 46 transported from one county to another. This designation corresponds to mixed freight, which is used for intermodal shipments. Using the same conversion factors as in the import model, the model converted the number of railcars into a number of TEUs transported.

The STB Waybill data observations include both full and empty containers transported by rail, without a distinction between the two. These observations can be used as lower limits on the link flows because they only include rail movements to the ports and exclude TEUs shipped by truck. Therefore, the total TEUs shipped across those links, as determined by the model, must be at least as large as that implied by the 2005 STB Waybill data. Let

- n_{op} = an observation from the STB Waybill data, where *o* is the TAZ origin that the observation pertains to and *p* is the port

[34] U.S. Maritime Administration, "Data and Statistics, Waterborne Databank (2004)," accessed on line at http://www.marad.dot.gov/MARAD_statistics/index.html, 24 August.

- k_{op}^{+} = a variable that represents the amount by which the flows, f_r, are smaller than suggested by the 2005 STB Waybill
- k_{op}^{+} = constrained to be non-negative

Constraint (Equation 14) is then the parallel version of constraint (Equation 5) in the import model.

$$\sum_{r \in R_{ij} | i=o, j \in p} f_r + k_{op}^{+} \geq n_{op} \quad \forall \; o, \, p \qquad \text{Equation (14)}$$

The special treatment of the TAZs that include Chicago and Memphis, discussed for the import model, is also included in the export model, but in a "mirrored" way. If port *p* is on the west coast, then the flow to that port from a TAZ *o* that includes either Chicago or Memphis is composed of flows coming from that particular TAZ *o* as well as all TAZs to the east of the Mississippi River. Using this assumption, the model can estimate a lower limit constraint where it replaces *o* with $\tilde{o}$; that is, the set of all TAZs to the east of the Mississippi River. The model takes a similar approach for ports on the east coast, where $\tilde{o}$ is the set of all TAZs west of the Mississippi River plus the TAZs that include Chicago and Memphis.

NISAC also created upper bounds on the flows, using a structure parallel to constraint (Equation 6) in the import model and a gravity model (parallel to constraint [Equation 8] in the import model) to help define the structure of the export O-D table. The model handles deviations from the gravity model flows by a constraint parallel to constraint (Equation 9) in the import model, and the objective function is the same as in Equation (10).

For this analysis, NISAC used the 2005 MARAD on international trade, the 2004 Waterborne Databank from the MARAD, the 2005 STB Waybill data, and economic data from 2005; hence, the estimated O-D table is for 2005.

NISAC ran the optimization model multiple times with different values of λ, the exponent of the distance term in the gravity model (Equation 7), to select the value of λ that minimizes the value of the objective function. Figure 5-3 is a graph of a measure of error as a function of λ over the range [0,8] in increments of 0.25. The measure of error used is the ratio of the value of the objective function (excluding the last term in Equation [10]) to the magnitude of the estimated O-D table, expressed as a percentage. Values of λ associated with very small errors are between 0 and 4. For each of these values, the error is less than 4 percent and remains effectively constant throughout this region. Because different values of λ imply a different resultant O-D table, these results indicate that a range of different path flow solutions exist, each having effectively the same level of agreement with the observations extracted from the datasets and the resultant gravity model.

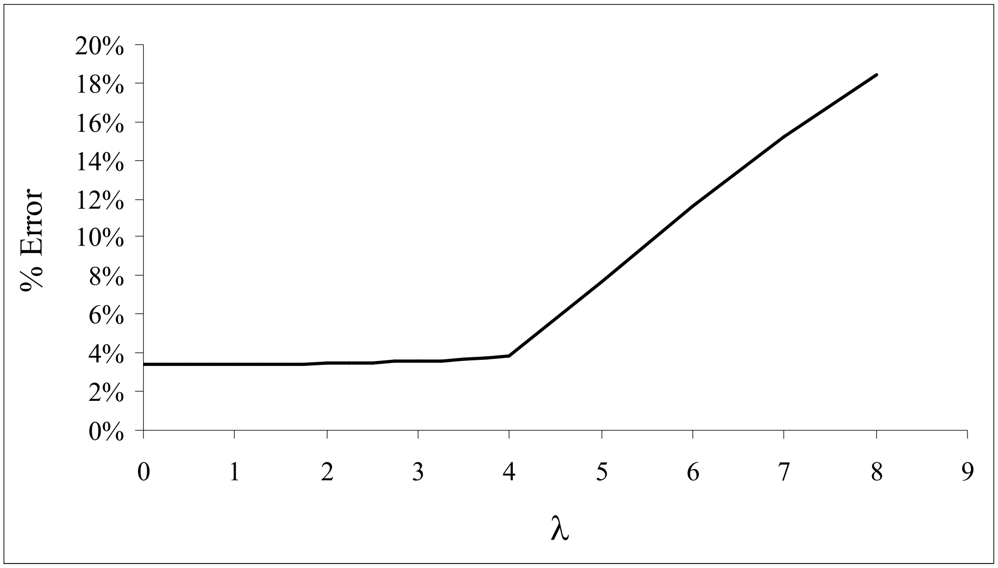
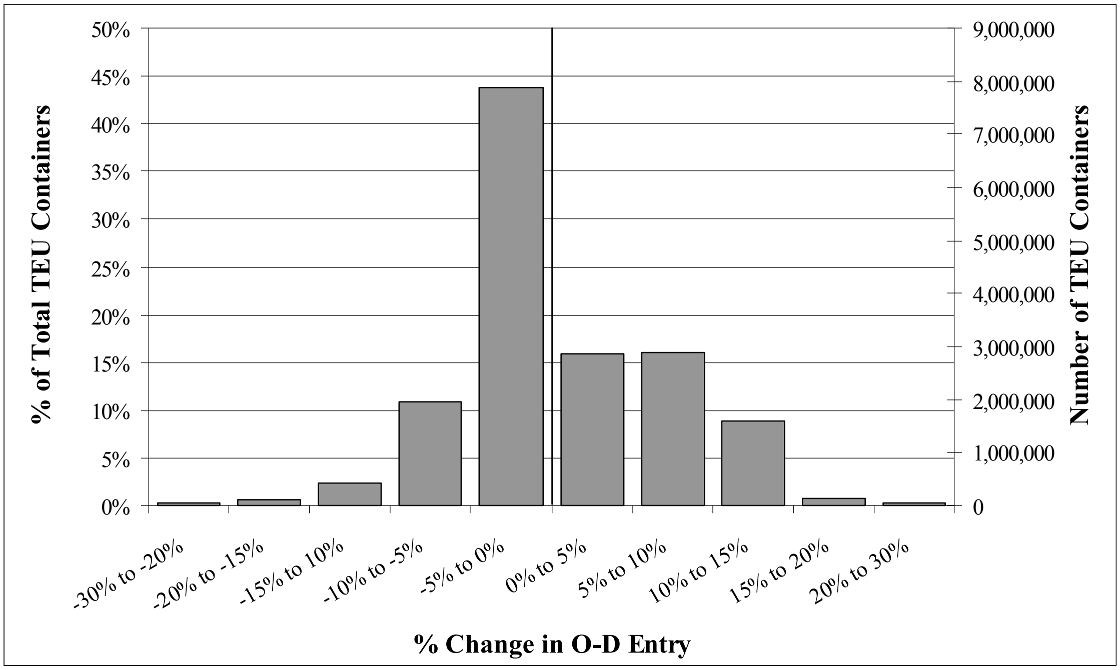


Figure 5-3: Percent error of model results as compared to the estimated origin-destination (O-D) table

These results occur primarily because there are constraints on most of the links from each TAZ to each U.S. port and on all links from each U.S. port to each foreign country, both of which provide a lower bound and can therefore be exceeded without penalty. For different values of λ, the solution can redistribute path flows to satisfy the gravity model while still satisfying the lower bounds, U.S. port total, and foreign country total constraints. For the range of λ from 0 to 4, the dominant types of errors are for the U.S. port to foreign country links and for the TAZ to U.S. port links. The sum of the lower limits on the links from each U.S. port to each foreign country is about 8.5 million TEUs. The average error for these constraints, when λ is between 0 and 4, is about 3.1 percent of this total. The sum of the lower limits incorporated in the model from the STB Waybill is about 4 million TEUs. The average error for these constraints, when λ is between 0 and 4, is about 9 percent.

Based on Figure 5-3, all values for λ that are less than approximately 4.0 are plausible, given the data used in this analysis. However, previous studies have indicated that the value of λ usually ranges from 0.8 to 1.2, so to analyze the sensitivity of the estimated O-D table to changes in λ, NISAC focused on solutions where λ is between 0.8 and 1.2. The histogram in Figure 5-4 shows the percentage of total containers (measured in TEUs) in the O-D table for which the entries change by a given range. If the range is negative, this implies that as λ increases from 0.8 to 1.2 the, containers that are estimated to move from the TAZ to the foreign country decrease. Conversely, if the range is positive, this implies that an increase in λ will increase movements of containers. This histogram shows that nearly 60 percent of the total TEUs in the O-D table changed by no more than 5 percent when λ is 1.2 instead of 0.8 and that nearly 90 percent of the TEUs in the O-D table changed by no more than 10 percent. Also, 60 percent of the TEUs in the O-D table correspond to approximately 10 million TEUs and 90 percent of the TEUs in the O-D table correspond to about 16 million TEUs. Therefore, the estimated O-D tables are very similar across this range of values for λ. NISAC used a value of λ = 1.0 in the subsequent analyses.



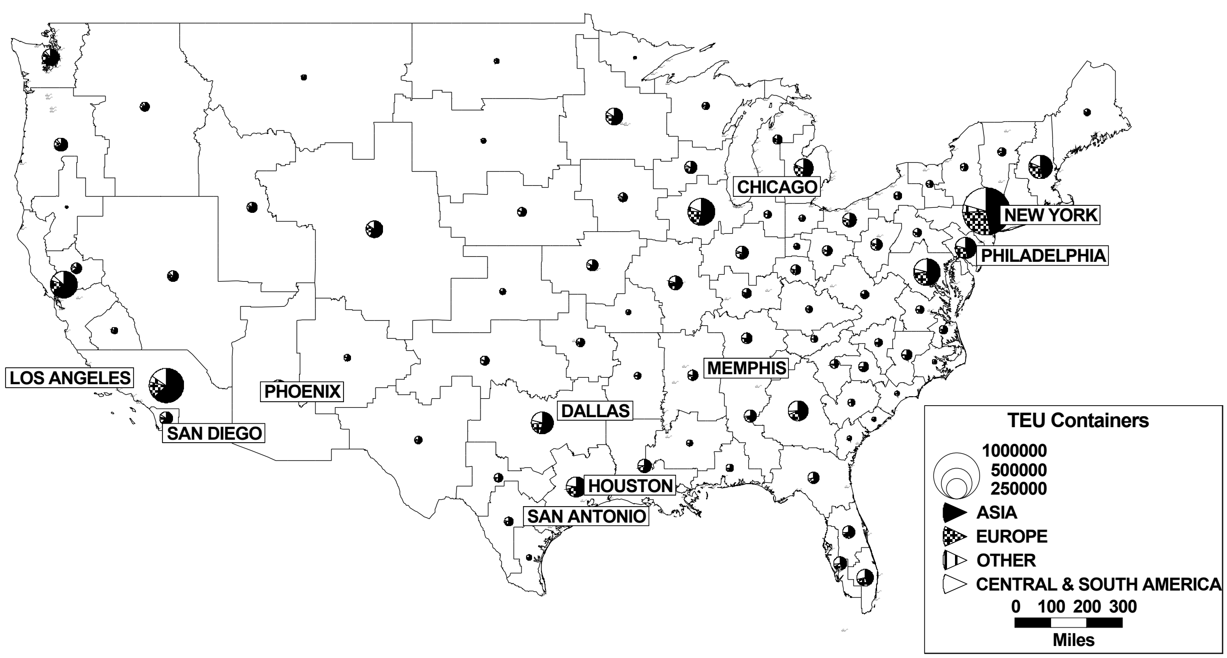
Note: O-D = origin-destination, TEU = twenty-foot equivalent unit

Figure 5-4: Sensitivity of the entries in the origin-destination (O-D) table as λ changes from 0.8 to 1.2

Figure 5-5 is a map of exports to China by TAZ for total TEUs and full TEUs. The percentage of full containers bound from the U.S. to China is about 22 percent. Figure 5-6 shows full TEUs by destination region for each TAZ. About 53, 22, 20, and 6 percent of full TEUs are destined for Asia, Europe, Central and South America, and other regions of the world, respectively. In contrast, those percentages are 68, 16, 13, and 3 percent, respectively, for total TEUs. This highlights the high trade-deficit with Asian countries. While Figure 5-6 illustrates that the distribution of exports to the different regions of the world is fairly constant across the U.S., TAZs on the west coast have a slightly higher fraction bound for Asia in comparison to the east coast and the gulf region. The east coast tends to emphasize trade with Europe and the gulf region with Europe and with South and Central America. Appendix B is a full estimated O-D table for exports (organized by port of export).

