SUPPLY CHAIN ANALYSIS: PORT SECURITY MEASURES AND CATASTROPHIC EVENTS

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ABSTRACT
The perception of maritime security in the post 9/11 era has dramatically shifted to a focus of prevention and managing risks of terrorist attacks on the nation's supply chains, specifically the ports. Ports remain a vulnerable terrorist target because of high volumes passing through large concentrated ports. Government and industry participants have played a major role in tightening maritime security by implementing legislation, programs, and technologies that focus on developing more secure and transparent supply chains.

The focus of this research effort was to evaluate the effects that various port security measures or catastrophic events have on an electronic firm's supply chain through the six major west coast ports. A constrained transportation optimization model was developed to represent the firm's distribution system. Three scenarios were evaluated: the first scenario estimated the effect of increasing the rate charged for services at the port by five, ten, and fifteen percent. Scenarios two and three investigated the impacts of shutting down operations at the Ports of Seattle and Long Beach.

Results indicated in all scenarios that the impacts at the ports caused an increase in per-unit costs, while the total transportation cost decreased because of loss of quantity demanded. Overall, the key insights of this study are the adjustments a firm makes to their distribution systems to counteract negative impacts imposed at ports, while meeting demands and maintaining supply chain efficiency.

INTRODUCTION

International trade is a large and integral component to the sustainability of both the Washington State and the U. S. economy. Global marine transportation and the U.S. Maritime Transportation System (MTS) are responsible for the majority of U.S. trade movements, thus making marine transportation a crucial asset to trade. Over the past decade, increased containerization, growth of foreign economies and globalization has dramatically increased trade to record levels. In 2004, U.S. trade exports grew 13.2 percent and imports 16.9 percent and this continued high growth is expected in the future. Today, containerized trade accounts for 90 percent of all cargo movements. As of 2005, approximately 18 million containers made 200 million trips *(1)*.

Over the past decade, trade in the Pacific Rim has become the heart of U.S. trade. Asian trade volumes have been increasing by double digits, with import volumes nearly doubling export volumes. China, Japan, Korea, Taiwan, and Hong Kong formulate the northeast region of Asia for trade. In 2004, 9.3 million twenty-foot equivalent units (TEU) were imported to the U.S. from the northeast region, which is the largest importing region for the U.S. Northeast Asia is also the largest market for U.S. exports. China is the number one receiver of U.S. exports, receiving about 42 percent, and Japan receives approximately 25 percent of the northeast region's trade. U.S exports to China have grown significantly compared to their share of 24 percent at the turn of the century *(2)*.

The evolution of just-in-time inventory systems and industry outsourcing has increased efficiency and productivity for U.S companies. From 1980 to 2000, one study estimated that business logistics costs dropped from 16.1 percent of U.S. GDP to 10.1 percent *(3)*. These logistics savings are not without cost; they have increased risk by creating almost complete dependence on an uninterrupted supply chain for many U.S. companies

Maritime Security

Prior to the terrorist attacks on September 11, 2001, the common perception of transportation security was controlling theft and reducing contraband such as drugs, illegal immigrants, and exports of stolen vehicles and machinery. Post 9/11 transportation security has been transformed to assessing threats of possible terrorist attacks on or through our supply chain systems. The top 50 U.S. ports account for approximately 90 percent of all cargo tonnage and 25 U.S. ports account for roughly 98 percent of all container shipments *(3)*. In light of 9/11 and the ongoing security concerns, government and industry participants have been working to develop and implement plans to secure our nation's ports and supply chains without stagnating trade flows.

Research Objectives

The primary objective of this research was to quantify and evaluate the impacts on a firm's containerized imports of port security measures and catastrophic events. Specific objectives were to:

1. Obtain a general understanding of the security measures implemented throughout the maritime transportation system.
2. Develop an industry representation of a typical import product by creating a model representing a specific firm's import supply chain from origin to destination.
3. Investigate and measure the effects that specific port security situations inflict on a firm's supply chain cost and distribution.
4. Determine the effects that specific port security situations have on the cost and distribution of the product at the industry level.

5. Investigate the impacts of the aforementioned security situations when the model is used to represent the entire west coast container volumes.

The Current Security Strategy

Prior to 9/11, the governmental agencies involved in protecting the homeland were numerous and disjointed. In June of 2002, President George W. Bush proposed the creation of a unified organization that would be focused solely on homeland security: the Department of Homeland Security (DHS). The DHS is divided into four divisions: Border and Transportation Security, Emergency Preparedness and Response, Chemical, Biological, Radiological, and Nuclear Countermeasures, and Information Analysis and Infrastructure Protection *(4)*. Security initiatives, programs, and regulations have been developed by the U.S. government to develop a more visible and secure supply chain *(for a detailed description, see 5)*.

ECONOMIC IMPACTS OF SUPPLY CHAIN SECURITY MEASURES, EVENTS, AND POLICIES

Two studies investigate the risk and economic impact of a terrorist attack on the ports of Los Angeles and Long Beach. The first study attempts to model the economic impact from the detonation of a radiological bomb in the twin ports *(6)*. The study utilizes the input-output Southern California Planning Model (SCPM) to analyze the direct, indirect, and induced effects that the impact would have on the five-county metropolitan economy of Los Angeles. Impacts in the model are measured in terms of the loss of economic activity, such as loss of demand for goods and services, employment, and transportation.

The second study involving attacks on the ports of Los Angeles and Long Beach addresses two issues: the probability of dirty bomb attacks on the twin ports, and the economic consequences associated with an attack *(7)*. The latter issue dealing with economic impacts was estimated with a regional, spatially disaggregated input-output model similar to the model used in the first study. Based on attack scenario assumptions, the findings indicated that the chances of a successful dirty bomb attack are no better than 60 percent. However, three independent attacks with a probability of 60 percent would increase the probability of one successful attack to 94 percent *(7)*.

