

**Issues in Container Transportation in the Northeast:
Background, Framework, Illustrative Results and Future Directions**

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December 2004

URITC PROJECT NO. 536185

**PREPARED FOR
UNIVERSITY OF RHODE ISLAND
TRANSPORTATION CENTER**

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1. Report No	2. Government Accession No.	3. Recipient's Catalog No.	
URITC FY00-10	N/A	N/A	
4. Title and Subtitle Issues in Container Transportation in the Northeast: Background, Framework, Illustrative Results and Future Directions		5. Report Date December 2004	
7. Authors(s) Thomas A. Grigalunas, Meifeng Luo, Simona Trandafir, Christopher Anderson, and Suk Jae Kwon		8. Performing Organization Report No. N/A	
9. Performing Organization Name and Address University of Rhode Island, Dept. of Env. & Natural Resource Economics, Kingston Coastal Institute, Kingston, RI 02881 (401) 874-4572 grig@uri.edu		10. Work Unit No. (TRAIS) N/A	
		11. Contract or Grant No. URI 536185	
		13. Type of Report and Period Covered Final	
12. Sponsoring Agency Name and Address University of Rhode Island Transportation Center 85 Briar Lane Kingston, RI 02881		14. Sponsoring Agency Code A study conducted in cooperation with U.S. DOT	
15. Supplementary Notes N/A			
16. Abstract An integrated framework for addressing container transportation issues in the Northeast US is developed and illustrated. The framework involves the extension of a spatial-economic coastal container port and related multimodal demand simulation model to include a hub and spoke feeder system, with the Port of New York and New Jersey (PNYNJ) as the hub. When applied, the extended model would incorporate the introduction of barges for short-haul of containers and enhanced rail to distribute containers from the PNYNJ to distribution centers throughout the Northeast, by that reducing truck travel or regional roads and bridges. Potential environmental benefits from reduced truck traffic, such as air emissions, road wear and tear, and fewer accidents, may result. Extensions of the model to include shadow prices for such external effects are described and illustrated using, as a case study, potential benefits from reduced emissions of NOx from a hypothetical feeder facility on Narragansett Bay. Inter-port competition also is described and estimates of cross demand effects for other coastal ports are simulated. Possible strategic behavior by a hub port against potential competitors using an entrance deterrent model is presented.			
17. Key Words Key words: Transportation economics, container transportation economics, container port demand, feeder systems, multimodal demand, least-cost routing, environmental issues.		18. Distribution Statement No restrictions. This document is available to the Public through the URI Transportation Center, 85 Briar Lane Kingston, RI 02881	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 25	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized (art. 5/94)

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I. INTRODUCTION AND BACKGROUND

I.A. Background

International trade plays a major and rapidly growing role in the United States economy, and increasingly the goods moving in trade are carried in containers on seemingly ever-larger vessels. The use of larger vessels allows for the capturing of scale economies in shipping (Cullinane and Khanna , 2001), but creates major pressures on carriers to stop at fewer ports and to move more containers at each port. This creates, in turn, severe economic pressures on ports hoping to serve as regional hub ports (Transportation Research Board, 2004).

To be a viable hub, ports must have adequate depth (at least 50 feet) to accommodate the newest generation of container ships, highly efficient port operations, and ready access to intermodal facilities to serve a wide market area. However, in practice many constraints limit port performance. The Port of New York and New Jersey, for example, is a dominant East-Coast port with 2.4 million (full and empty) containers (4.1 million Twenty-foot Equivalent Units (TEU)) moving into and out of the port in 2003 (www.panynj.gov). However, its growth has been constrained by several factors, including limited water depths, inefficient terminal operations (e.g., container moves per acre of land), and a distribution system greatly over-reliant on trucks. As recently as 2003, for example, trucks were used to move over 75% of the containers passing through the port. Movement of containers by trucks is hampered by congestion and, in turn, contributes to congestion, air pollution, and other external costs on area bridges and on highways within the metropolitan area and indeed in the Northeast corridor.

In short, ports hoping to thrive as a hub must simultaneously address transportation system issues on several fronts from dredging, to port efficiency, and multimodal distribution (Transportation Research Board, 2004). All of this must be done with keen awareness of environmental issues and interport competition, both of which provide external checks on port development and performance.

The multitude of issues to be addressed raises extraordinarily complex challenges for container transportation planning. Understanding the many interdependent factors involved requires an integrated approach, which brings together the major financial, economic, and environmental issues faced.

This report presents an integrated framework to begin to address regional container transportation issues. It involves a linked spatial-economic coastal port demand simulation model, which is expanded to include potential new multimodal links in a regional container distribution system described below. The case for new multimodal links has been made, in part, on potential environmental benefits (Ricklefs and Ellis, 2001), and the framework developed herein to address regional container transportation issues includes environmental factors (“shadow prices”). Elements of the framework are illustrated by generally drawing upon ongoing issues facing the Port of New York and New Jersey (PNYNY) and its plans to expand operations and improve its distribution system.

To achieve its ambitious expansion goals, the PNYNJ is (among other things) undertaking major dredging at the port and pursuing creative ways to rapidly distribute goods from and to the port (www.panynj.gov). A major proposal by the PNYNJ involves what is referred to as a Port Inland Distribution (PIDN) system. The PIDN would use systems of barges and trains to move containers from the port to key distribution centers throughout the Northeast. This system would reduce its current heavy reliance on use of trucks on congested regional roads and bridges with attendant environmental benefits.

A successful PIDN would relieve highways of considerable traffic, by that reducing losses imposed by congestion, emissions of air pollutants, noise, accelerated wear and tear on roads, accidents, and other potential social costs often associated with vehicular traffic in general and trucking in particular (e.g., Ozbay, Barten and Berechman, 2001; Ricklefs and Ellis, 2001; Grigalunas, et al., 2003, 2004;www.panynj.gov). However, what form the PIDN would take and the private and societal net benefits to be realized depends upon market forces, the financial incentives involved, environmental factors, and perhaps strategic factors.

If successful, the PIDN (and related initiatives) would (1) allow the PNYNJ to accommodate the newest generation of container ships, (2) reduce container dwelling time (the use of port land to in effect store containers) at the port, (3) connect the port with distribution centers throughout the Northeast, and (4) lower the use of trucks on congested regional bridges and highways, with the resultant avoidance of several external costs throughout much of the Northeast region. (Improved connections to the critical mid-West market also are high priority (Lipton, 2004)). However, implementing such an ambitious system is enormously expensive, the issues are highly complex, and success is by no means assured.

I.B. Purpose and Scope

This report presents an integrated transportation systems framework, which can be used to address several of the issues and challenges facing container transportation in the Northeast. We develop and illustrate elements of a linked financial-economic-environmental framework by analyzing the movement of containers to, from, and within the region. We do this for cases with and without a PIDN system, taking into account environmental concerns and interport competition within the context of a least-cost simulation model. We also outline data and research needs to later apply the framework and examine in detail a variety of important regional intermodal container transportation issues.

The framework is made up of three main elements. One is a spatial-economic, coastal container port demand simulation model (Luo and Grigalunas, 2004). This model can be extended to address the “short-haul” container transportation issue within a feeder system appropriate to the PNYNJ and its planned distribution network. However, first the model must be appropriately extended to include new alternative multi-modal -- marine barge and rail -- routes as part of a barge-rail feeder system. The model must also be updated with recent trade data for containerized goods and other information. The use of feeder systems for the short-haul container transportation problem has several variants and is a subject of ongoing, major interest not only in the US Northeast but also in many other market areas, virtually worldwide. For the case considered, we are interested in a hub and spoke system, described later.

