Sensitivity Analysis of Imported Container Volumes to Surcharge Fees via a User-Equilibrium Model

Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

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February 2016

ABSTRACT

Inspired by rapidly escalating congestion at the Ports of Los Angles and Long Beach as well as other West Coast container ports (Mongelluzzo, 2014), this study analyzes the impact of user fees on the flow of containerized imports into the United States from Asia. This analysis makes use of an equilibrium model where the link impedances include all the logistic fees as well other relevant modal charges. This analysis illustrates an Origin-Destination network that includes four origin-countries, six Ports of Discharge (PODs) and three U.S. areas as destinations. A user-equilibrium model is established for estimating the container flow. Sensitivity analysis of the imported container volume to surcharge fees will then be presented via the equilibrium model.

BIOGRAPHICAL SKETCH

Yuchen Yan is currently pursuing an M.S. in Civil and Environmental Engineering department at Cornell, specializing in Transportation Systems Engineering. She is originally from Beijing China. She did her undergraduate studies at Hong Kong Polytechnic University, where she graduated with a B.Eng. in Electrical Engineering in 2013. She had a summer internship in Madison NJ in 2014 in a freight forwarding and supply chain management services company. In her free time, she enjoys traveling and playing tennis.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my advisor, Prof. Linda K. Nozick, a responsible and resourceful mentor and scholar, who has provided me with valuable guidance in every stage of proceeding with this thesis.

I shall extend my thanks to Prof. H. Oliver Gao, who is my minor area advisor, for all his kindness and help on providing useful information.

My sincere appreciation also goes to Hao Wang, who helps me clarify the thinking at the beginning of my thesis.

Last but not least, I would like to thank my friends and parents, for their constant encouragement and support.

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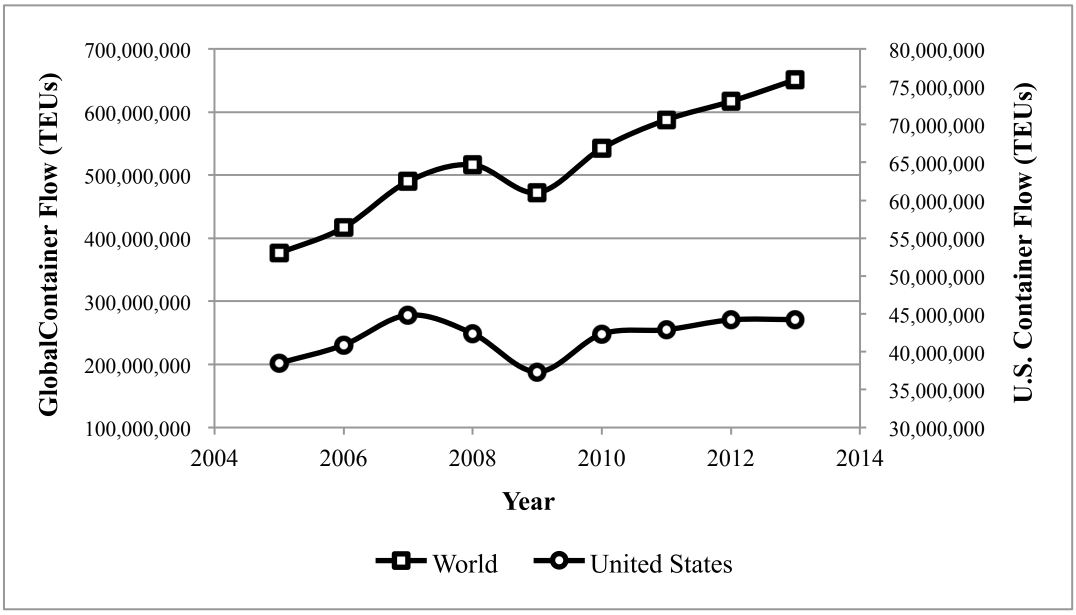
1 INTRODUCTION