An alternative approach to port focused research was presented in Lee and Song, 2003, where they focused on optimizing port throughput while incurring delays from security inspections. Using data on the operations at a major seaport, a near-optimal solution was derived by utilizing a genetic algorithm *(8)*. The findings display the expected vessel delays associated with various inspection levels based on different levels of security alert (high security alerts inflict higher inspection rates). Non-intrusive inspections improve inspection efficiency dramatically, thus increasing throughput and lowering vessel delays.

Another study illustrating a direct relationship between security and benefits was Lee and Whang *(9)*. This study demonstrated how lessons learned with the total quality management movement apply in the security realm. Using shipment data from a high-tech manufacturer, a simple evaluation was conducted to determine the probable effects of transportation and inspection dwell time on the safety inventory stock and the firm's ability to meet demand. The study concluded that obtaining advanced information through preventive security measures (CSI, C-TPAT) increases shipment information to a firm, thus allowing firms to lower inventory levels and avoid costly delays from inspections *(8)*.

The preceding studies illustrated various approaches surrounding the issue of maritime security. The objective of this study stems from the previous works, but investigates maritime security with an end user perspective. In this study, the objective was to develop a transportation optimization model based on a firm's specific supply network and evaluate the effect that various security impacts, such as a closure of seaport, have on the firm's costs and trade flows. Furthermore, by utilizing the firm's distribution network, an evaluation of similar security issues on the entire industry and west coast port volumes was conducted to measure the various scales of these impacts.

TRANSPORTATION OPTIMIZATION MODEL

Data and Methodology

To develop an accurate representation of container trade, it was important that the study use a typical containerized shipment. The most common containerized imports are consumer goods, such as clothing, shoes, electronics, furniture, auto parts, and toys *(3)*. Electronic products, specifically televisions, were chosen to represent import container flows. Imports of television (TV) receivers, video monitors, and projectors accounted for over $16 billion of trade in the U.S. in 2004, which is a dramatic increase from the $7.2 billion imported in 2000.

Since a majority of overseas television imports come from Asia, an importer was chosen to represent this trade. Through cooperation with a large U.S. electronics retailer, an accurate insight of television imports via the transpacific was developed (The electronic retailer requested to remain anonymous.) This retailer imports TVs from Xiamen, China and ships them via ocean carrier to the west coast, and then distributes them throughout the United States. (For a full description of the television supply chain for this distributor, *see 5*).

A transportation model was developed to represent movement of the firm's television shipments through the supply network. Using linear programming, a cost minimization objective was achieved by optimizing the least cost combination of transshipment points (port and distribution center) while satisfying demand at the retail stores.

The possible combinations of shipment routes from origin to destination are displayed in Figure 1. There are four segments of shipments: the vendor and port in Xiamen, the two intermediate destinations which include the west coast ports and the distribution centers, and the final retail store destination. For purposes of this study the vendor and the Port of Xiamen are assumed to be the combined starting point of the supply chain because of lack of information provided on the Chinese vendor. The available west coast port destinations are at Seattle, Washington, Tacoma, Washington, Portland, Oregon, and Oakland, Los Angeles, and Long Beach, all of California. Shipments then move from the ports to one of the nine distribution centers: Des Moines, Washington, Dinuba, California, Ardmore, Oklahoma, Bloomington, Minnesota, Findlay, Ohio, Franklin, Indiana, Staunton, Virginia, Dublin, Georgia, or Nichols, New York. The distribution centers serve as storage warehouses and ship products to the 826 retail stores to meet consumer demands.