Note: TEU = twenty-foot equivalent unit

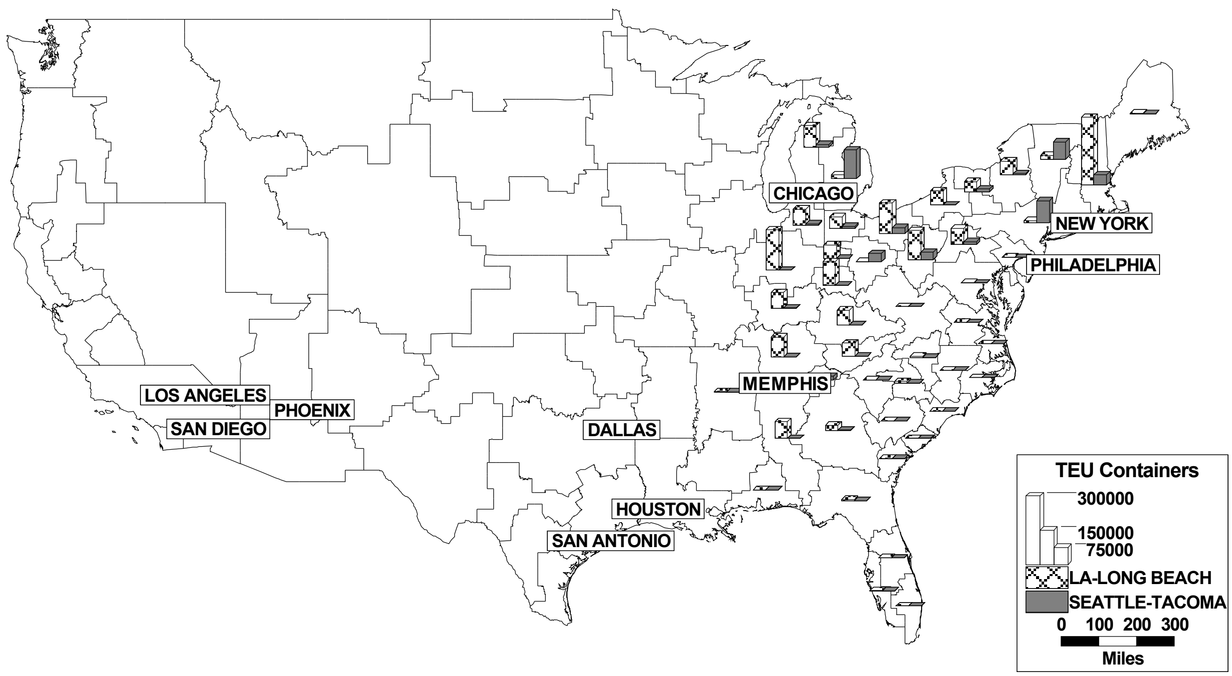
Figure 5-5: Container originations for exports to China



Note: TEU = twenty-foot equivalent unit

Figure 5-6: Full containers departing each Transportation Analysis Zone (TAZ) by region of destination

Figure 5-7 shows the total flow of containers from TAZs east of the Mississippi River to west coast ports. Because NISAC assumed that all transportation from TAZs east of the Mississippi River to west coast ports is done by rail, this is effectively a redistribution of the observations in the STB waybill data for those TAZs. The STB waybill data imply that about 44 percent of the TEUs shipped originated in either the Chicago or the Memphis TAZ (as a result of the practice of rebilling). For the ports of Los Angeles and Long Beach and the ports of Seattle and Tacoma, those percentages are 52 percent and 69 percent, respectively. The model has created a significantly more plausible distribution for the origination of those container movements. Also, the redistribution for the containers bound to the ports of Seattle and Tacoma is more heavily concentrated in the northern origin TAZs, whereas the redistribution for the ports of Los Angeles and Long Beach is estimated to originate in TAZs in the south. Fewer containers are estimated to originate in the southeast and go to these west coast ports because there are several ports in the southeast, including Norfolk, Charleston, Savannah, and Miami. U.S. exports from the southeast are primarily handled through ports in the southeast, not through west coast ports.



Note: TEU = twenty-foot equivalent unit

Figure 5-7: Inferred flows from eastern Transportation Analysis Zones (TAZs) to west coast ports

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6 Converting Twenty-foot Equivalent Unit Flows to Rail Carload Flows

The route flows for both imports and exports, estimated using the analysis process described in Sections 3 through 5, can be used in a variety of ways to interface with the domestic rail network model, R-NAS. For example, in one type of analysis, flows on the set of routes that all use the same U.S. port can be aggregated to produce a single flow at each port (to be distributed to various U.S. destinations for imports or originating at various U.S. origins for exports). This type of analysis is described more fully in Section 7. In another type of analysis, flows may be diverted from one route to another connecting the same origin and destination, but using a different port, in the event of a major disruption of service at a particular port facility. Other manipulations are also possible.

For any of these modes of analysis, it is necessary to estimate the flows of containers that move by rail and truck for the domestic part of their trip. Second, for those that move by rail, it is necessary to convert the flows of containers (in units of TEUs) to flows measured in rail carloads, as required by the R-NAS model.

The model separates rail flows from truck flows for the domestic parts of the routes using the $k^{+}_{p\tilde{d}}$ variables in Equation (5) for imports and the k^{+}_{op} variables in Equation (14) for exports. Where these variables are positive, the O-D table flows from/to a U.S. port exceed the estimated rail flows from the STB waybill data, and the model infers that these flows must be by truck.

The model converts rail TEU flows to carloads using the TEU/container values for each port shown in Tables 2-1 and 2-4 (Section 2), and the estimate of 1.7 containers per carload developed from the data provided by the IANA and the loading data from the AAR, also described in Section 2.

Appendices C and D summarize the import container flows (in rail carloads) by rail and truck, after the modal splitting and flow unit conversion. The truck flows are given in equivalent rail carloads because the flow unit in the R-NAS model overall is rail carloads. Appendices E and F give the comparable summaries for export containers.

The net flows of carloads (including both loaded and empty containers) are then passed to an extended form of the R-NAS model, to be included with flows of other commodities over the domestic network. This network flow model is described in the following section.

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7 Network Model Formulation

The purpose of the R-NAS network flow model is to determine how shipments of commodities will flow across links of the rail network to move from their specified origin to their specified destination. Because NISAC's focus is on the national network, not the sub-network belonging to any particular railroad, project analysts have adopted the perspective that this flow pattern should be "system optimal." That is, analysts seek the flow pattern that produces the lowest total cost for all shipments. This is not likely to be exactly how all individual shipments will flow across the real network, because there are several railroads making routing decisions and they can each be expected to optimize routing for their own sub-network without concern for any other railroad's decisions. Thus, the flow pattern that emerges on the real network is likely to be sub-optimal from a system-wide perspective, and the total cost NISAC estimated in its modeled network is likely to be lower than that actually experienced.

However, NISAC's primary interest is in being able to estimate likely impacts from disruptions to the network. Under disrupted conditions, the "normal" routing patterns will also be disrupted and some new flow pattern will emerge out of a combination of cooperation and competition among the railroads. By finding a system-optimal flow pattern under the disrupted conditions, NISAC is assuming that the railroads manage the disruption as effectively as possible. The difference between the 2 system-optimal solutions NISAC created (before and after the disruption) should be a conservative estimate of the change in total cost that would ensue from the disruption. NISAC believes that this conservative estimate represents a reasonable answer to the question: "How large would the impacts be?" Several illustrations of the use of the R-NAS model are contained in the report by Jones and others.[35]

Many previous models have been created to study optimization of rail operations and investments, but none of these models is focused on the impacts of disruptions to the network. For a complete review of previous modeling efforts, see Newman, Nozick, and Yano.[36] The majority of previous models focus on specific elements of the operating plan or railcar/locomotive investment. The operating plan for a railroad is a combination of blocking strategy, train frequency and makeup, redistribution plans for locomotives and empty freight cars, and crew scheduling. Railcars move in groups called blocks, and these blocks are grouped into trains. A block is treated as a single unit for a portion of a trip, but individual cars in a block may have different final destinations. At a yard, the individual cars in a block may be reclassified and reassembled into new blocks. Trains travel on predefined routes with specific frequency, speed, and priority.

The R-NAS model includes specific treatment of the operating differences for unit trains, intermodal services, auto trains, and manifest trains. It also includes specific delay models for use in the classification yards. For the incorporation of detailed O-D flows of international containers, NISAC has also included specific delay models for the port facilities.

The network problem formulation can be expressed as a mathematical optimization problem. The model refers to links in the network by the pair of nodes that they connect; thus, a link from node i to node j will be denoted as the link ij. The model assumes links are directional, so the characteristics of link ij are not necessarily the same as for link ji (and link ji may not even exist). The model

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[35] Jones, Dean A. et al., 2003, "Impact Analysis of Potential Disruptions to Major Railroad Bridges in the US" (OUO), Sandia National Laboratories, NISAC, 8 August

[36] Newman, A. M., L. K. Nozick, C. A. and Yano, 2002, "Optimization in the Rail Industry," *Handbook of Applied Optimization*, P. Pardalos and M. Resende (eds), Oxford University Press, New York, 704–19

denotes origin and destination zones by *r* and *s* and recognizes that these zones can be treated as nodes in the network. The set of commodity groups defined for analysis is indexed by *k*. Quantities of freight to be shipped and flows on links are measured in units of carloads. Let

Q_{rs}^k	=	carloads of commodity k to be shipped from origin r to destination s
f_{ij}^k	=	flow (carloads) of commodity k on link ij
p_{ijs}^k	=	carloads of commodity k on link ij headed for destination s
K_{ij}	=	set of commodities that are allowed to use link ij
x_{ij}	=	total flow on link ij
$t_{ij}(x_{ij})$	=	average travel time for a carload to cross link ij (as a function of flow, xij)

The problem of finding the minimum-cost flow pattern in the network can be expressed as a nonlinear optimization:

$$\min \sum_{ij} x_{ij} t_{ij}(x_{ij}) \qquad \text{Equation (15)}$$

subject to:

$$x_{ij} = \sum_k f_{ij}^k \qquad \forall\, ij \qquad \text{Equation (16)}$$

$$f_{ij}^k = \sum_s p_{ijs}^k \qquad \forall\, ij, k \qquad \text{Equation (17)}$$

$$\sum_j p_{rjs}^k - \sum_j p_{jrs}^k = Q_{rs}^k \qquad \forall\, r, s, k \qquad \text{Equation (18)}$$

$$\sum_{k \notin K_{ij}} f_{ij}^k = 0 \qquad \forall\, ij \qquad \text{Equation (19)}$$

$$x_{ij}, f_{ij}^k, p_{ijs}^k \geq 0 \qquad \forall\, ij, k, s \qquad \text{Equation (20)}$$

The objective function (15) expresses the total cost of flow in the network, which is to be minimized. It is a nonlinear function because $t_{ij}(x_{ij})$ is an increasing function of x_{ij} (of the general form shown in Figure 2-3). Constraints (16) and (17) define the relationships of the flow variables x_{ij} , f_{ij}^k , and p_{ijs}^k. Constraint (18) is a conservation-of-flow constraint. It says that, at a given node *r*, the difference between outbound flow of commodity *k* destined for node *s* and the inbound flow of the same commodity bound for the same destination must be the amount of that commodity that originates at *r* and is destined for *s*. Constraint (19) limits access to links to only those commodities that are allowed to use each link. Constraint (20) specifies that all the flow variables must be non-negative.

