Review of Previous Studies on Container Shipping: Infrastructure, Projections and Constraints

Towards a Global Forecast of Container Flows
Container Model and Analysis:
Longer Term Analysis fo Infrastructure Demands and Risks

Task 1: Review of previous studies on container shipping with a focus on infrastructure and projections

Task 6: Review previous studies to identify the current state of knowledge about port constraints and expansion possibilities and costs

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1. Introduction

The Institute for Water Resources's (IWR) Navigation Economic Technologies (NETS) Research program has developed a global spatial equilibrium model for the forecasting of grains.[1] This analytical approach to forecasting projects supplies and demand by region and transfers excess supplies to the excess demand regions by the least cost route. This approach also can be used to evaluate comparative statics to assess how changes in infrastructure impacts the equilibrium shipments during the projection period.

The objective of this research is to evaluate the applicability of this approach to the forecasting of container cargoes. This paper addresses two tasks as part of a larger overview of the container shipping industry.[2] In particular, it seeks to:

Task 1: Summarize results of a kick-off meeting and presents results of a literature review of previous studies on container shipping with a focus on infrastructure and projections.

Task 6: Review previous studies to identify the current state of knowledge about port constraints and expansion possibilities and costs.

This paper is organized as follows. Section 2 provides some relevant background on container shipping. Section 3 provides a discussion of some of the major issues confronting the container

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[1]This is available at Wilson, DeVuyst, Taylor, Dahl, and Koo (2006) and summarized in Wilson, DeVuyst, Taylor, Dahl and Koo, 2007. Additional papers from that study include are in Wilson, Koo, Taylor and Dahl (2008a and 2008b) and several articles under review including DeVuyst, Wilson and Dahl (2008) and Wilson, Dahl, Taylor and Koo (2008) which are available from the authors.

[2]Other tasks include the following, and are available in accompanying reports: Task 2 Describes historical movements in world container trade; Task 3 Analyzes historical movements in US container markets including an econometric analysis of container demands; Task 4 Rail rate analysis of container shipments; Task 5 Ocean rate analysis of container shipments; Task 6 is included in this report; and Task 7 An evaluation of alternatives for spatial modeling of container shipments.

Reports on each of these topics are available from the authors and IWR and are titled:

Report 1:	Review of Previous Studies on Container Shipping: Infrastructure, Projections and Constraints
Report 2:	Analysis of Container Flows: World Trade, US Waterborne Commerce and Rail Shipments In North American Markets
Report 3:	Container Demand In North American Markets: A Cross-Sectional Spatial Autocorrelation Analysis
Report 4:	Container Shipping: Rail and Ocean Shipping Rates
Report 5:	Optimization Models of Container Shipments in North America: Spatial Competition and Projections (Methodology)

shipping industry. Section 4 summarizes some of the major projects impacting container shipping. Section 5 provides and overview of the previous studies. There has been a large number of studies on container shipping and this section provides an overview of the breadth of the literature. Section 6 is a summary of the major issues these from these studies. It also provides a detailed discussion on some of the primary issues involved in developing a spatial optimization model of container shipping. Finally, the appendix contains more detailed descriptions of some of the specific studies that are relevant to this broader research program.

2. Background

2.1 Trade and Trends in Container Shipping: The container shipping industry is one of the fastest growing segments of the domestic and international logistical systems. International container volumes have increased from 47 million TEU (Twenty Foot Equivalent Units) to over 140 million TEU in the period from 1996 to 2008 (projected). This implies an annual average growth rate of nearly 10% per year and all but three years have had double digit increases. Most projections are for this to continue. Further, container shipping has also grown faster than any other category of shipping in the past 10 years, and is projected to grow at 3.4%/year from 2010-2015 (Table 2.1), in contrast to 1.5% growth for dry bulk and 1.4% growth for tankers (Global Insight).[3]

North America is the third largest importing market for containers (at 21 million TEU) following Asia (40 million TEU) and Europe (30 million TEU). The TransPacific trade routes have the highest trade volumes (22 million TEU at 10% average growth rate), followed by FarEast to Europe (17 million TEU at 12% average growth rate) and distantly the TransAtlantic route (6 million TEU at 5% growth) in 2007 and then domestic growth rates.

North America is also a large container exporter. Over one-half of its exports go to Asia and this trend has been forecast to continue (Drewry). However, North America imports more containers than it exports and forecasts for growth in U.S. container trade are greater for imports than exports.

[3] A very detailed and extensive presentation of changes in demands and trade flows for containers is contained in Wilson and Benson 2008b.

Table 2.1. Growth Rates of Four Major Service Types - Ocean Freight

	2000-05	2005-10	2010-15	2015-22
Dry Bulk	3.6%	2.6%	1.5%	1.2%
Tanker	1.2%	1.8%	1.4%	0.7%
General Cargo/Neo Bulk	3.1%	3.6%	2.8%	2.2%
Container	6.1%	4.5%	3.4%	2.8%

Source: Global Insight

Table 2.2. U.S. Container Trade by Region, 2000 to 2050				
	2000	2010	2020	2050
Volume of Trade (Million Metric Tons)				
Asia	77.9	127.6	215.9	388.7
Europe	32.0	44.7	62.0	80.0
South America	11.9	17.6	26.5	40.1
North America	8.7	13.2	20.8	32.5
Australia/New Zealand	3.6	5	6.9	9.1
Middle East	2.7	3.5	4.8	6.2
Africa	1.9	2.7	3.8	5.1
Other	0.5	0.7	1.2	1.8
Total	138.9	214.9	341.8	563.3
Shares (%)				
Asia	56%	59%	63%	69%
Europe	23%	21%	18%	14%
South America	9%	8%	8%	7%
North America	6%	6%	6%	6%
Australia/New Zealand	2%	2%	2%	2%
Middle East	2%	2%	2%	1%
Africa	2%	1%	1%	1%
Other	0%	0%	0%	0%