Containerized maritime transportation is the leading method for the import of manufactured goods into the United States. A key advantage of containerization is their standardized dimensions. Hence they can be loaded, unloaded, stacked and transported very efficiently. It also simplifies the counting, recording and tracking processes. Moreover, containers can also be easily transported by rail flatcars and trailer trucks. This is a significant advantage in the system of intermodal freight transport. According to the World Bank (Figure 1), global container flows have steadily increased with a slight dip associated with the Recession of 2009. In 2013, global container flow exceeded 650 million TEUs (Twenty-foot Equivalent Units), which about 40% larger than those same flow in 2009.

Figure 1: Container Port Traffic TEUs - Global and U.S.

(The World Bank, 2015)



Unfortunately, spending on marine ports has not kept pace with rising demands for these facilities. ASCE estimates that there is on the order of a $10 billion shortfall in funding of these facilities through 2020 and additional $17 billion shortfall through 2040 (ASCE, 2012). While not explicitly addressed in this report, this rapid escalation in volumes at these ports also leads to substantial congestion of the road and other infrastructure that lead to and from these facilities.

It is this mismatch between supply and demand that suggests that it is important to price these facilities so as to recover funds for investment as well as to encourage volumes at each of the ports that are more consistent with their capacities.

The next section discusses relevant literature. The third section describes the user-equilibrium model developed. The following section gives results and some discussion. The last section raises conclusions and opportunities for future research.

2 LITERATURE REVIEW

There are several studies focused on estimating container flow. Leachman (2008, p.313-331) studied the import of containers from Asia to the United States via San Pedro Bay, which is the site of the Port of Los Angeles and the Port of Long Beach. The study concluded that large and small importers have different sensitivities to the container fee per FEU (Forty-foot Equivalent Units). The study is sophisticated and a little restrictive on the categories of the imports.

Luo and Grigalunas (2003, p.158-178) develop a multi-modal container flow model. The model is used to estimate the U.S. container ports flows as the port fees change. The model minimizes total generalized costs, including transportation costs and time costs. To solve this model, a shortest path algorithm is iteratively applied. However, the model does not include port travel times as a function of port volumes. Thus, port congestion is not taken into account in this paper.

Rowinski *et al*. (2000) describes a generalized cost user-equilibrium assignment model to understand the impacts of tolls on route selection for truck traffic. Shibasaki *et al*. (2005, p.299–336) applies this same concept to international container shipping in the East Asia. The model is built on an inter-region O-D network, which covers all Japanese and major East Asian containers ports. It also discussed the impacts of the "global shipping lines alliances" to the traffic flow and ports. These are essentially the same analysis as contained in this thesis except our application is maritime container traffic between Asia and the Untied States.

This research also directly builds on Jones *et al.* (2011, pp.3-14). They also take advantage of the user-equilibrium modeling framework but they explicitly include capacity constraints at the ports in contrast to simply using an estimate of capacity in the volume to delay functions for the ports links. Further, they use a logit model to represent uncertainty in the domestic mode selection decision. We simplify this framework by relying on the volume to delay curve at the ports only to represent capacity constraints. However, we do integrate the port congestion fee and a port surcharge fee into the modeling.

3 METHODOLOGY

An Origin-Destination network is developed for the modeling, which includes four origin countries in Asia, six U.S. Ports of Discharge (PODs) and three destination areas in the United States. A user-equilibrium model is adopted to represent the competitive behavior of individual shippers. The impedances on the links are assumed to be consistent with the conversion of the Bureau of Public Roads Volume to Delay function (BPR) to costs via a per unit time price constant, which therefore serves a congestion fee. The Frank-Wolfe algorithm is used to solve the model.

3.1 Origins, Destinations and Ports

From Wang's total estimated U.S. imported container flow (Wang et al, 2015), the containers are transported from different countries around the world to the U.S. ports by sea and moved from the ports to each U.S. city via rail and truck. A logistic chain is formed from the origin country, Port of Discharge (POD) and destination area. Table 1 gives the top 10 countries of export to the U.S.