Second, we illustrate how environmental factors, such as air pollution, can be usefully integrated into transportation systems planning, including consideration of a hub feeder port system. As an illustration, we estimate “shadow prices” from NO_x emissions arising from container transportation, and then explain how this information can be employed in the container transportation demand simulation model to analyze short-haul container movement issues of interest in the Northeast.

When fully carried out, the simulation model could contribute to port planning and broader regional transportation decisions. It would model a PIDN-type system using a least-cost framework and includes potential competition from other ports (Luo and Grigalunas, 2003). It also can be used to provide insight into the importance and consequences of “full social cost pricing” of transportation facilities use. That is, the results would be used to estimate how the multimodal mix of barges and rail versus current reliance on trucks would change, if the prices charged by transportation facility providers were to reflect the full social costs of their operations, private plus external costs. An example of NO_x air pollution is used as a form of test bed to illustrate how environmental issues can be incorporated and how further analyses might proceed.

Third, we explain how the spatial-economic model can be extended to address decisions, which involve a high degree of strategic interdependency between ports. We illustrate interport competition based on market area and price (cost). This work can be extended using game theory, which can provide important additional insights in transportation system investment decisions concerning competition between potential new or expanded port facilities and established hub ports. A game theory approach for addressing selected interport competition issues, and the data needed to implement the model, are outlined later in this report.

I.C. Organization

In Chapter II, the basic spatial-economic coastal container port simulation model is described. Extensions of the model to include expanded multimodal features in a hub and spoke feeder port systems are explained. An extension of the model to encompass air emissions and other external costs also is described.

Chapter III provides an illustrative example of the potential reduction in regional air emissions of one pollutant, NO_x, because a successful PIDN-type barge system would reduce the use of trucks. The example is intended to be only illustrative and is incomplete. For example, we include only one potential environmental issue, NO_x air emissions, and even for this pollutant, we do not net out potential offsetting increases in emissions from added tug-barge activity and crane movements at a feeder port (e.g., PROVPORT), although all such factors would be considered in a complete analysis.

Chapter III concerns interport competition, recognizing that ports in fact compete for commodities and markets. First, we review estimates of the *conditional* demand for container services at the PNYNJ, assuming no response from competing ports when the PNYNJ (hypothetically) changes its fees. Then, we explain the nature of the entry deterrence problem.

In this problem, a hub port would consider whether and how to attempt to deter entry by a potential container port competitor interested either in expanding their operation or constructing a new facility in competition with the hub port.

II. THE SPATIAL-ECONOMIC CONTAINER PORT DEMAND MODEL

II.A. Introduction

This section outlines the basic container port and intermodal demand simulation model and key assumptions used to apply the model. Further details, including references and extensive discussion of data sources, are given in Luo (2002) and Luo and Grigalunas (2003).

The model is designed to estimate container port *demand* by simulating the container transportation process through a multi-modal transportation system including ports, rail, highway, and international shipping. The model is not a trade model; trade is taken as a given. Nor is it a market equilibrium model, since an equilibrium model must include both demand and supply and the model we use is a spatial-economic, cost-minimization model, which at this point, allows us to estimate demand only. The model assumes shippers select a route that minimizes the general cost over the whole multimodal transportation system. General cost includes the cost of using all transportation facilities plus the interest cost on the value of goods being shipped.

The original model uses 1999 as the base year for trade data, aggregate trade, and its composition; and at this point, readily available economic parameters are used for major system costs. The rationale for selecting the simulation method and the important implication of these (and other) assumptions are explained in detail in Luo (2002) and in Grigalunas, Luo and Chang (2002).

Next, the economic reasoning and model formulation for calculating general transportation cost are explained. We also discuss the computational algorithm and the simplified software architecture of this model.

II.B. The Original Spatial-Economic Model

II.B.1. Overview

Container transportation demand in the basic model 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 routes could be used 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, although 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. Introduction of larger and faster container ships, labor unrest and congestion at some West Coast ports, and low interest rates serve to encourage the use of an all-water route from the Far East to PNYNJ. 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 also will be realized but these items are not in the model.

In sum, trade offs exist between the transportation cost and the time cost in the route selection decision. In the model, the shipper selects the route which 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 interest cost on the value of cargo, which varies with the time spent in travel, cargo value, and the interest rate.

In the original 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 that port gives the simulated container transportation demand for that port.

In the next phase of research, the model will be expanded to include a coastal-rail feeder system – in this case, a hub and spoke model. The recent availability of improved statistics on inter-coastal container movements will facilitate this analysis

II.B.2. Mathematical Statement of the Model

Assume that during a given period (typically a year) 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 α 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 ($j \in [\text{truck}, \text{rail}]$) the unit cost is β_{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 container is V_i , and the daily unit cost of capital is ρ .

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 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_I) using n^{th} port is:

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

- Time Cost

The time spend on sea leg is: $\frac{l_{an}}{24S_s}$ days, port H_n days, and domestic $\sum_j \frac{l_{nmj}}{24S_{Lj}}$ days, thus total

number of days spent in transit is $D_n = \frac{l_{an}}{24S_s} + H_n + \sum_j \frac{l_{nmj}}{24S_{Lj}}$.

For cargo i , the opportunity cost of time for the cargo value:

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

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^{th} port is the sum of the costs in the above two part:

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

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_{ami}^n containers of cargo i move from a to m will use port n , then the annual demand of port n ($Q(n)^1$) is:

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

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 in markets will affect the demand for port services. The model can be used to examine changes in these (and other) factors.

The core of the simulation model is the shortest path algorithm, which has been widely applied in economic analysis transportation engineering (Bank, 1998; Ertl, Gerhard, 1998, Beuthe, et al., 2001; Fowler 2001; HDR Engineering, Inc, 2001), operations research (Hillier and Lieberman, 1974), 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

¹ As a conditional demand estimation, this research focuses on conditional demand and does not consider any constraints which may exists on $Q(n)$ for each existing port n . Of course, port throughput is constrained by natural or legal factors. These constraints need to be addressed in a port equilibrium analysis planned for subsequent research.

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 (Kronsjö and Shumsheruddin, 1992; Bertsekas, 1995):