Source: DRI-WEFA

Table 2.3. Annual Growth Rates for Asia-North American TEU Trade					
	2004	2005	2006	2007	2008
Asia to North America	13.7%	12.6%	10.9%	8.3%	4.6%
North American to Asia	6.1%	5.1%	4.7%	4.1%	3.8%

Source: Global Insight

The top five export commodities shipped by containerships are waste paper, synthetic resins, paper products, animal feed and refrigerated meat/dairy/fish (Hackett, Table 2.4). Of these, all but animal feeds utilize containers on 68% or more of shipments.[4] [5] For imports, the top five commodities are other manufacturing, metal products, furniture, beverages and wearing apparel, all of which utilize containers on more than 60% of volume shipped. Imports tend to be higher valued commodities, while exports generally are lesser valued commodities.

The Tioga Group discusses structural changes occurring in the shipping industry and suggest the linkage between the value of goods and transportation is changing (examples are Fed Ex and growth in high value electronics). The service economy is changing linkages between economics, trade and transportation. Transaction costs are declining, but this is countered by increased costs for security. The U.S. trade balance is increasing because much of the trade is one way leading to specialization at ports and a buildup of empty containers in the U.S.

The shift of the Asian manufacturing center toward India that has been forecast by others to occur and the subsequent shift in vessels movements from Asia to the West Coast of the U.S. via the Pacific to India via Suez Canal to East Coast of the U.S., has not occurred (Tioga Group). India appears more focused on a service economy. They indicate this is due to political, financial, and infrastructure problems in India and strong competition from Brazil, Russia, China and other Asian countries for manufacturing.

Another important trend is the growth in Mexican trade to the U.S. as companies shift production from Asia to Mexico for faster delivery, greater flexibility and immunity from seaport congestion or labor shutdowns. For logistics, they indicate the trend in outsourcing will lengthen supply chains and raise the share of total cost devoted to logistics. Customers will increasingly focus on logistical costs as potential area of cost reductions and be more likely to switch carriers, ports, or routes for better, faster, cheaper transportation.

Transportation and logistics will become more commoditized. There is a trend toward increased “time definite” deliveries (narrower window, less tolerance for variability). This is important for efforts to influence modal choice away from trucking toward maritime and rail. Delays at Panama Canal have reduced performance of all-water container service to east coast from Asia. In fact, this is one of the major reasons that was motivating the Panama Canal expansion, as well as its reservation system which is crucial to pricing and service.

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[4]Wilson and Benson 2008b provide a detailed and extensive presentation of the containerization process.

[5]In fact, these is even a trend for grain exports which have been traditionally shipped in bulk, to have an increase in containerized shipments. Mongelluzzo (2007) indicated a growth in container shipments of grain. He indicated specifically that grain exports in container has increased due to: 1) higher ocean rates on bulk commodities; 2) faster payment terms due to tighter shipping schedules; 3) flexibility allowing buyers to buy in smaller lots; and 4) the increased DDG shipments due to ethanol growth. Currently, he cites that container shipments of grain have increased by about 14% and are growing much faster than the export market as a whole, and, though container shipments are very popular to Asia, grain shipments by containers are also occurring in numerous other ports (Pacific, as well as East and Gulf coast ports).

Table 2.4. Top 10 U.S. Trade Commodities Transported by Containership, 2000 and 2020 (Millions of Metric Tons)

Export Commodities	*MMT*		*% Transported by containership*	
	2000	*2020*	*2000*	*2020*
Waste Paper	6.14	12.08	96	97
Synthetic Resins	5.43	9.10	77	80
Paper, Paperboard, and Products	4.32	8.38	70	74
Animal Feed	3.59	7.69	32	35
Refrigerated Meat/Dairy/Fish	3.18	7.12	68	74
Misc.	2.46	9.02	78	81
Refrigerated Produce	2.28	7.99	91	92
Organic Chemicals	2.04	3.09	13	14
Pulp	1.99	3.32	42	46
Cork and Wood	1.91	2.04	15	20
Import Commodities	*MMT*		*% Transported by containership*	
	2000	*2020*	*2000*	*2020*
Other Manufacturing, nec.	5.17	19.91	95	96
Metal Products	4.11	11.41	60	64
Furniture and Fixtures	3.98	16.13	97	98
Beverages	3.52	6.11	93	93
Wearing Apparel	3.40	13.70	82	82
Parts of Motor Vehicles	3.15	7.57	91	91
Non-Metallic Products, nec.	3.03	7.69	10	10
Other Food	2.99	6.07	78	79
Refrigerated Produce	2.79	9.68	46	44
Iron and Steel	2.60	3.84	7	7

Source: Hackett (DRI-WEFA).

Wilbur Smith Associates and Transystems identify several trends that are impacting container movements. First, they indicate the trend for empty containers to be returned to PAW ports for return to Asia are changing. Some of these empty containers are being shipped to Atlantic ports due to high costs of U.S. rail service and network rationalization by Ocean shippers. Some of the empty containers are also being shipped to San Pedro Bay ports (Los Angeles and Long Beach), due to increasing container ship size which make it more efficient to make fewer port calls. Panama Canal will open opportunity to offload loaded containers at West Coast Ports, and load empty containers at Atlantic ports.