Table 1: Top Ten Container Importers by TEU

Importer	Imported TEUs/Year
China Mainland	7,311,785
South Korea	1,236,034
Hong Kong	943,527
China Taiwan	828,515
Germany	624,597
Japan	578,216
Singapore	565,140
Vietnam	463,527
Italy	400,340
Belgium	383,102
Top Ten Total	**13,334,784**
Total from the World	**17,432,710**

The countries and areas exporting more than 500,000 TEUs a year to the U.S. from Asia are chosen as the origins. Given the similarity in logistics costs from Mainland China, Hong Kong and Taiwan, we aggregate these origins. Hence, the list of origins countries and associated volumes is as given in Table 2. The total volume from the selected origin countries is 65.76% of the imports from the world.

Table 2: Selected Origin Nodes for the Network

Importer	Imported TEUs/Year
China (Mainland, Hong Kong and Taiwan)	9,083,827
South Korea	1,236,034
Japan	578,216
Singapore	565,140
Selected Origins Total	**11,463,217**
Total from the World	**17,432,710**

Using the similar logic, the top areas receiving the imports as final destinations are:

NYNJ[1], Southern California[2] and Northern California[3]. When focusing on the import cargoes transported only from the selected origin countries, the top three final destinations are the same.

The Ports of Discharge (PODs) are chosen from the list of container ports handling the cargoes shipped from preselected origins to the destinations by TEU per year. All the ports and their volume are showed in Table 3.

Table 3: Selected Ports for the Network

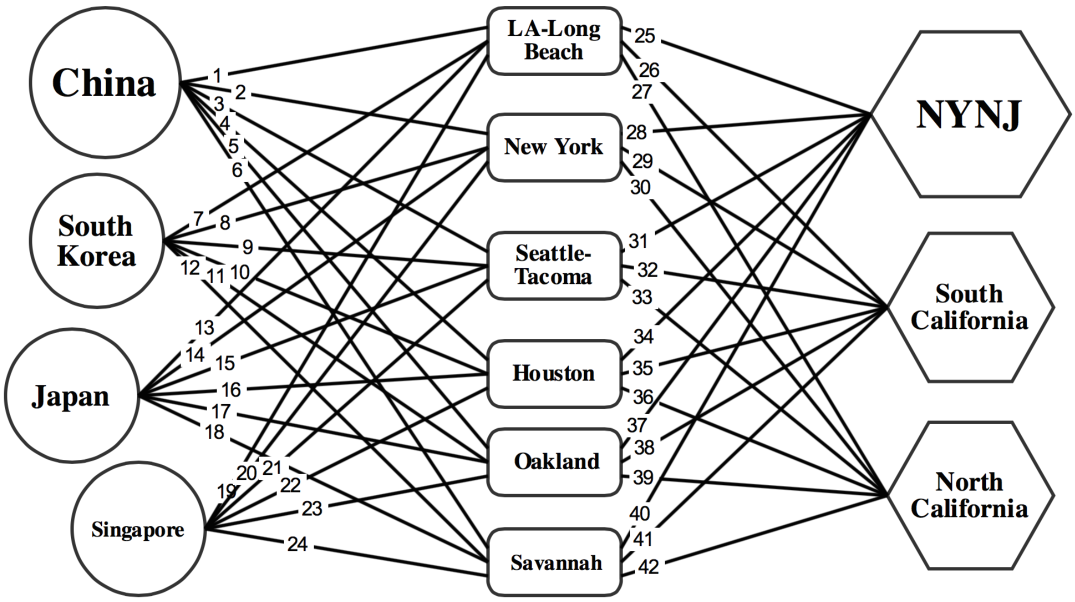
PODs	Handling TEUs/Year
LA-Long Beach	2,608,709
New York	412,448
Seattle-Tacoma	307,169
Houston	135,845
Oakland	57,889
Savannah	9,969
Norfolk	2,271
San Francisco	7.8
Total	**3,534,308**

The first five ports each receive more than 50,000 TEU a year. The total of the volume handled is about 99% of the cargoes shipped from the four origin countries to the three destinations. The Port of Savannah is also chosen as the POD in the network, since it is the fastest-growing import port in the U.S. for a decade and is likely to continue to grow (Newkirk & Nash, 2014).