The limitation of certain commodities to specific links, represented in constraint (19), is used in 2 primary places in the model: by allowing some commodities to bypass classification yards and on a set of "overflow" links that reflect movements that cannot be accommodated within the system. Some commodities are frequently handled in unit trains that do not require intermediate classification at yards. In addition, intermodal traffic is normally moved by dedicated trains that bypass en-route classification yards. The model's representation of classification yards contains a bypass link available to movements of commodities in unit trains and intermodal trains.

Overflow links for commodity movements that cannot be handled in the network are part of the way the model reflects the limitations of available capacity. The model addresses the capacity of the system through the increasing delays represented in the $t_{ij}(x_{ij})$ functions for the links and through the set of overflow links.

The form of a national rail network model reflected in Equations (15) through (20) does not attempt to represent the details of each railroad's operating plan, blocking strategy, specific train schedules, and so forth, nor the details of interchange movements of freight cars between railroads. As such, it should not be relied upon to answer detailed questions about a how an individual carload (one or more containers) will move between the Port of Long Beach, California, and a receiver in Knoxville, Tennessee, for example. The purpose of this model is to reflect the overall capacity and capability of the national network, and how rerouting of traffic in response to loss of capacity in some critical parts of the network might increase congestion and delays in remaining parts of the network (and perhaps lead to an inability to move some shipments). The model's focus is on aggregate flows, distances and delays, and the changes in those aggregate variables as capacity is reduced in parts of the network. This level of detail is appropriate for national-level impact analysis as well as for facilitating assessment of impacts on national security and public health and safety.

The network model is a static (or "steady-state") representation of the flow pattern in the network. When the O-D table input to the model represents an average day's demands to be met, the flow pattern across the network will represent an average day's flows (in carloads). This does not mean that commodities that enter the network in California will exit from the network in New York on the same day. The model can measure travel time between origins and destinations in the network, but cannot represent variations in that time from day-to-day. The average day's input trip table is an average for any day during a year; therefore, the model does not measure seasonal variations in daily traffic.

Figure 7-1 shows the representation of the national rail network in R-NAS. The rail lines represented are the major corridors for long distance freight movements. NISAC has eliminated many of the minor lines used for local movements in specific areas of the country.

Figure 7-1: Representation of national rail system

To integrate international movements of containers with the domestic rail network model, NISAC has made a series of enhancements to the network representation for the 13 major ports. These enhancements allow representation of capacity restrictions at the port facilities, possible diversions of container traffic among ports, connections of the ports to the domestic rail network, and provision of truck links for containers that move domestically by truck rather than by rail. Figure 7-2 illustrates the general structure of the network modifications in the vicinity of each port. The additions to the network focus on a node for imports entering the system, a node for exports leaving the system, a link to represent the movement (and delays) for containers through the port, and connections to both the rail system and trucking.

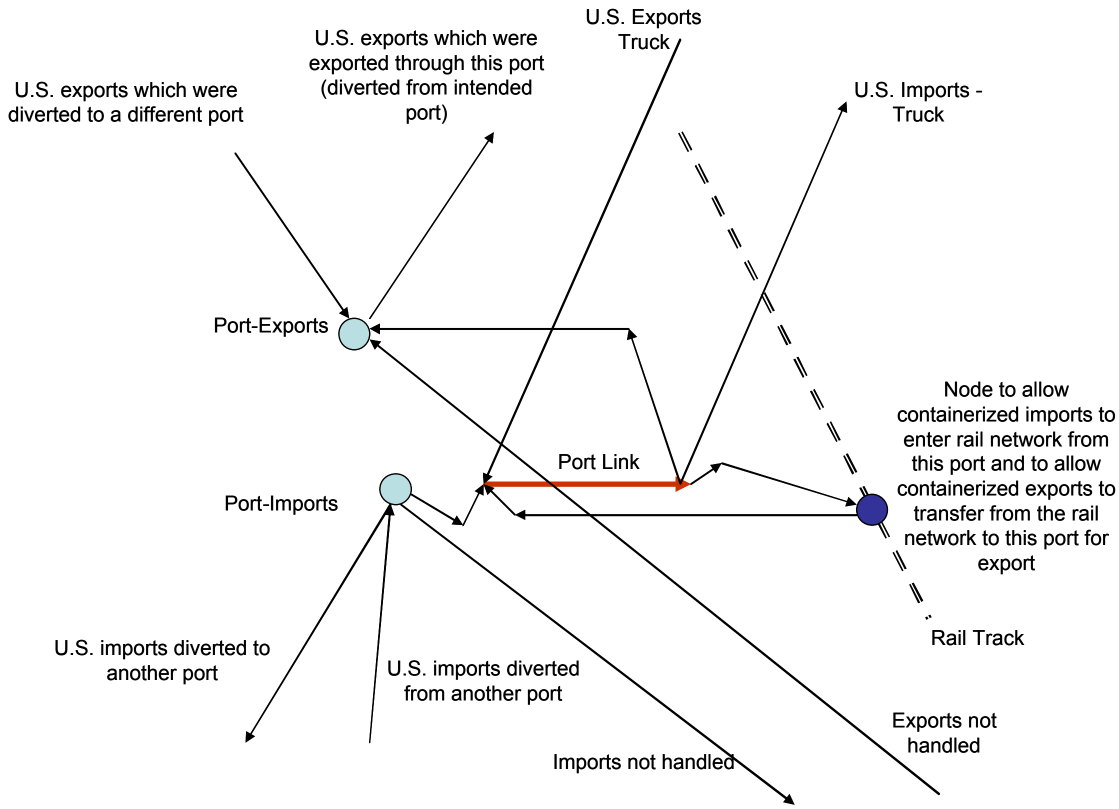

Figure 7-2: Network "wiring diagram" for U.S. ports to be connected to rail network

A container being imported to the U.S. enters the network at the "Port Imports" node. Normally, it will flow directly to the input side of the port link, through the port, and then out to either the truck link or onto the rail network. The truck links terminate in a "sink" node at the destination TAZ. The current model does not represent the highway network explicitly. The rail connection puts the container on the national rail network, as represented in Figure 7-1.

If there is severe delay in the port (or the port is completely closed), containers may be diverted to other ports. If all ports on a given coast are closed, an "overflow" link in the model allows it to track containers that are not handled at all.

Export containers arrive either via rail or truck and also enter the port link. Once they pass through the port, they are routed to the "Port Exports" node, which serves as the destination. If the export containers had to be diverted through another port, they are "moved" to the desired port export node as their ultimate destination, and the model tracks that they were really exported through an alternate port. In addition, export containers that could not be handled at all (perhaps because all ports are closed) are moved via the "overflow" links from origin TAZs to their destination nodes. Of course, these containers do not really move physically. They "move" in the network model over the overflow links so that the number of them can be tracked.

The port facility itself is represented by a single one-way link, so that all containers that are handled by the port (whether imports or exports) are counted and used as the basis for computing total volume through the port (and associated delays). The estimation of port delay functions for these links is a central part of the R-NAS model extension, and this process is described in detail in Section 8.

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8 Estimating Port Delay Functions

NISAC's approach to analyzing delays to cargo at container ports was to develop a queuing model to represent the process of loading and unloading containers from ships at specific ports. This is an approximation to the true delays because it is limited to dockside activities and does not consider the effects of capacity in the container yards on the land side of the terminal or the ability to transfer containers to and from rail facilities at the port. However, dockside operations are typically a limiting factor in port performance and represent a critical predictor of overall delays.

NISAC focused on the Port of Los Angeles because it is the largest of the seaports and has the best available data. The Port of Los Angeles has 8 terminals operated by various terminal companies. Each terminal has vessel berths, gantry cranes for loading/unloading ships, container yard facilities for staging and storing containers, and so forth. Different sets of ocean carriers have agreements with each terminal operator for use of their facilities. Table 8-1 summarizes important characteristics of the Port of Los Angeles terminals.

Table 8-1: Description of the terminals at the Port of Los Angeles[37]

Terminal Number	Terminal	Shipping Lines	Number of Cranes	Approximate Number of Vessel Calls in 2005
1	West Basin Container Terminal	China Shipping, Yang Ming, K-Line, Cosco, Hanjin, Sinotrans, Zim	4	a
2	West Basin Container Terminal	China Shipping, Yang Ming, K-Line, Cosco, Hanjin, Sinotrans, Zim	8	a
3	Trans Pacific Container Service Corp.	Mitsui, China Shipping, Norasia, Compania Sudamerica de Vapores, Zim, Wan Hai, APL, Hyundai Merchant Marine Co., CMA-CGM	11	a
4	Port of Los Angeles Container Terminal	N/A	4	75
5	Yusen Terminal	NYK, OOCL, Hapag-Lloyd	10	111
6	Seaside Terminal	Evergreen, Hatsu Marine Ltd., Italia Marittima	8	217
7	APL Terminal/Global Gateway South	APL, Hyundai, MOL, ANZDL, Fresco, HamburgSud, Maersk	12	a
8	APM Terminals/Pier 400	Maersk, Horizon	14	a

[37] Port of Los Angeles, 2007, "Container Terminals," http://www.portoflosangeles.org/facilities_Container.htm and U.S. Maritime Administration (2006). *Vessel Calls at U.S. Ports 2005*, Washington

Notes: [a] There were 933 total vessel calls among terminals 1, 2, 3, 7 and 8 but because of overlapping usage, data on how many occurred at each terminal individually are unavailable.

The Port of Long Beach is adjacent to the Port of Los Angeles and has 6 terminals. It has the same number of gantry cranes, 71, as Los Angeles.[38] Given the similarities in the traffic and terminal capabilities at these 2 adjacent seaports, NISAC focused on the Port of Los Angeles, with the understanding that similar conclusions are valid for the Port of Long Beach.

In general, the rate-limiting step in handling containers at ports is the rate at which the gantry cranes can unload and then reload the vessels. The key measure of capacity for a crane is the number of lifts per hour (LPH) that it can accomplish. NISAC's focus in this analysis was on the effective capacity of the cranes at dockside. The consequence of reduced effective capacity is increased delay to the vessels, both because unloading and reloading take longer and because they must wait longer for an available berth. This can be modeled using queuing theory and results in a nonlinear relationship, as indicated generically in Figure 8-1.

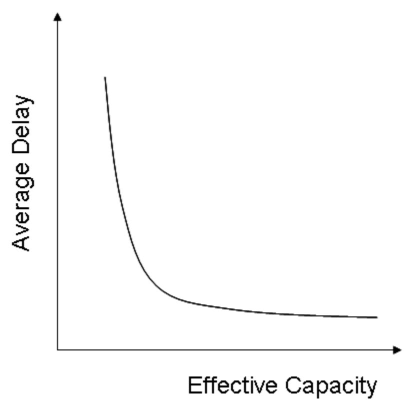


Figure 8-1: Generic relationship between effective crane capacity and average ship delay

The expected time required to process a ship (that is, berth the ship, unload the inbound containers, load the outbound containers, and have the ship leave the berth) can be estimated based on the total number of inbound and outbound containers, the total number of cranes assigned, the LPH of the cranes, the fraction of the containers that are 40-foot containers versus 20-foot containers, and the amount of time needed to position the ship at the berth and to move the ship from the berth. This relationship is given in Equation (21).

