# A CONTAINER PORT DEMAND SIMULATION MODEL FOR US CONTAINER PORTS*

Meifeng Luo
Christopher M. Anderson
Young-Tae Chang
Paul Tae-Woo Lee
Thomas A. Grigalunas

## INTRODUCTION

Assessing the potential demand for container ports and associated multi-modal transportation facilities is a major issue in port planning and development (Benacchio et al, 2000; Hoffmann, 1998), multi-modal facility development (US DOT, 1998), inter-port competition, and business decision-making in the international container transportation industry. Estimates of demand are key to evaluating not only the financial feasibility of a proposed port but also the economic benefits and costs and their distribution to the host state and to the nation as a whole (Bobrovitch, 1982; Bomba *et al*, 2001). In a related vein, estimates of port-specific demand can also provide important information on prospective multi-modal uses, useful data for assessing some environmental issues, for example, truck traffic on local roads and related potential external costs such as noise and air pollution (Grigalunas, *et al.*, 2001).

With the continuous economic growth in China, and the changes in its national and provincial port development policy (Wang et al, 2004a, b), container ports in the Chinese East Coast has caused fundamental changes in the role of the existing ports in this region. The new ports need to know their expected demand to estimate the financial feasibility, while the existing ports want to know their demand changes facing the competition of these new entrants, and what strategies they can adopt to safeguard their market share.

Demand estimation for container ports, however, is very complicated for many reasons. Among these are the inherent complexities of international trade and its determinants, competition from substitute ports, and potential strategic behaviour by substitute ports, shippers, and shipping lines (e.g., Jones and Qu, 1995; Gilman and Williams, 1996; Klein and Kyle, 1997; Tsamboulas and Kapros, 2000; Fagerholt, 2000; Panayides and Song, 2001). Difficulties also arise from the multiplicity of factors to be considered, major data requirements, and the computationally intensive nature of the problem (see Luo, 2002).

This paper presents a spatial-economic, multi-modal container transportation simulation model for US coastal container ports, developed by Luo (2002). The model is introduced and then used to evaluate the impact on port demand from varying port use fees, i.e., to evaluate the responsiveness (price elasticity) of demand to varying port use fees. The underlying theoretical framework is based on fundamental microeconomic theory and assumes shippers minimize the total general cost of moving containers from sources to markets. The model is applied to estimate ***annual*** container transportation service demand for major container ports in the United States (US). This paper will outline the model formulation, focusing on the model and the underlying economic reasoning, including basic assumptions and computational algorithms; explain the data used in developing the model; and illustrate the model simulation result using the estimated container transportation flow origin-destination (OD) matrix. Limitations in the modelling approach, needed refinements, and future directions are briefly described in the final section.

## THEORETICAL MODEL

This research uses a simulation framework, given the research focus on multiple ports and multi-modal shipments of containers in a national and international context. Other modelling approaches have been applied in the literature, using econometric methods (McFadden, 1974; Winston, 1981; Murphy *et al*, 1992; Jones and Qu, 1995; Bolduc, 1999; Garrido and Mahmassani, 2000; Malchow, 2001), operations research (Hillier and Lieberman, 1974; Emerson and Anderson, 1989) and related techniques (e.g., Hensher and Button, 2000; Kesic, 2001). However, the simulation approach is most suited to our work.

The model estimates container port demand by simulating the container transportation process through a multi-

---

* Funding provided by the University of Rhode Island Transportation Center, Korean-American Joint Marine Policy Research Center at URI.

modal transportation network including ports, rail, highway, and international shipping lines. The assumptions in this model include: (1) international trade is given; (2) each port has direction shipping line connection to each continent, and the unit cost per TEU per mile is the same in all the shipping lines; (3) user fees are the same at every port; and (4) shippers select a route that minimizes the general cost over the whole transportation process.

Here, we present the economic reasoning and model formulation for calculating general transportation cost. We also discuss the computational algorithm and the simplified software architecture of this model.

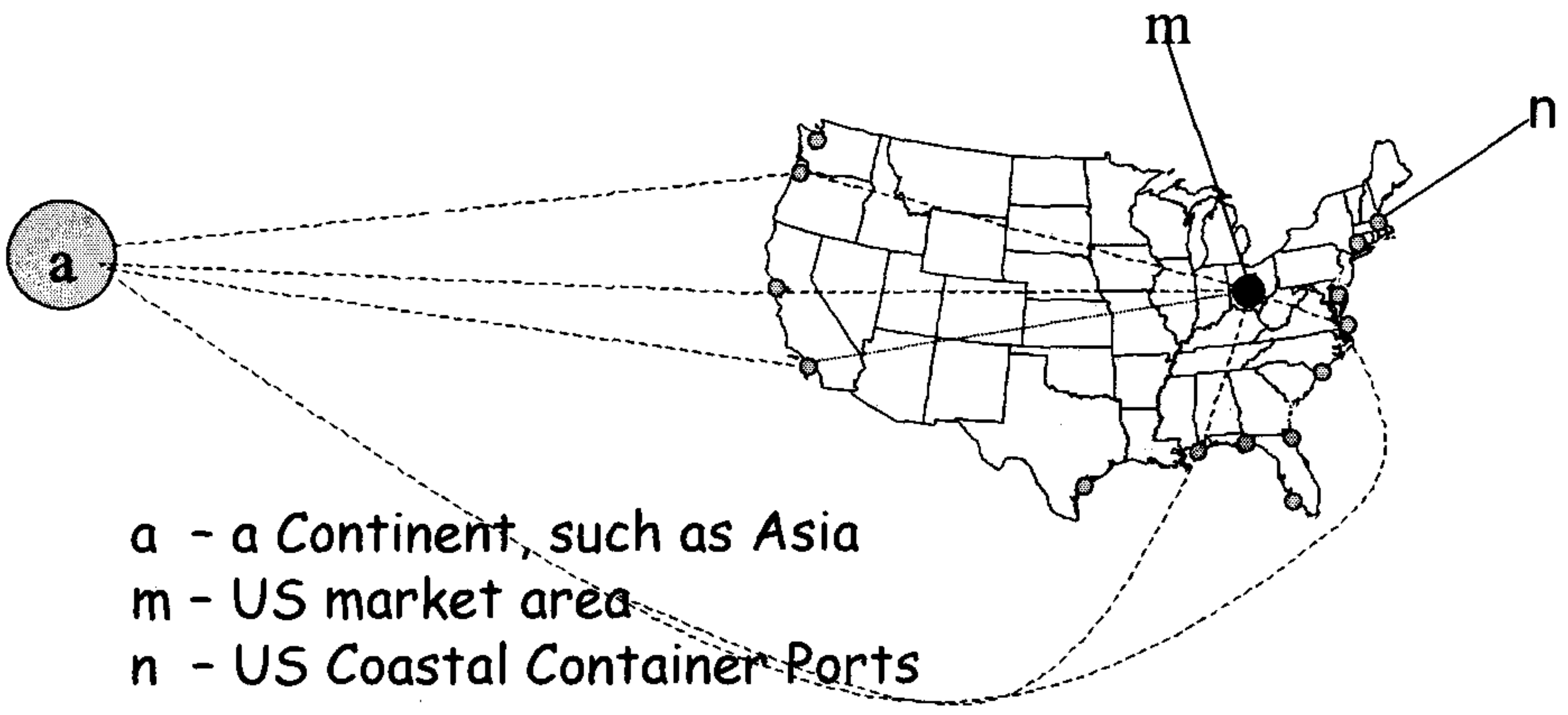
Container transportation demand is derived from the demand for international trade in containerized goods. Container routing in the model depends on the origin and destination of the cargo, and how shippers select the route along which to transport the cargo. Many possible routes exist for transporting a container between one point in the US and a foreign country. Some routes may use more water transportation but less land transportation (truck and rail), so the transportation cost is low, but it may take a longer time to reach the destination. Other routes use less sea transportation route but longer land transportation, so that the transportation cost is higher, but less time is needed to reach the destination. For the transportation process that is more shipping intensive, the model assumes some savings in lower freight rates will be realized, but it takes longer time, resulting in a higher opportunity cost of capital, higher depreciation cost for some cargo, and higher refrigerated box ("reefer-box") renting cost for cargoes that need to be frozen during the transportation process.