A major trend impacting container shipping is the increasing hinterland rail cost for shipment within U.S. and network rationalization by major ocean shippers. As exmaple, Maersk Lines is evaluating round trip economics of their networks. The combined effect is causing Maersk to consider reducing inland delivery points and ports of call for their networks.

With focus on round trip economics and growing trade imbalance, the return destination of containers is a concern. Diversion of containers to back hauls adds cost due to cleaning required before reuse, loss of time before reuse, etc.

Within the United States major changes are occurring in logistics, manufacturing, etc. In addition, major changes and challenges for infrastructure are occurring throughout the system. These include receiving ports, dredging needs and port infrastructure including the complex system of inter-modal transfer, as well as infrastructure and equipment needs for domestic shipping and receiving. This industry is continuing to evolve and will challenge infrastructure and logistical planners. Some of the interesting and important developments will be 1) impacts of larger container ships; 2) impacts of recent and proposed projects on spatial flows; 3) market power and concentration; 4) coordination of the total logistical movements; 5) congestion; 6) hub-port and short-sea concepts.

2.2 Constraints and Productivity Within the United States, several of the major modes and port areas are experiencing capacity constraints. These are being caused by increased demand as well as the impact of increased fuel costs, particularly for trucking. Further, railroads were rationalizing to overcome excess capacity, which since 2000 has largely evaporated and railroads are having to deal with demands for increased system capacity. Thus, rail system has shifted from an oversupply to an undersupply condition in the span of less than 6 years.

Ports are also confronting a number of operational barriers. The Tioga group indicated that: 1) ports will operate closer to capacity and more subject to disruptions; 2) security will increase costs and constrain capacity; 3) port highway connections will remain tight; 4) terminals will be more costly and take longer to develop; and 5) the concept of an efficient marine terminal will spread. Other trends will be shorter port terminal leases, trends toward development of ports by carriers or joint ventures, port consolidation and cooperation. Load centering involves few coastal load centers with truck, rail or vessel feeders to smaller ports and is predominant in Europe and Asia where feeder services are well established. This has not occurred in the U.S. because of capacity concerns at the largest ports and expansion in secondary markets.

Container terminal productivity in the United States are comparable to Asian and European ports in throughput and cost per TEU, while higher in TEU/acre as U.S. ports generally have more area. Most Asian terminals have no rail infrastructure and Asian volumes inflated by transhipment volumes.

U.S. ports are making operational refinements to increase productivity (Increased gate hours, improved rail networks, new terminal and gate management systems, appointment systems and virtual container yards to spread out peak periods and facilitate off-port container interchange and use).

3. Major Issues Confronting Container Shipping

There are many issues confronting the container shipping industry. While not exhaustive, this section briefly discusses some of the major issues. These are the pursuit of economies of size which are driving ocean shippers to move to larger and larger container vessels in order to reduce costs. As ship sizes increase, characteristics of ships change which puts demands on ports requiring larger drafts, berths, crane capacity, etc. Another issue is the market/firm structure for ocean shipping. Since ocean shipping lines own both the vessels and containers, they are the dominant decision maker in the ocean container industry. Thus, firm structure, conferences, alliances, mergers have important impacts on the ocean shipping industry.

3.1. Market Structure of Ocean Carriers and Firm Strategy: Impacts of Market Power, Conferences, Mergers, Acquisitions and Alliances.

The market structure of the ocean shipping industry is important as shipping lines typically own both the container vessels and the containers. Ocean carriers are also in many cases integrating back into operations and ownership of port facilities. Because of this, ocean carriers are important decision makers for container service and flows. In turn, the market structure, use of conference systems, mergers and acquisitions and alliances among ocean carriers have further impacts on the container market.

Conferences rose out of the need by ocean carriers to respond to competition among carriers in setting ocean rates that resulted in losses for carriers. The conferences system are alliances between carriers which set rates for specific routes (Notteboom). As ocean carriers expand capacities of containerships, the Conference system is continuing to be under pressure. An alliance (Trans Atlantic Conference Agreement) tried to extend the reach of conferences to include inland shipping at fixed rates, however, the European Commission decided that they would not allow bans on agreements enjoyed by maritime conferences to be extended to inland shipments (Notteboom). The Tioga Group predicts that conferences will be of little significance in 10 years and firms will focus on consolidation as a means to insulate themselves from competition. They argue that the industry is moving to a two tiered market structure dominated by global container carriers (serving all ports and services) and trade-specific carriers.

The ocean carrier industry is becoming highly concentrated. Most of the high capacity containers are owned by few firms, employed in high trade routes, and by firms with multi-trade strategic alliances (Notteboom, p 90). Notteboom evaluated slot capacity concentration measures for selected years from 1980 to 2003, a period where total slot capacity increased from 435,000 to 5,074,377. He indicates shares for the top 5 firms increased from 44% to 48% and for the top ten firms increased from 69% to 70%.

AXSLiners recent quarterly report for the top 50 container fleet operators shows a high degree of concentration. The top 50 operators hold more than 10.6 million TEUs of capacity and

91.1% of total liner TEU trade (Table 3.1.1). Ship capacity in TEUs is 48% owned and 52% chartered. The top 50 fleet operators have 4.9 million TEUs of capacity on order composed of 840 ships. The increased capacity on order represents 47% of TEU capacity of the top 50 fleet operators (Journal of Commerce, 2007).

The Mercator Transport Group forecast a continued increase in consolidation in the ocean shipping container industry. They forecast that the current structure where 5 alliances handle 70% of capacity will increase in concentration toward 6-8 alliances handling 95% of container capacity.