Service Time = [(TEUs to lift)/(1+fraction of 40 foot containers)]/
(# cranes assigned*LPH) + ship positioning time Equation (21)

A similar formula is used by both Turner[39] and Pachakis and Kiremidjian[40]. Equation (21) assumes that containers are either 20-foot or 40-foot containers. As described in Section 2, more than 90

[38] Port of Long Beach, 2007, "Container Trade in TEUs, Yearly TEU Totals," http://www.polb.com/about/port_stats/yearly_teus.asp, accessed 19 July

[39] Turner, H., 2000, "Evaluating Seaport Policy Alternatives: A Simulation Study of Terminal Leasing Policy and System Performance," *Maritime Policy and Management*, Vol. 27, No. 3, 283–301

[40] Pachakis, D., and A. Kiremidjian, 2003, "Ship Traffic Modeling Methodology for Ports," *Journal of Waterway, Port, Coastal and Ocean Engineering*, Vol. 129, Issue 5, 193–202

percent of containers are in these 2 categories at west coast ports, based on the data assembled by the PMA.[41] At Los Angeles, 72 percent of containers are in the 40-foot category. On the east coast, the Port of New York and New Jersey reports that from 2000 to 2005 about 70 percent of their containers were 40-foot.[42] Thus, there appears to be relative consistency across ports. As illustrated by Equation (21), this statistic is important because it takes about the same amount of time to lift a 20-foot container as to lift a 40-foot container. NISAC assumed that the time required to position the ship at the berth and to move it from the berth afterwards is a total of 3 hours. This is consistent with estimates given by Turner.[43]

The actual service time for a ship may vary from the value given in Equation (21) for a variety of reasons (crane breakdowns, crews not ready on time, other equipment problems, and so forth), but the largest source of variation in service times across processing of many vessels is the variation in the number of TEUs to lift for different ships. NISAC estimated this variation using data on vessel calls at the Port of Los Angeles for 2005.[44]

Figure 8-2 shows container vessel calls at Los Angeles for each month in 2005, the most recent year for which a full data set was available. Notice the relatively smaller values in the winter months and the peak in October. The general pattern across the year is also reflected in the number of TEUs handled by the port for the same time, as shown in Figure 8-3.[45]

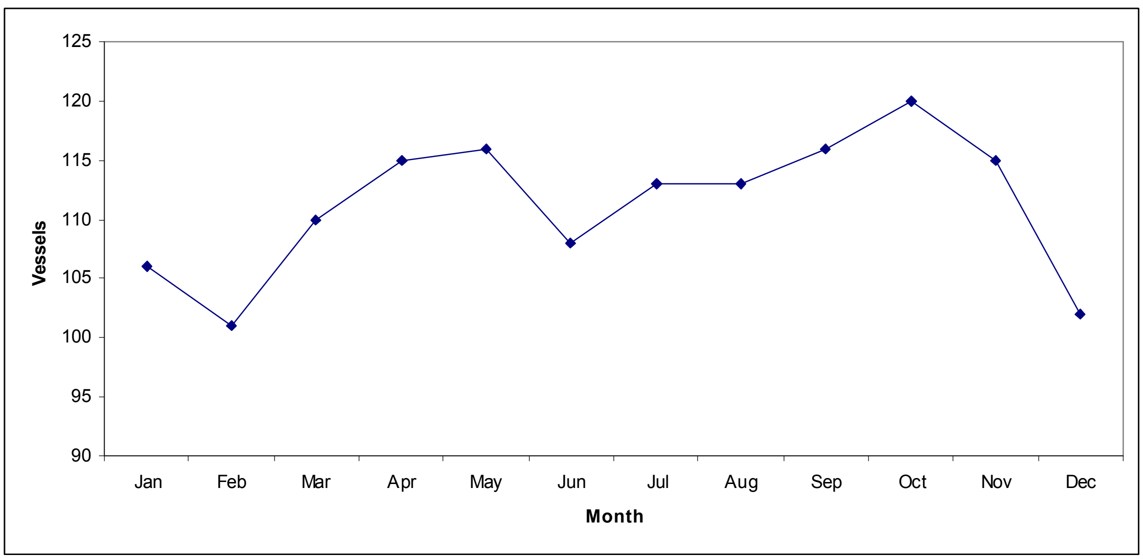


Figure 8-2: Monthly container vessel calls at Los Angeles in 2005

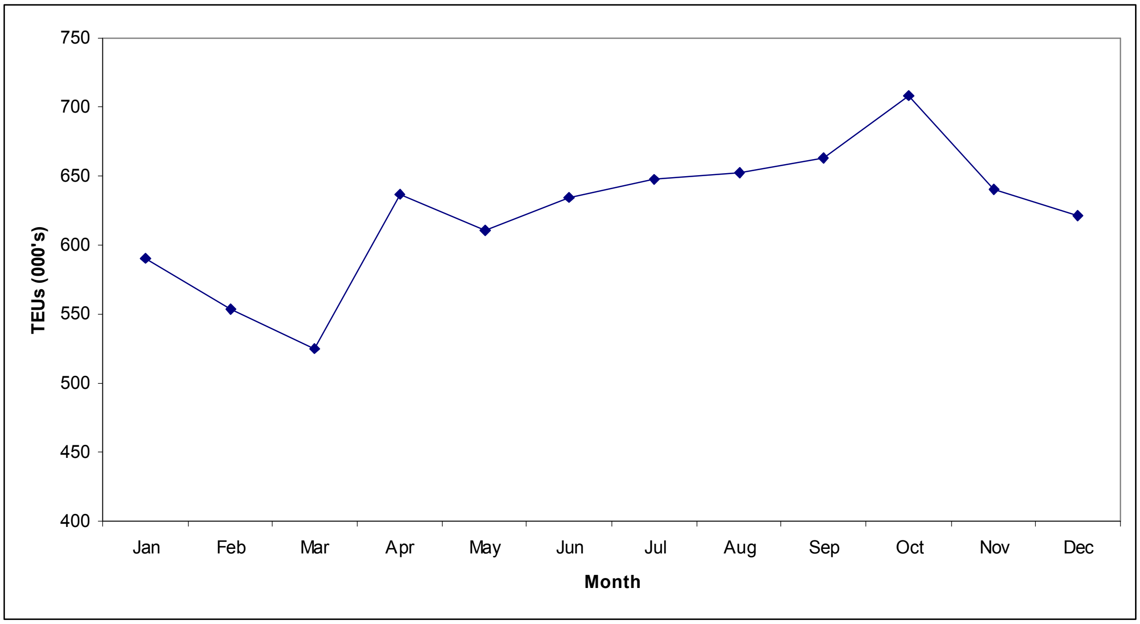
[41] PMA (Pacific Maritime Association), 2006, "2005 Annual Report: Statistical Information," accessed online at www.pmanet.org on 27 July

[42] Port of New York and New Jersey, http://www.panynj.gov/DoingBusinessWith/seaport/html/trade_statistics.html, as accessed in March 2007

[43] Turner, H., 2000, "Evaluating Seaport Policy Alternatives: A Simulation Study of Terminal Leasing Policy and System Performance," *Maritime Policy and Management*, Vol. 27, No. 3, 283–301

[44] U.S. Maritime Administration, 2006, "Vessel Calls at U.S. Ports 2005," Washington, DC

[45] Port of Los Angeles, 2007, "2005 TEU Statistics," http://www.portoflosangeles.org/factsfigures_Annual_2005.htm, accessed 19 July



Note: TEU = twenty-foot equivalent unit

Figure 8-3: Monthly twenty-foot equivalent units (TEUs) handled at Los Angeles in 2005

Using size information for the individual vessels in the vessel call data (from MARAD) and the aggregate number of TEUs handled each month (as reported by the Port), NISAC estimated the variation in TEUs to lift per ship, and from this, the probability distribution for the service times, using Equation (21). For a distribution of vessel sizes within some time period, the expected service time is denoted by *E[S]* and the second moment of the distribution by *E[S2]*.

Several previous authors[46,47] conclude that the arrival process of ships at seaports can be effectively modeled as a Poisson process where the mean varies by month. NISAC used this approach, focusing on analysis reflecting both an average month (with approximately 111 vessel arrivals) and a peak month (October), as indicated by Figure 8-2.

For a given arrival rate, λ, expressed in vessels/hour, the queuing model formula for the expected vessel time in port is as follows:[48]

$$\frac{\lambda^k E[S^2](E[S])^{k-1}}{2(k-1)!(k-\lambda E[S])^2\left[\sum_{n=0}^{k-1}\frac{(\lambda E[S])^n}{n!}+\frac{(\lambda E[S])^k}{(k-1)!(k-\lambda E[S])}\right]}+E[S]$$

Equation (22)

Where:

k = the number of servers,

[46] Turner, H., 2000, "Evaluating Seaport Policy Alternatives: A Simulation Study of Terminal Leasing Policy and System Performance," *Maritime Policy and Management*, Vol. 27, No. 3, 283–301

[47] Pachakis, D., and A. Kiremidjian, 2003, "Ship Traffic Modeling Methodology for Ports," *Journal of Waterway, Port, Coastal and Ocean Engineering*, Vol. 129, Issue 5, 193–202

[48] Nozaki, S., and S. Ross, (1978, "Approximations in Finite-Capacity Multi-Server Queues with Poisson Arrivals," *Journal of Applied Probability*, Vol. 14, No. 4, 826–834

E[S] = the expected service time

E[S2] = the second moment of the service time

To use Equation (22) effectively, analysts must specify the number of servers, *k*, available to a given stream of arrivals. For the Port of Los Angeles, this means that the model needs to segregate vessel arrivals by shipping company (or groups of shipping companies), because the ships of a specific company can only use certain terminals, as indicated in Table 8-2. As shown in Table 8-2, terminals 4, 5, and 6 can be considered individually because the set of shipping lines using each terminal is different. However, terminals 1, 2, 3, 7, and 8 must be considered together because there is overlap in the shipping lines using those terminals and the shipping lines can generally use more than one of those terminals.

Terminal 4 has only 4 cranes, so it is reasonable to assume that they will all be assigned to each ship arrival. This implies that the queuing model for Terminal 4 will only have 1 server with 4 cranes. Terminal 5 has 10 cranes, so it is reasonable to assume that it will have 2 servers with 5 cranes each. Terminal 6 has 8 cranes, so it is reasonable to assume that it has 2 servers with 4 cranes each. Terminals 1, 2, 3, 7, and 8 are to be modeled together, so it is reasonable to assume that there are 12 servers across all 5 terminals with 4 cranes each.

As of 2005, Terminal 6 operated 24 hours per day, but all other terminals operated only 2 shifts, or 16 hours per day. To incorporate the effects of the 16-hour day into the queuing model, NISAC estimated the raw service time (continuous) based on Equation (21) and added 8 hours to the service time for each increment of 16 hours needed beyond the first 16 hours.

To calibrate the queuing models of the Port of Los Angeles, NISAC used the vessel movement files available from the MARAD.[49] That dataset records the day of entrance and exit for each vessel call at every U.S. port. The latest year for which those data are available is 2005. Figure 8-4 shows a histogram of the number of days in port for ships entering the Port of Los Angeles in 2005. This average time from these data is comparable to the expected time-in-system estimate provided by Equation (21) and gives analysts a basis for evaluating the queuing model. However, since NISAC is separating the models by terminal (or groups of terminals), the evaluation is based on disaggregated data for the appropriate groups of shipping lines.