The four origin countries, six U.S. container ports and three destination areas form a network as illustrated in Figure 2.

[1] NYNJ area includes New York, New Jersey and some places in Connecticut, Pennsylvania, Massachusetts and Vermont.
[2] Southern California area includes Los Angeles County, Riverside County, Orange County and some places in California and Arizona.
[3] Northern California area includes San Francisco, Oakland, San Jose and some places in California.

Figure 2: The Origin-Destination Network of the User-Equilibrium Model with Number on the Link



3.2 The Equilibrium Model

The general form of the user-equilibrium model is as follows (Sheffi, 1984).

$$\sum_a \int_0^{x_a} C_a(\omega)d\omega \tag{1}$$

$$\text{s.t.} \qquad \sum_{k\in K_{od}} f_{od}^k = q_{od} \qquad \forall\, o, d \tag{2}$$

$$x_a = \sum_{od} \sum_{k\in K_{od}} \delta_{od}^{ak} f_{od}^k \qquad \forall\, a \tag{3}$$

$$f_{od}^k \geq 0 \qquad \forall\, o, d, k \tag{4}$$

The definitions of the variables in Eq. (1) - (4) are:

x_a: imported container flow on link *a* (TEUs/year);

$C_a(x_a)$: generalized cost (\$) on link *a* as a function of flow x_a;

q_{od}: total flow from origin *o* to destination *d* via all ports (TEUs/year);

f_{od}^k: flow (TEUs/year) on path *k*, which connects origin *o* and destination *d*;

K_{od}: set of all the paths from origin *o* to destination *d*;

δ_{od}^{ak}: 1 if the link *a* is on the path *k* that connects origin *o* and destination *d*; 0

otherwise.

From Figure 2, there are two segments in the transportation process for each container. The first part is the movement from the origin country to a port in the U.S. From the buyers' point of view, the main costs generated on this segment are the ocean rate and port (POD) fee under the assumptions of FOB[4] term. The insurance is also neglected for simplification. Assuming the containers are all FCLs (Full Container Loads), the ocean costs to transport one standard TEU are given in Table 4 (XpressRate.com, 2015).

Table 4: Ocean Rates from Origins to PODs[5]

Origins	Ports	$/TEU	Origins	Ports	$/TEU
China[6]	LALB	2,066	**Japan**	LALB	2,065
China	NY	3,515	**Japan**	NY	3,515
China	SeaTac	2,372	**Japan**	SeaTac	2,065
China	Houston	4,109	**Japan**	Houston	3,107
China	Oakland	2,203	**Japan**	Oakland	2,751
China	Savannah	3,654	**Japan**	Savannah	3,045
S. Korea	LALB	2,070	**Singapore**	LALB	2,074
S. Korea	NY	3,520	**Singapore**	NY	3,524
S. Korea	SeaTac	2,377	**Singapore**	SeaTac	2,377
S. Korea	Houston	4,215	**Singapore**	Houston	4,214
S. Korea	Oakland	2,207	**Singapore**	Oakland	2,207
S. Korea	Savannah	3,547	**Singapore**	Savannah	3,321

The port fee at POD is included via the BPR formula, a per unit time price constant and a port surcharge. The generalized function is then as given in Equation (5).

$$Port_p(x_a) = \gamma_p \times t \times \left[1 + \alpha \left(\frac{x_a}{Cap_p}\right)^{\beta}\right] + S_p \tag{5}$$

4 FOB is short for the Free On Board. It is a term used in the sea freight transaction. Briefly speaking, the term states that the buyer needs to pay for the ocean rate, port (POD) fee and related insurance.