$$d_1=0 \tag{6}$$

$$d_i= \min_{k \in E_i} \{c_{ki} + d_k\} \text{ for } i = 1, \dots, n \tag{7}$$

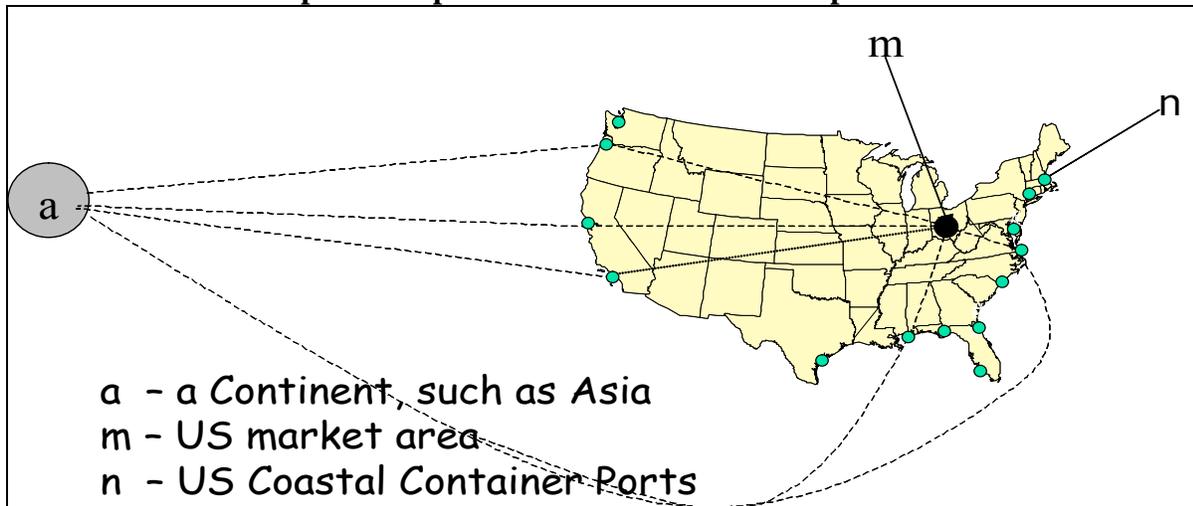
where n is the number of nodes in the network; d_i is the total cost from the starting node to node i; E_i is a subset of nodes that has a direct connection to node i, $E_i=\{v_i|i \in [1, k]\}$; c_{ki} is the general cost from one of these nodes to node i.

In applying the simulation model, we use one efficient version of the shortest path algorithm for the single source, multiple destination problems – the Dijkstra Algorithm. This has been classified as “Best First Search” algorithm (Bertsekas, 1995).

To apply the model, the simulation software used is developed using Java programming language. It is designed so that the users can interact with the simulation software and do simulation analysis using a Graphical User Interface (GUI). The GUI is designed using Java Swing technology. To facilitate the visualization of simulation data, this simulation software also included the design and implementation of a GIS data graphical representation using Java.

The original model has been applied in several cases. Sixteen major ports have been included in the model (Figure II.B.2.1). State and federal highways and Class I (national) rail systems have been included as well (see, Luo and Grigalunas, 2003). Of special note for analysis of a PIDN-type system, the unit of analysis is at the county level for the Northeast (New England plus New York) and at the state level elsewhere.

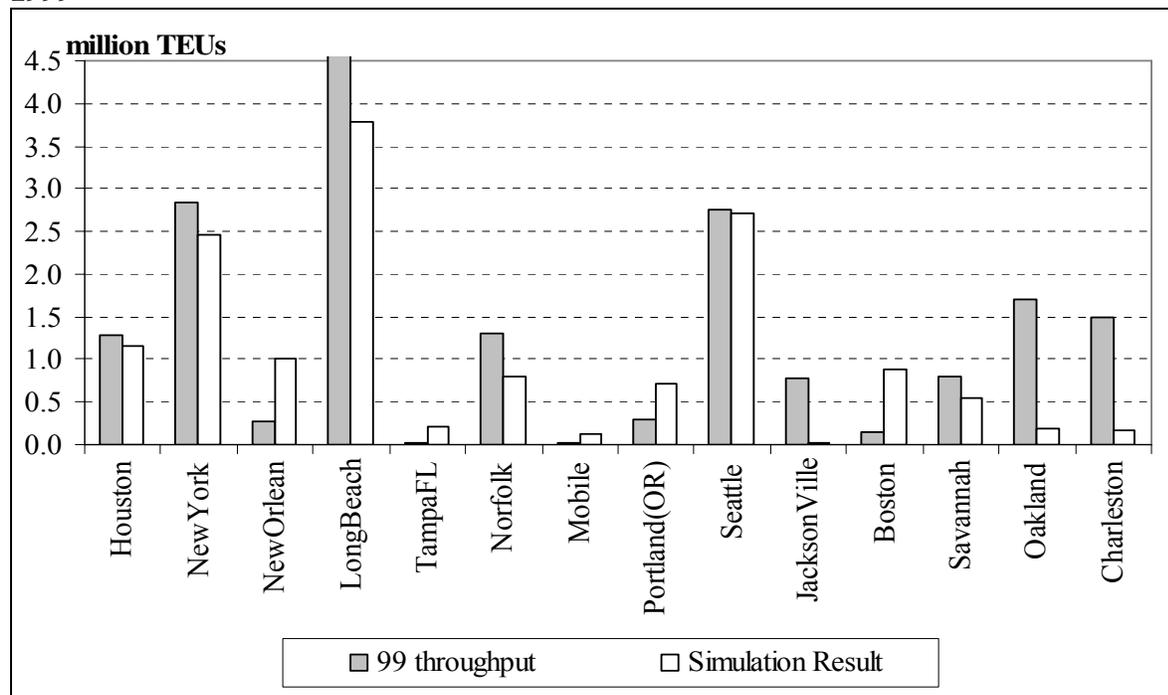
FIGURE II.B.2.1 Simplified Depiction for Multimodal Transportation Network



The results of earlier estimation of the demand for port services for major coastal container ports suggest that the model performs reasonably well. For example, the estimated moves of *full* TEUs are reasonably close to actual moves of full containers for most major ports (Figure II.B.2.2).

Of special interest for this report, the actual versus estimated moves of TEU for the PNYNJ were close (Figure II.B.2.2). These results suggest that even a simple model, based on cost-minimization, can reasonably track, and provide useful insights on, actual movements of containerized goods.

FIGURE II.B.2.2 Simulated Container Port Demand and the Actual Throughput for Year 1999



Notes: Due to the geographical closeness, some of the ports in West Coast used in the model 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.

II.B.3. Extensions of the Basic Model

II.B.3.a. Incorporating Additional Multimodal Features As noted, we will extend the basic model to include barge and additional rail links within the Northeast, once updated trade and cost data is obtained. Briefly, barge links from the PNYNJ to selected regional feeder ports would be treated as new “marine roads” or routes on coastal waterways. The costs of barge use will be introduced as a cost per mile, a fixed cost for loading and unloading boxes, and an interest cost on the value of the cargo sent via barge.

The general model for the extension is a hub and spoke system. In such a system, containerized cargoes are delivered to a hub (here, the PNYNJ) and then distributed to outlying distribution nodes: coastal feeder ports for movements via barges and inland distribution centers for rail. From these outlying distribution centers, area markets are served by truck. In turn, feeder ports

and inland distribution systems send cargoes (and empty containers) back through the hub port for export to international destinations.

The model to be developed initially will be a simplified version of a hub and spoke system under development by the Port of New York and New Jersey (PNYNJ). Referred to as the Port Inland Distribution Network (PIDN), the proposed system would involve a vast linking of markets throughout the Northeast with the PNYNJ as the hub. The PIDN also may involve intermediary stops by barges and trains, but this is not included in the model being discussed here.

To date, a lift on – lift off barge connection up the Hudson River to Albany has been established, and connections to other ports and inland distributions are at various phases of planning and implementation. Providence, Rhode Island (PROVPORT) is one of the coastal ports under consideration as a potential feeder port. The potential PIDN is illustrated in Figure 3. As indicated, several rail and barge links would be involved.

Integrating the PIDN in the existing spatial economic model would involve several steps. As noted, the cost per TEU of moving containers by barge or rail to and from the PNYNJ would be quantified. This would include extra costs of lifting boxes on to and off of barges, as well as cost per TEU from sources (PNYNJ) to destinations (e.g., Providence).