[49] U.S. Maritime Administration, 2007b, "Vessel Movement Files for 2005," Washington DC

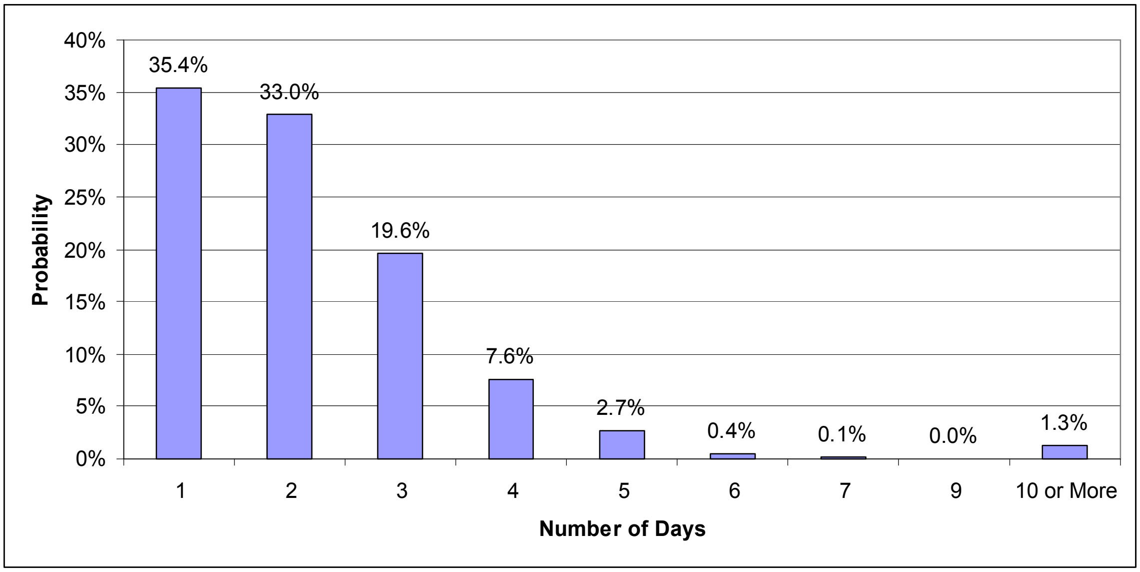
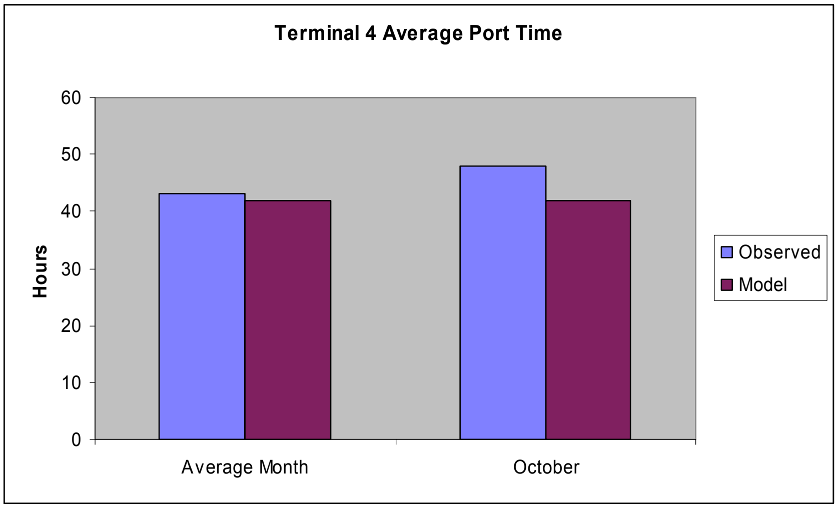
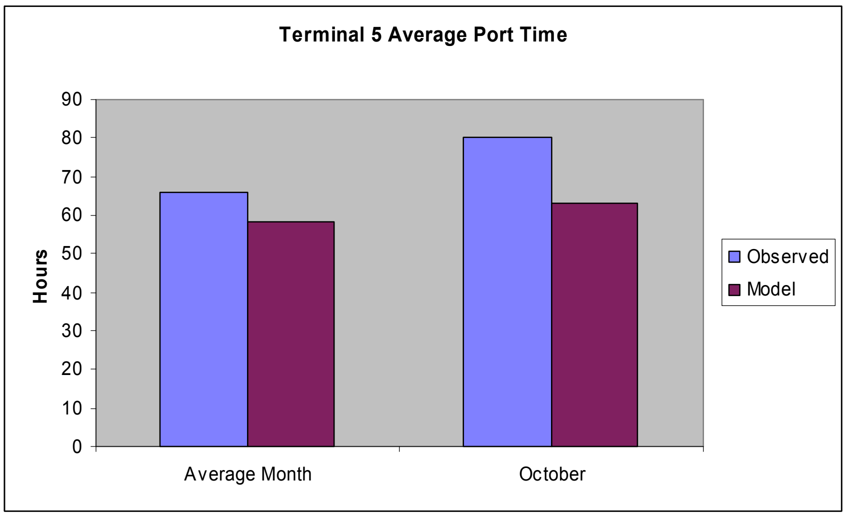


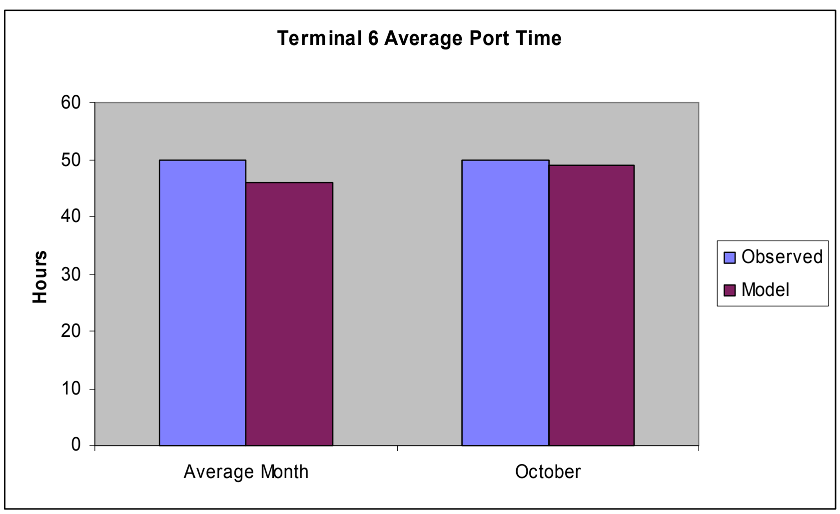
Figure 8-4: Histogram of days in port for container ships in Los Angeles in 2005

NISAC also built separate analyses for an average month during 2005 and for the month of October, because that month is the peak period for the port as a whole (although not necessarily for all individual terminals within the port).

Figure 8-5 presents a comparison of the mean time in port from the vessel movement files to the values predicted by the queuing models for the 4 terminal subsets. In general, there is good agreement between the queuing models and the observed values. The models of terminal 5 have the largest discrepancy. The under-prediction of time in port in Terminal 5 indicates that NISAC is over-estimating the capacity of that terminal. However, the overall fit of the queuing models appears to be reasonably accurate.


Terminal 4 Average Port Time
Hours
60
50
40
30
20
10
0
Average Month
October
Observed
Model


Terminal 5 Average Port Time
Hours
90
80
70
60
50
40
30
20
10
0
Average Month
October
Observed
Model


Terminal 6 Average Port Time
Hours
60
50
40
30
20
10
0
Average Month
October
Observed
Model

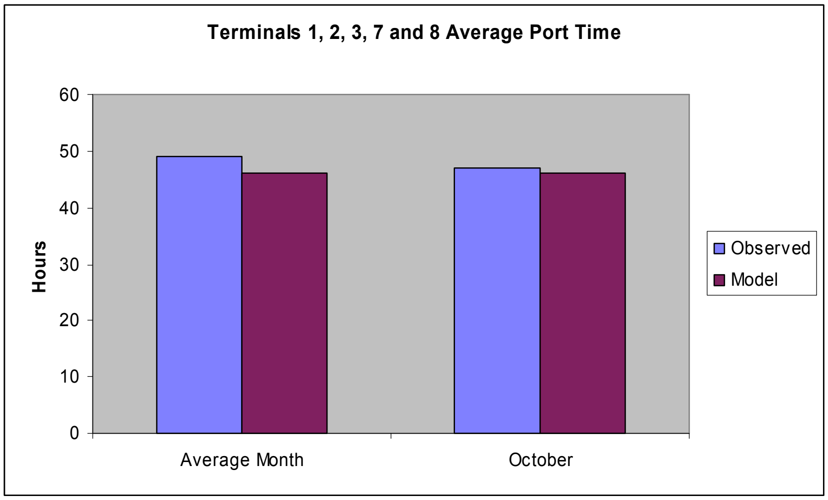


Figure 8-5: Comparison of average time in port (model versus observed) for the 4 terminal queuing models

The model calibration is based on 2005 data because 2005 the most recent year for which full datasets are available. However, TEUs handled at the Port of Los Angeles rose 13 percent from 2005 to 2006. If NISAC assumes that the same growth rate continues into 2007, the total number of TEU's handled at the port would rise to 9.6 million in 2007. In addition, all terminals at the Port of Los Angeles now operate 24 hours per day. For analysis of the scenarios, analysts have increased the overall demand level to 9.6 million TEUs and based the terminal service times on 24-hour operation.

The queuing analysis summarized in Equation (22) is the basis for a general delay curve for port operations, and can be integrated into the overall network model as the delay on the port link (in Figure 7-2), and represented as the $t_{ij}(x_{ij})$ function (see Equation 15) for the port links.

The Port of New York and New Jersey, in the New York City area, has a lower total volume of containers than the Los Angeles/Long Beach ports and a slower growth rate, but it has tighter constraints on expansion and a different set of capacity issues. NISAC has anecdotal data (from conversations with port officials) that the capacity-limiting element of the New York/New Jersey port is the container yard rather than the dockside operations. However, they have been unable to provide NISAC with hard data on which to base an analysis of this issue.

8.1 Intermodal Transfers

Beyond the process of unloading and loading containers at the dockside, there is potential concern about the transfer process through which these containers move from the port terminal to truck or rail for delivery across the nation. The severe congestion in Los Angeles/Long Beach that occurred in 2004, for example, had roots in both the rail system and in the port facilities themselves.[50] The inability to move containers through the port and away to their destinations by truck or rail can result from limitations in any step of that overall process.

NISAC has focused on the dockside operations because they are typically rate-limiting. Over the past 2 years, the change to 24-hour operations at the dockside in Los Angeles/Long Beach has been

[50] Machalaba, D., 2004, "Railroad Blues: Woes at Union Pacific Create a Bottleneck for the Economy," *Wall Street Journal*, 22 July 2004, page A1; Mongelluzzo, B., 2004, "From Bad to Worse in LA-Long Beach; Truckers Remain Unhappy about Delays at Southern California Ports," *Journal of Commerce*, 27 September 2004, p. 16.

accompanied by expansion to 24-hour gate operations on the land side of the terminals to help move containers more effectively into and out of the terminal area. Both Los Angeles and Long Beach have also increased the proportion of dockside rail loading, so that more containers are placed directly on rail cars at the dock and a labor-intensive intermediate handling of the containers is eliminated. These changes help the intermodal transfer process capacity keep pace with the unloading/loading capacity at dockside, and NISAC's focus on dockside operations remains appropriate. However, under some conditions, the bottleneck in port operations could shift to the container yard or intermodal transfer. In such an event, the delays might be worse than what NISAC has forecast here, but such an event would likely be of short duration. In general, the dockside operations are most likely to be the rate-limiting step in the operations.

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9 Conclusions

The focus of this effort is to examine the portion of the freight transportation system that moves containerized cargo by sea into the U.S. from foreign origins and from U.S. origins to foreign destinations. This document describes the results of the first of a two year effort to enhance the transportation modeling capability of NISAC. A primary element of the work has been to establish the intermodal connection of those movements to domestic movement of the containers within the U.S. The analysis includes both import flows and export flows through U.S. seaports, but the analysis does not include land-based imports from (and exports to) Canada and Mexico.

A major step in the project is analysis of available data on container movements. Data come from a variety of sources and are not always consistent. In this analysis, NISAC attempted to integrate data from 8 different sources:

- MARAD data on waterborne container imports and exports
- PIERS Global Intelligence Solutions® data for imports to the U.S.
- AAPA data on containers handled at ports
- PMA data on containers handled at west coast ports
- AAR data on intermodal carloadings by U.S. railroads
- STB Rail Waybill Sample data
- Data on domestic container volumes published by the IANA
- Data reported by individual port authorities and railroads through their websites and publications

The most recent data available from these different sources are not necessarily from the same year. For example, the PIERS data are for 2004, the AAR data are for 2005, the STB Waybill Sample is from 2003, and most port authorities currently report data through 2006. In a rapidly growing market, variations of 2 to 3 years in which data were collected can result in significant inconsistencies.

The modeling elements of the project include 4 major steps:

- Estimation of an O-D table for import container movements
- Estimation of an export O-D table
- Extension of the R-NAS model to include port facilities and container movements, with connections to both the domestic rail network and trucking movements
- Development of volume-delay curves to reflect the effects of capacity limitations in port facilities, particularly in Los Angeles and Long Beach

Completion of both the data analysis and the modeling work has created a capability for impact analysis of a variety of scenarios involving potential disruption of current operations in the ports, on the rail network, and in the intermodal connections. Such scenarios might reflect possible security-related incidents, occurrence of natural disasters, or reductions in capacity related to labor disruptions.

The goal of the first year's effort was to create the capability to perform such analyses, not to examine any specific potential scenarios. This goal has been met, and year 2 of the project will focus on using the modeling capability to examine a wide variety of situations of interest.

Appendix A: Estimated O-D Table for Imports

The following table presents the import flows of containers (summarized by port of import) from the O-D table estimation process. The units of flow are TEUs per year. The destination points (TAZs) are listed by National Transportation Analysis Region (NTAR) number. There are 84 destinations, but their numbers are not sequential. The table following the O-D table lists the cities associated with the NTAR numbers. These cities serve as the zone centroids for the TAZs.

