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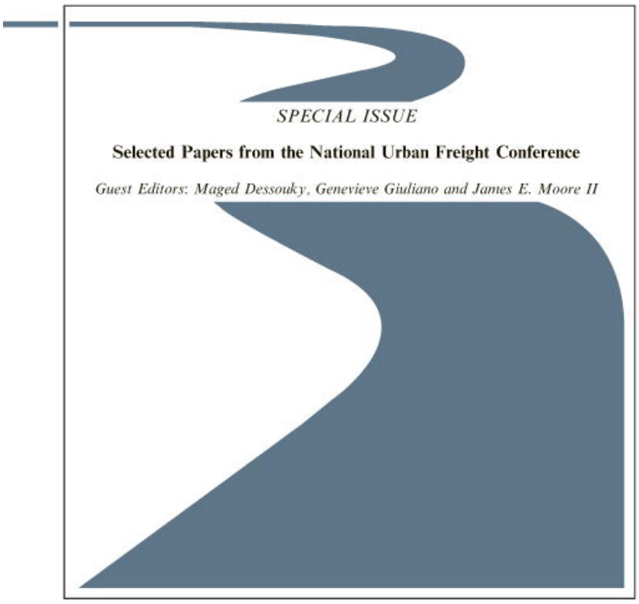


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# Port and modal allocation of waterborne containerized imports from Asia to the United States

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**Abstract**

An economic optimization model of waterborne containerized imports from Asia to the USA is described. Imports are allocated to alternative ports and logistics channels so as to minimize total transportation and inventory costs for each importer. Logistics channels include direct shipment of marine containers via truck or rail, and trans-loading in the hinterlands of the ports of entry from marine containers into domestic trailers or containers.

The model was exercised with 2004 actual transportation costs, import volumes and declared values, plus a range of hypothetical container fees assessed on imports routed via the San Pedro Bay Ports. The results show that, without reductions in container movement lead times, container fees would result in significant diversion of cargoes to other ports. In contrast, if infrastructure is improved such that lead times for container movement are significantly reduced, the model predicts little or no decrease in overall imports via San Pedro Bay but a substantial increase in trans-loaded imports for fees ranging up to $200 per 40-foot container.


*Keywords:* Containerized imports; Supply-chain optimization; Port and modal routing; Elasticity of port demands

## 1. Introduction and overview

This article analyzes the allocation of containerized imports of Asian goods to ports of entry, landside transportation modes and transportation channels, and develops methodology to predict changes in those allocations as a function of changes in transportation charges or transportation service quality. Such allocations must be understood in the context of importers' efforts to optimize supply chains. Clearly, transportation charges for the alternative modes and routes are important. But inventory management factors play an important role as well. Differences in the mean and variance of door-to-door transit times for the imports, as well as whether or not shipments to multiple destinations are pooled, may result in substantial differences in inventory costs.

Because domestic and marine transportation containers have different cubic capacities, large, sophisticated importers assess total transportation and handling costs in terms of the cost per cubic foot of imports, rather than a cost per container. Total inventory costs, considering both in-transit pipeline stocks and destination

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safety stocks, also can be expressed on the basis of cost per cubic foot of imports. To optimize supply chains, total transportation costs are combined with total inventory costs associated with each potential distribution strategy in order to identify the least costly strategy. As will be demonstrated, the best strategy for low-value goods can be quite different from the best strategy for high-value goods.

The inventory management aspects of imports from Asia to the United States are considered first. Expressions are developed for total inventory costs experienced by retail importers as a function of supply-chain strategy, volume and value of goods imported. Distributions of imports by customs-declared value and by importer are documented. Next, the development of total transportation costs per cubic foot for various ports of entry and landside transportation channels is discussed. Combining transportation unit costs and inventory cost expressions leads to the formulation of an economic optimization model for determining the best supply-chain strategy for each importer. The most efficient supply-chain strategies for various types of goods and importers are identified. Aggregating optimization results for all importers, total volumes imported through the San Pedro Bay ports (Los Angeles and Long Beach) are tabulated. Iterating model calculations for progressive assessment of hypothetical container fees, aggregate demand curves are constructed defining total and trans-loaded imports routed via the San Pedro Bay ports versus level of container fee. Curves are constructed for two scenarios, one for the case of no improvements in shipment lead times and lead time variability, and the other portraying the impact of major improvements in lead time distributions.

This paper is based on a three-year study sponsored by the Southern California Association of Governments (SCAG). Following sections focus on the methodology of the study and its results; for reasons of space, the voluminous input data is only generally described herein. However, the interested reader may download Leachman (2005b), the final report for the study, documenting all input data, assumptions and results, from the SCAG web site, http://www.scag.ca.gov.

## 2. Inventory analysis

As will be discussed below, the vast majority of imports to the United States from Asia are retail goods. A large US importer/retailer operates regional distribution centers (RDCs) that restock retail outlets mostly located within an overnight driving distance. Differences in inventory costs resulting from use of alternative supply channels typically extend only as far as the RDCs, not to the retail stores or other points of sale. For the purposes of this analysis, the origins for import shipments are factories in China and elsewhere in Asia, and the destinations are the RDCs.

Two types of inventories are a function of the choice of supply channel: One is the aggregate amount of goods in transit (so-called "pipeline stock"), the other comprises the total stocks of goods at destination RDCs. The stocks of goods at destination RDCs in turn may be subdivided into what is termed "cycle stock" and what is termed "safety stock."

The time-average pipeline stock is simply the product of the average re-supply lead time and the average import volume per unit time. Larger pipeline stocks result from using supply channels with longer lead times.

Cycle stock is a function of the replenishment frequency (e.g., weekly) and is otherwise independent of the selection of the supply chain channel. Just after a replenishment shipment arrives, the cycle stock level equals the amount of demand forecasted until the next shipment is due to arrive, then steadily drops to zero just before the next shipment arrives, whereupon the cycle starts over.

Safety stock is required by retailers who strive to have stock on hand to service customer demands without delay. This stock level is maintained as a hedge against potential delays to shipments and potential errors in sales forecasts upon which the shipment quantities were based. That is, if customer demands are to be met without backorder, safety stocks are necessary to buffer against unpredictable surges in demand while replenishment orders are in transit as well as against unpredictable extensions in lead times for replenishment shipments. As will be shown, safety stock is non-linear and highly sensitive to the average and standard deviation of container movement lead times. Use of supply channels that entail longer and/or more unreliable lead times result in the need for larger safety stocks at destinations.

Based on the author's interviews with a cross-section of importers and import logistics providers, the prevalent supply chain strategies practiced by importers of containerized Asian goods may be generally classified as follows:

(1) *Direct shipping*. Direct shipment of marine containers from Asian origins to RDC destinations in the USA;
(2) *Consolidation–deconsolidation*. Marine containers containing goods destined to multiple RDCs are channeled through a common port of entry and routed to a deconsolidation center in the hinterland of the port of entry. The goods are unloaded from the marine boxes, sorted and re-loaded into domestic containers or trailers for final landside movement to the RDCs, possibly after some valued-added processing. Because the goods change vehicles, hereafter a deconsolidation center will be referred to as a ''trans-load warehouse,'' and volumes of imports moving under the consolidation–deconsolidation strategy will be referred to as the ''trans-loaded volumes.'' Supply chains in which goods change hands from wholesaler to retailer at the trans-load warehouse are included under this strategy.

There are many variants of these two strategies reflecting alternative ports or entry and alternative landside modes for both strategies as well as alternative groupings of RDCs for the consolidation–deconsolidation strategy. Nonetheless, it is believed that the supply-chain strategies of the vast majority of importers of Asian goods may be characterized in terms of these two general strategies.

The consolidation–deconsolidation strategy can reduce the requirement for safety stocks at destination RDCs of large, nation-wide retailers. By pooling replenishment shipments for several RDCs, de-vanning the marine containers containing those replenishments at the trans-loading warehouse and re-stuffing domestic containers and trailers based on an updated match-up of supply versus demands, the risky exposure to demand surges or supply shortages over the long lead times from Asian factory to the RDCs can be reduced to a relatively low-risk exposure over the short lead times from the trans-load warehouse to the RDCs. In typical practice, the contents of five 40-foot marine containers are trans-loaded into three domestic containers or trailers that have much larger cubic capacities. The savings from fewer inland vehicle movements partially offsets the extra transportation costs for the circuitry and trans-load handling associated with the consolidation–deconsolidation strategy.