II.B.3.b. Using the Port and Multimodal Demand Simulation Model for Policy Analyses

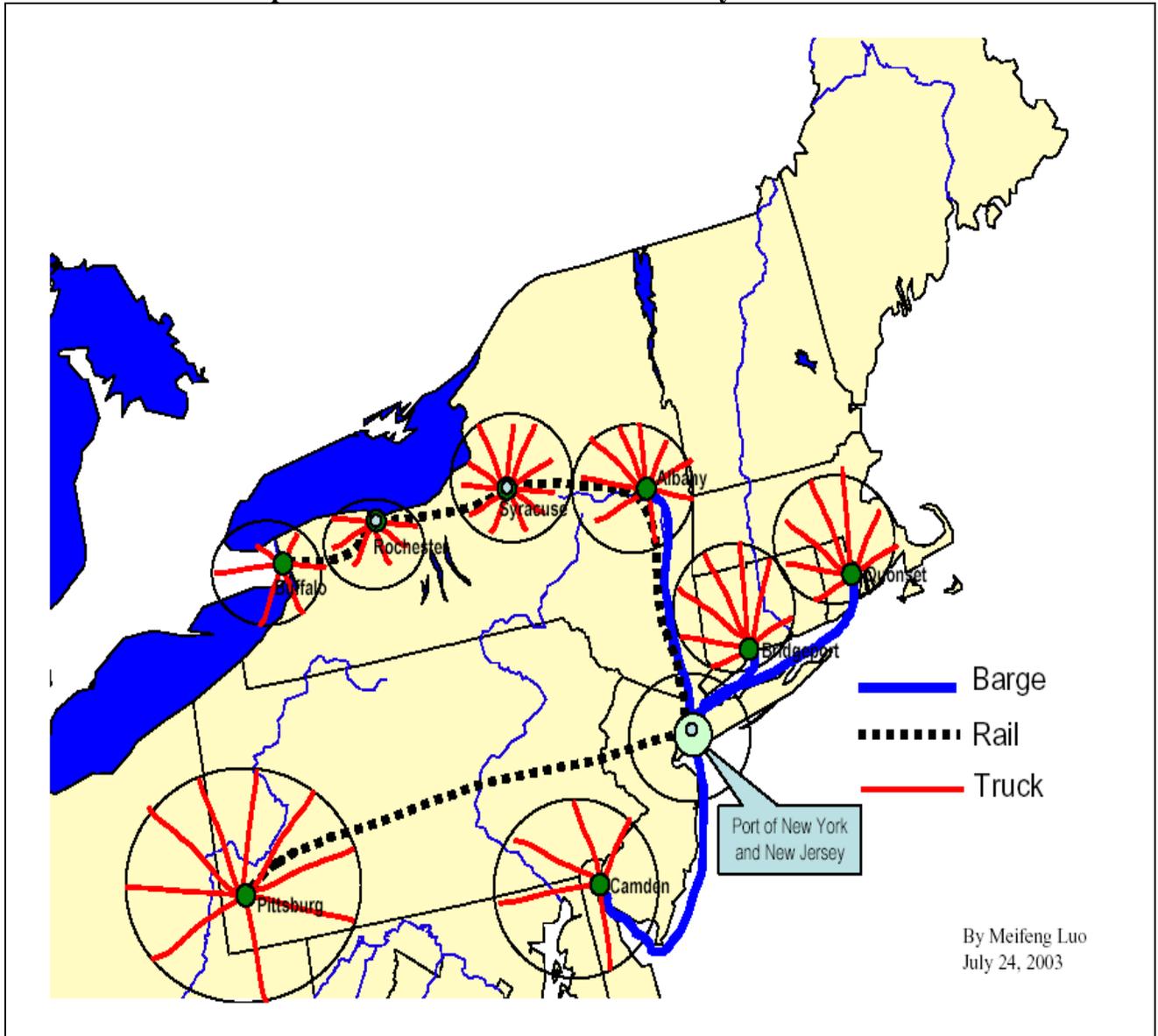
Here we describe the approach for analyzing policy issues with the simulation model, once updated data is acquired and the model is extended to incorporate a PIDN-type system. Several basic questions could be addressed. (1) Would a PIDN system become part of the least-cost container distribution system as estimated in the model? (2) What are the emissions and external costs of current reliance on the current truck-intensive system? How would the PIDN-type system reduce external costs by, for example, less truck traffic on the regions roads? (3) Would internalizing the external costs of the current system by charging “full social costs” for each transportation facility tilt the least-cost regional transportation of containers toward greater use of barges and trains and, if so, by how much? (4) What would be the resulting benefits and costs and what elements of the PIDN stand out as highest (and perhaps lowest) priority?

Specific steps to address the above policy applications would proceed as follows:

The Base Case. First, the model would simulate a Base Case for a given volume of containerized trade in the most recent year for which adequate data can be obtained. This Base Case analysis assumes *no* PIDN (or no PIDN links to certain distribution centers). Hence, the model results would simulate the least-cost use of East Coast coastal ports, highways and rail systems to move containerized goods to and from US destinations assuming the PIDN network is *not* extended to Providence or other ports north of Connecticut, for example.

This result for the Base Case implies a certain number of truck trips and miles on Northeast roads. The simulation model includes all state and federal highways. Therefore, it is straightforward to estimate changes in use of roads when analyzing the without versus with case for a PIDN-type system.

FIGURE II.B.3.b.1 Representation of the PIDN Container System



Introducing the PIDN. The port demand simulation model would be run again, this time with a PIDN system included (Figure II.B.3.b.1). This means new routes would be incorporated into the model with speed of barges, costs per TEU, and inventory costs (interest on the value of cargo) incorporated in a manner consistent with the base model. Barge routes in effect become “marine highways”.

The new solution will again indicate the least-cost movement of containerized goods for the *same* level of trade, sources, and destinations of goods as in the Base Case. With the PIDN now in the model, the transportation modes and routes *might* change from the Base Case.

Assuming the PIDN option of a barge system enters the solution, that is, is part of the least-cost solution for delivering containerized goods from sources from the PNYNJ to markets in the Northeast, and then the use of barges would correspondingly offset road use by trucks. Fewer truck miles, less wear and tear on roads, reduced air emissions, and possibly accidents would result. (Congestion might decline as well, although the present model is not well suited for addressing congestion, as noted, because it uses annual traffic flows and currently has no capacity constraints.) Hence, the simulation model lends itself to examining interesting and important environmental issues associated with container transportation.

II B.3.c. Extension of the Basic Model to Include Environmental Shadow Prices The Base Case model results for port, road, train, and barge use imply a corresponding level of air pollution emissions, E_{ij} , where i is the emission source (truck, train, tug-barge), and j is emission type, for example, NO_x , SO_x and CO . Here we illustrate how environmental issues can be included in the framework. For this illustration, consider air pollution by trucks, a major issue for much of the Northeast.

Figure II.B.3.c.1 and Table II.B.3.c.1 show emissions per mile for trucks as a function of speed, based on an application of the Environmental Protection Agency's (EPA) Mobil 5b model (Grigalunas, et al., 2003). The coefficients show that pollution intensity is a function of truck speed (and emissions while idling).