Destination	US Port of Import										
NTAR	BALTIMORE	CHARLESTON	HOUSTON	LA-LONG BEACH	MIAMI	NEW YORK	NORFOLK	OAKLAND	PT EVERGLADES	SAVANNAH	SEATTLE-TACOMA
2	0	37	0	4756	922	6063	0	0	140	0	27143
4	0	725	0	199901	6766	103022	0	870	2923	2196	71280
7	0	0	0	8240	1760	27066	0	0	281	0	11958
8	0	204	0	1601	1138	19684	0	0	123	231	42970
9	0	0	0	12260	393	19881	0	0	839	0	28276
10	18525	5043	310	9188	472	52	0	201	1886	0	40967
12	0	1428	1654	325184	12264	1224030	0	4617	16746	4508	37754
16	15070	4243	0	82103	3685	14797	0	0	1248	0	13710
17	24577	2037	0	49397	298	157	694	1204	2502	0	152
18	10457	347	207	2931	7523	1298	365774	870	5979	4162	228
19	48306	161997	207	11475	19989	0	6705	1271	5128	3584	255591
21	0	20917	0	43255	238	0	0	0	4112	2995	5608
22	0	61830	0	52	825	0	0	0	2130	0	0
23	0	23530	0	1172	857	0	42823	268	3026	2543	0
24	0	26541	0	21	779	0	0	0	383	0	0
25	0	29304	0	22	655	0	0	0	801	0	0
27	0	109375	0	82	1375	0	0	0	3072	0	0
28	0	21175	0	821	1403	578	0	0	2687	45200	0
29	0	30266	0	8793	1582	0	0	268	4507	60719	228
31	0	19990	0	61	1676	0	0	0	3946	58127	0
32	0	18411	0	44	986	0	0	0	3102	39240	0
34	462	16575	0	1290	1183	925	1387	0	331	4277	0
36	116	43581	21776	145882	29831	17224	1156	1338	1470	96475	304
39	694	1272	0	293	929	925	694	0	2096	20182	0
41	17918	6358	0	7328	9267	31212	1965	1606	36414	22324	228
42	925	3121	0	109	29978	1850	694	201	12777	103547	0
43	2428	6705	103	2110	190385	9942	462	401	44820	7514	0
44	2890	4855	0	410	43873	1850	0	268	14963	101888	0
47	347	925	26499	18022	0	0	0	134	2811	1734	0
49	0	4509	966	91790	13773	116	0	7093	8697	3134	1290
51	4490	2764	110	17174	430	19	0	0	522	573	2549
53	0	8374	20	37648	3698	0	0	0	2365	3436	0
54	0	14334	2701	84523	1530	347	347	0	2696	6589	0
55	0	12408	1033	52384	733	73	43558	0	1794	7577	0
57	0	4046	0	55346	986	347	29362	0	1218	4277	4629
58	0	81	18	37181	4907	0	231	0	2059	7834	0
65	1365	15425	415	22645	2681	22542	16415	0	6480	1841	113435
66	0	0	103	4119	1217	47512	42888	335	1346	0	15689
67	0	1503	0	71338	3393	1272	25663	67	345	6358	0
68	0	30	293	33442	4931	0	0	0	0	7444	0
70	0	5170	387	2081	3018	6358	0	0	0	0	34155
71	2081	51273	2922	196975	14487	22080	7745	134	0	4399	40948
73	0	8560	8965	61407	768	57	0	0	1144	210	7785
76	0	6682	4766	2857	3702	0	0	0	1712	759	46864
79	0	0	14907	118453	3220	20346	463	0	0	0	0
83	31311	134	11988	74220	679	265129	7511	249234	7081	896	0
89	2133	177	0	120680	1845	44110	0	0	0	180	34
94	4328	0	0	49761	743	14106	0	268	0	578	682
95	139	0	0	10124	123	3229	0	0	0	17	4
96	13693	0	0	122814	3012	60821	2428	2610	0	393	95922
104	1463	0	0	72241	1066	23894	309	13	0	0	17
105	925	578	0	112013	0	26588	9072	0	0	347	0
107	1156	231	827	105517	1021	30981	21302	11376	0	116	23981
108	0	2558	13	27585	211	110	6369	0	0	76	0
111	0	4354	40	41690	353	34	9988	0	0	119	0
112	0	5387	0	33952	229	31	9153	134	0	116	0
113	0	10288	7234	155742	0	462	347	0	809	14334	0
122	0	3253	76458	245932	805	925	11725	28506	3767	2522	1366
123	0	402	17691	66102	0	51	152	0	461	482	0
125	231	4999	1137	370603	358	12832	7396	37740	0	809	10397
129	231	0	18866	71506	73	578	161	870	0	0	152
131	0	196	8106	31674	33	25	74	0	0	0	0
133	0	919	10544	59058	341	116	101	0	0	302	0
137	0	3433	3428	77915	409	578	10371	0	62	0	0
138	0	3229	31	64969	490	255	17363	0	0	176	0
139	0	114	172	40083	221	8866	0	10	0	0	0
143	0	192	0	61180	52	19149	0	669	0	0	16316
146	102	0	0	27873	16	7465	96	0	0	0	10
152	0	48	0	29879	323	7923	0	0	0	70	228
153	0	0	0	37450	399	5970	0	0	0	0	758
157	16986	0	13332	222541	144	16856	0	9770	0	0	17985
160	0	739	7687	48857	140	313	12	1874	30	0	0
162	0	0	9621	232915	839	1040	45	0	0	0	0
163	116	0	0	146330	0	231	0	32	0	0	0
165	0	0	4857	111158	300	475	0	11268	43	0	1062
167	0	0	0	87388	30	9931	0	0	0	0	14293
171	0	0	6821	20124	2996	1413	116	4483	0	2913	289348
172	244	0	5994	210682	52	71	0	3413	0	0	152
176	0	116	30591	479817	0	6820	925	213958	0	0	759
177	0	0	0	13480	0	4	0	70	0	0	0
178	0	0	0	147032	41	11	116	308	0	0	0
179	0	0	0	61815	19	116	116	13	0	0	0
180	116	462	190376	888494	0	9132	462	9368	0	0	3491
181	0	0	0	202844	65	59	30	0	0	0	0

NTAR ID	City
2	Portland
4	Boston
7	Albany
8	Syracuse
9	Rochester
10	Buffalo
12	New York
16	Pittsburgh
17	Harrrisburg
18	Philadelphia
19	Baltimore
21	Roanoke
22	Richmond
23	Virginia Beach
24	Greenville
25	Wilmington
27	Raleigh
28	Greensboro
29	Charlotte
31	Asheville
32	Columbia
34	Charleston
36	Atlanta
39	Savannah
41	Jacksonville
42	Orlando
43	Miami
44	Tampa
47	Mobile
49	Birmingham
51	Chattanooga
53	Knoxville
54	Nashville
55	Memphis
57	Louisville
58	Lexington
65	Cleveland
66	Columbus
67	Cincinnati
68	Dayton
70	Toledo
71	Detroit
73	Grand Rapids
76	Fort Wayne
79	Indianapolis
83	Chicago
89	Milwaukee
94	Green Bay
95	Duluth
96	St. Paul
104	Des Moines
105	Kansas City
107	St. Louis
108	Springfield
111	Little Rock
112	Jackson
113	New Orleans
122	Houston
123	Austin
125	Dallas
129	San Antonio
131	Corpus Christi
133	El Paso
137	Oklahoma City
138	Tulsa
139	Wichita
143	Omaha
146	Sioux Falls
152	Fargo
153	Billings
157	Denver
160	Albuquerque
162	Phoenix
163	Las Vegas
165	Salt Lake City
167	Spokane
171	Seattle
172	Portland
176	San Jose
177	Redding
178	Sacramento
179	Fresno
180	Los Angeles
181	San Diego

Appendix B: Estimated O-D Table for Exports

The following table presents the export flows of containers (summarized by port of export) from the O-D table estimation process. The units of flow are TEUs per year. The origin points (TAZs) are listed by NTAR number.

Origin	Port of Export									
NTAR	BALTIMORE	CHARLESTON	HOUSTON	LA-LONG BEACH	MIAMI	NEW YORK	NORFOLK	OAKLAND	PT EVERGLADES	SAVANNAH	SEATTLE-TACOMA
2	0	112	0	473	234	0	0	379	327	52	2511
4	3344	15726	4729	358528	977	14797	3000	1775	14982	15	39996
7	561	997	803	20823	1323	0	28	65953	1257	844	4983
8	0	0	1707	897	1994	0	91	1990	12	630	79257
9	0	0	1842	5311	36	0	0	63976	748	185	4906
10	0	0	2541	80211	118	0	0	1677	462	221	8800
12	170177	151320	10569	4534	13063	1263376	81608	4969	77542	136148	60256
16	0	0	0	67217	1397	14912	0	2783	1532	0	91733
17	0	674	2301	84793	1965	1040	0	6389	2339	244	4369
18	0	601	1370	1323	709	0	494231	1656	4487	1295	122
19	0	461208	5256	1473	12647	0	122025	118	24158	95208	0
21	0	156	0	946	1829	0	0	0	4561	84143	0
22	0	57236	0	843	1168	0	4468	0	3804	16844	0
23	0	809	469	217	1625	0	96147	118	2795	1195	122
24	0	28065	0	340	1716	0	0	0	930	3367	0
25	0	29676	0	381	903	0	0	0	1852	5895	0
27	0	102753	0	1308	4873	0	0	0	3127	28903	0
28	0	0	0	5234	2228	8554	0	0	4661	64138	245
29	0	5664	0	7425	1249	0	0	947	8456	105930	612
31	0	0	102	1028	2658	0	0	0	5847	92360	0
32	0	313	0	749	2610	0	0	0	4388	67906	0
34	5780	2900	222	72	16878	0	1965	0	304	5697	0
36	0	46818	21224	22518	39766	29825	231	1420	9942	248489	1591
39	7976	2081	0	77	16300	694	1156	0	10	5797	0
41	0	1503	0	4869	55943	0	0	0	114383	1734	122
42	0	0	0	426	43405	1850	0	0	78636	45147	0
43	3237	8208	0	243	195593	8323	0	592	109626	4046	122
44	0	2196	1685	481	137240	0	0	0	42488	5159	0
47	0	2312	54092	271	52	0	0	0	34	5433	0
49	0	8439	12126	92140	4162	1387	0	4023	63	4854	122
51	0	0	933	32571	0	0	0	604	174	80	1739
53	0	0	3254	56096	385	0	0	0	2738	231	0
54	0	35836	20211	84138	0	1503	0	0	389	9017	0
55	0	58612	5780	475	4118	0	45841	0	44	30631	0
57	0	7514	0	65760	116	347	46356	0	27	3237	979
58	0	0	234	63434	355	0	0	0	572	42	0
65	0	0	1752	179224	355	27628	13641	190	41	0	27194
66	0	0	976	47518	0	47627	27975	637	955	0	11709
67	0	4508	762	100222	3006	1156	23929	592	26	1040	0
68	0	0	1870	58549	95	0	0	0	11	0	0
70	0	0	456	316	96	4277	0	947	11	0	60105
71	4277	0	1684	77794	116	36183	19074	270089	68	0	26495
73	0	0	872	86314	0	0	0	36455	20	0	587
76	0	0	2185	1369	0	0	0	2165	15	0	84176
79	0	347	0	173397	0	21039	19074	0	43	0	0
83	146581	0	37108	0	8767	390628	110009	113702	144	0	0
89	0	0	0	457	2129	198311	7196	0	20	325	0
94	0	0	0	191	281	84908	1247	0	13	0	48
95	0	0	0	38	42	456	183	0	0	0	16062
96	116	0	116	25683	1129	12708	7417	9229	17	0	315172
104	0	0	0	349	1011	119009	2049	0	21	0	0
105	1734	116	1526	177907	1294	82	1223	0	0	0	0
107	2081	844	6275	93968	2903	36183	62502	26267	56	1643	14198
108	0	0	1791	44120	524	0	320	0	11	84	0
111	0	0	68550	282	662	0	506	0	21	211	0
112	0	28169	1104	730	722	347	1110	0	0	23865	0
113	0	25779	4740	174546	14797	116	0	2974	0	11328	0
122	0	0	372	484663	0	116	0	328	0	0	308
123	0	0	31160	71777	0	0	734	0	0	0	0
125	0	6127	17986	412121	3352	8323	0	100572	0	3699	9180
129	116	0	6998	104986	231	925	231	592	0	116	0
131	0	0	47075	1696	0	116	246	0	0	0	0
133	0	0	4046	85354	0	462	231	237	0	0	0
137	0	0	863	119058	0	0	816	945	0	0	0
138	0	0	7139	99392	116	0	757	426	0	0	0
139	0	0	508	61251	0	0	419	0	0	0	0
143	0	0	231	81709	0	301	804	13843	0	0	25704
146	0	0	92	270	0	112	291	0	0	0	43371
152	0	0	0	487	0	262	304	0	0	0	46649
153	0	0	0	359	0	111	321	0	0	0	53593
157	116	0	4508	346209	0	0	542	11004	0	0	10404
160	0	0	0	73918	0	1272	0	0	0	0	0
162	0	0	1272	303436	0	2543	0	0	0	0	0
163	0	0	756	177880	0	116	962	0	0	0	0
165	116	0	7167	121774	0	2890	0	28042	0	0	245
167	0	0	454	854	0	0	776	0	0	0	137834
171	0	0	1850	1902	231	231	917	58	0	0	407595
172	694	0	1618	13754	0	462	0	0	0	0	197556
176	1387	0	63811	443377	694	4508	231	381218	0	0	9914
177	0	0	35	16282	0	0	96	11	0	0	0
178	0	0	709	175907	0	0	1023	67	0	0	0
179	0	0	313	75001	116	0	440	0	0	0	0
180	11098	462	513380	759609	4624	28553	347	14790	0	116	21665
181	0	0	1088	243537	0	0	1452	0	0	0	0