In this paper it is assumed that each importer chooses one of these two general supply-chain strategies. As will be shown, the relative merits of the direct shipping and the consolidation–deconsolidation strategies depend on the relative magnitudes of transportation and inventory costs; that comparison in turn depends on the values of the imported goods. For this reason an examination was made of the distribution of values of containerized goods imported from Asia.

### 2.1. Classification of Asian imports

Year 2003 customs data for US West Coast ports, as summarized by PIERS and by the World Trade Atlas (WTA), were analyzed to determine the distribution of declared values of containerized imports from Asia. The PIERS data provided total 20-foot-equivalent units (TEUs) imported from Asian origins through US West Coast ports, broken out by 99 commodity codes. The WTA data provided total declared values for the Asian imports passing through US West Coast ports, again broken out by the 99 commodity codes but with one additional commodity code entitled Miscellaneous Manufactured Goods.[1] The data sets were joined to impute an average declared value per TEU for each of the 99 commodity codes.

Next, data was secured from the Pacific Maritime Association concerning the mix of 20-foot (12.3%), 40-foot (80.3%) and 45-foot containers (7.4%) carrying imports through West Coast ports during 2003.[2] A further breakdown of 40-foot containers into standard (40%) and high-cube (60%) was assumed. Usable cubic capacities for these four sizes of marine containers, as well as for larger containers used only for domestic shipments, are documented in Table 1.

[1] The PIERS summarization of customs data includes logic to allocate Code 00, Miscellaneous Manufactured Goods, among other more specific categories, based on its reading of the description of the shipment contents on each bill of lading; the WTA summarization does not. In order to fully match PIERS and WTA data, the author therefore made a judgment to express Category 00 as a weighted combination of other commodity codes.

[2] These data are available on the PMA website, http://www.pmanet.org.

Table 1
Space capacities of containers and trucks

| Vehicle type | Usable space for lading (cubic feet) | Space as a % of average 40 ft space (%) |
|---|---|---|
| 20 ft standard container | 1163 | 45.29 |
| 40 ft standard container | 2395 | 93.26 |
| 40 ft hi-cube container | 2684 | 104.52 |
| Wtd. avg. 40 ft container | 2568 | 100.00 |
| 45 ft standard container | 3026 | 117.83 |
| 48 ft standard container | 3471 | 135.16 |
| 53 ft standard container | 3830 | 149.14 |
| 53 ft hi-cube container | 3955 | 154.01 |
| 53 ft truck | 4090 | 159.27 |

*Note.* The equipment specifications shown above represent those most commonly found in the industry. Actual specifications vary from carrier to carrier and across carrier fleets.

The 2003 West-Coast weighted-average cubic capacity per TEU works out to be 1274.4 cubic feet. This figure in turn enabled estimates to be made of the average declared value per cubic foot of shipping capacity for each commodity code. Table 2 provides an excerpt of these data, displaying the 18 highest-volume commodity codes for imports from Asia through US West Coast ports in 2003. The table also displays the average declared value per cubic foot of usable container capacity. As may be seen, furniture and bedding is the highest-volume commodity, with an average declared value of only $8.27 per cubic foot. Next highest is electronics and electrical equipment, with an average declared value of $37.46 per cubic foot, and so on.

The commodity codes were then grouped by ranges of declared values, resulting in a distribution of total shipment volume versus average declared value. The results are graphed in Fig. 1. The bars represent the distribution as derived from PIERS, WTA and PMA data. Because a single average declared value is associated with each of the 99 commodity codes in lieu of the actual range of declared values for each code, the depicted distribution is much lumpier than reality. It is postulated that the real distribution of declared values should exhibit a Pareto curve. The line in the figure represents the author's smoothing of the raw data into a more realistic distribution, and this distribution will be assumed in follow-on analysis. As may be seen, the distribution of declared values reaches a peak at the low end of the spectrum ($8–$12 per cubic foot of container capacity), with the distribution extending up to $175 per cubic foot in steadily declining volumes.

It should be kept in mind that Fig. 1 displays the value per cubic foot of container capacity and not the value per cubic foot of the actual cargo within the container. Anecdotal evidence received from trans-loading service providers suggests that, while shippers strive to fully utilize the available space, sometimes the full cubic capacity can not be utilized because of inability to stack cargoes, need for handling space, racking or blocking and bracing, etc. A second factor to keep in mind is that the declared values reflect the manufactured or purchased cost of the goods in Asia plus waterborne transportation rather than their full retail values in the United States.

### 2.1.1. Large retail merchant importers

A different view of the PIERS data is a break-down by importer. In Special Report (2005), the *Journal of Commerce* published a lost of the top 100 US importers via ocean container transport. The author adopted this list, less 17 companies (all food and beverage, forest products, or chemical companies) that are not major importers of Asian goods. The remaining 83 are large retailers or large merchants of goods such as tires, electronics or appliances that are ready for retail marketing. While the imports these firms market are not solely sourced from Asia, the author believes the vast majority are.[3]

Table 3 displays an excerpt of these data, listing the top 12 and last three of the 83 large retail merchant importers. A summary by importer type also is provided. Shown are the author's estimates for the average

[3] The reader is cautioned that the PIERS data is known to be quite incomplete. As an extreme case, the *Journal of Commerce* article lists Target Corp. as importing 202,700 TEUs in 2004. Target Corp. advised the author that in 2004 it actually imported from Asia 315,766 TEUs, i.e., the PIERS figure for Target is low by more than a third.

Table 2
Total volume and average declared value by commodity for 2003 Asian imports through US West Cost ports

| Commodity | TEUs (1000 s) | Average declared value ($ per cu ft) |
|---|---|---|
| Furniture and bedding | 1014 | 8.27 |
| Electronics and electrical equipment | 749 | 37.46 |
| Toys, games and sports equipment | 663 | 16.56 |
| Machinery | 661 | 50.23 |
| Auto parts and motorcycles | 480 | 20.19 |
| Plastic goods | 353 | 13.18 |
| Apparel – not knitted | 329 | 27.93 |
| Footwear | 318 | 24.37 |
| Misc. manufactured goods | 274 | 23.42 |
| Steel goods | 265 | 14.13 |
| Leather goods | 199 | 18.05 |
| Rubber goods | 198 | 14.63 |
| Apparel – knitted | 149 | 53.81 |
| Ceramic goods | 109 | 8.38 |
| Wood products | 105 | 10.91 |
| Paper and paperboard products | 100 | 12.31 |
| Textile art and needlecraft | 87 | 24.72 |
| Optical, photo and med. instruments | 83 | 45.32 |
| All other | 1085 | |

*Source:* PIERS, WTA and PMA data.

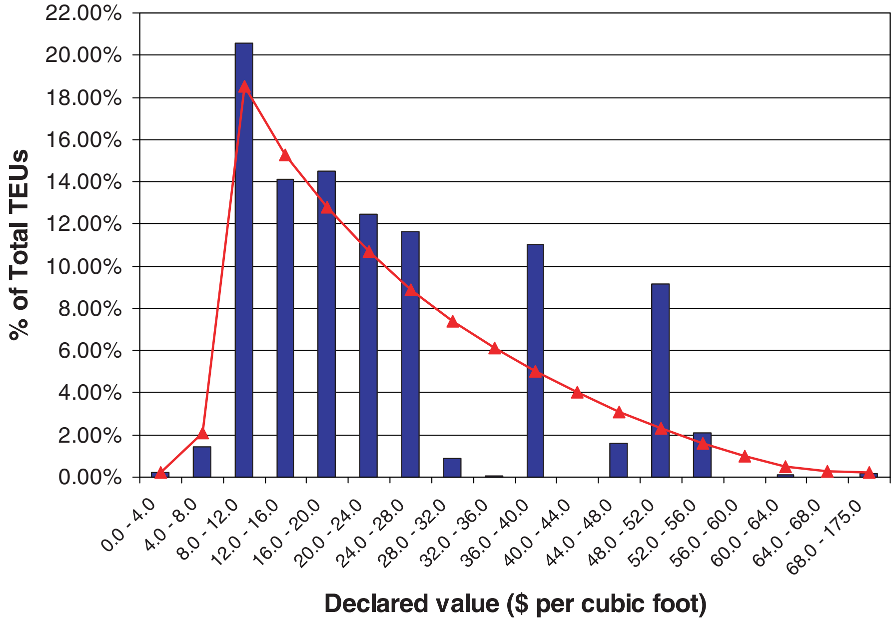


Fig. 1. Distribution of declared values for 2003 Asian imports through US West Coast ports.

declared value of imports, the PIERS-reported volumes, and the volumes inflated by 10% (a level that in the author's judgment is a suitable assumption for the merchant's import level from Asia, for the purposes of this study). Also shown is the average off-peak weekly volume to one of 21 equal-volume regions encompassing the continental United States. This is derived assuming 50% of the annual shipping volume is concentrated in three peak months of late summer and early fall. As may be seen, the volume towards the end of the list is quite low; Eckerds is importing on average only 215.7 TEUs per week. This equates to only about 10 TEUs per week per region, and Eckerds' off-peak weekly volume per region is only seven TEUs. For such merchants the transloading strategy is marginally feasible from a volume point of view, quite apart from whether or not it is economically attractive from a unit cost point of view.