Brooks analyzed the container industry from a market structure and firm strategy perspective. She utilizes a framework that looks at five competitive forces: 1) the entry of new competitors, 2) the threat of substitutes, 3) the bargaining power of buyers, 4) the bargaining power of suppliers, and 5) rivalry among competitors (Porter, 1980) and discusses each of these in context of the ocean container industry in the late 80's early 1990s. She suggested sources of firm competitive advantages focus on: 1) Cost containment and asset utilization, 2) Services, 3) Agency Networks, 4) Access to capital, and 5) Vertical integration into the Input supply. Further, sources of competitive disadvantages are: 1)Loss of market identity and 2) service homogeneity. She also discusses strategies to exploit competitive advantage which include: 1) Cost Leadership, 2) Focus Strategies, 3) Service Differentiation, 4) Sustaining Competitive Advantage.

Table 3.1.1 Top 10 Global Container Fleet Operators and Total for Top 50

		Total		Owned		Chartered		Orderbook		
Operator	*Market Share*	*TEU*	*Ships*	*TEU*	*Ships*	*TEU*	*Ships*	*TEU*	*Ships*	*% of existing (TEUs)*
APM-Maersk Line	16.1%	1,874,502	524	975,054	184	899,448	340	469,712	92	25.1%
Mediteranean Shipping Co.	10.5%	1,217,013	370	691,334	212	525,679	158	626,912	60	51.5%
CMA CGM Group	7.4%	864,669	360	267,921	87	596,748	273	541,191	71	62.6%
Evergreen Line	5.3%	618,458	175	376,331	107	242,127	68	16,537	4	2.7%
Hapag-Lloyd	4.2%	487,283	139	247,831	60	239,452	79	105,000	12	21.5%
China Shipping	3.8%	437,183	141	251,192	87	185,991	54	244,782	39	56.0%
Cosco	3.6%	420,410	139	222,437	93	197,973	46	332,097	44	79.0%
APL	3.4%	400,865	122	139,690	38	261,175	84	263,806	41	65.8%
NYK Line	3.2%	375,949	125	229,333	48	146,616	77	235,755	44	62.7%
OOCL	2.9%	343,228	81	195,759	34	147,469	47	143,366	23	41.8%
Total (Top 50)	91.1%	10,310,241	3,936	5,134,563	1,652	5,475,678	2,284	4,935,575	839	46.5%

Source: AXS-Alphaliner, as of December 3, 2007 in *Journal of Commerce*, 2007.

3.2 Economies of Size of Ocean Shipping

Container shipping lines enjoyed profitability during the 1980s, but underperformed compared to other industries in the 1990s. The weaker performance is related to their capital-intensive operation and the high risks associated with revenues (Notteboom). These factors result in shipping lines becoming less capable at setting and maintaining rates and shipping lines become rate takers, thus the major focus of shipping lines is on reducing costs.

The effects of the shipping lines push for scale efficiencies to reduce costs on composition of container fleet is shown in Table 3.2.1

Table 3.2.1 Scale Increases in Vessel Size: Evolution of the World Cellular Fleet, 1991-2006.

TEU	*1991*	*Share*	*1996*	*Share*	*2001*	*Share*	*2006**	*Share*
> 5000	0	0%	30648	1%	621855	13%	2355033	30%
4000-5000	140032	8%	428427	14%	766048	16%	1339978	17%
3000-4000	325906	18%	612377	21%	814713	17%	892463	11%
2000-3000	538766	29%	673074	23%	1006006	21%	1391216	18%
1500-2000	238495	13%	367853	12%	604713	12%	719631	9%
1000-1500	329578	18%	480270	16%	567952	12%	596047	8%
500-1000	191733	10%	269339	9%	393744	8%	438249	6%
100-500	92417	5%	117187	4%	134472	3%	114976	2%
Total	1856927		2979177		4907503		7847593	

Source: BRS Alphaliner Fleet Report, 2003
*Projection for 2006 as compiled with existing fleet and order book as of June 15, 2003.
** Volume for Year are listed as TEU capacity.