5 Port of Los Angeles, Tokyo, Seattle, Busan and Singapore are used to get the ocean rate.

6 The ocean rate of China is the average rate of costs shipping from Mainland (Port of Shanghai), Hong Kong (Port of Hong Kong) and Taiwan (Port of Kaohsiung) to the 6 PODs.

The definitions of the variables and coefficients in Equation (5) are:

$Port_p(x_a)$: the port fee ($) of POD p as a function of flow x_a[7];

x_a: imported container flow on link a (TEUs/year);

γ_p: a per unit time price constant for port p (Jones et al, 2011, pp.3-14);

t: free flow travel time;

α, β: calibration parameters;

Cap_p: estimated port p capacity (TEUs/year) (Jones et al, 2011, pp.3-14);

S_p: port surcharge fee ($).

The second part of the transportation is the in-land haulage from PODs to the destinations. Since the transportation mode is either the rail or truck, the penetration of each mode is calculated for each Port-Destination pair based on Wang *et al.* (2015). Using these penetrations, a per TEU cost is computed from each port to each demand region as given in Table 6 using the per mile costs by mode given in Table 5.

Table 5: Unit Costs of Using Truck and Rail

Truck[8]	**Midwest**	**Northeast**	**Southeast**	**Southwest**	**West**	**National**
Cost $/Mile	$1.65	$1.76	$1.62	$1.68	$1.69	$1.68

Rail[9]	**Average**
Cost $/Mile	$0.42

[7] According to Figure 2, the port fee is only added for link 1 - 24 (a = 1, 2,...,24).
[8] The truck rate is the average marginal cost per mile by region estimated by ATRI (2014).
[9] According to Congressional Budget Office (2014), the average cost of rail service is $0.047 per ton-mile. Since the average import TEU in the Trans-Pacific trade weighed on 9 tons (World Shipping Council, 2010), the unit cost is $0.423 per mile.

Table 6: In-land Move Costs from PODs to Destinations

Ports	Dest.	$/TEU	Ports	Dest.	$/TEU
LALB	NYNJ	2030	**Houston**	S. Cali	1098
NY	NYNJ	56	**Oakland**	S. Cali	310
SeaTac	NYNJ	2023	**Savannah**	S. Cali	2611
Houston	NYNJ	1799	**LALB**	N. Cali	703
Oakland	NYNJ	2095	**NY**	N. Cali	3233
Savannah	NYNJ	586	**SeaTac**	N. Cali	831
LALB	S. Cali	204	**Houston**	N. Cali	2209
NY	S. Cali	2966	**Oakland**	N. Cali	120
SeaTac	S. Cali	894	**Savannah**	N. Cali	3133

For each path connecting the origin, POD and destination, the path *k*'s cost is the sum of the links' costs that on the path *k*. For example, consider the route from China to the LA-Long Beach ports and then to NYNJ area. The path contains two links as given in Equation (6).

$$2066x_{China-LALB} + \left(\gamma_{LALB} \times 1 \times \left[1 + \alpha\left(\frac{x_{China-LALB}}{Cap_{LALB}}\right)^{\beta}\right] + S_{LALB}\right)$$

$$+2030x_{LALB-NYNJ} \tag{6}$$

,where \$2,066 is the per TEU shipping cost from China to LALB and \$2,030 is the in-land transportation cost from LALB to NYNJ.

3.3 Model Calibration

Since the α and β are unknown in the cost function, we select values that match the volumes at each of the ports as closely as possible as estimated from Wang *et al.* (2015). Results and comparison are given in Table 7. Using this method, α and β are set to 0.2 and 4.