Table 3
Largest US importers of asian goods via ocean container transport

| Importer | Type | Assumed average value per cu ft. for Asian imports | PIERS 2004 import volume (TEUs) | Actual 2004 Asia volume (TEUs) | Assumed 2004 Asia volume (TEUs) | TEUs per week per region (off-peak) |
|---|---|---|---|---|---|---|
| 1. Wal-Mart | Big box | $15 | 576,000 | | 633,600 | 387 |
| 2. Home depot | Furniture | $9 | 301,200 | | 331,320 | 202 |
| 3. Target | Big box | $20 | 202,700 | 315,766 | 222,970 | 136 |
| 4. Sears (K-Mart) | Big box | $20 | 186,000 | | 204,600 | 125 |
| 5. Ikea | Furniture | $9 | 100,000 | | 110,000 | 67 |
| 6. Lowe's | Furniture | $9 | 100,000 | | 110,000 | 67 |
| 7. Costco | Big box | $20 | 66,400 | | 73,040 | 45 |
| 8. Ashley furniture | Furniture | $9 | 63,800 | | 70,180 | 43 |
| 9. Payless shoesource | Shoes | $25 | 54,200 | | 59,620 | 36 |
| 10. Samsung | Electronics | $40 | 52,800 | | 58,080 | 35 |
| 11. Matsushita | Electronics | $40 | 52,100 | | 57,310 | 35 |
| 12. Toyota | Auto parts | $20 | 52,000 | | 57,200 | 35 |
| 81. Hamilton beach | Appliances | $25 | 10,400 | | 11,440 | 7 |
| 82. Honda | Auto parts | $20 | 10,300 | | 11,330 | 7 |
| 83. CVS (Eckerds) | Big box | $10 | 10,200 | | 11,220 | 7 |
| Average value per cu ft | | $18.79 | | | | |
| Total TEUs | | | 3,447,654 | | 3,792,419 | |
| *Subtotals* | | | | | | |
| Big box retailer | | | 1,445,700 | | 1,590,270 | |
| Furniture | | | 665,154 | | 731,669 | |
| Electronics | | | 371,700 | | 408,870 | |
| Appliances | | | 218,000 | | 239,800 | |
| Auto parts | | | 219,200 | | 241,120 | |
| Tires | | | 145,300 | | 159,830 | |
| Shoes | | | 144,000 | | 158,400 | |
| Toys | | | 102,800 | | 113,080 | |
| Electrical equipment | | | 22,600 | | 24,860 | |
| Machinery | | | 37,100 | | 40,810 | |
| Textiles | | | 29,500 | | 32,450 | |
| Apparel | | | 32,300 | | 35,530 | |
| Photographic film | | | 14,300 | | 15,730 | |

For the purposes of this study, the top 83 Asian importers were assumed to be the only candidates for adopting a consolidation–deconsolidation supply chain strategy featuring transloading from marine containers to domestic containers or trailers. These importers accounted for an estimated 26% of total 2004 Asia–US imports.

## 2.2. Inventory cost modeling

To motivate the consolidation–deconsolidation strategy, consider the following simple case: suppose there are 10 RDCs, each serving the same total amount of retail demand. Suppose 10 containers of goods are ordered each week, one for each RDC. If sales are 15% higher than expected at five RDCs but 15% lower at the other five RDCs, then no safety stock is required to meet demands if the 10 shipments were consolidated. Further, suppose one of the 10 containers gets delayed at customs in Asia and misses its scheduled vessel and must transit on the next vessel one week later. If the 10 shipments were pooled, each RDC could receive 90% of what was needed. If not, one RDC would receive nothing. In the former case, a 10% safety stock would have been adequate; in the latter, a 115% safety stock was required.

To quantify the safety stock savings from the consolidation–deconsolidation strategy, mathematical formulas are developed as follows for pipeline and safety stocks for the direct shipping and the consolidation–deconsolidation strategies for the case of $N$ equal-volume RDCs and $M$ deconsolidation facilities each serving $M/N$ RDCs.

*Notation for parameters*

$D$ nation-wide average sales volume per week (in physical units, not dollars)
MAPE mean absolute percentage error (expressed as a fraction of one) in one-week-ahead forecasts of nation-wide sales
$N$ number of RDCs. The sales volume per week served by each RDC is initially assumed to be $D/N$ (this assumption is relaxed later)
$M$ number of ports carrying out trans-load deconsolidation of Asian shipments. Each such trans-load facility is assumed to supply $N/M$ RDCs (this will be generalized later)
$R$ time between replenishment orders (from Asian suppliers). $R$ is assumed to be one week for all importers
$L_{\mathrm{AO}}$ lead time (expressed in weeks) from when order is placed until port of entry for shipment is selected. This lead time is assumed to be deterministic
$L_{\mathrm{AW}}$ mean lead time (expressed in weeks) from when POE (port of entry) for shipment is selected until shipment completes over-water transport from Asia and commences land transport to North American RDC. For the consolidation–deconsolidation strategy, $L_{\mathrm{AW}}$ ends at the time the destination RDC is selected
$L_{\mathrm{W}}$ mean lead time (expressed in weeks) from departure from point of origin until shipment commences land transport to RDC. For the consolidation–deconsolidation strategy, $L_{\mathrm{W}}$ ends at the time the destination RDC is selected
$L_{\mathrm{NA}}$ mean lead time (expressed in weeks) from when shipment commences land transport from POE until processed through the RDC. For the consolidation–deconsolidation strategy, $L_{\mathrm{NA}}$ starts at the time the destination RDC is selected
$\sigma_{L_{\mathrm{AW}}}$ standard deviation of $L_{\mathrm{AW}}$. All shipments are assumed to be independent
$\sigma_{L_{\mathrm{NA}}}$ standard deviation of $L_{\mathrm{NA}}$. All shipments are assumed to be independent
$K$ safety factor determining the level of safety stocks at RDCs (choosing $k = 2$ implies approximately a 98% probability of no stock-out)

*2.2.1. Pipeline stock*

The total in-transit inventory is simply

$$(L_{\mathrm{W}} + L_{\mathrm{NA}})(D). \quad (1)$$

*2.2.2. Safety stocks*

A standard assumption in inventory analysis is to estimate the standard deviation of unbiased forecast errors as 1.25 times the mean absolute deviation of the errors (e.g., Silver and Peterson, 1985). The standard deviation of errors in one-week-ahead forecasts of nation-wide sales is therefore approximately given by

$$\sigma_D = (1.25)(\mathrm{MAPE})(D). \quad (2)$$

Assuming independence of forecast errors across RDCs, the standard deviation of errors in one-week-ahead forecasts of sales served by a single RDC is

$$\sigma_D/\sqrt{N}. \quad (3)$$

Consider first a single destination for imported goods. Suppose the frequency of shipments from Asia is once every $R$ time periods. Suppose the lead time between ordering goods from Asia and receipt at destination has mean value $L$ and standard deviation $\sigma_L$. Considering the replenishment lead time and the frequency of replenishments, sales must be forecasted over an interval of length $(L + R)$ in order to determine the proper quantity to be ordered from the Asian supplier. To analyze the impact of differences in lead time, the growth of forecast errors as a function of lead time must be characterized. Mathematically, the standard deviation of forecast errors grows with lead time according to the general model

$$\sigma_{R+L} = (L + R)^c \sigma_D \quad (4)$$

where $c$ is a constant that depends on the correlation of week-to-week sales (i.e., does higher-than-expected sales last week imply higher-than-expected sales this week) and $\sigma_D$ is the standard deviation of errors in one-period-ahead forecasts. Perfectly correlated sales would imply $c = 1$. It is assumed in this analysis that $c = 0.5$, which has been found to be accurate for household consumer products marketed in the United States (Gascon et al., 1993). That is, to good approximation, forecast error grows as the square root of the time interval over which sales are forecasted. Hence the standard deviation of forecast errors over $(L + R)$ is

$$(\sqrt{L+R})\sigma_D. \tag{5}$$

As a function of the standard deviations of the lead time and the sales forecasting errors, the required level of safety stock ss may be expressed as (Silver and Peterson, 1985)

$$\mathrm{ss} = k\sqrt{(L+R)\sigma_D^2 + D^2\sigma_L^2}, \tag{6}$$

where $R$ denotes the time between replenishments, $L$ denotes the average lead time, $\sigma_L$ denotes the standard deviation of lead time, $D$ denotes the average shipment quantity per replenishment, $\sigma_D$ denotes the standard deviation of one-period-ahead forecast errors and $k$ is a safety factor corresponding to the desired probability of no stockout.