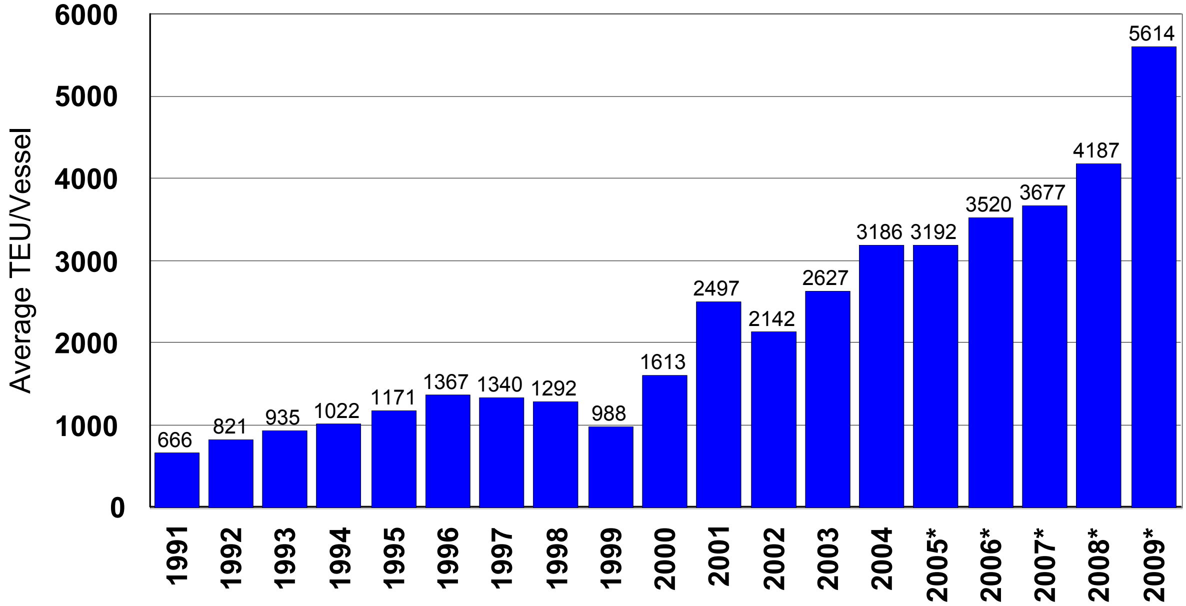
From 1991 to 2006, the total capacity of the world cellular fleet grew from 1.8 million TEU's to 7.8 million TEUs. Thus, the container fleet increased in capacity by more than 4 times over that period. In contrast, the proportion of the fleet allocated to TEU groups less than 3000 TEU declined from period to period. For example, ships in the 2000-3000 TEU group fell from 29% in 1991 to 23% in 1996, 21% in 2001 and 18% in 2006. This share reduction occurred as TEU capacity in the 2000-3000 TEU group increased from year to year, indicating that even though capacity was being added to this group, growth in capacity was occurring slower than for the fleet as a whole and for the larger TEU groups in particular. What is notable is the increase in shares of the greater than 5000 TEU group which grew from 0% of fleet in 1991 to 30% by 2006.

The increase in larger capacity containerships as a proportion of the containership fleet has increased average capacity of containerships which has grown from 666 TEU/Vessel in 1991 and is projected to be 3520 by 2006 (Figure 3.2.1).

The traditional ship size was typically in the 3000 TEU range (Panamax). This accommodated most ports and transiting of the Panama Canal. However, in recent years there has been an important shift toward larger container ships. For example, in March 2007, Clarkson (2007c) reported that the order book for 2009 forward was skewed substantially toward containerships in the 8000+ TEU range with some new ships being built in the 12,000-14,000 TEU range. To quote from the most recent Clarkson report (2007c):

> *At the beginning of the 4^{th} quarter, the VLCS (8000+ TEU Post-Panamaxes) totaled 1.27 m TEU of capacity spread across 145 vessels. However, this area is expected to show very high growth over the next few years, with the VLCS fleet expected to reach 1.4 m TEU at the start of 2008 and grow to 1.8m TEU by the start of 2009, representing an increase of 94% on the start of 2007.* (P. 32). ..... *The boxship orderbook is dominated by the VLCS size range which represents nearly 48% of the whole orderbook by capacity....1.5m TEU is scheduled to be delivered in 2007 and 1.7m in 2008, but with the orderbook now running an unprecedented 5 years ahead, 2.5m TEU is scheduled to be delivered between 2010 and 2012. ...The average size of vessels ...in 2010 and beyond is an impressive 7089 TEU thanks to the huge levels of Post-Panamax ordering* ...p. 34.

However, much of the cost savings from increased ocean vessel capacities has not accrued to shipping lines (Notteboom). He indicates that 1) larger ships have to lower rates in order to fill ships, 2) upgrading fleet size for a movement requires increasing all the ships for a firm for a move as movements typically require similar sized moves and upgrading all ships takes time, and 3) first mover advantage in upgrading size which results in fierce competition as other firms respond. Finally he indicates that there is a danger that the move to increase capacity may accelerate resulting in overbuilding and falling margins.



Source: Containerisation Internation, From CDM, Tioga Group.

Figure 3.2.1. Container Vessel Deliveries: Average TEU/Vessel.

3.3 Changes in Container Vessel Characteristics

Containerships in the world fleet evolved through several generations and are continuing to evolve toward larger capacities with higher shares of larger capacity ships. Harrison et al, describes the first five generations of container ships by capacity and length (Table 3.3.1) and Hackett describes containership characteristics by capacity (Table 3.3.2). These have continued to evolve with the newest capacity containerships being designed with capacities of 14,000 to 18,000 TEU (Table 3.3.3) (Mercator Transport Group).

Table 3.3.1 Containership Evolution

Generation	*Years Produced*	*Typical Capacity (TEUs)*	*Typical Length (ft)*
First	Pre 1960-1970	<1000	450-630
Second	1970-1980	1000-2199	700
Third	1985 onwards	2200-3199	860-950
Fourth	1986-2000	3200-4799	900-1000
Fifth	1996-onwards	4800	1100

Source: Harrison et al, citing Muller.

Table 3.3.2. Design Draft Characteristics of Containership Fleet, 2001

Capacity (DWT)	*Number*	*% of Fleet Capacity*	*Average (ft)*	*Max (ft)*	*Min (ft)*
500-1000	533	8	26	36	17
1000-2000	863	24	32	40	21
2000-3000	420	21	38	43	33
3000-4000	249	17	40	46	33
4000-5000	165	15	43	46	35
+5000	137	16	45	48	39

Source: Hackett (DRI-WEFA).

Table 3.3.3. Prospective (Future) Maximum Vessel Characteristics for Panama and Suez Canals

	Future Panamax	***Future Suezmax***
Capacity	12000 TEU	18000 TEU
LOA	394 m	440 m
LBP	380 m	426 m
Beam	52 m	60 m
Depth	32 m	35 m
Draft (design)	15.7 m	18.0 m
Deadweight (tonnes)	140700 t	207000 t

Source: Herbert Engineering Corp. as cited in Mercator Transport Group.