Figure 3.4 Possible Shipment Routes to Destination

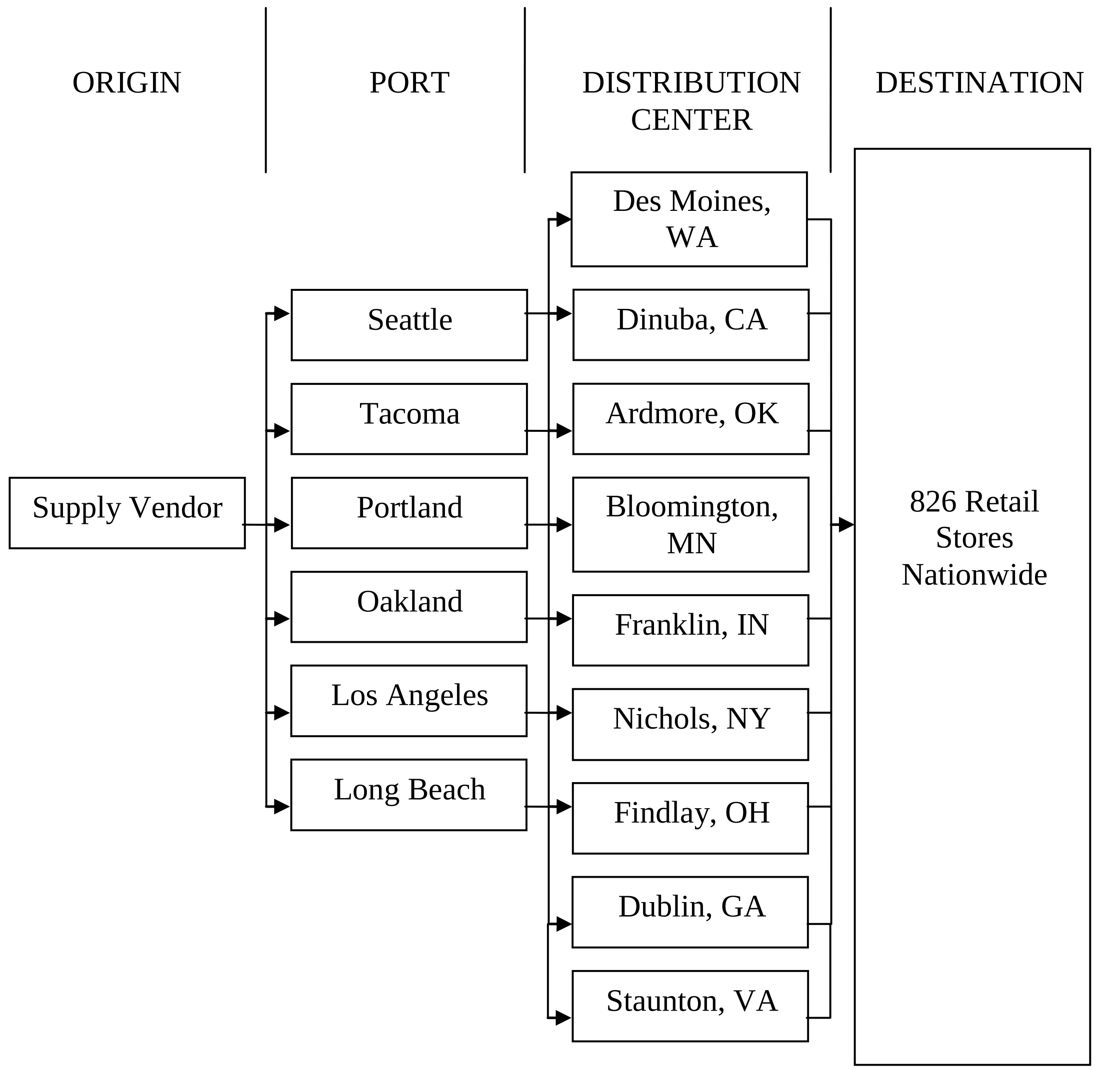

FIGURE 1 Possible shipment routes to destination.

The firm's objective was to determine the optimal allocation and routing of shipments that minimize total transportation costs. The cost per-unit (c_{ijkl}) for shipments between origin (i), intermediate port (j), intermediate distribution center (k), and final destination (l), is multiplied by the number of FEUs shipped (x_{ijkl}) from the origin through the corresponding port, distribution center, and final retail store. The objective function is defined as follows:

$$\text{Minimize } \sum_i \sum_j \sum_k \sum_l x_{ijkl} c_{ijkl} \qquad (1)$$

Where:

i = origin
j = intermediate port

k = intermediate distribution center
l = final destination (retail store)
s_j = supply of televisions at origin (FEUs)
d_l = demand for televisions at destinations (FEUs)
c_{ijkl} = cost per FEU shipment between origin i, intermediate port j, intermediate distribution center k, and final destination l.
x_{ijkl} = the number of FEUs shipped from origin i, intermediate port j, intermediate distribution center k, and final destination l.

The exogenous variables (x_{ijkl}) were decided by the model and determine the optimal objective value. The exogenous variables (x_{ijkl}) are equal to the number of FEUs shipped from origin (i), through intermediate ports (j) and intermediate distribution centers (k), to the final destination (l) and must be equal to or greater than zero (2).

$$x_{ijkl} \geq 0 \text{, for all i, j, k, l.} \quad (2)$$

The optimization model was constrained by the available supply at the origin and the final demand at the retail stores. The supply constraint limits the quantity (FEUs) that can be shipped by the Xiamen vendor, defined by S_i (3). The demand constraint ascertains that the sum of all shipments from origin (i), intermediate port (j), intermediate distribution center (k), are equal to or greater than the demand at each final destination (l), defined by D_l (4).

Observe supply limits at origin (i):

$$\sum_{il} x_{ijkl} \leq S_i \text{, for i} \quad (3)$$

Satisfy demand at final destination (l):

$$\sum_{il} x_{ijkl} \geq D_l \text{, for all l} \quad (4)$$

Constraints were placed on port volumes to more accurately represent the firm's shipments through the ports; otherwise the model would have the option of shipping all flows through a single port, thus decreasing the reality of the results. Constraints were created for each port based on each ports' typical annual television shipments by applying weighted averages of the total west coast television receiver imports to the firm's annual shipment volume. Since ports have the capacity to fluctuate considerably in volume, the constraints were allowed to fluctuate up or down 50 percent.

The rate structure for container throughput at the ports is complex to say the least. Two entities are involved, the port and the container terminal operator. Container terminals at the ports are leased by shipping carriers from the port; hence the port operates primarily as an administrative unit. The terminal operators provide services at the ports, such as drayage, devanning, storage, labor, etc. for a set rate per container. The service rate charge for a FEU of television products averaged $325 for shipments through the six ports (Jonathon Pan, Yang Ming Shipping Lines, "unpublished data" 2006). This rate varies depending on each ports tariff rates, container terminal operator, and terminal lease rates. Terminal lease rates vary with different contracts and ports.

To develop a representation of the varying rates among the ports, a weighted average of each port's total revenues from leasing facilities and/or land, scaled by their corresponding container volumes, was applied to the average rate of $325 *(5)*. The most relevant weakness in this method is with the revenue component. Each port's leasing revenues were divided by their annual container volumes, thus establishing a rate per container. A problem exists because not all of a port's revenue is produced by container services alone; port revenue is also produced by the leasing of other types of shipping facilities. The most obvious outlier in these estimated rates was the Port of Portland, which produced a very high rate per container because their facility is not primarily a container facility. The Port of Portland is involved in shipping and receiving more bulk and roll-on/roll-off cargo than container cargo. Keeping these points in mind, the method did provide a relative rate that represented the supply and demand and economies of scale at each port.