However, the emission coefficients and the accompanying figure reflect the current case (as of 2003) and do not incorporate changes, which will occur with implementation of new, strict EPA regulations under the Clean Air Act. Emissions per mile will substantially decrease over time as the regulations are phased in. Therefore any modeling of regional economic environmental issues pertaining to trucking over time should include the phasing in of the new regulations on air emissions (Grigalunas, et al., 2003)

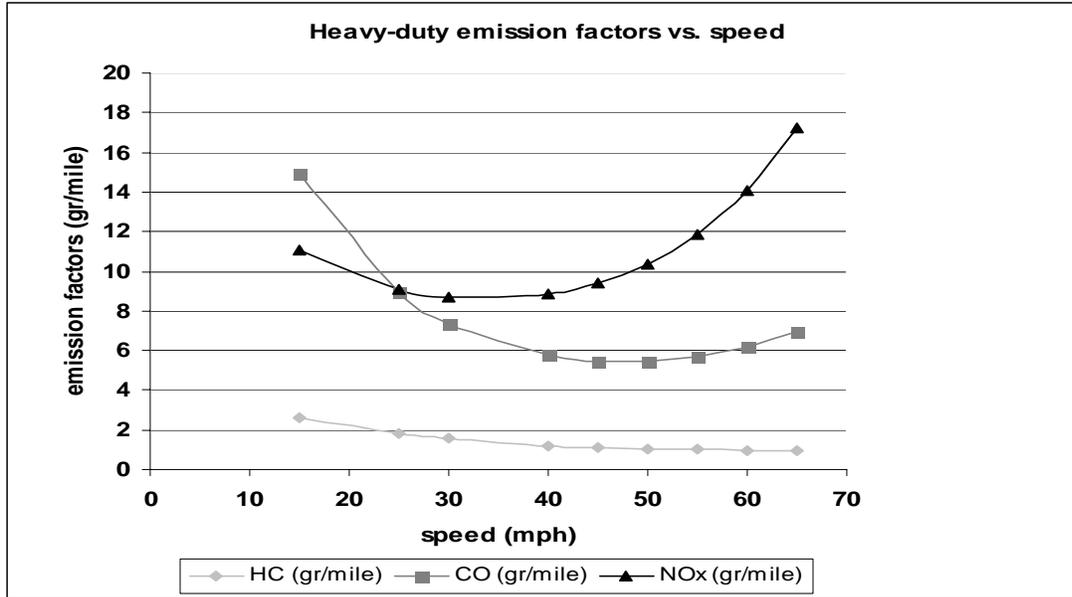
To take the new regulations into account, we allow for phasing in of compliance over an extended period as new trucks meeting the new EPA regulations gradually enter into the fleet replacing older, more polluting trucks. This is illustrated in Figure II.B.3.c.2, which shows the percent of trucks meeting current, Phase I and stricter Phase II EPA standards. Emission coefficients for trucks for any year reflect the *mix* of different trucks in the fleet in that year.

Information on emissions per unit of activity potentially allows for an assessment of total damages from air pollution, using benefit transfer or perhaps other, more sophisticated approaches. For example, in prior research the estimated damage per metric ton of NO_x (\$5,618) used by the Office and Management and Budget (2003) was employed to provide a perspective of damages from container transportation-related NO_x emissions (Grigalunas, et al, 2003).

In addition to air pollution from NO_x and other air pollutants, the estimated number of truck trips in the Base Case directly relates to road use – truck miles traveled -- and hence potentially to wear and tear and accidents on state or regional highways. Congestion, wear and tear on roads, and accidents also is a function of traffic (among other determinants) and might be included (see, e.g, Ozbay, Bekir, and Berechman, 2001). Some of these external costs can be incorporated into

the model, ideally through original research or alternately, through judicious use of benefit transfer. However, congestion may not be addressable with the current model. This is because the model does not include supply constraints for ports, roads or other facilities, and further, like most models on this scale, the period of analysis is traffic per year, by that ignoring peak period (day or seasonal) demand. Therefore, congestion and the related air emissions, value of lost time and other related costs could not be included without wholesale modification of the model or use of an additional short-term model, such as a dynamic event model.

FIGURE II.B.3.c.1 Emissions of HC, CO and NO_x from Heavy Duty Trucks as a Function of Speed



Source: Application of EPA Mobile 5b model (US EPA, Office of Air Resources, 2002)

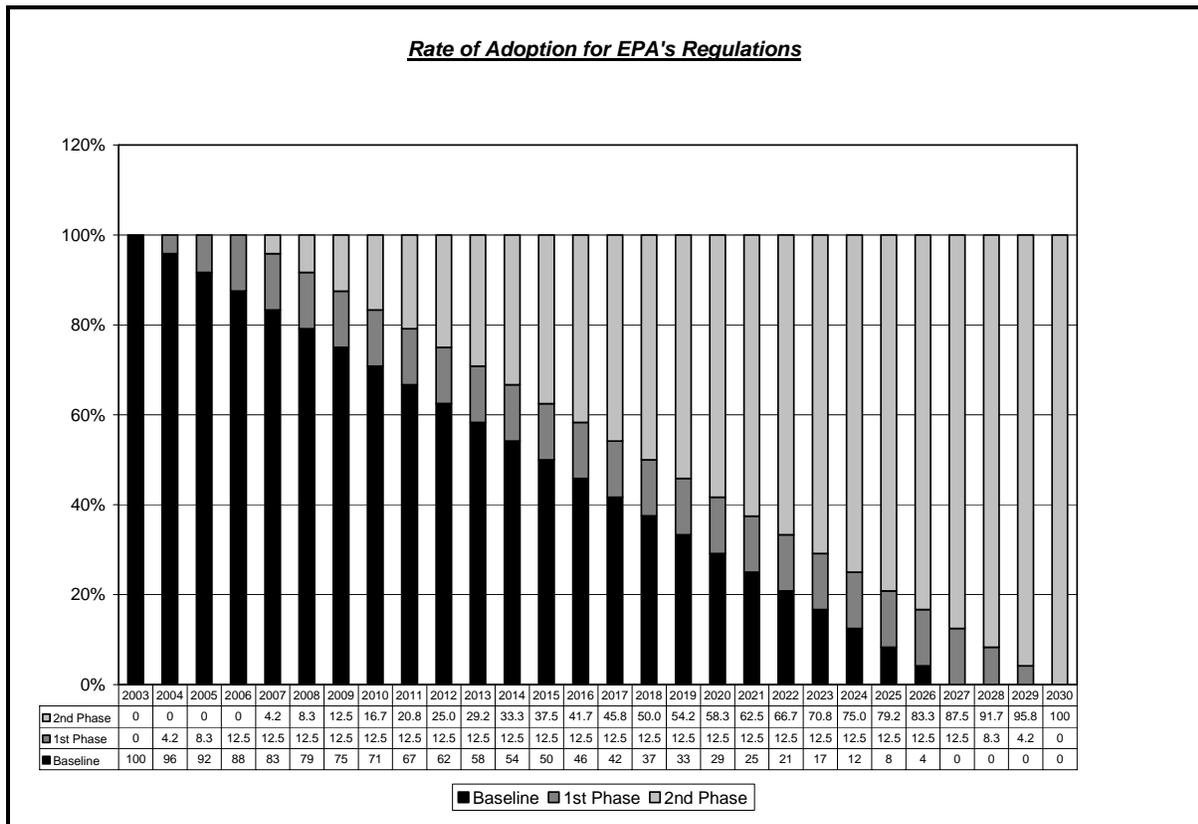
TABLE II.B.3.c.1 2002 Heavy-Duty Diesel Emission Factors vs Speed (Mobile 5b)