Table 7: Observed and Estimated Penetrations of Each Port

PODs	Handling TEUs/Year (Wang et al, 2015)	Port Penetration (Wang et al, 2015)	Port Penetration with α =0.2, β =4
LALB	2,608,709	74%	73%
NY	412,448	12%	12%
SeaTac	307,169	9%	9%
Houston	135,845	4%	4%
Oakland	57,889	2%	2%
Savannah	9,969	0.3%	0.3%
Total	**3,532,029**	**1**	**1**

4 RESULTS AND DISCUSSION

Based on the calibrated user-equilibrium model, the sensitivity of imported container flow to the surcharge fee can be analyzed. The experiment involves surcharging all the imported containers at the LA-Long Beach ports. We focus on these two ports because of the severity of the congestion at those ports in particular. This experiment estimates how the container flow changes in the selected six ports when the fee is added to LALB. The remainder of this section discusses the results of these experiments.

4.1 Experiment: Port Surcharge Fee

The LA-Long Beach ports and other West Coast maritime container ports are charging extra fee as of November 2014 (Egan, 2014). The surcharge is \$800 per TEU, \$1,000 per 40-foot container, \$1,125 per 40-foot high cube and \$1,266 per 45-foot container. This information helps set the beginning port surcharge fee for this experiment. By increasing the LA-Long Beach ports fee, the costs to ship containers from all four origin-countries to six PODs are changing, which affects the flow assignment to each port. We explore fees from \$0 to \$2,000. Table 8 and Figure 3 give the impacts on the volume at LALB. Figure 4 shows the shifts at all six ports.

Table 8: The List of Port Surcharge Fees at LALB and

Subsequent Penetrations of LALB

Port Surcharge ($/TEU)	Volume Ratio
0	73%
500	71%
800	69%
1,000	68%
1,500	66%
2,000	63%

Figure 3: The Sensitivity of Container Flow (Penetration)