In short, trade offs exist between the transportation cost and the time cost in the route selection decision. In the model, the shipper selects the route that minimizes the total cost in the transportation process from the origin to the destination, where total cost includes the freight rate paid to the transportation facility provider according to usage, and the inventory cost based on the value of cargo and the interest rate.

In the model, each route is assumed to use only one coastal port. By selecting a least-cost route, the port that a container of typical cargo will go through is also determined in the model. The aggregation of all containers that go through a port gives the simulated container transportation demand of that port.

Next, the basic model for the simulation of container transportation for US coastal container ports is described. A simplified depiction for the transportation process is illustrated in Figure 1.

**Figure 1: Simplified Depiction for Multimodal Transportation Network**



Assume there are $Q_{ami}$ containers (in TEU) of cargo category $i$ ($i \in [1, I]$) that are to be imported from world region ***a*** (a continent) to one destination ***m*** in US (exporting is a reverse process of importing). The ship cost is $\alpha$ dollars per mile per TEU. There are N coastal ports to choose from in the US, the distance of region a to the $n^{th}$ ($n \in [1, N]$) container port is $l_{an}$. The port charge at $n^{th}$ port is $p_n$ per container. The domestic transportation cost from the $n^{th}$ port to the destination m is the sum of the costs of each mode. Assume for mode $j$ ($j \in$[truck, rail, inland waterway]) the unit cost is $\beta_{nmj}$ per container per mile, with inland transportation distance $l_{nmj}$. The sea transportation speed is $S_s$ miles per hour, domestic transportation speed is $S_{lj}$ miles per hour and the port dwelling time for $n^{th}$ port is $H_n$ days. Also assume the value of each container is $V_i$, and the daily unit cost of capital is $\rho$.

Transportation Costs

Transportation cost is the sum of the fees paid to the transportation facility providers for the use of the facilities (truck, rail, port and container vessel). For some routes, railway may not be used, so the rail cost may not appear.

For one container from an origin in a particular world region, ***a***, to a particular place $m$ in the US, the transportation cost ($C_1$) using the $n^{th}$ port is:

$$C_1(n) = \alpha * l_{an} + p_n + \sum_j \beta_{nmj} * l_{nmj} \quad (1)$$

Inventory Cost

The time spent on the sea leg is: $\frac{l_{an}}{24S_s}$ days, port $H_n$ days, and domestic $\sum_j \frac{l_{nmj}}{24S_j}$ days, thus total number of days spent in transit is $D_n = \frac{l_{an}}{24S_s} + H_n + \sum_j \frac{l_{nmj}}{24S_j}$.

For cargo *i*, the inventory cost:

$$C_2(n) = V_i[(1+\rho)^{D_n} - 1] \quad (2)$$

Other costs that can be expressed as a function of time, like cargo depreciation, refrigerated container rental, can also be included in this part.

Total cost in the transportation process

The total cost in transit by using n<sup>th</sup> port is the sum of the costs in the above two parts:

$$TC_i(n) = \alpha * l_{an} + p_n + \sum_j \beta_{nmj} * l_{nmj} + V_i[(1+\rho)^{D_n} - 1] \quad (3)$$

Assuming the shipper selects least-cost route, the selected port is the one that minimizes $TC_i(n)$. i.e.,

$$\min_n \{TC_i(n)\} \quad (4)$$

Assume through the selection of the least cost route, $Q^n_{ami}$ containers of cargo *i* move from ***a*** to ***m*** will use port ***n***, then the annual demand of port ***n*** is:

$$Q(n) = \sum_a \sum_m \sum_i Q^n_{ami} \quad (5)$$

As can be seen from the above discussion and equations, changes in sources, speed of transportation facilities, availability and/or costs of different ports or multi-modal facilities, and markets will affect the demand for port services. The model can be used to examine changes in these (and other) factors.

### Shortest Path Algorithm

The core of the simulation model is the shortest path algorithm, which has been widely applied in economic analysis transportation engineering (Bank, 1998; Ertl, 1998; Beuthe, 2001; Fowler, 2001; HDR Engineering, Inc., 2002), operations research (Hillier and Lieberman, 1973), and computer network routing (Kurose and Ross, 2000). It is one of the dynamic programming approaches described by Bertsekas (1995).

Shortest-path problems can be stated in many ways. Here, we adopt the common notation used in the dynamic programming method. Assume the multimodal transportation network consists of a set of nodes $V=\{v_i|i\in[1, n]\}$, then the shortest path from one node (assume node 1) to all other nodes can be formulated as a deterministic dynamic programming problem as follow (Kronshö and Shumsheruddin, 1992; Bertsekas, 1995):

$$d_1 = 0 \quad (6)$$

$$d_i = \min_{k\in E_i}\{c_{ki} + d_k\} \quad \text{for } i = 1, \ldots, n \quad (7)$$

where n is the number of nodes in the network; di is the total cost from the starting node to node i; $E_i$ is a subset of nodes that has a direct connection to node i, $E_i=\{v_i|i\in[1, k]\}$; $c_{ki}$ is the general cost from one of these nodes to node i.

In implementing the simulation model, we use one efficient version of the shortest path algorithm for the single source, multiple destinations problem – the Dijkstra Algorithm. This has been classified as "Best First Search" algorithm (Bertsekas,1995).

## DATA

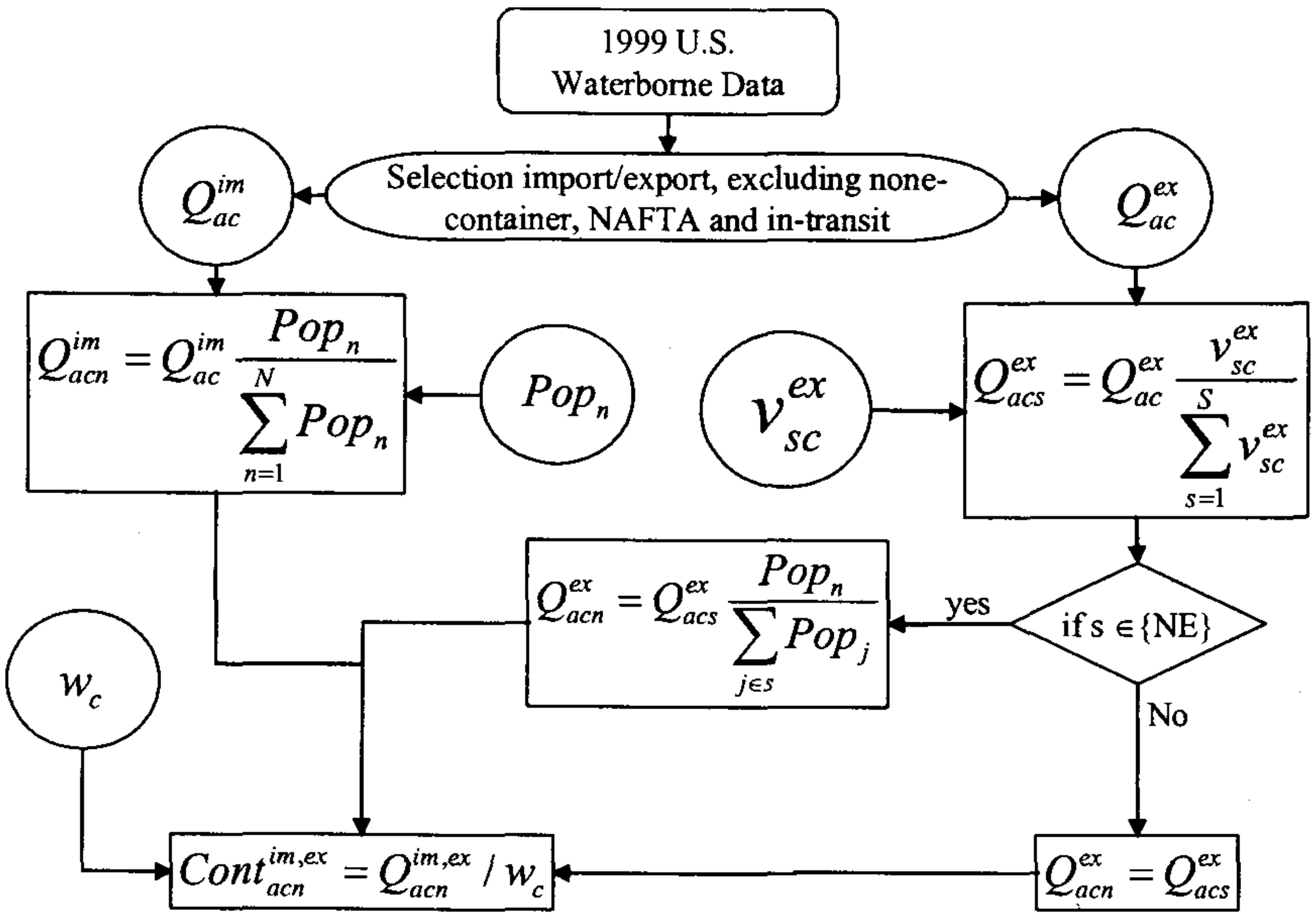
Three different kinds of data are needed to implement the model: (1) container trade flow origin and destination (OD) data between each state to each continent, (2) economic parameters, and (3) transportation networks. Below we outline data sources and the data estimation process. Given the importance of each data source for development of the model, each is described in some detail.