To represent capacity limits and typical throughput volumes, the model was volume constrained at the distribution centers. Data on the distribution centers throughput capacities were inaccessible; consequently, assumptions were made to approximate these flows. The original eight distribution centers range in size from 425,000 to 1,028,000 square feet, which was used to provide an indication of possible throughputs. Weighted averages of each distribution center's square footage were applied to the total volume shipped to develop a range of possible throughput volumes. To make the approximation more realistic the throughput volumes were allowed to fluctuate up or down 20 percent. The size of the Des Moines distribution center was established by taking an average size of the Washington distribution centers in Seattle, Tacoma, Renton, Fife, Auburn, Everett, Puyallup, Federal Way, and Kent. The data on these distribution centers was cited from a warehouse distribution study conducted by the Transportation Research Group at Washington State *(10)*.

Demand volumes at the retail stores were assumed to be a function of city populations (ESRI Inc, 1994-2004). The total volume demanded, 11,903 FEUs, was distributed by a weighted average of each city's population, thereby establishing a static demand at each store location. A static demand quantity is not a realistic assumption for television products; therefore a downward sloping linear demand function was estimated by denoting quantity demanded as a function of transportation cost and a demand elasticity coefficient. The price elasticity of demand for radio and television receivers has been estimated to be elastic with a value of -1.2 *(11)*. Using this elasticity coefficient, demand functions were estimated for each retail location that respond to changes in price, which in this cost minimization model was represented by transportation cost per-unit shipped.

For the purposes of this model, it was assumed that the television vendor in Xiamen had the ability to meet all reasonable demands of this firm, thus the supply was considered constant. When quantity demanded changes as a result of a transportation cost change, the vendor's supply curve shifts horizontally up or down to satisfy the quantity demanded.

FINDINGS AND RESULTS

Three scenarios were analyzed to evaluate the effects of port security measures and catastrophic impacts on the firm's distribution flows and costs. The first scenario measured the effect of increasing the rate charged at the port for container services by five, ten and fifteen percent to show the impact of ports passing on the increased costs associated with increasing the security of the facilities. The second and third scenarios measured the impacts on the firm when the Port of Seattle and Port of Long Beach were shutdown, respectively.

Firm Level Scenarios

The base scenario optimized the 11,903 FEUs at a total cost of $70,823,077.20, giving an average cost per FEU of $5,950.23 (Tables 1, 2). Long Beach handled the largest volume of 4,730 FEUs while incurring a cost of $13.6 million, and Portland handled the smallest volume at only 14.5 FEUs for a cost of $51,199. The Ports of Seattle and Portland are the highest cost ports for container throughput, which definitely influenced the smaller volumes there. These ports were also the only ports that were volume constrained by their respective lower bounds; however, their shadow price values were rather small *(5)*. The Ports of Tacoma and Oakland were constrained by upper volume constraints with low corresponding shadow prices, while the Ports of Los Angeles and Long Beach maintained slack between their constraints. The total cost of shipments from origin to port was $34.5 million, which included the port charges for container services at the ports.

The selection of ports for shipments by the model depends not only on the cost between port and origin, but is greatly influenced by constraints and costs at the distribution centers and the retail locations. The Bloomington distribution center (DC) sources all shipments from the Pacific Northwest ports reaching maximum capacity at a total of 941 FEUs, which was expected since the northwest ports are closer in proximity than the California ports (Table 1). The Des Moines DC is strategically located halfway between the Seattle and Tacoma ports, making it a viable option for either of the two ports, however, with Seattle having a $38 higher charge than Tacoma *(5)*, the Des Moines DC received all of its volume from Tacoma, pushing the port to its maximum volume constraint. Port of Oakland, a lower cost alternative than the northwest ports, shipped its maximum volume to the closest DC, which was Dinuba, California. Many retail stores are concentrated in California, and consume almost all of Dinuba's volume. The remaining supply for Dinuba was provided by the Port of Los Angeles. The large capacity ports, Los Angeles and Long Beach, supplied all of the Midwest and eastern distribution centers. The most apparent reasons for that were the two ports' large capacity, closer proximity, and lower cost per-unit of throughput. All the distribution centers maintained excess capacity except for Dinuba, Ardmore, Des Moines, and Bloomington. In fact, Findlay, Nichols, and Staunton DCs were constrained by their lower bound parameters with shadow prices in the $100 to $300 range. These positive shadow prices on the lower bound parameter demonstrate the potential cost savings of allowing one less FEU to pass through these distribution centers. Dinuba and Ardmore had high shadow prices of $-1,640 and $-1,654, respectively, which represent the per FEU cost savings of relaxing the volume constraints. The total bill for the port to distribution center movement was $28.9 million, over five million more than the origin through port movement.

Increased Port Charges

Increasing the rate charged at the ports by five, ten, and fifteen percent caused a slight decrease in demand of -0.21 percent, -0.41 percent, and -0.62 percent, respectively (Table1). As a result of the reduction in quantity demanded, the total transportation cost decreased in similar intervals of -0.06 percent, -0.11 percent, and -0.17 percent. Though the total transportation costs decreased as expected with a loss of quantity demanded, the key finding in these scenarios was the incremental increase in per-unit costs. The five, ten, and fifteen percent rate increases caused the firm's average per-unit costs to increase incrementally by 0.15, 0.30, and 0.45 percent, respectively (Table 2). The increase in per-unit cost is not large, increasing only $27 per FEU for the highest rate increase, but when also considering the firm's loss of quantity demanded due to increasing prices and the shifting that occurs between ports, DCs, and retail stores, the results are noticeable.