4. Port Constraints and Projects Impacting Container Shipping

4.1 Port Constraints: The overall growth of container shipping and the expansion of container shipping from China has resulted in a building spree of new ports and expansions of existing port facilities. This expansion of port capacity has kept pace with the growth of Chinese container shipping demand, however, there are indications that excess capacity could arise as soon as 2009 in the Pearl River Delta Region (Hong Kong area) (Leach).

New projects in the Pearl River Delta Region would add 15 million TEUs by 2009 to existing capacity of 25 million TEUs for the region. Leach cautions that this overcapacity will likely be short lived as much of the current expansion is being funded by foreign investors utilizing tax incentives to foreign investors by the Chinese government which are slated to end in 2008 which will slow the growth in expansion projects. Leach reports on a recent Drewry analysis of the China container market which reports major port expansion projects between 2006 and 2009 in China would add an additional 45 million TEUs to China's container capacity.

As a result of past and anticipated growth, many ports are beginning to operate at capacity or some type of constraint. Port constraints and expansion have been reviewed in several recent publications (Hackett, Mercator Transport Group and The Tioga Group).

Hackett assessed U.S. National dredging needs. He used global forecasts for trade from DRI-WEFA to estimate constrained/unconstrained vessel calls on U.S. ports to 2020. The Atlantic ports have the largest number of cargo vessel calls constrained by channel dimensions, followed by the Gulf ports. With planned U.S. Army Corps channel project improvements all coastal regions will experience reductions in constrained vessel calls. However, the largest improvements will occur for the Pacific ports. They project that for container vessels constrained calls will drop from 40% to 4% with completion of projects in 2020.

Mercator Transport Group (MTG) discusses constraints and expansion with focus on affects on San Pedro Bay Ports (SPB Ports include Los Angles and Long Beach ports) of Super post-Panamax container ships (8,000-18,000 TEU and up to 16 meter draft). They indicate that Asian ports of Pusan, Qingdao, Singapore, Yantian Yokahama and Tanjung Pelepas have or will soon have the ability to accommodate super post-Panamax ships. Competitor ports are evaluated on an individual port basis covering port characteristics, capacity constraints, inland constraints, new or current projects planned, limitations to expansion, etc.

MTG evaluated port capacity for 1) Pacific NorthWest/BC, 2) Other California, 3) Pacific Mexico, 4) South Atlantic, and 5) North Atlantic. They concluded that Pacific Northwest ports have landside constraints that would limit ships larger than 8000 TEU. These are generally due to rail infrastructure problems (Seattle, Tacoma, Vancouver), draft constraints (Vancouver) and inability to expand facilities due to environmental concerns (Vancouver). They have concerns on the ability of Prince Rupert to become a super post-Panama port due to questions on their ability to attract business because they have not handled containers before, there is no local demand for containers, it is not cost effective to relocate empty containers from Vancouver to Prince Rupert, and they do not foresee opportunities for multiport offloads.

For other California ports, Oakland has established itself as competitor to SPB but they questioned whether Oakland will be able to handle containers of 6000+ TEU due to rail and depth restrictions. Other ports are limited because of poor rail access (Eureka, San Fran, Redwood City, and San Diego); environmental/community group opposition to expansion; limited water depth and opposition to dredging; and small local market (Eureka and Port Hueneme).

Two established ports in the Pacific for Mexico (Manzamillo and Lazaro Cardenas) have adequate depth or could be dredged to provide additional draft. Both question the ability of Mexican Rail lines to provide efficient service, while Manzamillo has expansion limits. A third proposed port is south of Ensenada (port Colonet). Prospective annual capacity would be 5 million TEU per year. Rail service would be by new mainline connection to Yuma where it would connect to UP.

They argue that all ports other than SPB have limits on prospective applicability of Post-Panamax containers. Also, SPB has less rail capacity restrictions than other west coast ports. The major restriction across most ports relates to rail infrastructure. The Mexican ports need substantial upgrades to become competitive land bridge service corridors.

Currently no ports in the South Atlantic are able to accommodate fully laden 8000 TEU containerships with draft of 14 m. Most of the ports are on rivers (high dredging costs), or have environmental opposition to improvements at areas where dredging costs are lower. One planned project with deep water access is Jasper County SC, however state agencies in both Georgia and South Carolina are opposing the project.

In the North Atlantic, Halifax has deep water port capable to handle post-panamax ships via all water service via Suez. Boston has depth to service post-panamax ships, however landside rail access is a constraint and unlikely to be improved due to high land values. Thus, they do not view this port as service provider for high volume container services.

In New York, the ACE has a large dredging project to increase draft to 13.6 meters and has approval to further deepen to 15.2 meters. Due to the high dredging cost (bottom rocky), it is unlikely to allow for further draft increases. Also the port has bridge problems which limit ship height. Plans are ongoing to replace these bridges. Philadelphia has draft restrictions limiting port that has ACE approval to increase to 13.6 meters since 1992, but work has not been done. Maryland also has bridge problems that limit the size of ships and requires dredging. Its inland location (100 miles from ocean) will limit super post panamax adoption (requires pilotage of 10 hours in both directions). Hampton Roads is best positioned of the Atlantic ports to handle super post panamax container ships.

Thus, for East Cost Ports, New York/New Jersey and Hampton Roads will be able to handle the largest container vessels of 10-14,000 TEU with draft of 14 meters. Limitations at other ports indicate that variety of container ship capacities must be maintained for East Coast fleet.