### Containerized trade flow OD matrix

To apply the model, containerized cargo imports and exports, measured in TEUs, and on the total value of cargoes per TEU between each OD pair is needed. As the Port Import Export Reporting Service (PIERS: www.piers.com) data is not available, the model starts from estimating a container OD flow matrix from 1999 National Waterborne Trade Database from US Maritime Administration, Department of Transportation (MARAD).

This database contains trade information between the US and foreign countries in weight and in value, but not in TEU, for detailed cargo categories. A conversion algorithm (Figure 2) is developed to convert the data into the container flow OD matrix, for import ($Q_{ac}^{im}$) and exports ($Q_{ac}^{ex}$) between different continents (subscript *a*) and each cargo category (subscript *c*). Then, the national imports were distributed to the state level by population ($Pop_n$, *n* here is the state number, or county number if it is in Northeast Region), with Northeast region detailed to the county level.

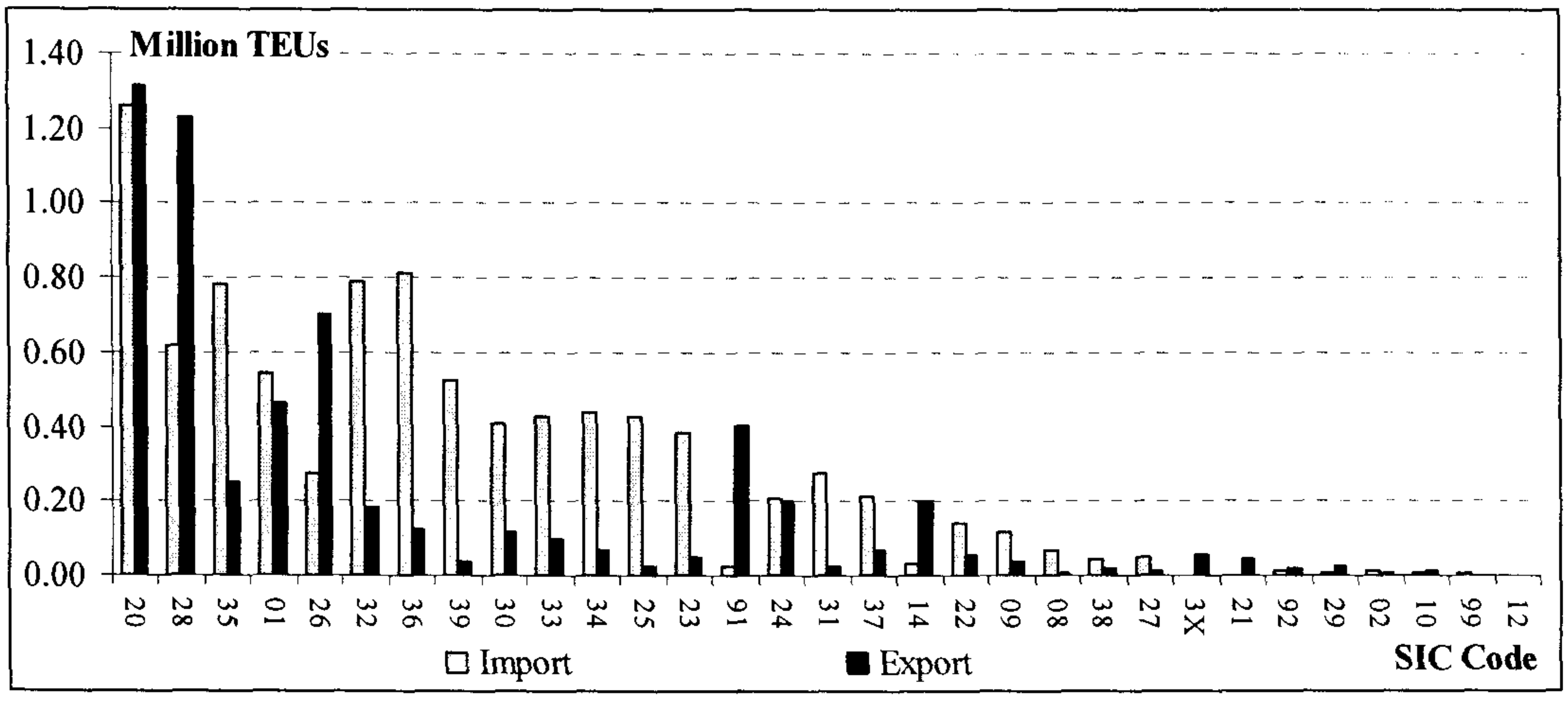
**Figure 2: Conversion from 1999 US Waterborne Trade Data to Container Flow OD Matrix**



The national export data was distributed to the state level by MISER (Massachusetts Institute for Social and Economic Research) state export data (MISER, 2002) ($v_{sc}^{ex}$). For the Northeast region, the state exports were further detailed for the county level. Finally, all the weight data were converted to number of TEUs, using the research result on estimating weight of containers ($w_c$) by Hancock *et al* (2001).

The total converted number of TEUs for US container imports and exports in 1999 is about 15 million. Container trade by state ranges from 18,768 to 1,792,092 TEUs. Four states, California and Texas, followed by New York and Louisiana, dominate in TEUs. By cargo, four cargo categories prevail: Food and Kindred Products, Chemicals and Allied Products, Paper and Allied Products and Agriculture Products (Figure 3). These four categories alone account for an estimated 3.08 million TEUs, about 53% of the total export containers. For detail explanation of the SIC code please refer to http://www.census.gov/epcd/www/sic.html.