The formulas for nation-wide safety stocks are different for the direct shipping and consolidation–deconsolidation strategies. Formulas are developed for these two cases as follows.

#### 2.2.3. Direct shipping

Uncertainties in water-side and land-side lead times are assumed to be independent. It is further assumed that errors in sales forecasts grow as the square root of lead time. If there were only a single RDC with demand rate $D$ and variance of forecast errors $\sigma_D^2$, the required safety stock is

$$k\sqrt{L_{\mathrm{AO}}\sigma_D^2 + (L_{\mathrm{AW}} + L_{\mathrm{NA}} + R)\sigma_D^2 + D^2(\sigma_{L_{\mathrm{AW}}}^2 + \sigma_{L_{\mathrm{NA}}}^2)}. \tag{7}$$

Considering the fleet of $N$ RDCs each with demand rate $D/N$ and variance of forecast errors $\sigma_D^2/N$, the required total nation-wide safety stock is therefore

$$(k)\sqrt{L_{\mathrm{AO}}\sigma_D^2 + N^2(L_{\mathrm{AW}} + L_{\mathrm{NA}} + R)(\sigma_D^2/N) + N^2(D/N)^2(\sigma_{L_{\mathrm{AW}}}^2 + \sigma_{L_{\mathrm{NA}}}^2)} \tag{8}$$

or

$$(D)(k)\sqrt{[L_{\mathrm{AO}} + (N)(L_{\mathrm{AW}} + L_{\mathrm{NA}} + R)](1.25)^2(\mathrm{MAPE})^2 + (\sigma_{L_{\mathrm{AW}}}^2 + \sigma_{L_{\mathrm{NA}}}^2)}. \tag{9}$$

#### 2.2.4. Consolidation–deconsolidation

It is assumed that each of the $M$ trans-load facilities serves $N/M$ RDCs. Fluctuations in demands among these RDCs over the lead time $L_{\mathrm{AW}}$ may be pooled. Eppen and Schrage (1981) proved that, for the case of zero variability in lead times, the total safety stock across $N$ RDCs served by a single trans-load facility is

$$(k)\sqrt{(L_{\mathrm{AO}})\sigma_D^2 + (L_{\mathrm{AW}})\sigma_D^2 + (N)^2(L_{\mathrm{NA}} + R)(\sigma_D^2/N)}. \tag{10}$$

Incorporating terms reflecting the variability in lead times, the total safety stock across $N$ RDCs served by a single trans-load facility is expressed as

$$(k)\sqrt{(L_{\mathrm{AO}})\sigma_D^2 + (L_{\mathrm{AW}})\sigma_D^2 + (N)^2(L_{\mathrm{NA}} + R)(\sigma_D^2/N) + D^2\left(\left(\frac{\sigma_{L_{\mathrm{AW}}}^2}{N}\right) + \sigma_{L_{\mathrm{NA}}}^2\right)}. \tag{11}$$

Here, the variance in across-the-water lead time has been reduced by a factor of $1/N$ from the direct-shipping case because $N$ otherwise separately-committed replenishment shipments become interchangeable in the case of trans-loading. The total nation-wide safety stock in the case of $M$ trans-load facilities each serving $N/M$ RDCs is then

$$(k)\left[L_{\mathrm{AO}}\sigma_D^2 + (M)^2(L_{\mathrm{AW}})\sigma_D^2/MN^2(L_{\mathrm{NA}}+R)\sigma_D^2/N(D)^2\left(\frac{M}{N}\sigma_{L_{\mathrm{AW}}}^2+\sigma_{L_{\mathrm{NA}}}^2\right)\right]^{1/2} \quad (12)$$

or

$$(D)(k)\sqrt{[L_{\mathrm{AO}}+(M)(L_{\mathrm{AW}})+(N)(L_{\mathrm{NA}}+R)](1.25)^2(\mathrm{MAPE})^2+\left(\frac{M}{N}\sigma_{L_{\mathrm{AW}}}^2+\sigma_{L_{\mathrm{NA}}}^2\right)}. \quad (13)$$

Note that if $M = N$, then (13) reduces to (9), the formula for direct shipping alternative, as expected.

*2.2.5. Numerical example*

Suppose $N = 21$, $M = 3$, $D = 6072$ TEUs per week, MAPE = 0.06, $L_{\mathrm{AO}} = 7$, $L_{\mathrm{AW}} = 4$, $L_{\mathrm{W}} = 2$, $L_{\mathrm{NA}} = 1$, $R = 1$, $\sigma_{L_{\mathrm{AW}}} = 5/7$, $\sigma_{L_{\mathrm{NA}}} = 1/7$ and $k = 2$. (These are believed to be fairly realistic data for a large US "big-box" retailer.)

Applying formula (1), the total pipeline inventory is 18,216 TEUs. Next, safety stocks are calculated. Applying formula (2), direct shipping results in total nation-wide safety stock equal to 13,733 TEUs. Applying formula (3), deconsolidation of Asian imports at three trans-load facilities results in a nation-wide safety stock equal to 8023 TEUs. In this case, the consolidation–deconsolidation strategy reduces RDC safety stocks by 0.941 weeks of demand. Put another way, the retailer's total supply chain is reduced by almost 7 days.

Let's suppose the investment in landed imports is \$20 per cubic foot, assume 1250 usable cubic feet per TEU, and assume an inventory carrying cost of 20% per year. For direct shipping, the total inventory cost is

$$(18,216 + 13,733)(1250)(\$20)(0.20/52) = \$3,072,019 \text{ per week} \quad (14)$$

or about \$159.7 million per year.

The savings in nation-wide safety stock over direct shipping from consolidation–deconsolidation at the ports of entry is calculated as

$$(13,733 - 8023)(1250)(\$20)(0.20/52) = \$549,038 \text{ per week} \quad (15)$$

or about \$28.6 million per year.

Expressed a different way, the savings per cubic foot of imports is

$$(\$549,038)/[(6072)(1250)] = \$0.072. \quad (16)$$

This savings is linear in the total import volume, the value of the imports and in the assumed inventory carrying cost, but it is non-linear in the numbers of RDCs and ports of entry, the forecast error, and the standard deviations of the lead times. Advantages from consolidation–deconsolidation grow with

– Increasing import volume (linearly).
– Increasing import value (linearly).
– Increasing inventory carrying cost (linearly).
– Increasing numbers of RDCs (square root function).
– Decreasing numbers of ports of entry (square root function).
– Average forecast error (square root function).

*2.2.6. Generalization for unequal lead times and volumes*

The general case must accommodate multiple North American ports of entry and multiple destination RDCs. The different channels may have different lead times. Moreover, the volumes at the various RDCs may be unequal. More complex formulas proposed for the general case are provided in the Appendix.

*2.2.7. Inventory holding costs*

The opportunity cost of working capital is customarily expressed as an interest rate times the amount of capital invested per unit inventory times the average inventory level. For the simple example above, the relevant inventory costs per unit time are expressed as

$$(i)(V_{\mathrm{P}})(L)(D)+(i)(V_{\mathrm{RDC}})(\mathrm{ss}) \tag{17}$$

where $i$ is the interest rate, $V_{\mathrm{P}}$ is the amount of capital tied up in a unit of pipeline stock, $(L)(D)$ is the average pipeline inventory level, $V_{\mathrm{RDC}}$ is the amount of capital tied up in a unit of RDC safety stock, and ss is the level of safety stock at the RDC. (The cost of cycle stock has been omitted because that cost is independent of supply channel alternative.)