The Panama expansion would allow for 12000 TEU vessels to move through the canal. The Mercator Group constructed a lift ratio to compare efficiency of larger size vessels for Asia-USWC to Asia-USEC via Panama. The lift ratio is a measure of expected reliability, it is the ratio of maximum possible lifts that could be completed within the available port time divided by the number of lifts required per voyage when fully loaded (minimum should be at least 1, desired levels 1.25 to 1.50). They found that larger ships show lower reliability, however the US East Coast services have a higher lift ratio than for same size ship at US West Coast ports (likely due to longer voyage times and sufficient labor to operate longer at US East Coast ports). This suggests that as ship size increases it is better to stop at fewer ports and steam fewer miles. However, the lower lift ratios (higher efficiency) at USEC ports indicate that larger ships should move via Canal to USEC than to USWC ports.

They provides alternative scenarios for growth of container demand and evaluates impact of Panama Canal improvements on port calls at SPB. Assumes growth occurs at 7% (base case), 5% (low) and 9% (high).

Kaufmann discusses congestion impacts on ocean container shipping. He argues that congestion problems at North American west coast ports are tied to freight operations. This results in environmental degradation which is the focus of new fees and taxes by many government entities. He argues that SPB ports are least impacted by new fees and taxes, but this phenomena is driving interest in the development of Mexican Ports and Prince Rupert. He cautions that if governments try to reduce congestion and environmental degradation by increasing fees and taxes above the port costs at Mexican Ports or Prince Rupert, ocean liners will divert to Mexico or Canada.

4.2 Major Projects Impacting Container Shipping: There are many new projects that have been recently developed and/or are under varying stages of planning. These are summarized briefly:

Panama Canal Expansion The Panama Canal is one of the major routes in international shipping. With the growth in container shipping, the outlook for the Panama Canal has escalated. The Canal projects increases in container transits from 2025 range at 296 Million PCUMS to a high of 407 million PCUMS for an optimistic forecast (Panama Canal Authority, 2006, P. 26) by 2025.

The Panama Canal is limited by width, and total throughput. Ships are limited to widths of 105 feet and locks restrict vessel transits to 23 per day. The forecast for the Panama Canal is that traffic through the canal will reach maximum capacity in 2010 (limiting additional traffic through the canal). For the planned expansion, new locks will open in 2014 (Tioga Group). The canal expansion would add a third lane for traffic along the canal by constructing a new set of locks and would widen and deepen Pacific and Atlantic channels and the navigation channel on Gatun Lake (Panama Canal Authority, 2007a).

> "The third set of locks project is a plan to expand the Canal's capacity composted of three integrated components: 1) the construction two lock facilities - one on the Atlantic side and the another on the Pacific side - each with three chambers, each which include three water reutilization basins; 2) the excavation of new access channels to the new locks and the widening of existing navigational channels; and, 3) the deepening of the navigational channels and the elevation of Gatun Lake's maximum operating level," (Panama Canal Authority, 2006, P. 1).

The construction of the third set of locks will take from seven to eight years. If the project is approved in 2006, new locks could begin operations between 2014 and 2015 and is estimated to cost 5,250 million Balboas. The third set of locks will be able to transit and additional 1,250 million PCUMS (a TEU is equivalent to approximately 13 PCUMS) during its first 11 years of operation and produce 6,000 million in total revenues in 2025.

Each lock complex will have three chambers similar to the existing Gatun Locks. The project will create a new lane with one lock on each side that will handle vessels up to 49 meters wide, 366 meters long and 15 meters deep. This will allow ships with cargo volumes up to 170,000 CWT or 12000 TEU. The expanded Canal will have a maximum capacity of 600 million tons per year (Panama Canal Authority, 2006, P.27). In addition to these, the Panama Canal is in the process of expanding. This expansion will allow for more vessels to transit the canal, transits would occur with greater reliability, and would allow for larger vessels to transit the Canal. Previously, the Canals' capacity was restricted in a number of dimensions (ACP 2006). The expansion will result in an expansion of the existing lane, and create a new lane for larger vessels. The vessel capacity of the new lane is shown below (Quijano, J. 2007):

Item	Current Canal	Expanded Lane
Width (meters)	32	49
Length (meters)	294	366
Draft (meters)	12	15
Capacity (teu)	4,400	12,000

Source: ACP 2006 and Quijano (2007)

Hence, the capacity of the new canal will be expanded sharply, and allow for substantially larger vessels.

Concurrent with this expansion is for an increase in Canal tolls. The ACP announced in June 2007 that they would propose increased fees from $ 49 to $72/ laden TEU. These are all drastic changes and will have important impacts on spatial flows and intermarket competition.

Suez Canal Expansion The Suez Canal Authority has a 10 year project to widen and deepen the Canal to accommodate VLCC and ULCC class tankers with cargos up to 350,000 DWT by 2010. These improvements should allow increase capacity of containerships able to utilize the Suez Canal from 12000-12500 TEU up to 18000 TEU (Mercator Transport Group).

Prince Rupert Container Terminal Prince Rupert is developing a New Container Port able to handle 12000 TEU containerships. Phase 1 involves building a 500,000 TEU terminal per year expanding to 2 million TEU by Phase 2 to serve Chicago, Memphis, Winnipeg, Toronto and Montreal. Phase 1 openned in August of 2007 and is planning to have a draft of 16 meters and 3-4 Super Post Panamax Cranes. Phase 2 is set for completion in 2010 and with have draft of 16 meters and 8-12 Super Post Panamax Cranes (Tioga Group, Prince Rupert Port Authority).