**Figure 3: Estimated number of TEUs imported/exported for each cargo category in 1999**

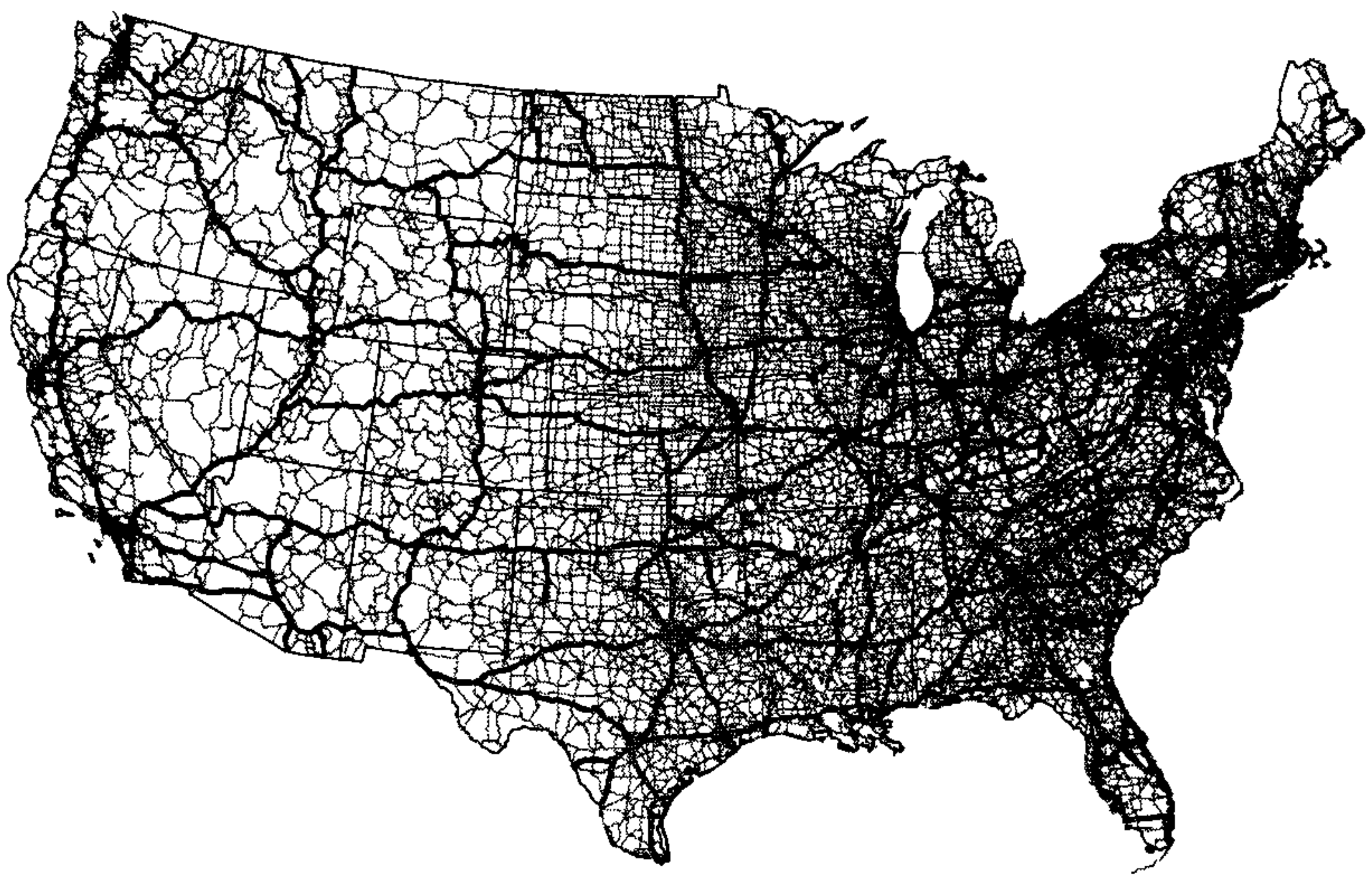


### Multi-modal Transportation network

The multi-modal transportation network used in this model contains rail, highway and international shipping line sub-networks. These sub-networks are extracted from multimodal transportation network maintained by the Center for Transportation Analysis of the Oak Ridge National Laboratory (ORNL). The rail sub-network includes not only the railways system in Continental US, but also the rail system at Eastern part of Canada. The Canadian part is included because of the need to simulate competition of Canadian ports (Halifax and Montreal) on US East Coast cargoes.

Both interstate and state highways are included in the highway sub-network (Figure 4). This sub-network overlaps with the rail sub-network, except for Canada; Canadian highways are not included. Including Canadian highway is not necessary because eastern Canadian ports will compete with US container ports for multi-modal cargoes only.

**Figure 4: Highway transportation system in the simulation model**



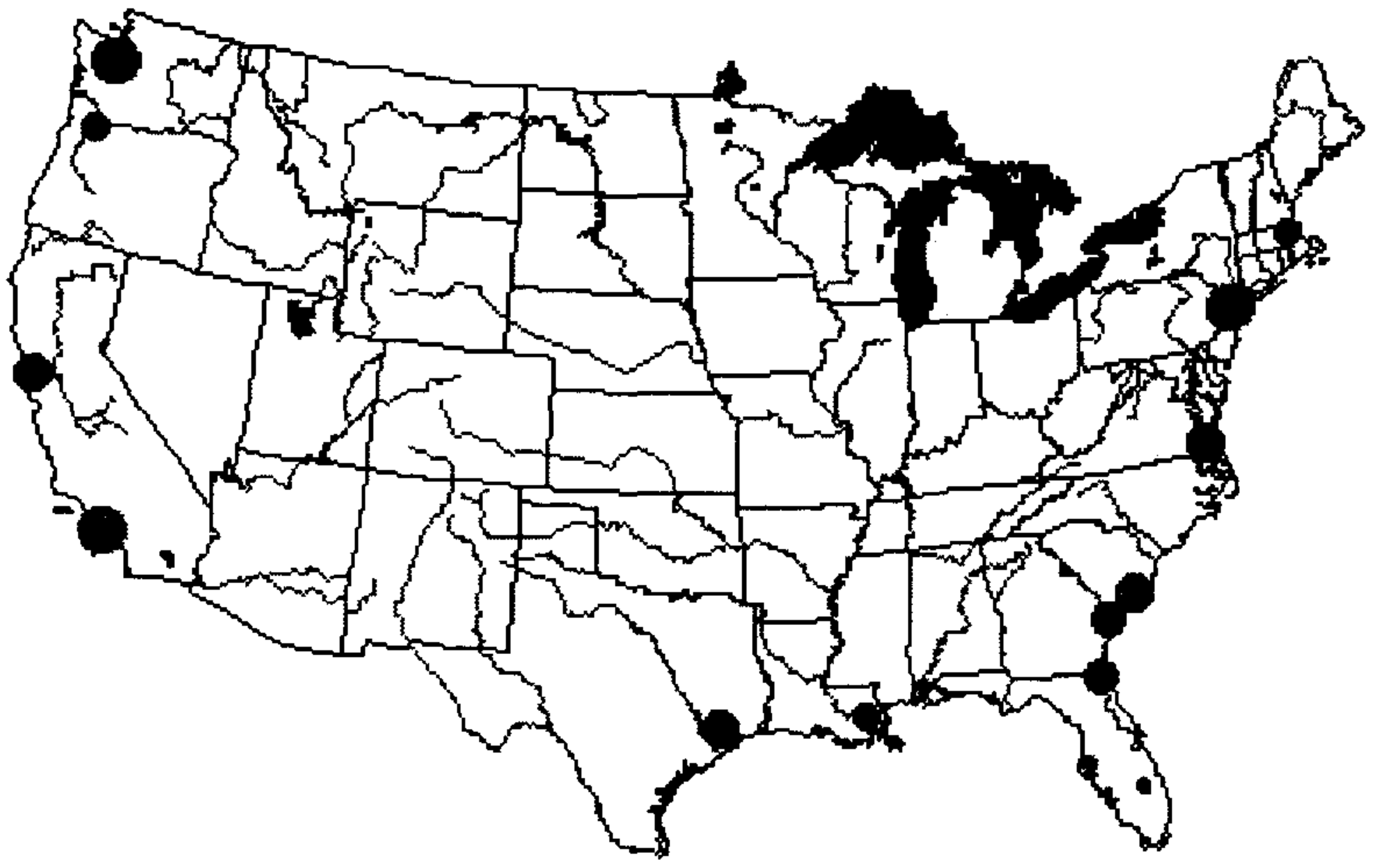
The international shipping lines are extracted from the ORNL deep sea sub-network. As foreign countries are aggregated into continents, the international shipping line sub-network is simplified by using the shortest path between each port and each continent directly.

To visualize the multi-modal system used, each modal network (of rail and highway) can be imagined as occupying a horizontal plane, while inter-modal terminals connecting 2 modes lie between the planes and are attached above and below by vertical access links. The connection of land transportation networks (rail and highway) and sea transportation is at the coastal ports. The whole multi-modal transportation network is represented by a unified routable network, with a single node list, a single link list, and a topology defined by the links' endpoint nodes. This structure is common to most network analysis program.

### Selected Major US Container Ports

In this model, 14 major US container ports are included: 4 on the west coast, 4 on the Gulf coast, and 6 on east coast (Figure 5). More ports can be added, according to the issue faced. The size of the red circle indicates the throughput of each port in 1999. The TEU statistics include not only containers loaded with cargoes for import and export, but also empty containers, in-transit containers, and transhipments. Smaller ports were either neglected, or combined with nearby port. The inclusive nature of the reported TEU statistics becomes important later, when we compare our estimates of moves of *loaded* TEUs with actual moves.

**Figure 5: Selected US Coastal Container Ports**



### Parameters and economic variables in simulation model

To simulate the transportation process and calculate the total cost of transportation, many basic transportation variables must be specified. These include: the speed of movement, the unit cost per mile, and delay in the terminal and interlink, cost in the rail terminal, and the opportunity cost of time in trucking activities (Table 1).