The decline in quantity demanded was only felt at the Port of Los Angeles in all three rate change scenarios; the other ports maintained the same volume as the base scenario while experiencing increased costs (Table 2). The largest shift between port and DCs occurred with Los Angeles and Long Beach and the Findlay DC. As the rate increases, Findlay shifted some of its volume from Los Angeles to Long Beach. The primary shifts in distribution at the retail outlets *(5)* occur in the northeastern region where the distribution centers are more geographically concentrated. Shifts between the Findlay and Franklin DCs are the most common, which was expected because they are located in close proximity of one another. Most of these shifts were away from Franklin and to Findlay, most likely because Findlay was satisfying its lower bound parameter and Franklin had excess capacity. Franklin and Dublin experienced an overall decrease while the remaining DCs maintained the same volumes just by shifting volumes between each other to satisfy their constraints. As the rate increased, the shadow prices remained nearly the same, only decreasing slightly for each of the constrained DCs, which was expected given the decrease in quantity demanded.

Port of Seattle Shutdown

The Port of Seattle shutdown caused a loss of 464.30 containers that typically traveled through Seattle, which also meant a loss of one of Bloomington's optimal suppliers (Table 3). The overall loss of quantity demanded was approximately 31 FEUs and an increase in per-unit cost of about $11.00. The resulting shadow price for the Port of Seattle was $-333.00, which implies the incremental cost savings of allowing an additional container through that port. Previously, the port was not constrained, and therefore had no shadow price. Seattle's neighboring port, Tacoma, was already constrained in the base scenario, yet the value of potentially using Tacoma increased dramatically with the shadow price jumping from only $-23.00 to $-357. Portland's volume did not increase from its lower parameter, which would normally be expected. The main reason for this as discussed , as discussed earlier, is while the rate charged at the Port of Portland provides a good, relative comparison to the other ports as being the most expensive container port, yet the actual charge is extremely high in comparison to the other ports, thus causing Portland to lose its comparative advantage.

Seattle's volume shifted completely to the Port of Los Angeles, which was the only port that had the capacity available for all of Seattle's volume and also provided the lowest cost. Long Beach remained an unfeasible alternative for the shipments because it was already handling its maximum volume allowed. With Seattle's volume shifting to Los Angeles, the Bloomington DC also shifted to Los Angeles for the remaining volume not supplied by Tacoma or Portland. This shift in supply caused the per-unit costs to increase for Bloomington, thus making it a less desirable DC.

Consider the shifts between the retail stores and the distribution centers. Bloomington lost volume to Des Moines most likely because of the higher costs of their supply, and Franklin experienced an overall decrease in volume that was primarily due to Staunton, Nichols, and Findlay meeting their lower constraints. Dublin, Bloomington, and Franklin were not constrained after the Seattle shutdown. Franklin, Ardmore, and Des Moines retained the same volumes and shadow prices as in the base scenario, yet experienced some shifting between them.

Port of Long Beach Shutdown

The Port of Long Beach shutdown inflicted a greater loss of capacity in the supply network, but yielded a smaller change in total cost; the per-unit cost increased by approximately $6 (Table 3). All of the Long Beach volume was transferred to the neighboring Port of Los Angeles; thus total transportation costs were not significantly increased. No significant changes occurred in the shadow prices, since Los Angeles had the capacity to take all of the Long Beach volume without reaching capacity; however, the shadow price at Long Beach increased by $16. Per-unit costs increased for all of the distribution centers that transferred from Long Beach to Los Angeles, which caused some shifting at retail locations. No major shifts occurred at the retail stores, which is primarily due to the minor impact that the firm felt when switching from Long Beach to Los Angeles.

The major cost component that was not considered in this model was the impact as a result of port congestion. If a major port such as Long Beach was actually shutdown, the firm would experience a larger negative effect than this transportation model conveyed. Increased congestion would occur because many other firms would switch to Los Angeles.

TABLE 1 Effect of Port Charges on Volume of Firm's Shipments

Shipment Segment		Base Scenario	Scenario 1: 5% Increase in Port Charge	%Δ from Base Scenario	Scenario 2: 10% Increase in Port Charge	%Δ from Base Scenario	Scenario 3: 15% Increase in Port Charge	%Δ from Base Scenario
		Volume (FEUs)						
Total Volume		11,902.57	11,878.05	-0.21%	11,853.53	-0.41%	11,829.01	-0.62%
Origin To Port:								
Xiamen, China	Seattle	464.30	464.30	0.00%	464.30	0.00%	464.30	0.00%
	Tacoma	1,902.00	1,902.00	0.00%	1,902.00	0.00%	1,902.00	0.00%
	Portland	14.50	14.50	0.00%	14.50	0.00%	14.50	0.00%
	Oakland	562.50	562.50	0.00%	562.50	0.00%	562.50	0.00%
	Los Angeles	4,229.77	4,205.25	-0.58%	4,180.73	-1.16%	4,156.21	-1.74%
	Long Beach	4,729.50	4,729.50	0.00%	4,729.50	0.00%	4,729.50	0.00%
Total		11,902.57	11,878.05	-0.21%	11,853.53	-0.41%	11,829.01	-0.62%
Port To Distribution Center:								
Seattle	Bloomington, MN	464.30	464.30	0.00%	464.30	0.00%	464.30	0.00%
Tacoma	Bloomington, MN	462.00	462.00	0.00%	462.00	0.00%	462.00	0.00%
	Des Moines, WA	1,440.00	1,440.00	0.00%	1,440.00	0.00%	1,440.00	0.00%
Portland	Bloomington, MN	14.50	14.50	0.00%	14.50	0.00%	14.50	0.00%
Oakland	Dinuba, CA	562.50	562.50	0.00%	562.50	0.00%	562.50	0.00%
Los Angeles	Ardmore, OK	1,252.80	1,252.80	0.00%	1,252.80	0.00%	1,252.80	0.00%
	Dinuba, CA	1,712.70	1,712.70	0.00%	1,712.70	0.00%	1,712.70	0.00%
	Findlay, OH	1,264.27	1,239.75	-1.94%	1,215.23	-3.88%	1,190.71	-5.82%
Long Beach	Dublin, GA	991.68	989.62	-0.21%	987.56	-0.42%	985.51	-0.62%
	Findlay, OH	226.13	250.65	10.84%	275.17	21.69%	299.69	32.53%
	Franklin, IN	1,414.89	1,392.43	-1.59%	1,369.97	-3.18%	1,347.50	-4.76%
	Nichols, NY	1,062.40	1,062.40	0.00%	1,062.40	0.00%	1,062.40	0.00%
	Staunton, VA	1,034.40	1,034.40	0.00%	1,034.40	0.00%	1,034.40	0.00%
Total		11,902.57	11,878.05	-0.21%	11,853.53	-0.41%	11,829.01	-0.62%