SPEED (mph)	HC (gr/mile)	CO (gr/mile)	NO _x (gr/mile)
5	4.19	30.5	15.54
10	3.29	20.72	12.89
15	2.64	14.95	11.08
20	2.17	11.29	9.84
25	1.82	8.92	9.11
30	1.56	7.38	8.71
35	1.36	6.39	8.63
40	1.22	5.79	8.86
45	1.12	5.49	9.43
50	1.05	5.45	10.39
55	1.01	5.66	11.86
60	0.98	6.15	14.04
65	0.98	6.99	17.21
Idle	4.64 gr/hr	35.31 gr/hr	16.91 gr/hr

Source: US EPA, Office of Air Resources, Mobile 5b, 2002

Next, operating costs for transportation models would be altered to better reflect social costs. To do this, estimates of shadow prices for environmental costs (externalities) would be imposed. For example, suppose marginal damage from use of transportation mode j , D_j , is a function of miles $D_j = D_j(m)$, such as air pollution cost per vehicle mile. Hence, the marginal cost per mile is D_j' . Then, the cost per mile for transport mode j , β_j , in equation 1 above would be increased by $D_j'(m)$ by that internalizing external cost. This marginal damage cost will differ by transport mode because each mode (truck, train, vessel) differs in its pollution intensity. It may also differ by route if speed limits vary considerably along major routes.

FIGURE II.B.3.c.2 Rate of Adoption for EPA’s Air Emission Regulations on Heavy Duty Trucks



A simple example is used to illustrate the scope and scale of the important environmental issues involved with the PIDN. The example assumes that a feeder port is established at the Port of Providence – PROVPORT. The numbers used are based on assumptions but are based on available information and judgments by port officials and are not wholly fanciful.

We assume that initially, one barge arrive per week, each carrying 100 full containers from the PNYNJ facility in New Jersey. On the return leg, each barge is assumed to carry 50 containers (Table II.B.3.c 2).

TABLE II.B.3.c.2 Summary of Key Assumptions and Estimates of Reduced Truck Traffic, NO_x Emissions, and Annual Damages Avoided because of Hypothetical Feeder Port in Providence

	Barges per week	Growth Rate	Boxes per Barge In	Boxes per Barge Out	Boxes per Truck	Miles NY - PVD	Working Days per year	Working Weeks per year
Assumptions	12	3%	100	50	1	180	365	52

Year	Barges	Truck Trips Avoided	Truck Vehicles Miles Avoided	NO _x Emissions Avoided (Tons)	Annual NO _x Damages Avoided (\$)*
1	52	7,821	1,407,857	14.38	80,809
2	54	8,056	1,450,093	14.56	81,822
3	55	8,298	1,493,596	14.74	82,824
4	57	8,547	1,538,404	14.59	81,942
5	59	8,803	1,584,556	14.41	80,931
6	60	9,067	1,632,092	14.20	79,787
7	62	9,339	1,681,055	13.97	78,501
8	64	9,619	1,731,487	13.72	77,065
9	66	9,908	1,783,431	13.43	75,474
10	68	10,205	1,836,934	13.12	73,717
11	70	10,511	1,892,042	12.78	71,787
12	72	10,827	1,948,804	12.40	69,675
13	74	11,151	2,007,268	11.99	67,371
14	77	11,486	2,067,486	11.55	64,867
15	79	11,831	2,129,510	11.06	62,151
16	81	12,186	2,193,396	10.54	59,215
17	84	12,551	2,259,197	9.98	56,046
18	86	12,928	2,326,973	9.37	52,634
19	89	13,315	2,396,783	8.72	48,966
20	91	13,715	2,468,686	8.02	45,032

* 2002 Dollars

Hence, the number of containers moved per week at the outset is 150. Barge shipments (but not necessarily the number of barges) are assumed to increase at 3% per year. This is a modest growth rate compare to current and projected growth for the PNYNJ, which are more than twice this rate.

For this illustrative example, 7,821 (= 52*150) boxes would move by barge the first year, taking an equivalent number of trucks pulling containers off the road, primarily Interstate Route 95 in this case. Assuming each reduced trip saves 180 miles, a total 1.41 million fewer truck road miles occur in the first year on the major route from PNYNJ and onto Route 95 north. If traffic grows at 3%, in year 10 of operation barges would deliver 10,205 TEUs, decreasing road truck traffic by this amount and avoiding 1.84 million truck miles of traffic (Table II.B.3.c.2).

Now, consider air pollution, an important regional environmental issue. Other things equal, emissions are a function of speed. In an earlier study, the emissions per mile for a truck traveling 50 miles per hour were estimated. Under the Clean Air Act, EPA regulations will reduce emissions in two phases over the period 2004 to 2030 (Figure II.B.3.c.2).

For this simple illustration, for year 1 (before implementation of phase I or II), air pollution damages for NO_x per *mile* of truck traffic avoided is \$0.0583:

$$\partial D/\partial M = \partial D/\partial E \times \partial E/\partial M, \text{ or}$$

$$\partial D/\partial M_1 = (\$5,6180 * (10.39 \text{ g/mile})*10^{-6} = \$0.0583 \text{ per truck mile (in 2002 dollars)}$$

Hence, total air pollution damages avoided in year 1 from reduced NO_x emissions alone for this one PIDN connection is \$80,809 (0.0583*1,410,000). By year 10, the number of trucks miles reduced is 1.84 million miles and the damages avoided from NO_x per truck mile are:

$$\partial D/\partial M_{10} = (\$5,618 * (4.805 \text{ g/mile})*10^{-6} = \$0.027 \text{ per truck mile}$$

Total benefits from the drop in NO_x because of reduced miles traveled for this one PIDN site in year 10 is \$73,717.

Discounted at 3% (the rate often used in natural resource damage assessments) over 20 years, damages avoided because a barge system reduces NO_x from trucks would be \$1.1 million for this one pollutant for one potential PIDN site. Across many environmental issues (air emissions, congestion wear and tear on roads, accidents, and noise) and many sites, the total environmental benefits could be considerable. Of course, benefits must be reduced by offsetting, additional costs from implementation of the PIDN, such as barge-tug emissions.

The external cost per mile for NO_x given above is one example of how shadow prices for environmental damages could be used as “environmental adders” to private costs for use of transportation facilities. When several such shadow prices are included in the container simulation model, the case for a PIDN-type network including full social cost pricing can be assessed. This is the ultimate goal of the framework to be employed in further research, once updated data can be obtained and programming done to extend the model to deal with emerging regional container transportation issues.

III. INTERPORT COMPETITION AND STRATEGIC BEHAVIOR

III.A. Introduction

The continued success of a hub port depends importantly on the competitive environment in which it operates. Competition for a particular port can have many elements, such as cost, proximity to markets, quality of multimodal facilities and connections, frequency of carrier or liner services, quality of services, labor costs and reliability, distance from other ports, and congestion (e.g., Tiwari, Itoh, and Doi, 2003).

In the section immediately below, we focus on one important factor -- the relative costs of using different ports. We use the spatial-economic container port simulation model to illustrate how hypothetical changes in cost at the PNYNJ affect container moves through its port. We also show how changes in price at the PNYNJ affect demand at other ports -- essentially, cross demand effects. Then, we outline changes needed to extend the model to better assess a PIDN-type system within a multiport framework. Finally, we show how the framework can be extended further to analyze strategic behavior -- potential competition with another port using a simple game theory formulation, which involves “entry deterrence” by the hub port.