**Table 1: Economic Variables and Parameters Used in the Simulation Model**

| Name | Value | Notes |
|---|---|---|
| Intrate | 15% | Annual Interest Rate |
| ShipSpeed | 20 MPH | From Martin Stepford "Maritime Economics" |
| ShippingCost | $0.09 /TEU*Mile | Cullinane and Khanna (2000) |
| RailCost | $0.20 /TEU*Mile | National Transportation Statistics, 1999, 2000 |
| railSpeedHigh | 64 MPH | The highest rail speed |
| railSpeedLow | 10 MPH | The lowest train speed |
| railInterlinkFixCost | $10 | Interlink cost |
| truckCost | $2 /TEU*mile | National Transportation Statistics, 1999 |
| truckOCT | $60 /hour | Opportunity cost of trucking |
| truckToRailCost | $100 | Fixed cost to use rail transportation |
| truckSpeedHigh | 52 mph | The average highest speed of trucking. |
| truckSpeedLow | 10 mph | The lowest speed of trucking |
| SuezCanalSpeed | 5/3 mph | The speed in Suez Canal, for only short length |
| SuezCanalFixCost | $10 | |
| PanamaCanalSpeed | 5/3 mph | |
| PanamaCanalFixCost | $10 | |

The economic variables and parameters are, at this early stage, selected based on availability. The interest rate (15% is used) should be the opportunity cost of capital in the business operation. Unit cost per TEU for rail and truck is calculated from average revenue per ton-mile for class I rail and truck, respectively (National Transportation Statistics, 1999, 2000). These variables serve to start the simulation process. They all can be changed, for sensitivity analysis or policy analysis, and will be refined in later applications to specific issues. Selected results, described next, illustrate the potential uses of the simulation model.

### SIMULATION RESULTS

To illustrate the model, three sets of results are presented: (1) simulated transportation *routes* between representative US ports and continents, (2) simulated *conditional demand* of the existing US container ports, and

(3) simulated demand curves when one of the container ports changes its *prices*.

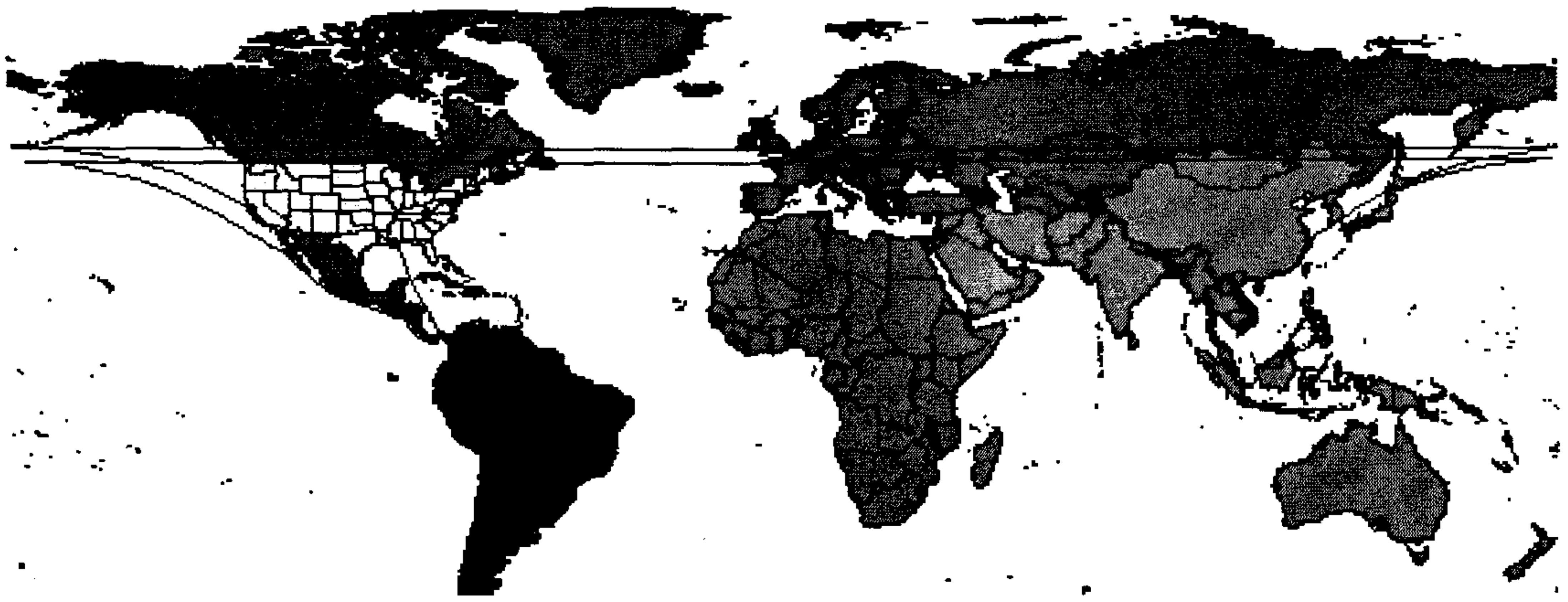
**Simulated container transportation routes**

Our data on the container transportation OD matrix is converted from waterborne trade, i.e., is estimated; hence, it is different from the actual throughput. Simulating transportation routes provides a ways of checking the validity of the simulation model. It is not possible to compare between simulated demand with actual throughput for validity checking, because throughput includes not only full containers but empty and in-transit containers, while the simulation result only includes full containers.

US trade with Asia is almost half of the US international containerized trade and is concentrated in four major states: California, Texas, New York and Washington. Containerized cargo value for this trade ranges from approximately $1.5 thousand to over $254 thousand per TEU.

The model results show that the decision to use rail or the all-water service depends on which an alternative has the lower general cost. Trade between East Asia with West Coast states will always use the direct trans-Pacific routes, since use of rail will not reduce the general cost. Trade between East Asia and Gulf Coast States (e.g., Louisiana), when the cargo value is low (around $10,000 per TEU), would use as much water transportation as possible, by going through the Panama Canal and using a Gulf Coast container port directly. With high cargo value (around $100,000), trade uses a North Pacific Coast port for import or export and multi-modal facilities to and from the port (Figure 6). Trade between New York City and East Asia (e.g., China) uses the all-water route through the Panama Canal when the cargo value is low. In contrast, high cargo value imports or exports will move through West Coast Ports and use rail between the port and market area.

**Figure 6: Container Transportation Routes between East Asia and Gulf Coast States**



**Estimated Demand for Major Container Ports**

Our estimate of the demand for one container port is the *potential* number of containers that will use a port to import and export, conditioned on a given level of fees charged at this port and at all other ports.