As imports move through the supply chain, they accumulate more cost. First, the vendor in Asia must be paid to procure the goods. Next, local transportation in Asia and steamship line transit must be purchased. If other vendors are involved for North American landside handling, their services must be procured. Finally, handling at the importer's own destination RDC entails more accumulated cost.

One index to the amount of capital tied up is the value declared to US customs. This value typically includes the cost of purchase of the goods from the Asian vendor plus the cost of transportation and logistics services up to the termination point for the importing carrier. Costs for any additional carriers or logistics providers utilized to move the goods to the RDC, and costs of handling at the destination RDC, are not included.

For the purposes of this study, the assumption was made that pipeline inventories are valued by importers at 125% of the value declared to Customs. It was further assumed that RDC inventories are valued at 150% of the value declared to Customs.

The appropriate interest rate to apply depends on a number of factors. If the goods represent replenishment of goods with long-term demand, then an interest rate reflecting the cost of working capital for the importer is appropriate. A reasonable value for this was assumed to be 20%.

A higher interest rate is more appropriate if retail prices are declining with time or if the products experience rapid obsolescence, such as is the case for technology goods, style goods and goods for special sales events. For example, prices of many electronics products such as personal computers, video games, hand-held devices, etc., decline as much as fifty percent in the first year they are marketed and become completely obsolete within 2–3 years. Style goods are even more extreme, some having a selling season of only several months. In such cases, larger requirements for pipeline stocks and safety stocks result in revenue loss, and such losses should be accounted for in inventory costs. For such cases, an interest rate of 50% is more appropriate.

The sales of most retailers are a mixture of event items and standard items. For simplicity a simple average of the two cases was assumed, i.e., an interest rate of 35% is assumed for the purposes of costing pipeline and safety stocks. For importers of solely electronics and fashion items, an interest rate of 50% was assumed.

#### *2.2.8. Lead time parameters*

Data was secured from shippers and carriers concerning the mean and variance of lead times experienced for container movement in various channels. See Leachman (2005b) for the specific data and assumptions.

## 3. Transportation costs

In this section the modeling assumptions and data sources for transportation costs are described. A restricted set of destinations is assumed as a proxy for all USA destinations for containerized Asian imports. The development of the matrix of transportation rates from Asia to these destinations for alternative ports of entry and alternative landside modes is described.

There are various carrier options available to importers for the shipment of containerized Asian imports to North America:

- Alternative vessel-operating common carriers and non-vessel operating common carriers (NVOCCs), and alternative ports of entry.
- Through movement of marine containers from port of entry to inland destination via local dray (“Direct Dray”) or long-haul truck (“Direct Truck”).
- Through movement of marine containers from port of entry to inland destination via rail double-stack train and final dray from rail terminal to destination. An initial dray from port terminal to origin rail terminal is required if the rail terminal is not on-dock (“Direct Rail”).

- Dray of marine containers from port of entry to a transloading warehouse in the hinterland of the port of entry, transloading to the goods to a 53-foot trailer for truck movement to inland destination or local dray ("Trans-load Truck" or "Local Trans-load").
- Dray of marine containers from port of entry to a transloading warehouse in the hinterland of the port of entry, transloading to the goods to a 53-foot trailer, dray to origin rail terminal, rail movement of the 53-foot trailer via premium intermodal train service, and final dray from rail terminal to destination ("Trans-load Rail Trailer").
- Dray of marine containers from port of entry to a transloading warehouse in the hinterland of the port of entry, transloading to the goods to a 53-foot container, dray to origin rail terminal, rail movement of the 53-foot container via double stack train, and final dray from rail terminal to destination ("Trans-load Rail Container").

The portions of the overall movement of each vehicle type (marine container, 53-foot trailer or 53-foot container) may be procured separately from multiple vendors, or they may be purchased as a bundled service from a single service provider. The vendors may be carriers or they may be third parties such as intermodal marketing companies (IMCs). Further complexity arises because many rates are contractual and confidential, with different rates applying to different customers.

The author was able to view rates offered by various vendors. The costs utilized in the study were based on averages across baskets of rates charged by various vendors to various customers and therefore do not necessarily reflect the specific rates of any individual contract or individual carrier. Costs components that were included are as follows:

- All modes/channels: steamship line rate from Shanghai to dockside at each port of entry for a 40-foot container.
- Direct Rail of 40-foot container: weighted average of Joint Powers Authority gate charges (if any), dray to near-dock rail ramps and dray to off-dock rail ramps.
- Direct Rail of 40-foot container: rail line haul rate (This is the difference between the steamship rate for "store-door" delivery at a warehouse site near port of entry and the steamship rate for "inland point intermodal" service to an inland warehouse).
- Direct Rail of 40-foot container: destination dray.
- Direct Truck or Direct Dray of 40-foot container: truck line haul rate or local dray rate.
- All trans-load modes: dray from port to trans-load warehouse plus trans-loading fee.
- Trans-load Rail Container: dray from trans-load warehouse to domestic rail ramp.
- Trans-load Rail Container: rail line haul rate to third party for 53-foot container.
- Trans-load Rail Container: destination dray.
- Trans-load Rail Container: third-party (e.g., IMC) booking fee.
- Trans-load Truck or Local trans-load: truck line haul rate or local dray rate.

Cubic capacities of marine and domestic vehicles enabling conversion of container or trailer rates to a cubic foot basis are explained as follows. Domestic freight vehicles are not only longer than marine containers, they are also taller and wider. The usable cubic space thus grows faster than the increment in length. Table 1 displays the useable cubic space of various vehicles. Note that a hi-cube 53-foot domestic container offers about 65% more useable space than a standard international 40-foot container; a 53-foot truck offers about 71% more useable space. For the purposes of this analysis, it was assumed that shipments in 40-foot marine containers are 60% in high-cube 40-foot boxes and 40% in standard 40-foot boxes, leading to the weighted average cubic capacity shown in the table. Shipments trans-loaded into domestic containers for rail intermodal movement were assumed to utilize hi-cube 53-foot containers.

A matrix of total transportation and handling charges as faced by importers was developed for specific ports of entry and alternative modes of transport. Ten major North American ports of entry were included in the analysis, as follows:

Vancouver, BC. Assumed trans-load warehouse site is Abbotsford, BC.
Seattle-Tacoma, WA. Assumed trans-load warehouse site is Fife, WA.

Oakland, CA. Assumed trans-load warehouse site is Tracy, CA.
Los Angeles–Long Beach, CA. Assumed trans-load warehouse site is Ontario, CA.
Houston, TX. Assumed trans-load warehouse site is Baytown, TX.
Savannah, GA. Assumed trans-load warehouse site is Garden City, GA.
Charleston, SC. Assumed trans-load warehouse site is Summerville, SC.
Norfolk, VA. Assumed trans-load warehouse site is Suffolk, VA.
Port of New York–New Jersey. Assumed trans-load warehouse sites are 50% East Brunswick, NJ and 50% Allentown, PA.

To model landside transportation costs, the continental United States was divided into 21 destination regions. It was assumed that one regional distribution center (RDC) located in a suburb of a major city within each region was the destination for all imported goods consumed within the region, as detailed below. Transportation costs for alternative modes/channels for Asian imports via alternative potential ports of entry to these distribution center sites were tabulated.