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Appendix C: Rail O-D Table for Imports

The following table presents the import flows of containers (summarized by port of import) that move domestically by rail. The units of flow are carloads per year.

Destination					US Port of Import						
NTAR	BALTIMORE	CHARLESTON	HOUSTON	LA-LONG BEACH	MIAMI	NEW YORK	NORFOLK	OAKLAND	PT EVERGLADES	SAVANNAH	SEATTLE-TACOMA
2	0	0	0	1563	0	0	0	0	0	0	8870
4	0	0	0	65692	0	12288	0	294	78	726	23294
7	0	0	0	2708	0	0	0	0	0	0	3908
8	0	0	0	526	0	1789	0	0	0	76	14043
9	0	0	0	4029	0	0	0	0	0	0	9240
10	0	0	112	3019	0	0	0	68	0	0	13388
12	0	389	597	106863	0	119	0	1561	272	1490	12338
16	0	0	0	26981	0	5090	0	0	0	0	4480
17	0	0	0	16233	0	40	236	407	0	0	50
18	0	117	75	963	0	40	0	294	855	1375	74
19	0	2137	75	3771	0	0	2280	430	428	1184	83526
21	0	0	0	14214	0	0	0	0	0	0	1833
22	0	0	0	17	0	0	0	0	0	0	0
23	0	932	0	385	0	0	0	91	0	840	0
24	0	0	0	7	0	0	0	0	0	0	0
25	0	0	0	7	0	0	0	0	0	0	0
27	0	0	0	27	0	0	0	0	0	0	0
28	0	0	0	270	0	199	0	0	0	0	0
29	0	1360	0	2890	0	0	0	91	0	1490	74
31	0	0	0	20	0	0	0	0	0	0	0
32	0	0	0	15	0	0	0	0	0	0	0
34	176	0	0	424	0	318	472	0	39	1413	0
36	44	14649	0	47940	0	5925	393	452	155	10467	99
39	265	428	0	96	0	318	236	0	0	0	0
41	6844	2137	0	2408	0	10737	668	543	12240	2407	74
42	353	1049	0	36	0	636	236	68	39	1604	0
43	927	2254	37	693	0	3420	157	136	7072	2483	0
44	1104	1632	0	135	0	636	0	91	0	2942	0
47	133	311	0	5923	0	0	0	45	0	573	0
49	0	1516	0	30164	0	40	0	2398	39	917	422
51	0	0	0	5644	0	0	0	0	0	0	833
53	0	0	0	12372	0	0	0	0	0	0	0
54	0	4818	0	27776	0	119	118	0	0	2177	0
55	0	4171	373	17215	0	25	14810	0	603	2504	0
57	0	1360	0	18188	0	119	9984	0	0	1413	1513
58	0	0	0	12218	0	0	79	0	0	0	0
65	88	0	75	7442	0	7754	5581	0	0	115	37070
66	0	0	37	1354	0	16344	14583	113	155	0	5127
67	0	505	0	23443	0	438	8726	23	39	2101	0
68	0	0	0	10990	0	0	0	0	0	0	0
70	0	0	0	684	0	2187	0	0	0	0	11162
71	795	0	0	64730	0	7595	2633	45	0	0	13382
73	0	0	0	20180	0	0	0	0	0	0	2544
76	0	0	0	939	0	0	0	0	0	0	15315
79	0	0	0	38926	0	6999	157	0	0	0	0
83	11960	45	4326	24390	0	91204	2554	84258	2380	296	0
89	815	60	0	0	0	15174	0	0	0	59	0
94	1653	0	0	96	0	4853	0	91	0	191	223
95	53	0	0	0	0	1111	0	0	0	5	0
96	5230	0	0	4065	0	20922	826	882	0	130	31347
104	559	0	0	48	0	8219	105	0	0	0	0
105	353	194	0	36810	0	9146	3085	0	0	115	0
107	442	78	298	21094	0	10657	7243	3846	0	38	7837
108	0	860	0	0	0	38	2165	0	0	25	0
111	0	1463	0	0	0	12	3396	0	0	39	0
112	0	1811	0	308	0	11	3112	45	0	38	0
113	0	3458	2611	51180	0	159	118	0	272	4737	0
122	0	1094	0	63071	0	318	3987	9637	1266	833	446
123	0	135	0	0	0	17	52	0	155	159	0
125	88	1680	410	121789	0	4414	2515	12759	0	267	3398
129	88	0	0	15257	0	199	55	294	0	0	50
131	0	66	0	0	0	8	25	0	0	0	0
133	0	309	1231	11770	0	40	34	0	0	100	0
137	0	1154	0	655	0	199	3526	0	21	0	0
138	0	1085	0	0	0	88	5904	0	0	58	0
139	0	38	0	0	0	3050	0	0	0	0	0
143	0	65	0	4623	0	6587	0	226	0	0	5332
146	39	0	0	0	0	2568	33	0	0	0	0
152	0	16	0	0	0	2726	0	0	0	23	74
153	0	0	0	0	0	2054	0	0	0	0	248
157	6488	0	4811	8977	0	5798	0	3303	0	0	5878
160	0	248	112	616	0	108	4	634	10	0	0
162	0	0	3095	154	0	358	15	0	0	0	0
163	44	0	0	0	0	79	0	0	0	0	0
165	0	0	1753	6396	0	164	0	3809	14	0	347
167	0	0	0	0	0	3416	0	0	0	0	25
171	0	0	2462	5432	0	486	39	1516	0	963	0
172	93	0	2163	10248	0	24	0	1154	0	0	50
176	0	39	11040	3448	0	2346	315	45	0	0	248
177	0	0	0	0	0	1	0	0	0	0	0
178	0	0	0	0	0	4	39	0	0	0	0
179	0	0	0	0	0	40	39	0	0	0	0
180	44	155	68703	58	0	3141	157	3167	0	0	1141
181	0	0	0	0	0	20	10	0	0	0	0

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Appendix D: Truck O-D Table for Imports

The following table presents the import flows of containers (summarized by port of import) that move domestically by truck to their destination. The units of flow are equivalent rail carloads per year.

Destination						U.S. Port of Import					
NTAR	BALTIMORE	CHARLESTON	HOUSTON	LA-LONG BEACH	MIAMI	NEW YORK	NORFOLK	OAKLAND	PT EVERGLADES	SAVANNAH	SEATTLE-TACOMA
2	0	12	0	0	327	2086	0	0	47	0	0
4	0	244	0	0	2397	23152	0	0	905	0	0
7	0	0	0	0	624	9311	0	0	95	0	0
8	0	69	0	0	403	4982	0	0	41	0	0
9	0	0	0	0	139	6839	0	0	282	0	0
10	7076	1695	0	0	167	18	0	0	634	0	0
12	0	92	0	0	4346	420944	0	0	5357	0	0
16	5756	1426	0	0	1306	0	0	0	420	0	0
17	9388	685	0	0	106	14	0	0	841	0	0
18	3994	0	0	0	2666	407	124371	0	1155	0	0
19	18452	52316	0	0	7083	0	0	0	1296	0	0
21	0	7031	0	0	84	0	0	0	1382	990	0
22	0	20783	0	0	292	0	0	0	716	0	0
23	0	6977	0	0	304	0	14561	0	1017	0	0
24	0	8921	0	0	276	0	0	0	129	0	0
25	0	9850	0	0	232	0	0	0	269	0	0
27	0	36765	0	0	487	0	0	0	1032	0	0
28	0	7118	0	0	497	0	0	0	903	14937	0
29	0	8814	0	0	561	0	0	0	1515	18576	0
31	0	6719	0	0	594	0	0	0	1326	19209	0
32	0	6189	0	0	349	0	0	0	1043	12968	0
34	0	5571	0	0	419	0	0	0	72	0	0
36	0	0	7858	0	10571	0	0	0	339	21415	0
39	0	0	0	0	329	0	0	0	705	6669	0
41	0	0	0	0	3284	0	0	0	0	4971	0
42	0	0	0	0	10623	0	0	0	4256	32615	0
43	0	0	0	0	67465	0	0	0	7994	0	0
44	0	0	0	0	15547	0	0	0	5030	30729	0
47	0	0	9563	0	0	0	0	0	945	0	0
49	0	0	349	0	4881	0	0	0	2884	119	0
51	1715	929	40	0	152	7	0	0	175	189	0
53	0	2815	7	0	1310	0	0	0	795	1136	0
54	0	0	975	0	542	0	0	0	906	0	0
55	0	0	0	0	260	0	0	0	0	0	0
57	0	0	0	0	349	0	0	0	410	0	0
58	0	27	7	0	1739	0	0	0	692	2589	0
65	433	5185	75	0	950	0	0	0	2178	494	0
66	0	0	0	0	431	0	0	0	297	0	0
67	0	0	0	0	1202	0	0	0	77	0	0
68	0	10	106	0	1747	0	0	0	0	2460	0
70	0	1738	140	0	1069	0	0	0	0	0	0
71	0	17235	1054	0	5134	0	0	0	0	1454	0
73	0	2877	3235	0	272	20	0	0	385	69	0
76	0	2246	1720	0	1312	0	0	0	576	251	0
79	0	0	5380	0	1141	0	0	0	0	0	0
83	0	0	0	0	241	0	0	0	0	0	0
89	0	0	0	39658	654	0	0	0	0	0	11
94	0	0	0	16256	263	0	0	0	0	0	0
95	0	0	0	3327	43	0	0	0	0	0	1
96	0	0	0	36295	1067	0	0	0	0	0	0
104	0	0	0	23692	378	0	0	5	0	0	5
105	0	0	0	0	0	0	0	0	0	0	0
107	0	0	0	13581	362	0	0	0	0	0	0
108	0	0	5	9065	75	0	0	0	0	0	0
111	0	0	14	13700	125	0	0	0	0	0	0
112	0	0	0	10849	81	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0	0
122	0	0	27592	17748	285	0	0	0	0	0	0
123	0	0	6384	21723	0	0	0	0	0	0	0
125	0	0	0	0	127	0	0	0	0	0	0
129	0	0	6808	8241	26	0	0	0	0	0	0
131	0	0	2925	10409	12	0	0	0	0	0	0
133	0	0	2574	7637	121	0	0	0	0	0	0
137	0	0	1237	24950	145	0	0	0	0	0	0
138	0	0	11	21350	173	0	0	0	0	0	0
139	0	0	62	13172	78	0	0	4	0	0	0
143	0	0	0	15482	19	0	0	0	0	0	0
146	0	0	0	9160	6	0	0	0	0	0	3
152	0	0	0	9819	114	0	0	0	0	0	0
153	0	0	0	12307	141	0	0	0	0	0	0
157	0	0	0	64155	51	0	0	0	0	0	0
160	0	0	2662	15439	50	0	0	0	0	0	0
162	0	0	377	76387	297	0	0	0	0	0	0
163	0	0	0	48087	0	0	0	11	0	0	0
165	0	0	0	30134	106	0	0	0	0	0	0
167	0	0	0	28718	11	0	0	0	0	0	4646
171	0	0	0	1181	1062	0	0	0	0	0	94558
172	0	0	0	58986	19	0	0	0	0	0	0
176	0	0	0	154231	0	0	0	72287	0	0	0
177	0	0	0	4430	0	0	0	24	0	0	0
178	0	0	0	48318	14	0	0	104	0	0	0
179	0	0	0	20314	7	0	0	4	0	0	0
180	0	0	0	291922	0	0	0	0	0	0	0
181	0	0	0	66659	23	0	0	0	0	0	0

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Appendix E: Rail O-D Table for Exports

The following table presents the export flows of containers (summarized by port of export) that move domestically by rail to the port of export. The units of flow are rail carloads per year.