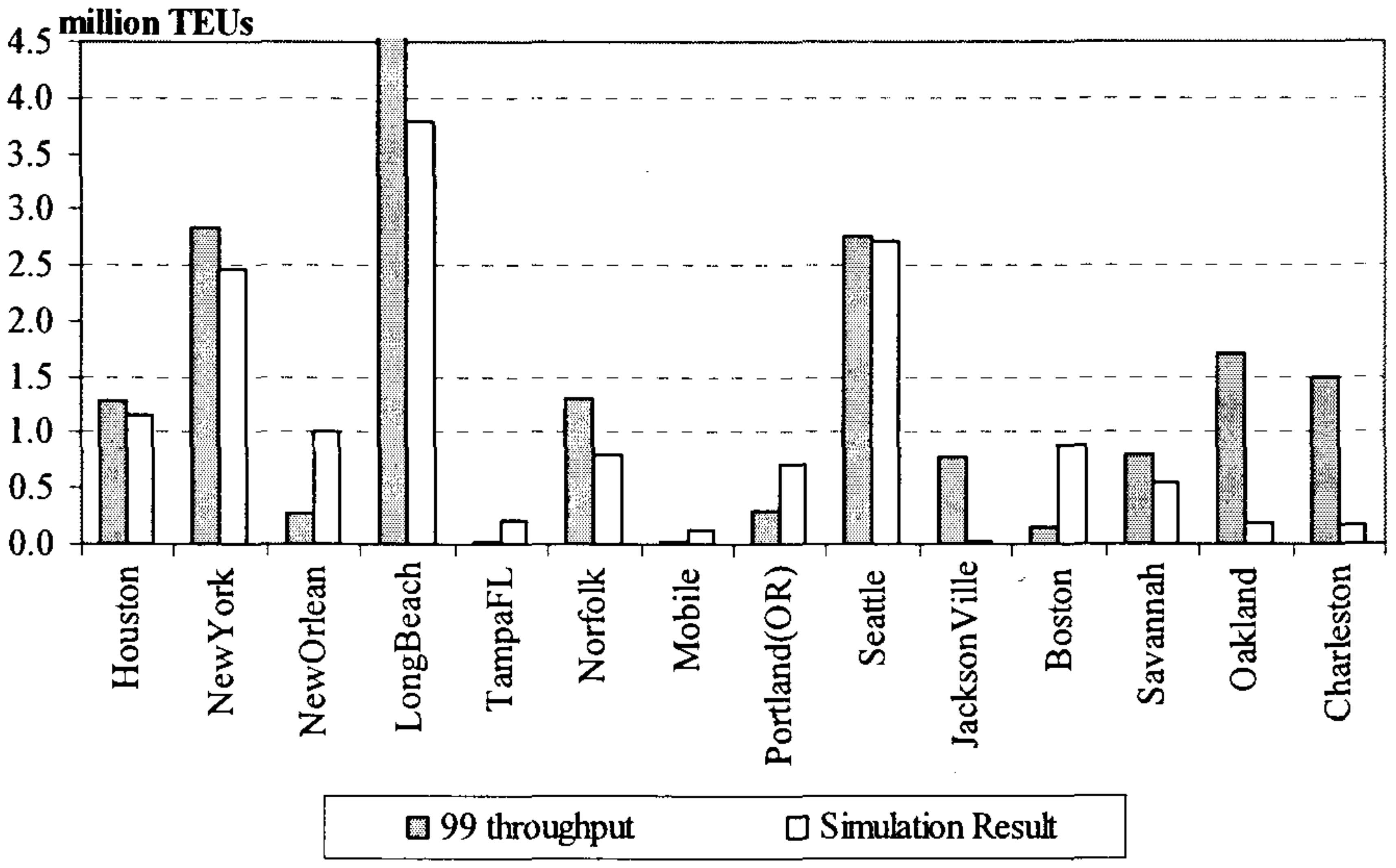
The simulated demand at major container ports will be presented in two ways. First, we show the number of containers that will go through each port, for a certain level of charges at every port. Second, we simulate the effect of inter-port competition, by showing the demand change at other ports due to the fee change in one port, conditional on the fees charged at all other ports (cross-price effects). The demand measured here is a pure substitution effect, which follows from our assumption that international trade is given.

Figure 7 presents the model simulation results and actual throughput for selected existing container ports, using the 1999 waterborne transportation data. Simulated demand is generally lower than the actual throughput, because, in part, that the total number of TEUs estimated in this research (around 15 million) does not include empty containers, domestic movements of containers, transhipments through barge operations, and in-transit cargoes*.

---

* Empty containers at major ports in 1999: Long Beach (>1 million TEUs), Port of Los Angeles (4.76% of inbound and 53% outbound ); Oakland (400,000 empty TEUs), Seattle (220,000)

**Figure 7: Simulated Container Port Demand and the Actual Throughput for Year 1999**



*Notes: Due to the geographical closeness, some of the ports in the West Coast are the sum of two nearby two ports. **Long Beach** throughput is the sum of Long Beach and Los Angeles (about 8.23 million TEUs in 1999). **Seattle** throughput is the sum of Seattle and Tacoma.*

Despite this, the simulated demand of each port reasonably reflects the relative magnitude of actual throughput for major container ports (Figure 5). For example, Long Beach and Los Angeles have the highest throughput of US ports, and this is reflected in the simulated demand. New York is the second largest port, which is also captured in this simulation. Seattle and Tacoma, when added together, are comparable with NY/NJ, and this reflects the actual relative order in throughput. Estimated demand for Oakland is very low relative to actual throughput, as we would expect. This is because for each state, the model allocates imports on the relative population of the state. Then, within each state (except for the Northeast, which is at the county level) *all imports* are allocated to one market destination -- the metropolitan area with the largest population. Hence, in California the market destination for all CA imports is the LA-LB metropolitan area. Hence, deviations between the simulated result and actual throughput are expected, not only because actual TEUs include empties and transhipments, but also because the current model uses states as the geographical unit (again, except for the Northeast). Use of states is insufficient to distinguish between the ports located in one state, like Long Beach-Los Angeles and Oakland. In future research, states will be disaggregated to reflect more realistic markets.

### Demand change with the change of port use fees

The previous section presents the simulated results when the port costs are the same for all ports. The result is a point-estimation for the demand of the "conditional demand" for each port in that it depends on the given level of port charges at all ports.

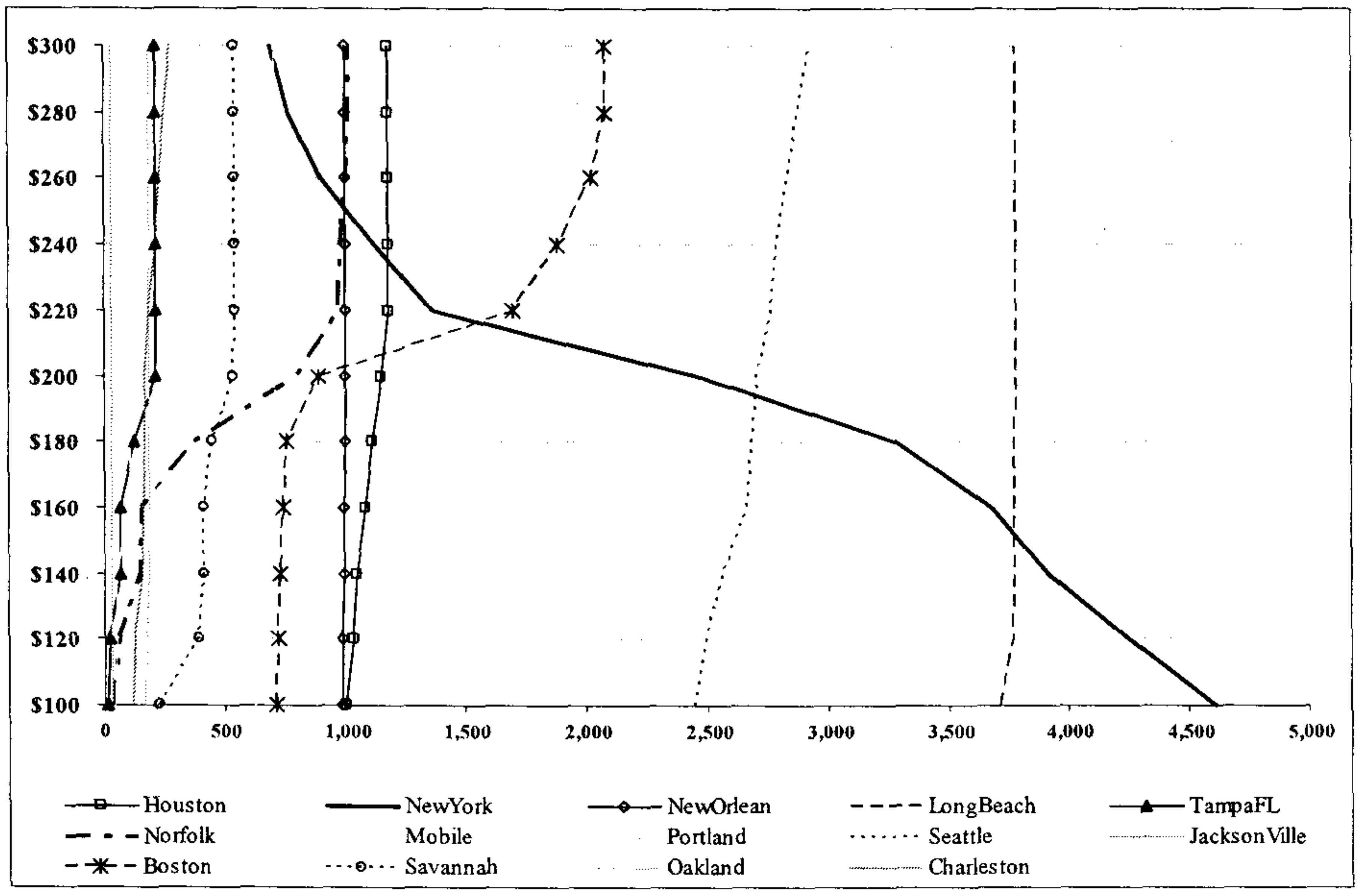
Since this model takes the container trade from each state to each continent for each cargo category as given, the simulated demand reflects the combined effects of international trade pattern, the spatial advantage of port location and the availability and condition of transportation facilities, including rail and highway systems. This conditional demand reveals the potential demand for container transportation services at various price level (such as terminal charges), which could be used for identifying potential competitors of given port.