The destination regions and assumed sites for the RDCs within each region are as follows:[4]

*Seattle Region* – including Washington, Oregon, Idaho and Montana. RDC assumed to be in Fife, WA.
*Oakland Region* – including Wyoming, 50% of Colorado, 67% of Utah, 34% of California, and 33% of Nevada. RDC assumed to be in Tracy, CA.
*Los Angeles Region* – including Arizona, New Mexico, 66% of California, 67% of Nevada, 33% of Utah, and 50% of Colorado. RDC assumed to be in Ontario, CA.
*Dallas Region* – including Oklahoma and 50% of Texas. Regional distribution center assumed to be in Midlothian, TX.
*Houston Region* – including Louisiana, Mississippi and 50% of Texas. RDC assumed to be in Baytown, TX.
*Memphis Region* – including Arkansas, Tennessee and Kentucky. RDC assumed to be in Millington, TN.
*Kansas City Region* – including Kansas, Nebraska, Iowa and Missouri. RDC to be in Lenexa, KS.
*Minneapolis Region* – including North Dakota, South Dakota, Minnesota and 50% of Wisconsin. RDC assumed to be in Rosemount, MN.
*Chicago Region* – including Illinois, Indiana, Michigan 50% of Wisconsin. Regional distribution center assumed to be in Joliet, IL.
*Columbus Region* – including 50% of Ohio. RDC assumed to be in Springfield, OH.
*Cleveland Region* – including 50% of Ohio and 25% of New York. RDC assumed to be in Chagrin Falls, PA.
*Pittsburgh Region* – including West Virginia and 50% of Pennsylvania. RDC assumed to be in Beaver Falls, PA.
*Harrisburg Region* – including 50% of Pennsylvania. RDC assumed to be in Allentown, PA.
*Atlanta Region* – including Alabama, Georgia and 50% of Florida. RDC assumed to be in Duluth, GA.
*Savannah Region* – including 50% of Florida. RDC assumed to be in Garden City, GA.
*Charleston Region* – including 50% of South Carolina. RDC assumed to be in Summerville, SC.
*Charlotte Region* – including North Carolina and 50% of South Carolina. RDC assumed to be in Salisbury, SC.
*Norfolk Region* – including Virginia. RDC assumed to be in Suffolk, VA.
*Baltimore Region* – including Maryland, DC and Delaware. RDC assumed to be in Frederick, MD.
*New York Region* – including New Jersey, Connecticut and 75% of New York. RDCs are assumed to be located 50% in East Brunswick, NJ and 50% in Allentown, PA.
*Boston Region* – including Rhode Island, Massachusetts, New Hampshire, Vermont and Maine. RDC assumed to be in Milford, MA.

[4] A percentage specified for a state defines the portion of import volume terminating in that state that is assumed to be assigned to a distribution center in the named region. For example, 50% of imports terminating in Pennsylvania are assumed to be served from an importer's Harrisburg Region distribution center, and 50% are assumed to be served from the importer's Pittsburgh Region distribution center.

The resulting total transportation unit costs ranged from $1.40 up to $3.00 per cubic foot of vehicle capacity, depending on the destination, choice of port and choice of mode. For the complete matrix, see Leachman (2005b).

Of particular interest is a comparison of costs for transloading and direct shipping channels. For shipment via West Coast ports, overall handling and transportation costs to trans-load to 53-foot containers are not much more than total costs for direct rail movement in marine containers and are sometimes even less, ranging from $0.02 per cubic foot less up to $0.05 per cubic foot more. For reverse intermodal movements from East Coast ports, overall handling and transportation costs to trans-load to 53-foot containers generally range $0.07–$0.15 per cubic foot more than that for direct rail movement of marine containers. Direct truck and Trans-load truck costs are comparable with each other. Both types of truck movements generally range $0.40–$0.60 more per cubic foot than that for direct rail movement from West Coast ports, but generally range $0.05–$0.15 more per cubic foot that that for direct rail movement from East Coast ports. Short-haul truck cost is often comparable and sometimes even less than rail.

## 4. Calculation of aggregate demand curves

As indicated above, the top 83 importers account for about 26% of total Asian imports. To account for the remaining import volumes, a set of "generic proxy" importers was generated, stratified along the value distribution of Fig. 1 in value increments of $4 per cubic foot from a low of $2 to a high of $70. The total amount of generic proxy imports was calibrated so that the sum of generic proxy imports and major-shipper imports added to the total 2004 imports from Asia to the USA.

For all importers (both real and proxy), the distribution of import volumes by destination region was assumed to be proportional to the total purchasing power in each region. Data on per-capita personal incomes by state and on state populations were obtained from the US Dept. of Commerce web sites.[5] Purchasing power figures for each state (population multiplied by per-capita income) were then allocated into the 21 destination regions as defined above.

The unit transportation costs outlined above and the inventory cost formulas derived above were combined to provide the basis for calculating total costs faced by an importer for a given supply chain strategy. For each importer, total costs for alternative strategies were computed to deduce the least-cost strategy for each type of importer. The alternative strategies so tested were as follows:

- Direct shipping via nearest port to each region.
- Direct shipping via least-cost West Coast ports to each region (least cost considering all transportation and inventory costs).
- Trans-load only at LA–Long Beach, then least-cost shipping.
- Trans-load Los Angeles Region imports at LA–Long Beach, but trans-load everything else at Seattle-Tacoma, then least-cost shipping.
- Trans-load only at Seattle-Tacoma, then least-cost shipping.
- Trans-load only at Oakland, then least-cost shipping.
- Trans-load only at Seattle/Tacoma and LA–Long Beach, then least-cost shipping.
- Trans-load at Seattle/Tacoma, LA–Long Beach and Norfolk, then least-cost shipping.
- Trans-load at Seattle/Tacoma, LA–Long Beach, Savannah and New York, then least-cost shipping.

It was assumed each importer applies a single homogenous supply-chain strategy to handle all of its imported goods at the least overall cost for the assumed average declared value of its imports. Only direct shipping alternatives were evaluated for the generic proxy importers. Total costs were tallied for each alternative strategy for each importer and the best strategy identified for each importer.

[5] State populations and personal incomes per capita were obtained from www.census.gov/popest/states.php and www.bea.gov/bea/regional/spi, respectively.

Once distribution strategies for all importers were optimized, total import volumes passing through the San Pedro Bay Ports were tallied across importers. This process was repeated assuming the application of a fee on loaded containers imported through the San Pedro Bay Ports. This fee was assumed to be borne by the importer. Fee values in increments of $30 from $0 to $1200 were tested in runs of the model. Combining results, an aggregate demand curve of port demand versus fee value was constructed. The slope of the aggregate demand curve reveals the elasticity of imports to increasing fee charges.

This analysis is termed a *Long-Run Elasticity Model*. It is "long-run" because congestion effects resulting from calculated traffic shifts are ignored; lead time statistics and transportation charges are exogenous to the model. In the short-run, San Pedro Bay Ports' traffic may be somewhat more inelastic than predicted by Model calculations, in light of current capacity limitations at other ports and other "stickiness" factors such as current contractual obligations of shippers and carriers. However, in the longer run, one may expect new capacity investments to follow traffic demands. Moreover, transportation infrastructure investments are very long-term in nature (both in terms of time to construct and life of investment); relying on short-term traffic inelasticity seems unwise. A long-term elasticity analysis is more prudent for informing public policy concerning potential infrastructure investments and user fees to pay for them.

The Long-Run Elasticity Model was applied to two scenarios: As-Is and Congestion Relief. Both scenarios utilize the 2004 Asia–US import volumes, but featuring different assumptions about lead times.

### 4.1. The As-Is Scenario

The starting point in this scenario reflects year 2004 lead time statistics and transportation charges, without imposition of any new container fees. For a $0 container fee, the best distribution strategies as a function of average declared value of imports are summarized in Table 4. The results suggest that a large nation-wide importer of furniture or building materials, such as Home Depot or Lowe's, should opt for direct shipping of their imports. It suggests that a large "big-box" department store importer such as Wal-Mart, K-Mart, or Target should trans-load imports at multiple ports, while an importer of high-value electronics such as Samsung or Matsushita should trans-load all its imports in the hinterland of San Pedro Bay. By and large, these predictions are borne out by actual practice.

Overall, the model calculates about 19% of total 2004 Asian imports are most cost-effectively accommodated using transloading channels. It was calculated that large nation-wide retailers practicing consolidation–deconsolidation realize 18–20% reductions in their total supply-chain inventories, yielding a net savings (inventory cost reductions less additional transportation and handling expenses) to the American economy of about $1.1 billion per year.