to Port Surcharge Fee at LALB

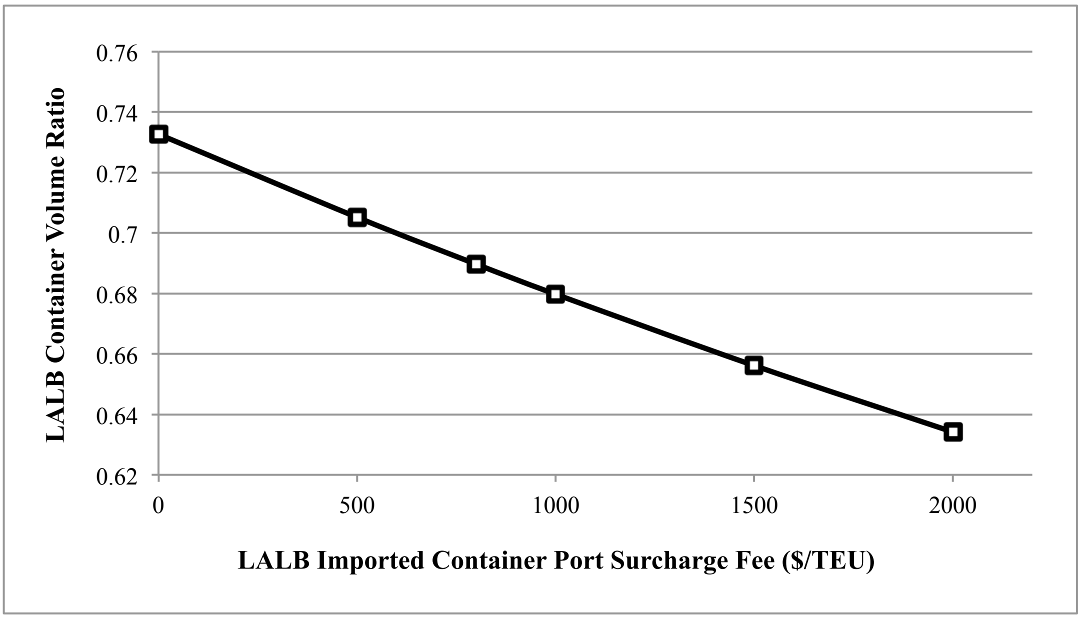
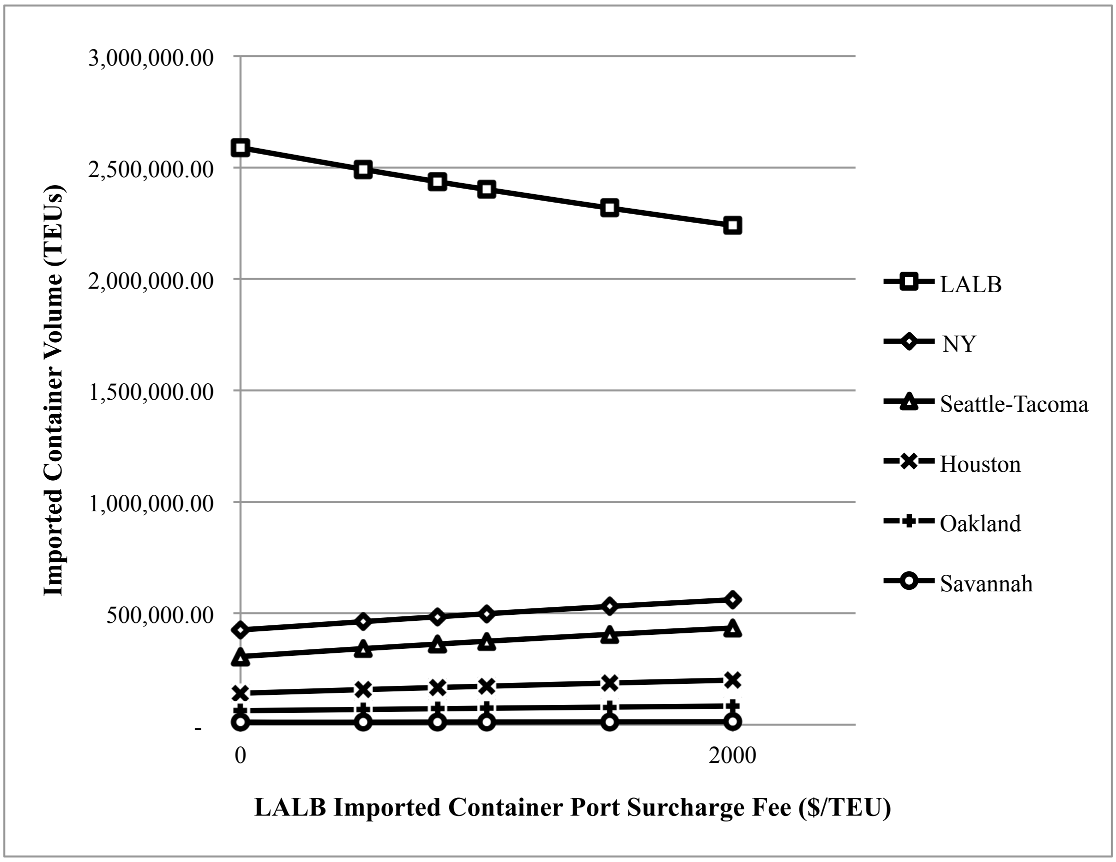


Figure 4: The Container Volumes at PODs as Port Surcharge Increasing



According to Figure 4, the Port of New York and Seattle-Tacoma ports are more attractive than others to the containers that abandon the LA-Long Beach ports. The outstanding advantages of these two PODs are the port capacities. Although the Port of Oakland is also located in the West Coast, the limited capacity becomes its biggest constraint.

5 CONCLUSION

The primary objective of this thesis is to analyze the sensitivity of container flow to the surcharges. To test the sensitivity, an O-D network and a user-equilibrium model are established. After verifying the model by using observed data, an experiment is conducted. The sensitivity experiment demonstrates that the port surcharge fee could have effective mechanism to relieve congestion at the ports and in the surrounding infrastructure.