Many methods can be used to improve the market competitiveness of a port, one common approach being varying terminal charges. Generally speaking, if we assume international trade is exogenous, increasing terminal cost at one port will reduce the incentive for shippers to use the port, and shippers may seek a less expensive port. Therefore, the quantity demanded at a port raising fees will decrease while demand in the competing ports will increase.

Figure 8 exemplifies the result of simulated demand for each port, assuming the terminal cost at one port (NY/NJ) changes from $100/TEU to $300/TEU. It shows that (1) when NY/NJ hypothetically decreases its terminal price from $300/TEU to $100/TEU, the annual demand of NY/NJ will increase from 480 thousand TEUs to 4.9 million

TEUs, and (2) the $300 per TEU level ($100 more than all other ports, an unlikely case) is near the choke price for *multi-modal* cargo. Also, at $300 per TEU, only local cargoes to and from NYC Metropolitan area will use the PNYNJ. (3) For terminal charges between $220 and $180 at the PNYNJ, the quantity demanded is most elastic. (4) Below $200, a price is lower than the prices at all other ports in this example, it quantity is less responsive to fee change by NY/NJ because the PNY/NJ cannot capture local markets served by other ports

**Figure 8: Simulated Demand Change for all existing ports when Port of NYNJ changes its terminal charge from $100 to $300 per TEU**



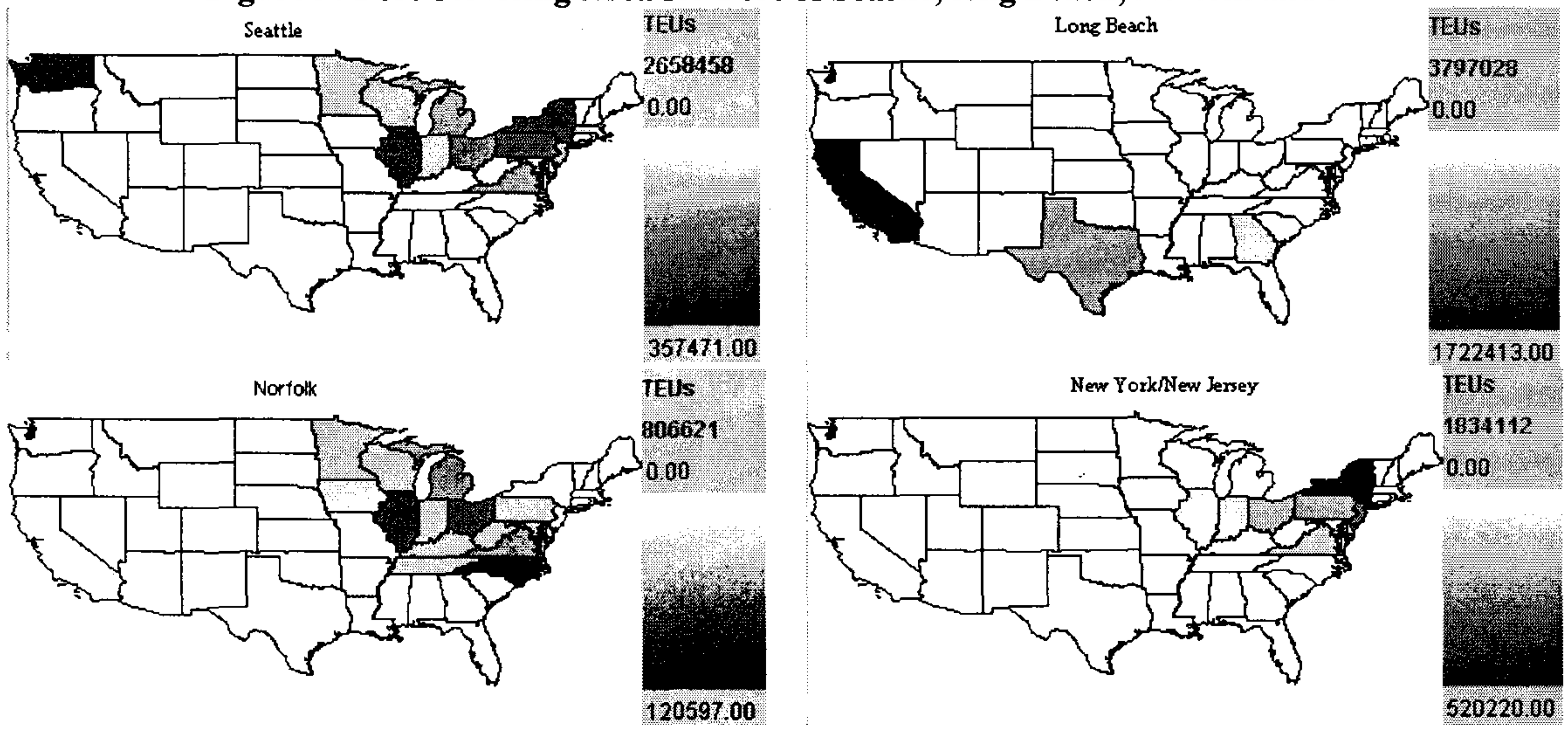
This result also shows the quantity of demand at other ports for different terminal charges at the PNYNJ, with Boston and Norfolk suffering most from reduced fees at PNYNJ. An interesting set of results is that many ports also suffer a demand reduction from the price falls in NYNJ--not only East Coast ports, but also ports in Gulf Coast and West Coast. When the price is higher than $200, most of the ports in West Coast and Gulf Coast are not affected. When it continues to drop, the number of affected ports will increase.

### Geographical distribution of Port Servicing Area

The increasing weight of multi-modal transportation has increased the interlacing of port hinterland. A port will not just serve markets in the vicinity of the port, but also compete for markets in areas that are far away from the port, through use of high-speed, low-cost rail connections.

The simulation of port servicing areas is one of the important features of this model. It supplements the demand estimation, as illustrated in the previous sections, by providing detail information on the spatial composition of the simulated demand. This will help in understanding the demand change with port competition, not only among nearby ports, but also the ports in other side of the continents. It will also help in identifying the important market areas for container ports and for estimation of the geographic distribution of the benefits from potential transportation cost savings. Figure 9 on the next page depicts the port servicing areas for Port of Seattle, Long Beach, Norfolk and NY/NJ. It reveals the vast geographic market areas serviced by major ports on both coasts, and hence demonstrate the potential for national competition among ports. For example, the Seattle/Tacoma market extends as far as East Coast states, South Pacific ports compete with South Atlantic ports and Gulf ports, and Norfolk competes with PNYNJ over containers in the Mid-East region.

**Figure 9: Port Servicing Area for Port of Seattle, long Beach, Norfolk and NY/NJ**



## SUMMARY, CONCLUSIONS, AND FUTURE DIRECTIONS

This paper summarized the development of a container port transportation demand simulation model for major US coastal container ports. Use of the model was illustrated by estimating the demand for 14 major, existing US ports through using the best available data from various sources to estimate a container flow OD matrix for different cargoes. The model can be used to simulate container transportation routes for different cargoes between the US and other continents, the conditional demand at each port, and port service areas. It can also simulate changes in the transportation route, port demand and demand changes due to different combinations of economic policies, such as higher trucking, rail, or shipping costs, changes in the opportunity cost of capital, or new ports or multi-modal facilities. The model also might be used to assessing the consequences of energy cost changes, of new environmental regulations, and national security concerns.

In summary, this research reveals that (1) the international trade pattern, (2) the geographical location of a port with respect to sources and markets, (3) the availability of multi-modal transportation networks, and (4) the associated general total cost are all major factors influencing container transportation demand at ports. Further, the results demonstrate that competition among container ports is not limited to the vicinity of the port. Instead, the service area of individual ports and the cross-price demand curve shows that policies at a given port may have impacts on distant ports. At the same time, demand for ports near major coastal population centers is high, since most of the container trade is imports and most US imported cargoes are consumer cargoes.