Next, model calculations were iterated with the addition of a container fee assessed on all containers entering through the ports of Los Angeles and Long Beach. Fee values expressed in increments of $30 per forty-foot equivalent unit (FEU) ranging from $0 to $1200 were tested. As an increasingly larger fee is imposed, the model predicts that some importers are induced to change strategy. For example, an importer of high-valued goods currently trans-loading only in Southern California would be induced to begin trans-loading at Seattle-Tacoma as well as in Southern California, once the fee is large enough. As the fee is progressively increased, eventually the importer will be induced to discontinue importing through the San Pedro Bay Ports altogether and truck or use rail to supply its Southern California distribution center from its trans-load warehouse in the hinterland of the Seattle-Tacoma or Oakland ports. The "break points" in fee value for each importer, i.e., where the importer has the economic incentive to change strategy, were calculated using the Long-Run Elas-

Table 4
Import strategy as a function of declared value – As-Is Scenario

| Importer type | Declared value per cubic foot | Least-cost import strategy |
|---|---|---|
| Large importer | $0–$13 | Direct shipping using nearest port |
| Large importer | $13–$27 | Trans-load at multiple ports |
| Large importer | $27 and up | Trans-load only at LA–Long Beach |
| Small importer | $0–$46 | Direct shipping using nearest port |
| Small importer | $46 and up | Direct shipping using only West Coast ports |

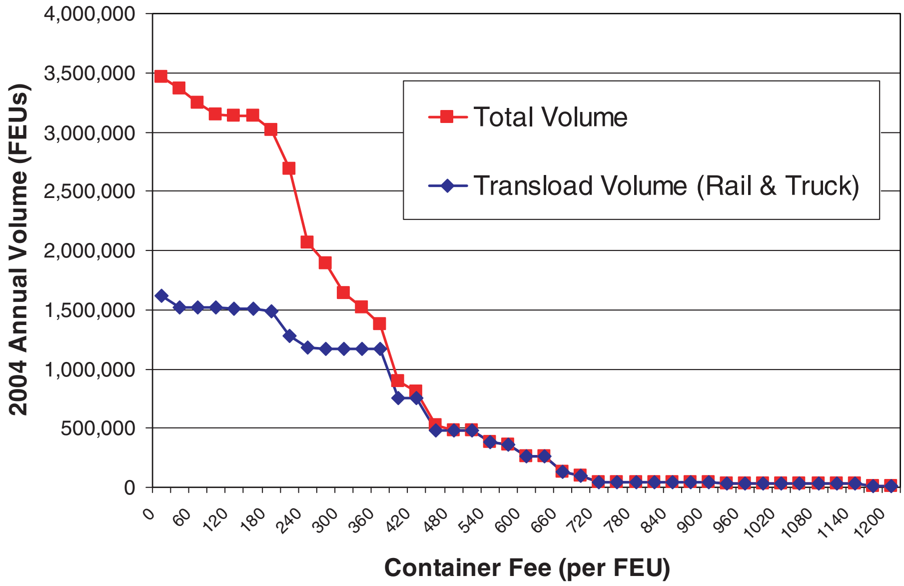


Fig. 2. Imports routed via the San Pedro Bay ports versus container fee, As-Is Scenario.

ticity Model. At these points the importer's volume through the San Pedro Bay Ports is predicted by the model to be reduced.

Fig. 2 displays calculated aggregate demand curves for the case of current lead time values (the ''As-Is'' Scenario). This can be interpreted to represent the case where container fees are assessed but are not used to pay for improvements to the ports and port access infrastructure. Shown are curves for the total LA–Long Beach inbound container volume (in FEUs) as well as the portion of inbound volume that passes through deconsolidation warehouses (i.e., trans-load volume). The aggregate demand curves are somewhat ''lumpy'' because many importers were assumed to share the same average declared value of imports and so it was optimal for many of them to reduce LA–Long Beach volumes at the same point on the fee scale.

The model predicts that, at present, about 46% of imports through the San Pedro Bay Ports pass through deconsolidation centers. At first glance, this figure may seem too high. But this figure includes not only imports destined to intermodal regions but also imports destined to points within the Los Angeles Region that are passed through deconsolidation centers. This is done so as to pool local forecast errors and lead time variability with those for other regions, thereby reducing safety stock levels at destination RDCs. The model predicts about 37% of San Pedro Bay imports are direct rail, 34% are trans-loaded imports re-shipped by truck or rail outside the Los Angeles Region, 12% are trans-loaded imports consumed within the Los Angeles Region, and 17% are direct truck or local direct dray.

As may be seen, imports at San Pedro Bay Ports are fairly inelastic until fees in the range of $180 are introduced. At that point, total volume has declined about 13% and trans-load volume has declined about 8%. Note that trans-loading traffic is much more inelastic to container fees than is direct shipping: for fees increasing from $180, the analysis predicts steep declines in total container volumes through the San Pedro Bay Ports, but trans-load volumes hold up much better until fees above $360 are encountered, at which point they too begin steep declines.

As a reference point, a recent proposal passed by the California Legislature but vetoed by the Governor suggested a $30 per TEU (i.e., $60 per FEU) container fee. From Fig. 2 it may be seen that in the case such a fee were imposed before implementation of new infrastructure providing reductions in container movement lead times, the Long-Run Elasticity model predicts a 6.3% drop in imports through the San Pedro Bay Ports as a result of this fee. For the same fee, the model predicts trans-loaded imports would decline 5.9%.

### *4.2. The Congestion Relief Scenario*

A different scenario was developed in which certain lead time parameters at only the San Pedro Bay Ports were reduced. In particular, the mean lead time from port to trans-load warehouses was reduced from 3 days

Table 5
Import strategy as a function of declared value – Congestion Relief Scenario

| Importer type | Declared valueper cubic foot | Least-cost import strategy |
|---|---|---|
| Large importer | \$0–\$13 | Direct shipping using nearest port |
| Large importer | \$13–\$17 | Trans-load at multiple ports |
| Large importer | \$17 and up | Trans-load only at LA–Long Beach |
| Small importer | \$0–\$46 | Direct shipping using nearest port |
| Small importer | \$46 and up | Direct shipping using only West Coast ports |

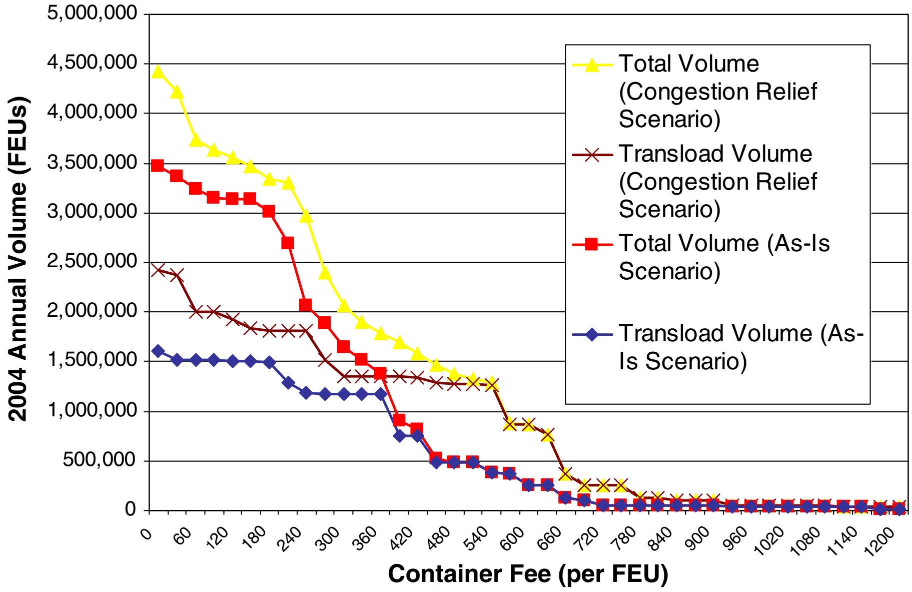


Fig. 3. Imports routed via the San Pedro Bay ports versus container fee – Congestion Relief Scenario.

to 2 days, and the standard deviation of this lead time was reduced from 2 to 1.6 days. In addition, the standard deviations of rail transit times for movements out of the LA Basin were reduced by 0.1 days, with that for rail movement of marine containers dropping from 3 to 2.9 days and that for rail movement of domestic containers dropping from 1 to 0.9 days. This is termed the "Congestion Relief" Scenario.