TABLE 2 Effect of Increased Port Charges on Cost of Firm's Shipments

		Transportation Costs						
Shipment Segment		Base Scenario	Scenario 1: 5% Increase in Port Charge	%Δ from Base Scenario	Scenario 2: 10% Increase in Port Charge	%Δ from Base Scenario	Scenario 3: 15% Increase in Port Charge	%Δ from Base Scenario
Total Cost		$70,823,077.20	$70,783,946.02	-0.06%	$70,744,431.50	-0.11%	$70,704,556.30	-0.17%
Volume		$11,902.57	$11,878.05	-0.21%	$11,853.53	-0.41%	$11,829.01	-0.62%
Cost Per FEU		$5,950.23	$5,959.22	0.15%	$5,968.22	0.30%	$5,977.22	0.45%
Origin to Port:								
Xiamen, China	Seattle	$1,384,296.52	$1,390,830.85	0.47%	$1,397,365.17	0.94%	$1,403,899.50	1.42%
	Tacoma	$5,599,183.68	$5,622,372.86	0.41%	$5,645,562.05	0.83%	$5,668,751.23	1.24%
	Portland	$51,198.78	$51,801.21	1.18%	$52,403.65	2.35%	$53,006.09	3.53%
	Oakland	$1,640,953.13	$1,647,063.28	0.37%	$1,653,173.44	0.74%	$1,659,283.59	1.12%
	Los Angeles	$12,213,756.96	$12,182,390.63	-0.26%	$12,150,564.37	-0.52%	$12,118,278.18	-0.78%
	Long Beach	$13,663,099.85	$13,707,772.34	0.33%	$13,752,444.83	0.65%	$13,797,117.32	0.98%
Total		$34,552,488.90	$34,602,231.18	0.14%	$34,651,513.51	0.29%	$34,700,335.92	0.43%
Port To Distribution Center:								
Seattle	Bloomington, MN	$1,239,866.72	$1,239,866.72	0.00%	$1,239,866.72	0.00%	$1,239,866.72	0.00%
Tacoma	Bloomington, MN	$1,240,377.60	$1,240,377.60	0.00%	$1,240,377.60	0.00%	$1,240,377.60	0.00%
	Desmoines, WA	$46,080.00	$46,080.00	0.00%	$46,080.00	0.00%	$46,080.00	0.00%
Portland	Bloomington, MN	$40,321.60	$40,321.60	0.00%	$40,321.60	0.00%	$40,321.60	0.00%
Oakland	Dinuba, CA	$181,800.00	$181,800.00	0.00%	$181,800.00	0.00%	$181,800.00	0.00%
Los Angeles	Ardmore, OK	$2,806,272.00	$2,806,272.00	0.00%	$2,806,272.00	0.00%	$2,806,272.00	0.00%
	Dinuba, CA	$619,312.32	$619,312.32	0.00%	$619,312.32	0.00%	$619,312.32	0.00%
	Findlay, OH	$4,644,422.27	$4,554,343.01	-1.94%	$4,464,263.74	-3.88%	$4,374,184.47	-5.82%
Long Beach	Dublin, GA	$3,741,410.30	$3,733,645.08	-0.21%	$3,725,879.86	-0.42%	$3,718,114.64	-0.62%
	Findlay, OH	$828,178.51	$917,983.15	10.84%	$1,007,787.78	21.69%	$1,097,592.41	32.53%
	Franklin, IN	$4,785,723.94	$4,709,746.80	-1.59%	$4,633,769.65	-3.18%	$4,557,792.51	-4.76%
	Nichols, NY	$4,569,169.92	$4,569,169.92	0.00%	$4,569,169.92	0.00%	$4,569,169.92	0.00%
	Staunton, VA	$4,251,797.76	$4,251,797.76	0.00%	$4,251,797.76	0.00%	$4,251,797.76	0.00%
Total		$28,994,732.94	$28,910,715.95	-0.29%	$28,826,698.96	-0.58%	$28,742,681.96	-0.87%