There are several opportunities to extend this research. The proposed network in this thesis focuses on the containers imported from Asia to the three top destinations in the U.S. via six maritime container ports. It is important to expand this network to include more countries, at least another 10 container ports and to refine the regions inside the U.S. Also, it is useful to understand what the impacts are of implementing surcharge fees at other ports, and how the magnitude of those charges impact port penetrations. Finally, the fees analyzed in this thesis are not time of day dependent. There is un-used capacity at night at many ports. Extending this analysis to be dynamic in the estimation of the flows over the 24 hour day as well as investigating pricing schemes that vary by time of day is also useful.

6 REFERENCES

ASCE, 2012, Failure to act - The economic impact of current investment trends in airports, inland waterways, and marine ports infrastructure., pp.21.

ATRI, 2014, An Analysis of the Operational Costs of Trucking: A 2014 Update., pp.19 Table 14.

Congressional Budget Office, 2014, Social-Cost Pricing in Freight Transportation., pp.6 Shippers Pay Higher Rates for Truck Transport.

Egan, C., 2014. *13 carriers reinstate congestion surcharges to US West Coast*. Available at: <http://www.joc.com/maritime-news/container-lines/mediterranean-shipping-co/13-carriers-reinstate-congestion-surcharges-us-west-coast_20141125.html> [Accessed: July 24, 2015].

Jones, D.A., Farkas, J.L., Bernstein, O., Davis, C.E., Turk, A., Turnquist, M.A., Nozick, L.A., Levine, B., Rawls, C.G., Ostrowski, S.D. & Sawaya, W., 2011, U.S. import/export container flow modeling and disruption analysis. *Research in Transportation Economics*, 32(1) pp.3-14.

Leachman, R.C., 2008, Port and modal allocation of waterborne containerized imports from Asia to the United States. *Transportation Research E*, 44(2) pp.313-331.

Luo, M., Grigalunas, T.A., 2003, A spatial-economic multimodal transportation simulation model for US coastal container ports. *Maritime Economics & Logistics*, 5 pp.158-178.

Mongelluzzo, B., 2014. *Congestion worsens at LA-LB port complex with no relief in* *sight*. Available at: <http://www.joc.com/port-news/us-ports/port-los-angeles/congestion-worsens-la-lb-port-complex-no-relief-sight_20141006.html> [Accessed: July 24, 2015].

Newkirk, M. & Nash, J., 2014. *Savannah Surges as Major Port for Imports on U.S. Growth*. Available at: <http://www.bloomberg.com/news/articles/2014-10-28/savannah-surges-as-major-port-for-imports-on-u-s-growth> [Accessed: July 24, 2015].

Rowinski, J., Boilé, M.P., Spasovic, L.N. & Wang, Y., 2000, A Multi-Commodity, multi-class generalized cost user equilibrium assignment model. *Transportation Research Forum*, (TRB ID: 01-2596).

Sheffi, Y., 1984. Urban transportation networks: *Equilibrium analysis with mathematical programming methods*, Prentice-Hall, Inc.: Englewood Cliffs.

Shibasaki, R., Ieda, H. & Watanabe, T., 2005, An international container shipping model in East Asia and its transferability. Research in Transportation Economics, 13 pp.299–336.

The World Bank, 2015. *Container port traffic (TEU: 20 foot equivalent units)*. Available at: <http://data.worldbank.org/indicator/IS.SHP.GOOD.TU/countries/US?display=default> [Accessed: July 24, 2015].

Wang, H., Gearhart, J., Jones, K., Frazier, C., Nozick, K.L., Levine, B., & Jones, D., 2015, Estimation of an origin - destination table for U.S. imports of waterborne containerized freight. (not published yet).

World Shipping Council, 2010, Facts About Serving U.S. Export Commerce., pp.2 Vessel Capacity.

XpressRate.com, 2015. *Compare International Shipping Rates for Free*. Available at: <http://www.xpressrate.com/serchrates.do> [Accessed: July 24, 2015].