This scenario represents the case where proceeds from the assessment of container fees are used to retire bonds financing major port access infrastructure improvements, including dedicated truck lanes from the ports to the warehouse district plus rail capacity and terminal improvements permitting more reliable service. The modeled reductions in the port-to-warehouse dray lead time mean and standard deviation are justified as follows: at present, dray operations for "store-door" traffic typically start on the third day after vessel arrival and complete on the fifth day. (Drays to rail intermodal ramps are completed beforehand.) Utilizing dedicated truck lanes from the port to the warehouse district, it is assumed "double-bottom" drays (two containers/chassis per dray) would be permitted. This infrastructure would substantially reduce the duration to complete all store-door drays; the author estimates the mean would drop by one day and the standard deviation would drop by 0.4 days. On the rail side, a major program of capacity improvements to main lines in Southern California (Leachman, 2005a) plus the addition of substantial new rail terminal capacity would serve to improve the reliability of rail services. The author conservatively estimates the reduction in standard deviation of rail transit times from the Los Angeles Basin afforded by such improvements to be 0.1 days.[6]

[6] The low value of reduction for rail transit time variability relative to the reduction in dray transit time variability reflects the fact that most of the transit time variability for rail movement occurs outside the Los Angeles Basin.

The Congestion Relief Scenario significantly changes the economics for importers. Assuming no container fee, the break points between import strategies are shifted markedly from the As-Is Scenario. The new break points in value and the corresponding optimal supply-chain strategies are summarized in Table 5.[7]

As before, model calculations were iterated with the addition of a variable container fee assessed on all containers entering through the ports of Los Angeles and Long Beach. The direct and trans-load volumes via LA–Long Beach were then totaled for each fee value in order to construct aggregate demand curves of volume versus container fee. Results are plotted in Fig. 3. The curve passing through points marked by a triangle shows the total inbound container volume through the San Pedro Bay Ports versus fee value; the curve passing through points marked by an "x" shows the trans-loaded inbound container volume versus fee value. For ease of reference, the curves for the As-Is Scenario also are plotted, the curve passing through points marked by a square showing the total inbound container volume and the curve passing through points marked by a diamond showing the trans-loaded inbound volume for that scenario.

As may be seen, congestion relief makes the LA–Long Beach ports more attractive to importers. Even for a fee of $150, total San Pedro Bay Ports inbound volume is higher than for a $0 fee in the As-Is Scenario. There is a "knee" in the total inbound volume curve for a fee equal to $210; at this point, the total volume is only 4.3% below the total volume in the As-Is Scenario with no fee. At this same point, the trans-load volume is 12.5% above the trans-load volume in the As-Is Scenario with no fee.

## 5. Conclusions

An economic optimization model has been developed to optimize the allocations of containerized Asia–USA import volumes as a function of transportation and handling charges in alternative channels, the distribution of declared values of imports, and the distribution of importers. The model has been applied to predict the re-allocation of imports among ports and landside channels in response to hypothetical container fees at the San Pedro Bay Ports.

The analysis reveals that import volumes routed through the North American West Coast ports are sensitive to transportation charges. Imposition of container fees without compensating improvements in container transit times would result in traffic diversion. It is predicted that even a modest $30 per TEU fee assessed on imports at the San Pedro Bay Ports would result in approximately a 6% in loss in both total and trans-loaded import traffic. For fees above $100 per TEU, traffic losses would be much more substantial.

But the analysis also reveals that imports are highly sensitive to congestion relief, more specifically, highly sensitive to compression of the distributions of lead times for container movement. When juxtaposed with container fees of $100 per TEU or less, a major program of infrastructure improvements in Southern California featuring dedicated truck lanes from ports to trans-load warehouse districts plus increased rail and rail terminal capacities would result in a major increase in trans-loaded traffic handled through the San Pedro Bay ports, with only minor loss in total import volume.

The growth of Asian imports is overwhelming port, road and rail infrastructure in Western North America. Ports and carriers able to mitigate existing or potential congestion and offer importers more reliable and shorter lead times stand to gain larger shares of traffic, but only if the increases in transportation charges do not outweigh the economic value of the reduced lead times. The model proposed herein is a useful tool for assessing this trade-off.

## Acknowledgements

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[7] While only one of the figures given in Table 5 differs from the figures in Table 4 (i.e., $27 drops to $17), this change is very significant. As may be seen in Fig. 1, a considerable portion of Asian imports falls into the range of $17–$27 per cubic foot in declared value. These imports are shifted from being candidates for trans-loading at multiple ports to candidates for trans-loading only at the San Pedro Bay Ports.

The Port of Long Beach and MARAD provided access to PIERS and World Trade Atlas data for this study. Interviews with many stakeholders, including large retail importers, steamship lines, railroads, port and terminal operators, dray and trucking firms, and third-party logistics and warehouse service providers, contributed to the author's understanding of import practices and economics. My thanks go to all who assisted this study.

## Appendix. Safety stock formulas proposed for the general case of lead times and volumes varying by region

The index $n$ is added for RDC and the index $m$ for POE. The parameters are generalized as follows:

$D$ – nation-wide average sales volume per week (in physical units, not dollars).

MAPE – mean absolute percentage error (expressed as a fraction of one) in one-week-ahead forecasts of nation-wide sales.

$D_n$ = amount of sales distributed from RDC $n$. It is assumed that $\sum_n D_n = D$ and the proportion of nation-wide sales handled by each RDC is fixed.

$D_{mn}$ = amount of imports en route to RDC $n$ that are passed through port $m$. It is assumed that $\sum_m D_{mn} = D_n$.

$R$ – time between replenishment orders (from Asian suppliers). R is assumed to be 1 week for all importers.

$L_{AO}$ – mean lead time (expressed in weeks) from when order is placed until port of entry for shipment is selected.

$L_{AW}(m)$ – mean lead time (expressed in weeks) for a shipment from point of origin to port of entry (POE) $m$, measured from when POE for shipment is selected until land transport to RDC from POE $m$ begins (direct shipping) or until destination RDC is selected for land transport from POE $m$ (consolidation–deconsolidation).

$L_W(m)$ – mean lead time (expressed in weeks) from departure from point of origin until land transport from POE $m$ to RDC begins (direct shipping) or until destination RDC is selected for land transport from POE $m$ (consolidation–deconsolidation).

$L_{NA}(m,n)$ – mean lead time (expressed in weeks) from departure from POE $m$ (direct shipping) or from when RDC $n$ is selected for land transport from POE $m$ (consolidation–deconsolidation) until processed through the RDC $n$.

$\sigma_{L_{AW}}(m)$ – standard deviation of $L_{AW}(m)$.

$\sigma_{L_{NA}}(m,n)$ – standard deviation of $L_{NA}(m,n)$.

$k$ – safety factor determining the level of safety stocks at RDCs. (Choosing $k = 2$ implies approximately a 98% probability of no stock-out.)

*Formula for pipeline stock*

The total in-transit inventory is expressed as

$$\sum_{m,n}(L_W(m) + L_{NA}(m,n))D_{mn}. \tag{18}$$

Expression (18) is the generalization of expression (1).

*Formulas for safety stock*

In the direct shipping case, the total nation-wide safety stock is expressed as

$$(k)\left[L_{AO}(1.25)^2(\text{MAPE})^2D^2 + \left(\sum_n\left(\frac{\sum_m D_{m,n}\sqrt{L_{AW}(m)+L_{NA}(m,n)+R}}{D_n}\right)\sqrt{\frac{D_n}{D}}(1.25)(\text{MAPE})D\right)^2 + \left(\sum_{m,n} D_{m,n}\sqrt{\sigma^2_{L_{AW}}(m)+\sigma^2_{L_{NA}}(m,n)}\right)^2\right]^{1/2} \tag{19}$$

Expression (19) is the generalization replacing expression (9).

In the deconsolidation case, the total nation-wide safety stock is expressed as

$$(k)\left[L_{\mathrm{AO}}(1.25)^2(\mathrm{MAPE})^2D^2+\left(\sum_m\sqrt{\sum_n\left(\frac{D_{m,n}L_{\mathrm{AW}}(m)}{D_n}\right)\left(\frac{D_n}{D}\right)(1.25)^2(\mathrm{MAPE})^2D^2}\right)^2\right.$$
$$\left.+\left(\sum_n\left(\frac{\sum_m D_{m,n}\sqrt{L_{\mathrm{NA}}(m,n)+R}}{D_n}\right)\sqrt{\frac{D_n}{D}}(1.25)(\mathrm{MAPE})D\right)^2+\left(\sum_{m,n}D_{m,n}\sqrt{\frac{\sum_m D_{m,n}}{\sum_n D_{m,n}}\sigma^2_{L_{\mathrm{AW}}}(m)+\sigma^2_{L_{\mathrm{NA}}}(m,n)}\right)^2\right]^{1/2} \tag{20}$$

Expression (20) is the generalization replacing expression (13).

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