TABLE 3 Effects of Port of Seattle Shutdown on Firm

		Base Scenario		Scenario 4: Seattle Shutdown			
		Volume (FEU)	Costs	Volume (FEU)	%Δ in Volume	Costs	%Δ in Cost
Total Cost		11,902.57	$70,823,077.20	11,871.36	-0.26%	$70,774,485.89	-0.07%
Cost Per FEU			$5,950.23			$5,961.78	0.19%
Origin To Port:							
Xiamen, China	Seattle	464.30	$1,384,296.52	0.00	-100.00%	$0.00	-100.00%
	Tacoma	1,902.00	$5,599,183.68	1,902.00	0.00%	$5,599,183.68	0.00%
	Portland	14.50	$51,198.78	14.50	0.00%	$51,198.78	0.00%
	Oakland	562.50	$1,640,953.13	562.50	0.00%	$1,640,953.13	0.00%
	Los Angeles	4,229.77	$12,213,756.96	4,662.86	10.24%	$13,464,338.87	10.24%
	Long Beach	4,729.50	$13,663,099.85	4,729.50	0.00%	$13,663,099.85	0.00%
Total		11,902.57	34,552,488.90	11,871.36	-0.26%	$34,418,774.30	-0.39%
Port to Distribution Center:							
Seattle	Bloomington, MN	464.30	$1,239,866.72	0.00	-100.00%	$0.00	-100.00%
Tacoma	Bloomington, MN	462.00	$1,240,377.60	462.00	0.00%	$1,240,377.60	0.00%
	Des Moines, WA	1,440.00	$46,080.00	1,440.00	0.00%	$46,080.00	0.00%
Portland	Bloomington, MN	14.50	$40,321.60	14.50	0.00%	$40,321.60	0.00%
Oakland	Dinuba, CA	562.50	$181,800.00	562.50	0.00%	$181,800.00	0.00%
Los Angeles	Ardmore, OK	1,252.80	$2,806,272.00	1,252.80	0.00%	$2,806,272.00	0.00%
	Bloomington, MN	0.00	$0.00	448.48		$1,389,205.43	
	Dinuba, CA	1,712.70	$619,312.32	1,712.70	0.00%	$619,312.32	0.00%
	Findlay, OH	1,264.27	$4,644,422.27	1,248.88	-1.22%	$4,587,898.31	-1.22%
Long Beach	Dublin, GA	991.68	$3,741,410.30	989.08	-0.26%	$3,731,600.33	-0.26%
	Findlay, OH	226.13	$828,178.51	241.52	6.80%	$884,530.14	6.80%
	Franklin, IN	1,414.89	$4,785,723.94	1,402.10	-0.90%	$4,742,475.40	-0.90%
	Nichols, NY	1,062.40	$4,569,169.92	1,062.40	0.00%	$4,569,169.92	0.00%
	Staunton, VA	1,034.40	$4,251,797.76	1,034.40	0.00%	$4,251,797.76	0.00%
Total		11,902.57	28,994,732.94	11,871.36	-0.26%	$29,090,840.81	0.33%
Retail Distribution Shifts:							
San Jose 1, CA	Des Moines, WA	14.92	$19,598.91	5.63	-62.26%	$7,396.18	-62.26%
	Dinuba, CA	45.55	$13,045.52	54.68	20.05%	$15,660.63	20.05%
Tulsa 1, OK	Bloomington, MN	25.95	$28,814.88	12.86	-50.46%	$14,275.15	-50.46%
	Des Moines, WA	0.61	$1,972.50	13.63	2135.16%	$44,088.51	2135.16%
San Antonio 1, TX	Ardmore, OK	9.14	$5,410.88	12.40	35.68%	$7,341.32	35.68%
	Dinuba, CA	29.53	$73,376.14	26.17	-11.39%	$65,021.58	-11.39%
Niles, IL	Bloomington, MN	0.33	$214.90	0.00	-100.00%	$0.00	-100.00%
	Franklin, IN	3.73	$1,324.90	4.05	8.56%	$1,438.33	8.56%
Grand Rapids2, MI	Findlay, OH	7.76	$2,868.10	8.89	14.52%	$3,284.50	14.52%
	Franklin, IN	1.15	$585.12	0.00	-100.00%	$0.00	-100.00%
Grand Rapids3, MI	Findlay, OH	0.00	0	8.26		$3,052.40	
	Franklin, IN	8.91	$4,533.41	0.63	-92.95%	$319.52	-92.95%
New York 1, NY	Findlay, OH	139.02	$126,118.94	133.16	-4.22%	$120,800.65	-4.22%
	Nichols, NY	77.44	$25,276.42	82.73	6.84%	$27,004.63	6.84%
Brooklyn 1, NY	Nichols, NY	154.48	$50,916.61	151.36	-2.02%	$49,889.16	-2.02%
	Staunton, VA	12.11	$7,362.88	14.79	22.13%	$8,992.59	22.13%

TABLE 4 Effects of Port of Long Beach Shutdown on Firm

		Base Scenario		Scenario 5: Long Beach Shutdown			
		Volume (FEU)	Costs	Volume (FEU)	%Δ in Volume	Costs	%Δ in Cost
Total Cost		11,902.57	$70,823,077.20	11,887.96	-0.12%	$70,800,166.69	-0.03%
Cost Per FEU			$5,950.23			$5,955.62	0.09%
Origin To Port:							
Xiamen, China	Seattle	464.30	$1,384,296.52	464.30	0.00%	$1,384,296.52	0.00%
	Tacoma	1,902.00	$5,599,183.68	1,902.00	0.00%	$5,599,183.68	0.00%
	Portland	14.50	$51,198.78	14.50	0.00%	$51,198.78	0.00%
	Oakland	562.50	$1,640,953.13	562.50	0.00%	$1,640,953.13	0.00%
	Los Angeles	4,229.77	$12,213,756.96	8,944.66	111.47%	$25,828,327.27	111.47%
	Long Beach	4,729.50	$13,663,099.85	0.00	-100.00%	$0.00	-100.00%
Total		11,902.57	$34,552,488.90	11,887.96	-0.12%	$34,503,959.37	-0.14%
Port to Distribution Center:							
Seattle	Bloomington, MN	464.30	$1,239,866.72	464.30	0.00%	$1,239,866.72	0.00%
Tacoma	Bloomington, MN	462.00	$1,240,377.60	462.00	0.00%	$1,240,377.60	0.00%
	Des Moines, WA	1,440.00	$46,080.00	1,440.00	0.00%	$46,080.00	0.00%
Portland	Bloomington, MN	14.50	$40,321.60	14.50	0.00%	$40,321.60	0.00%
Oakland	Dinuba, CA	562.50	$181,800.00	562.50	0.00%	$181,800.00	0.00%
Los Angeles	Ardmore, OK	1,252.80	$2,806,272.00	1,252.80	0.00%	$2,806,272.00	0.00%
	Dinuba, CA	1,712.70	$619,312.32	1,712.70	0.00%	$619,312.32	0.00%
	Dublin, GA	0.00	$0.00	996.11		$3,770,861.21	
	Findlay, OH	1,264.27	$4,644,422.27	1,490.40	17.89%	$5,475,133.44	17.89%
	Franklin, IN	0.00	$0.00	1,395.85		$4,759,296.26	
	Nichols, NY	0.00	$0.00	1,062.40		$4,582,768.64	
	Staunton, VA	0.00	$0.00	1,034.40		$4,263,383.04	
Long Beach	Dublin, GA	991.68	$3,741,410.30	0.00	-100.00%	$0.00	-100.00%
	Findlay, OH	226.13	$828,178.51	0.00	-100.00%	$0.00	-100.00%
	Franklin, IN	1,414.89	$4,785,723.94	0.00	-100.00%	$0.00	-100.00%
	Nichols, NY	1,062.40	$4,569,169.92	0.00	-100.00%	$0.00	-100.00%
	Staunton, VA	1,034.40	$4,251,797.76	0.00	-100.00%	$0.00	-100.00%
Total		11,902.57	$28,994,732.94	11,887.96	-0.12%	$29,025,472.83	0.11%