Origin						Port of Export					
NTAR	BALTIMORE	CHARLESTON	HOUSTON	LA-LONG BEACH	MIAMI	NEW YORK	NORFOLK	OAKLAND	PT EVERGLADES	SAVANNAH	SEATTLE-TACOMA
2	0	0	0	278	0	0	0	223	0	0	1477
4	0	0	272	210899	272	8704	0	1044	0	0	23527
7	0	0	0	12249	0	0	0	38796	0	0	2931
8	0	0	0	527	272	0	0	1170	0	0	46622
9	0	0	0	3124	0	0	0	37633	0	0	2886
10	0	0	136	47183	0	0	0	986	0	0	5177
12	0	0	408	2667	7684	0	0	2923	0	0	35444
16	0	0	0	39539	0	8772	0	1637	0	0	53961
17	0	0	204	49878	1156	612	0	3758	0	0	2570
18	0	0	204	778	408	0	0	974	0	0	72
19	0	0	0	866	1836	0	8636	70	0	0	0
21	0	0	0	556	0	0	0	0	0	0	0
22	0	0	0	496	0	0	0	0	0	0	0
23	0	476	0	128	0	0	0	70	0	136	72
24	0	0	0	200	0	0	0	0	0	0	0
25	0	0	0	224	0	0	0	0	0	0	0
27	0	0	0	769	0	0	0	0	0	0	0
28	0	0	0	3079	0	5032	0	0	0	0	144
29	0	3332	0	4368	204	0	0	557	0	4556	360
31	0	0	0	605	0	0	0	0	0	0	0
32	0	0	0	441	0	0	0	0	0	0	0
34	3400	0	0	42	9928	0	1156	0	0	884	0
36	0	27540	0	13246	23392	17544	136	835	5848	32368	936
39	4692	1224	0	45	9588	408	680	0	0	0	0
41	0	884	0	2864	32908	0	0	0	67284	1020	72
42	0	0	0	251	0	1088	0	0	0	68	0
43	1904	4828	0	143	0	4896	0	348	0	2380	72
44	0	1292	0	283	0	0	0	0	0	2652	0
47	0	1360	0	160	0	0	0	0	0	3196	0
49	0	4964	0	54200	2448	816	0	2366	0	2855	72
51	0	0	0	19159	0	0	0	355	0	0	1023
53	0	0	0	32997	0	0	0	0	0	136	0
54	0	21080	0	49493	0	884	0	0	0	5304	0
55	0	34477	3400	280	2422	0	26965	0	26	18018	0
57	0	4420	0	38682	68	204	27268	0	0	1904	576
58	0	0	0	37314	0	0	0	0	0	0	0
65	0	0	68	105426	204	16252	8024	112	0	0	15997
66	0	0	0	27952	0	28016	16456	374	0	0	6888
67	0	2652	0	58954	1768	680	14076	348	0	612	0
68	0	0	0	34441	0	0	0	0	0	0	0
70	0	0	0	186	0	2516	0	557	0	0	35356
71	2516	0	0	45761	68	21284	11220	158876	0	0	15585
73	0	0	0	50773	0	0	0	21444	0	0	345
76	0	0	0	805	0	0	0	1274	0	0	49515
79	0	204	0	101998	0	12376	11220	0	0	0	0
83	86224	0	21828	0	5157	229781	64711	66884	85	0	0
89	0	0	0	0	1252	116654	4233	0	12	191	0
94	0	0	0	0	165	49946	734	0	8	0	0
95	0	0	0	0	25	268	108	0	0	0	0
96	68	0	68	15108	664	7475	4363	5429	10	0	39960
104	0	0	0	0	595	70005	1205	0	12	0	0
105	1020	68	898	104651	761	49	720	0	0	0	0
107	1224	497	2992	55275	1708	21284	36766	15451	33	967	8352
108	0	0	0	0	308	0	188	0	6	49	0
111	0	0	816	0	390	0	298	0	12	124	0
112	0	16570	0	430	425	204	653	0	0	14039	0
113	0	15164	2788	102674	8704	68	0	1749	0	6664	0
122	0	0	136	285096	0	68	0	193	0	0	181
123	0	0	0	0	0	0	431	0	0	0	0
125	0	3604	884	215015	1972	4896	0	59160	0	2176	5400
129	68	0	0	14535	136	544	136	348	0	68	0
131	0	0	0	215	0	68	145	0	0	0	0
133	0	0	2380	16038	0	272	136	139	0	0	0
137	0	0	0	4296	0	0	480	556	0	0	0
138	0	0	0	72	68	0	445	251	0	0	0
139	0	0	0	0	0	0	246	0	0	0	0
143	0	0	136	11170	0	177	473	8143	0	0	15120
146	0	0	0	0	0	66	171	0	0	0	0
152	0	0	0	286	0	154	179	0	0	0	3096
153	0	0	0	0	0	65	189	0	0	0	0
157	68	0	2652	7733	0	0	319	6473	0	0	6120
160	0	0	0	143	0	748	0	0	0	0	0
162	0	0	748	0	0	1496	0	0	0	0	0
163	0	0	0	215	0	68	566	0	0	0	0
165	68	0	4216	9666	0	1700	0	16495	0	0	144
167	0	0	0	0	0	0	456	0	0	0	144
171	0	0	1088	0	136	136	540	0	0	0	0
172	408	0	952	8091	0	272	0	0	0	0	576
176	816	0	37536	4511	408	2652	136	0	0	0	5832
177	0	0	0	0	0	0	56	0	0	0	0
178	0	0	0	0	0	0	602	0	0	0	0
179	0	0	68	0	68	0	259	0	0	0	0
180	6528	272	301988	0	2720	16796	204	8700	0	68	12744
181	0	0	0	0	0	0	854	0	0	0	0

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Appendix F: Truck O-D Table for Exports

The following table presents the export flows of containers (summarized by port of export) that move domestically by truck to the port of export. The units of flow are equivalent rail carloads per year.

Origin						Port of Export					
NTAR	BALTIMORE	CHARLESTON	HOUSTON	LA-LONG BEACH	MIAMI	NEW YORK	NORFOLK	OAKLAND	PT EVERGLADES	SAVANNAH	SEATTLE-TACOMA
2	0	66	0	0	137	0	0	0	192	31	0
4	1967	9251	2510	0	303	0	1765	0	8813	9	0
7	330	586	472	0	778	0	17	0	740	497	0
8	0	0	1004	0	901	0	53	0	7	370	0
9	0	0	1083	0	21	0	0	0	440	109	0
10	0	0	1358	0	69	0	0	0	272	130	0
12	100104	89012	5809	0	0	743162	48005	0	45613	80087	0
16	0	0	0	0	822	0	0	0	901	0	0
17	0	397	1149	0	0	0	0	0	1376	144	0
18	0	353	602	0	9	0	290724	0	2640	762	0
19	0	271299	3092	0	5604	0	63143	0	14211	56004	0
21	0	92	0	0	1076	0	0	0	2683	49496	0
22	0	33668	0	0	687	0	2628	0	2237	9908	0
23	0	0	276	0	956	0	56557	0	1644	567	0
24	0	16509	0	0	1010	0	0	0	547	1980	0
25	0	17456	0	0	531	0	0	0	1089	3468	0
27	0	60443	0	0	2866	0	0	0	1839	17002	0
28	0	0	0	0	1310	0	0	0	2742	37728	0
29	0	0	0	0	531	0	0	0	4974	57756	0
31	0	0	60	0	1563	0	0	0	3439	54329	0
32	0	184	0	0	1536	0	0	0	2581	39945	0
34	0	1706	130	0	0	0	0	0	179	2467	0
36	0	0	12484	0	0	0	0	0	0	113802	0
39	0	0	0	0	0	0	0	0	6	3410	0
41	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	25533	0	0	0	46257	26489	0
43	0	0	0	0	115055	0	0	0	64486	0	0
44	0	0	991	0	80730	0	0	0	24993	382	0
47	0	0	31819	0	31	0	0	0	20	0	0
49	0	0	7133	0	0	0	0	0	37	0	0
51	0	0	549	0	0	0	0	0	102	47	0
53	0	0	1914	0	227	0	0	0	1611	0	0
54	0	0	11889	0	0	0	0	0	229	0	0
55	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	16	0	0
58	0	0	138	0	209	0	0	0	337	25	0
65	0	0	963	0	5	0	0	0	24	0	0
66	0	0	574	0	0	0	0	0	562	0	0
67	0	0	448	0	0	0	0	0	15	0	0
68	0	0	1100	0	56	0	0	0	7	0	0
70	0	0	268	0	57	0	0	0	7	0	0
71	0	0	990	0	0	0	0	0	40	0	0
73	0	0	513	0	0	0	0	0	12	0	0
76	0	0	1285	0	0	0	0	0	9	0	0
79	0	0	0	0	0	0	0	0	26	0	0
83	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	269	0	0	0	0	0	0	0
94	0	0	0	112	0	0	0	0	0	0	28
95	0	0	0	22	0	0	0	0	0	0	9448
96	0	0	0	0	0	0	0	0	0	0	145435
104	0	0	0	205	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
107	0	0	699	0	0	0	0	0	0	0	0
108	0	0	1053	25953	0	0	0	0	0	0	0
111	0	0	39508	166	0	0	0	0	0	0	0
112	0	0	650	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0	0
122	0	0	83	0	0	0	0	0	0	0	0
123	0	0	18330	42222	0	0	0	0	0	0	0
125	0	0	9696	27409	0	0	0	0	0	0	0
129	0	0	4116	47222	0	0	0	0	0	0	0
131	0	0	27691	783	0	0	0	0	0	0	0
133	0	0	0	34170	0	0	0	0	0	0	0
137	0	0	508	65738	0	0	0	0	0	0	0
138	0	0	4199	58394	0	0	0	0	0	0	0
139	0	0	299	36030	0	0	0	0	0	0	0
143	0	0	0	36895	0	0	0	0	0	0	0
146	0	0	54	159	0	0	0	0	0	0	25512
152	0	0	0	0	0	0	0	0	0	0	24344
153	0	0	0	211	0	0	0	0	0	0	31526
157	0	0	0	195920	0	0	0	0	0	0	0
160	0	0	0	43338	0	0	0	0	0	0	0
162	0	0	0	178492	0	0	0	0	0	0	0
163	0	0	445	104421	0	0	0	0	0	0	0
165	0	0	0	61966	0	0	0	0	0	0	0
167	0	0	267	502	0	0	0	0	0	0	80935
171	0	0	0	1119	0	0	0	34	0	0	239762
172	0	0	0	0	0	0	0	0	0	0	115633
176	0	0	0	256299	0	0	0	224246	0	0	0
177	0	0	21	9577	0	0	0	7	0	0	0
178	0	0	417	103475	0	0	0	39	0	0	0
179	0	0	116	44118	0	0	0	0	0	0	0
180	0	0	0	446829	0	0	0	0	0	0	0
181	0	0	640	143257	0	0	0	0	0	0	0

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