Refining and extending the model could include many directions. One is to study the shipper's choice on all possible routes of transportation. Also, the detailed treatment of multi-modal transportation will allow us to carry out with-versus-without analysis to assess the value of new or improved infrastructure facilities and to analyse selected net environmental effects, for example, truck usage and miles, net air emissions and vehicle-related noise around a hypothetical new port.

Finally, our ultimate goal is to development experimental simulation facilities for study strategic behaviour in container port competition. This simulation capacity will be used by stakeholders, policy makers, businesses and other interested parties in study the market competition result for each policy changes.

## BIBLIOGRAPHY

AAPA (2002). U.S./Canada Container Traffic in TEUs (1990-2000). *American Association of Port Authority.* http://www.aapa-ports.org/pdf/US_Canada_Containers.PDF, Accessed June 11, 2002

Bank, James H.. *Introduction to Transportation Engineering.* New York: McGraw Hill, 1998

Benacchio, Marco, Claudio Ferrari, Hercules E. Haralambides, Enrico Musso. On the Economic Impact of Ports: Local vs. National Costs and Benefits. *Forum of Shipping and Logistics, Special Interest Group on Maritime Transport and Ports International Workshop.* Genoa – June 8 – 10, 2000

Bertsekas, Dimitri P. (1995). *Dynamic programming and optimal control.* Belmont, Mass.: Athena Scientific, c1995

Beuthe, Michel, Bart Jourquin, Jean-Francois Geerts, Christian Koul a Ndjang' Ha. Freight transportation demand elasticities: a geographic multimodal transportation network analysis. *Transportation Research Part* E 37 (2001) 253-266

Bobrovitch, Dov. Decentralised planning and Competition in A National Multi-port System. *Journal of Transport Economics and Policy,* 16 (1982): 31-42

Bolduc, Denis. A Practical Technique to Estimate Multinomial Probit Models in Transportation. *Transportation Research Part* B 33(1999): 63-79

Bomba, Michael S., Robert Harrison and C. Michael Walton. Planning for Mega-containerships: A Statewide Transportation Planning Approach. Washington, D.C.:*Transportation Research Board 80th Annual Meeting* July 7-11, 2001

Bureau of Transportation Statistics, US DOT. *National Transportation Statistics 1999.* BTS99-04, Washington, DC:1999

Bureau of Transportation Statistics, US DOT. *National Transportation Statistics 2000.* BTS01-01, Washington, DC:2001

Cullinane, Kevin and Mahim Khanna. Economies of scale in large containerships: optimal size and geographical implication. *Journal of Transport Geography.* 8 (2000): 181-195

Emerson, William and James Anderson. A Spatial Allocation Model for the New England Fisheries, *Marine Resource Economics.* 6 (1989): 123-144

Ertl, Gerhard. Shortest path calculation in large road networks. *OR Spektrum* 20 (1998): 15-20

Fagerholt, Kjetil (2000). Evaluating the trade-off between the Level of Customer Service and Transportation Costs in a Ship Scheduling Problem. Maritime Policy and Management. 27 (2000): 145-153

Fowler, Chris. Application of the Least-Cost Transportation Model in Estimating the Impacts of Major Transportation System Changes – A case study of Dam Breaching on the Snake River. *Transportation Research Board, Washington, D.C.:80th Annual Meeting,* July 7-11, 2001

Garrido, Rodrigo A., Hani S. Mahmassani. Forecasting Freight Transportation Demand with the Space-time Multinomial Probit Model. *Transportation Research Part* B 34 (2000): 403-418

Gilman, S. and G. F. Willians (1976). The economics of multi-port Itineraries for Large Container Ships. *Journal of Transport Economics and Policy.* 10 (1996): 136-149

Grigalunas, Thomas A., M. Luo and YT. Chang (2001). Comprehensive Framework for Sustainable Container Port Development for the United States East Coast Year One Final Report, URI – TC Project No. Grant 536106, October 11, 2001

Hancock, Kathleen L., A. Sreekanth (2001). Conversion of Weight of Freight to Number of Railcars. *Transportation Research Board 2001.* Paper No. 01-2056

HDR Engineering, Inc. (2001) and John Martin & Associates. *Port of Portland Marine Economic Impact Study: Container Transportation Cost-Benefit Analysis.* <http://www.portofportlandor.com/htmlpop/a%5F200111191l5cntrcostbenefitrls.htm>, accessed 12 June 2002

Hensher, David A. and Kenneth J. Button (ed) (2000). *Handbook of Transport Modelling.* Pergamon.:Elsevier Science Ltd:UK.

Hillier, Frederick s., Gerald j. Lieberman. *Operations Research.* 2nd ed. San Francisco:Holden-Day, Inc., 1974.

Hoffmann, Jan. Concentration in liner shipping: its causes and impacts for ports and shipping services in developing regions. Unidad de Transporte: Santiago: ECLAC, 1998. 97 p.

Jones, James R. and Lu Qu. A spatial equilibrium port cargo projection model. *Maritime Policy and Management*, vol. 22. no. 1 (1995): 63-80,

Kesic, B., P. Komadina, D. Cisic (2000). Towards the Unified Theory of the Port Gravitational Areas – Introducing Information Centrality. *Transportation Research Board,80th Annual Meeting*, January 7-11, 2001

Klein, Christopher C. and Reuben Kyle. Technological Change and the Production of Ocean Shipping Services. Review of Industrial Organization. 12 (1997):733-750

Kronsjö, Lydia and Dean Shumsheruddin. Ed. *Advances in Parallel Algorithms*. New York, Toronto:Halsted Press-John Wiley & Sons, Inc, 1992

Kurose, James F. and Keith W. Ross (2000). *Computer Networking: A Top-Down Approach Featuring the Internet*, Addison-Wesley, 1st Edition,

Luo, Meifeng (2002). Container Transportation Service Demand Simulation Model for U.S. Coastal Container Port. Ph.D. Diss. Uni. Of Rhode Island, USA, 2002

Malchow, Matthew Brain. *An analysis of port selection*. Diss. Uni. Of California, Berkeley, 2001

McFadden, Daniel. The measurement of Urban Travel Demand. *Journal of Public Economics*. 3 (1974): 303-328

MISER (2000). *Foreign Trade Database. Massachusetts Institute for Social and Economic Research*. http://www.umass.edu/miser/axes/oldstuff/. Accessed June 11, 2002.

Murphy, Paul R., James M. Daley and Douglas R. Dalenbery (1992). Port Selection Criteria: An Application of a Transportation Research Framework, *The logistics & Transportation Review*, Vol. 28, No 3, September 1992

PNYNJ Press Release (2001). Port Authority Seeks Financial Support from Congress for more than $100 Million in Vital Dredging Projects – Channel Deepening Work is Key to Continuing Economic Growth in Ny-NJ Region. http://www.panynj.gov/hrd/hrdframe.HTM, accessed 12 June 2002

Panayides, P.M. and D.-W. Song, 2001. Liner Shiping Strategic Alliances as Cooperative Games: A conceptual Approach. *Proceedings*. The International Association of Maritme Economists, Annual Conference 2001. Hong Kong. 344-363.

Preston, John. Integrating Transport with Socio-economic Activity – a Research Agenda for the New Millennium. Journal of Transport Geography. 9 (2001): 13-24

Southworth, Frank and Bruce E. Peterson. Intermodal and International Freight Network Modeling. Transportation Research Part C. 8 (2000): 147-166

Stepford, Martin. *Maritime Economics*, Routledge: July 1997

Tsamboulas, Dimitrios A. and Seraphim Kapros. Decision-Making Process in Intermodal Transportation. *Transportation Research Record* 1707, Paper No. 00-1304, 2000

US DOT. The Impacts of Changes in Ship Design on Transportation Infrastructure and Operation. Office of Intermodelism, US DOT, Feb. 1998

Wang, James J., Adolf Koi-Yu Ng, Daniel Olivier (2004a). Port governance in China: A review of Policies in an era of internationalizing port management practices. *Transport Policy* 11(2004):237-250

Wang, James J., Brian Slack (2004b). Regional Governance of port development in China: A case study of Shanghai International Shipping Center. *Maritime Policy and Management*. Vol. 31, No. 4, pp. 357-373

Winston, Clifford. A Multinomial Probit Prediction of the Demand for Domestic Ocean Container Service. *Journal of Transportation Economics and Policy*, 15 (1981): 243-52