III.B. Interport Competition

To illustrate interport competition, we begin by taking the base case results for the PNYNJ. We estimate the *conditional* demand for services at the PNYNJ. By “conditional” we mean that only the fees charged by the PNYNJ change; all else is equal, and price changes at the PNYNJ do not generate any responses by competitors. We also simulate how hypothetical changes in fees at the port might affect the quantity of services (measured as TEUs) demanded at other ports, i.e., interport competition. Again, for simplicity at this point we assume that the other ports do not respond to fee changes at the PNYNJ.

III.B.1. Illustration of Conditional Demand at PNYNJ

The simulation model results estimate the transportation route for each cargo category and each cargo origin and destination by minimizing the general cost in the total transportation process. Then, the aggregate demand for port container services is derived by the total number of loaded containers (in TEU) which will move through the port.

Therefore, the simulated demand from one port is a function of the international trade pattern, the costs for using container transportation facilities (include truck, rail, inland container yard, container port, and vessel transportation), and the complete transportation network. Since the opportunity cost of the capital tied up in the containerized cargo can also be an important element in the total general cost, the discount rate is also involved in the demand function.

The general demand model is summarized as follows. Assume there are N coastal ports, the demand for i^{th} port can be written as:

$$Q_i = Q_i(Q, P_s, P_r, P_t, P_i, P_{\bar{i}}, Z, \rho) \quad (1)$$

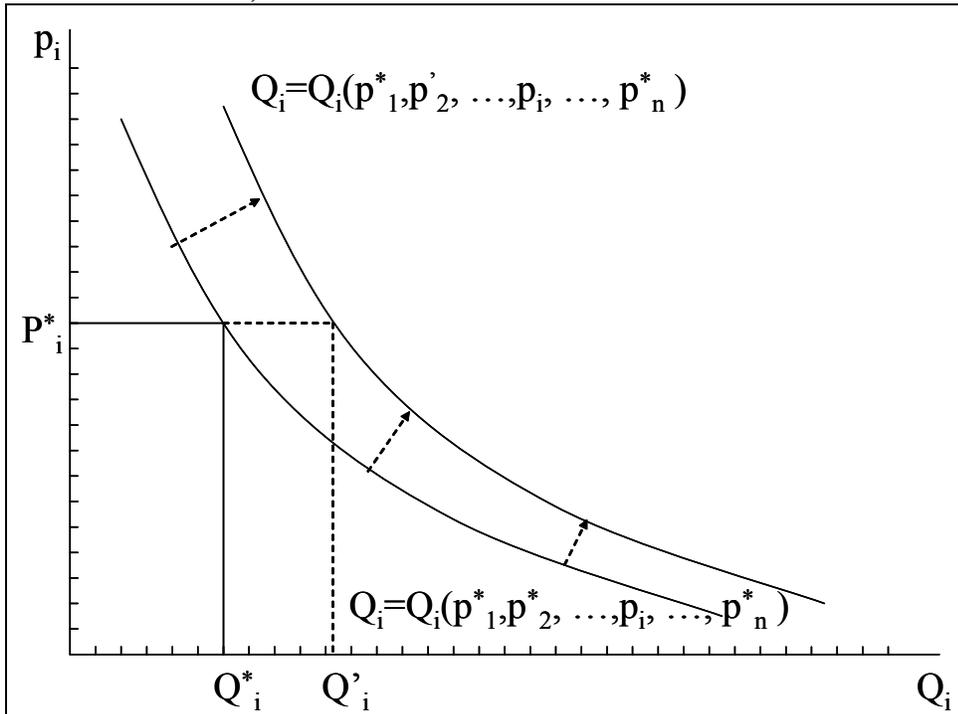
and
$$\sum_{i=1}^N Q_i = Q \tag{2}$$

Where:

- Q_i : Quantity of demand at port i
- p_s, p_r, p_t : unit cost per TEU*mile by shipping, rail and truck, respectively
- $p_i, p_{\bar{i}}$: Port cost at port i and all other port, respectively
- N: The number of ports under consideration
- Q: Total demand
- Z: all other attributes for transportation network
- ρ : the interest rate

If we consider the effect of only port charges ($p_i, p_{\bar{i}}$) on port demand, port demand depends not only a function of its own price p_i , but in principle also depends upon the price at all other ports ($p_{\bar{i}}$). Given information on charges for all ports, then the simulation result is conditional demand *point* estimate (conditional on the price and characteristics of all ports). This case is illustrated by Q_i^* in Figure III.B.1.1 which shows the conditional demand *function*, Q_i , for the i^{th} port – the relation between quantity of demand and its service charge is conditional on the charges at all other ports. The function $Q_i=Q_i(p_1^*, p_2^*, \dots, p_i, \dots, p_n^*)$ in Figure III.B.1.1 refers to this conditional demand function. Change at any one of them may shift this conditional demand curve. Figure III.B.1.1 shows that if the price at port 2 decreases from p_2^* to p_2' , then the conditional demand function for port i will increase – i.e., shift out. In this case, the conditional demand point estimate will be Q_i' .

FIGURE III.B.1.1 Illustration of Conditional Demand Point Estimate, Conditional Demand Function, and Shift of Conditional Demand Function for a Container Port



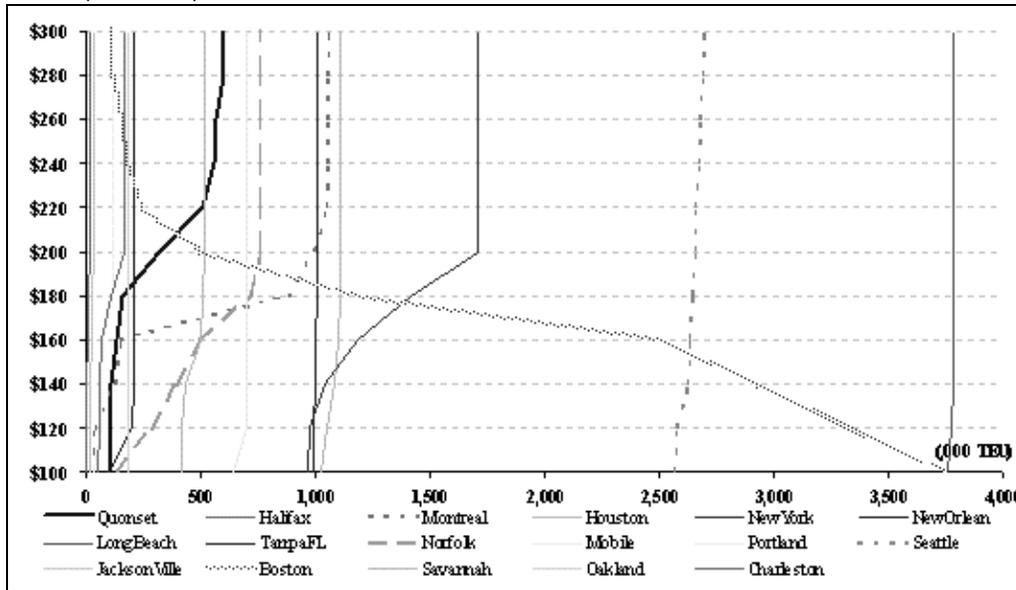
Market competition among geographically dispersed ports enables each port to charge different prices. Therefore, to simulate the throughput, it is necessary to have actual port charges at all ports. At present the primary objective of the simulation model is to estimate demand, not market equilibrium. For this analysis, we use a price of \$200 per TEU at all the ports. Therefore, the demand estimated using the simulation model is a conditional demand. We emphasize that we are estimating demand – not throughput, which involves equilibrium (i.e., demand and supply) in the market. Later research may simulate market throughput, if further research can incorporate port supply functions in the simulation process.