SUMMARY AND CONCLUSION

The post 9/11 era created urgency for maritime security reform in order to protect one of the nation's most vulnerable entities, the U.S. ports. Pre 9/11 security focused on controlling events, such as theft and illegal exporting/importing. Post 9/11 security focuses on preventing possibilities of events, mainly terrorist attacks on one of our nation's ports or major cities. A wave of research, legislation, and programs has been developed to promote increased security from origin to destination without significantly impeding transportation flows and increasing costs. These security measures focus on developing a more transparent and traceable supply chain through information exchange/sharing in industry and customs partnerships, and in alliances with foreign trade partners.

Ports represent one major nexus in the international supply chain, thus making them vulnerable for a terrorist attack. A terrorist attack on a major port would have detrimental local and macroeconomic effects on the U.S. economy, but also would significantly impact transportation costs and distribution routes for individual firms.

In this study, a constrained transportation optimization model was developed to estimate the effects that security related impacts had on an electronic firm's supply chain of televisions through the six major west coast ports. This modeling effort was developed using primary data obtained through interviews with the firm, and maritime experts.

Three different scenarios involving port security measures and impacts were presented and evaluated. The first scenario involved increasing the rate charged for port services by five, ten, and fifteen percent. The second scenario considered the impact resulting from a shutdown of the Port of Seattle, and the third scenario evaluated the effect of a shutdown at the Port of Long Beach.

The rate increases caused a slight decrease in quantity demanded and thus the total transportation costs, yet the average cost per container shipped increased by $27 during the highest rate increase. The Port of Seattle shutdown created an $11 increase in per-unit costs, and caused Seattle's volume to shift to the lower cost Port of Los Angeles. The shift in distribution increased costs and decreased throughput for the Bloomington distribution center, which was previously supplied by Seattle. The Port of Long Beach shutdown caused a direct shift of Long Beach bound shipments to Los Angeles in the firm and industry scenarios. The per-unit cost increase was only $5 because of the firm's ease of redirecting shipments to the neighboring port. Perhaps a more realistic conclusion was reached when the Port of Long Beach shutdown was imposed on all container volumes. The cost increase from the loss of the port caused an 8.5 percent decrease in quantity demanded. The large volume from Long Beach was reallocated across all of the remaining ports, which increased per-unit costs at each port and resulted in a $183 increase in average cost per container shipped.

The shadow prices for the ports and the distribution centers in each scenario provide meaningful insight of the value that the corresponding port or distribution center holds in the modeling framework. Throughout most of the scenarios, the Dinuba, Ardmore, Bloomington, and Des Moines distribution centers were operating at maximum capacity and maintained the highest shadow prices. With all of the supply originating on the west coast, the closest distribution centers were expected to be in high demand because they were en route to all the eastern retail locations.

The northeastern distribution centers of Staunton, Nichols, and Findlay consistently shipped volumes at their lowest capacity causing positive shadow prices, which indicated the cost savings achieved if one less unit was shipped through these DCs. The shadow prices were significantly lower than the distribution centers operating at maximum capacity, but they existed primarily for the same reason. These distribution centers were a less desirable option because of their location in regards to their supply on the west coast. In many cases, the supply would be shipped to one of these eastern distribution centers and shipped westward to a retail store, thus increasing the transportation cost and diminishing their competitiveness.

Using a firm perspective, this study demonstrated the effects that port security measures and catastrophic events might impose on a typical importer, and estimated the possible outcomes of these effects on the television industry and all the west coast imports. Though a great deal of insight can be gained in evaluating these effects through a transportation cost model, there are several improvements that would produce more robust results. The anomaly that existed in this study was not considering the effects of congestion at the nation’s ports on both the water and land side. With record breaking volumes each year, the ports experience ever increasing problems of congestion. In the model, the firm was able to easily change ports without facing the problems and costs associated with congestion, when in all reality; every other firm would also change shipment ports, thus magnifying the problem. If the congestion component was implemented into the model, the costs incurred by the firm would be more accurately represented.

The rates established for container services at the ports successfully demonstrated the economies of scale characteristics at the ports. However, the rates were estimations based on port lease revenues and typical container service fees. In the future, further investigation of each port’s cost structure and terminal lease rates would assist in establishing a more precise representation of the rates assessed at the ports.

Lastly, the firm analyzed in the study also used some rail as a means of transportation to some of the distribution centers located in the eastern parts of the United States. Information and data regarding the firm’s use of rail was not provided. Adding the rail mode of transportation would most likely increase the competitiveness of the northeastern distribution centers and decrease the dependence on the western distribution centers for the lowest cost transportation, which would result in a more accurate representation of the firm.

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