The model is applied using waterborne trade and other data for 1999. Given that aggregate trade is fixed, the demand change due to port construction or facility development at one port will always be accompanied by the opposite change in demand at all other ports, i.e.,

$$\frac{\partial Q_i}{\partial p_i} + \sum_{j \neq i} \frac{\partial Q_j}{\partial p_i} = 0 \quad (3)$$

This property can be easily derived by differentiate the equation (2). It shows that the demand increase at port *i* due to a price decrease at this port will always equal to the sum of demand reductions at all other ports. If port *i* is the new port, then the estimated demand at this port is a mere shifting of demand from other existing ports.

FIGURE III.B.1.2 Demand Change for each Port when Cost per TEU at Boston Changes from \$100 to \$300.



The results in the above figure illustrate important aspects of interport competition.. Demand at the PNYJ is responsive to price up to \$220 per TEU and the PNYNJ competes with several ports, some quite distance, for example, Seattle-Tacoma, Montreal and Norfolk. Initial increases in fees per TEU cause container traffic to switch to substitute ports. Hence, the PNYNJs market power is constrained up to about \$220 per TEU. However, at high fees per TEU, the PNYNJs market is relatively unresponsive to demand, suggesting that the PNYNJ has considerable more market power over importers and exporters, likely throughout metropolitan areas near the port region for which use of other ports by exporters/importers would be too costly.

Thus far, only the effect of fee changes has been considered. The effect of a PIDN would be to create additional routes to markets throughout the Northeast (see PIDN Figure). A successful PIDN may reduce costs at the PNYNJ and perhaps reduce the overall costs of distribution, for several reasons. For example, a major problem at the PNYNJ has been that containers on average have stayed at the port (“dwelling time”) 6 days. In effect, port land is used as a warehouse to store incoming goods at low or zero cost until the goods get shipped to their final destination (Hannan, 2003).

Long dwelling times for containers requires substantial land, and at the PNYNY this land is extremely expensive. For example, 2003 land rents at or near the PNYNJ were some \$65,000 per acre. Use of a PIDN would expedite movement of containers and, by that, help reduce dwelling time and economize on the use of costly port land (Hannan, 2003). Overall port efficiency, measured simply as throughput of containers per acre, would increase, perhaps dramatically. This potential savings might allow the PNYNJ to pay PIDN participants a subsidy of, say, \$25 per box, and this can be included in an updated spatial-economic model which specifically includes a PIDN.

In extensions of the spatial economic model, it would be possible to estimate a shadow price for the costs saved when a PIDN reduces container dwelling time. This would be one element of the cost (here, a cost savings) of adopting the PIDN.

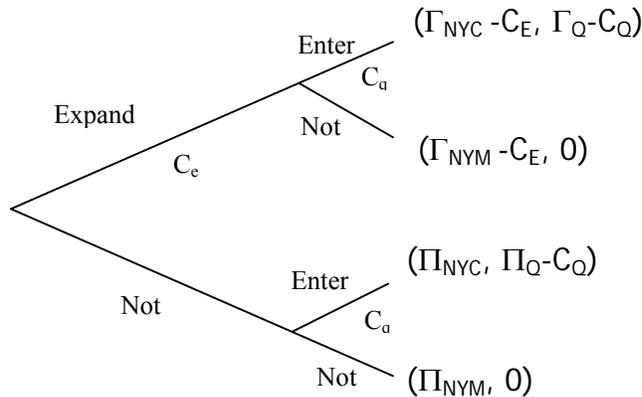
III.B.2. Strategic Behavior

Although the analysis above indicates there is competition among ports, it also shows that ports retain an element of local market power for the area it primarily serves. This control over the local market can be eroded, and market share competed away, by the entry of new ports (or expansion of existing ports) in the same geographic area. In this section, we outline a model, which allows for strategic behavior by the hub port faced with potential competition.

The basic problem is that a hub will lose market share if a competitor expands or if a new port is created. This threat of entry may lead the hub port to take actions—which may not pass a short run benefit-cost analysis test—in order to position itself to compete aggressively, should a expansion of an existing port or development of a new port threaten its region. It might develop a new feeder system of build or (more likely) upgrade rail access to the area. If demand is to be accurately modeled, such defensive actions must be explicitly considered. Knowing the incumbent hub port is positioned to compete away profits, the potential port expansion or development projects may decide against entering the market.

The general problem is that of entry deterrence and is illustrated in our case in the figure below. Facing a potential entry by a competitor, say Quonset Point (a proposed but since cancelled new hub port proposal), the hub port, say PNYNJ, must decide whether or not to expand, an action which would make it less expensive to serve the region which would be better served by Quonset, and would cost C_E . Having observed whether the incumbent has expanded, a potential new port decides whether or not to develop, at a cost of C_Q . If the hub expands, and the competitor does enter, then the hub port realizes the profits associated with Cournot-style competition, Γ_{NYC} at an expanded level of development, less C_E . If the potential competitor does not enter then, the hub realizes its local monopoly profit, Γ_{NYM} , less C_E . The competitor earns profits $\Gamma_Q - C_Q$, the amount it earns from competing with the incumbent less the cost of development, if it enters, and zero otherwise.

On the other hand, if the hub does not expand and the potential competitor enters, the two compete with the incumbent earning Γ_{NYC} and the entrant earning $\Gamma_Q - C_Q$, profit from competing plus the cost of development. If the entrant does not enter, the incumbent continues to earn local monopoly profits.



The strategically interesting case arises when $\Gamma_Q - C_Q < 0$, so the entrant should not enter if the incumbent expands, and $\Gamma_Q - C_Q > 0$, so it is optimal for the entrant to enter if the incumbent does not expand. In this case, the incumbent must make a strategic decision about whether to protect its market share: it can pick between $\Gamma_{NYM} - C_E$, where it expands and the entrant stays out, and Γ_{NYC} , where it competes with the entrant. The incumbent compares these two alternatives, and moves to protect its market share if $\Gamma_{NYM} - C_E > \Gamma_{NYC}$.

This case is interesting because the incumbent takes costly action which is not directly profit-enhancing; rather it is intended to discourage entry.

In sum, interport container competition has many elements. The effect of changes in relative costs of using ports is illustrated through the conditional demand. In earlier research, conditional demand was estimated only for direct movement to and shipment from coastal container ports. The framework developed herein would expand the early analysis to include a PIDN-type feeder system, that is, a hub and spoke system with coastal use of barges and inland use of trains to

distribution centers and subsequent distribution to nearby areas. This would provide a much more realistic analysis of this major regional transportation system program.

A game theory approach would build on the PIDN analysis. It would uncover the potential incentives a hub port (here PNYNJ) would have to expand the PIDN (or elements of the PIDN) if other existing ports or a potential new port were considering competing with the hub port for a share of the market. Given information on the profitability of different scales of operation and on a PIDN network as described in preceding sections, this research on this set of issues could be implemented.

To carry out these analyses substantial data updating is required. As well, additional programming to extend the simulation model to include inter-coastal (short haul) shipping.

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