West Coast Mexico The Port of Lazaro Cardenas has plans to expand which are underway (Mercator Transport Group). The Kansas City Southern became the sole owner of Transportacion Ferroviaria Mexicana, S.A. de C.V. (TFM) in late 2005 and renamed it the Kansas City Southern de Mexico (KCSM) which serves the port of Lazaro Cardenas with a direct line to Kansas City (KCS).

A third port is being proposed south of Ensenada (port Colonet). Prospective annual capacity would be 5 million TEU per year. Rail service would be by new mainline connection to Yuma where it would connect to U.S. Rail lines (Mercator Transport Group). The Union Pacific has pulled out of this. The Mexican Government plans to start bidding on projects by December of 2007 (American Shipper).

Other Port Expansions in the US There are several other U.S. planned expansions still being debated. These include a

» Houston: a 1.4 million container Bayport terminal expansion;
» Mobile is planning a container port with 300-400 TEU in Phase I expanding to 1 million TEU for Phase 2;
» Tacoma: The Port of Tacoma is purchasing land for a prospective new large container terminal and SSA Puyallup is building a new terminal at Tacoma which could reach 1 million TEU/year (DiBenedetto, June 11, 2007b).

Dredging Projects Dredging is underway in New York where the ACE has a dredging project to increase draft to 13.6 meters and has approval to further deepen to 15.2 meters. Dredging projects are also ongoing in Norfolk and should be finishing in Oakland in 2008 (Tioga Group). Dredging has been authorized by the USACE for Philadelphia since 1992, but work has not been initiated.

Other The Port of Vancouver is replacing several bridges that limit transit times of larger container vessels and adding container terminals (DiBenedetto, March 5, 2007a). Deltaport in British Colombia is expanding from capacity of 900,000 TEU/year to 1.3 million TEU by 2009 (Tioga Group).

5. Previous Studies on Specific Issues

There are some specific issues of importance to the IWR in their planning group and process. Of particular importance are issues related to infrastructure planning, including port expansion, port pricing, landside modal shares, economies of size, and costs. This section reviews studies on these issues in detail. In addition, other areas of interest are identified, including interport competition, projections, port constraints and expansion. Each of these are discussed including a summary of the problems being addressed, the relevant studies, their procedures, results etc.

5.1 Infrastructure Planning Several aspects of infrastructure planning are important for the container shipping industry. These include: Port expansion; port pricing; outbound modal shares; economies of size and costs. Each are discussed.

5.1.1. Port Expansion Planning for port facilities involves several factors. Harrison et al. 2000 indicate that ocean transportation is only one element of the transportation system and studies looking at demand should consider a whole systems approach.

> " The recent growth of logistics and the emphasis on providing service across the entire supply chain suggests that the mega-containership issue should be treated as an element in the transhipment of commodities from producer to consumer. Such a treatment widens the system approach and has important implications for the highway and rail elements at the landside access" P. 14).

A prime element in infrastructure planning and design of ports. Several articles focus on a potential move to a "Load Center" port system where containers are moved in large ships to selected hubs or Load Centers and then moved to smaller ships for continued movements. Harrison et al. (2000) uses the terms load centers or regional hubs interchangeable and indicates that movement toward a global network of giant terminals is now fast approaching. Others note these are present in well established European ports but have not materialized in U.S. port regions yet. Thus, several U.S. ports are competing for service to the largest container vessels. The later parts of the Harrison et al. projects initially focused on identifying a Load Center for the U.S. Gulf. This objective was modified to determining factors important for port location.

Bomba and Harrison (2000) developed a model to identify potential Load Centers for Containership ports in the Gulf. They discuss relevant topics for container port development including: 1) infrastructure demands, 2) environmental constraints, 3) locational attraction and landside access, and 4) port finance. Then they developed a load center selection model based on heuristic methods, weights and scores.

5.1.2. Port Pricing Bennathan and Walters (1979) reviewed theories of port pricing. They utilize a definition for port activities that includes sea, land and deliver related services and developed a simple economic model of ship costs that focuses on effects of port conditions, investments and charges on the costs of shipping. Under competitive conditions or where a monopolist is pursuing to maximize profits, when determining optimal ship size there is a basic tendency to a "square root law" such as in simple models of inventories and other models of economies of scale. This results in larger vessel sizes being optimal for longer voyages.

The optimal vessel sizes vary according to $(gL\text{-}mA)^{-1/2}$ where g is port cost for each ton, L is Tons unloaded each day irrespective of size, m is increase in tons unloaded each day for additional DWT of ship, and A is fixed port cost. This is complicated for ports by the fact that different parties have differing control over these parameters. For containers, a rough approximation is m=0 (i.e., bottleneck tends to be in transit shipping areas, although larger ships may employ multiple cranes). When effects of idleness in port are added to a simple model, the optimal ship size increases as idleness increases. Port developments that reduce ship congestion (idleness) will benefit small vessels, while increases in the amount of cargo worked per day (L or m) act just like increasing distance (promote larger optimum ship size).

Port prices are largely user and service charges. For containers, port charges are paid by shipping lines. For others, charges may be split between different parties. Cargo working costs form the major portion of port charges, accounting for 30-36% of voyage operating cost for conventional vessels and 50% or more for containers. Other port charges account for 4-9% of the voyage cost of conventional liners (e.g., for a 1210 TEU container they listed 56% for cargo expenses and 8% for other port charges).

They evaluated the elasticity of demand for port services. If there is an absence of port competition, the elasticity of demand is likely to be very low. The proportion of total port charges in the price for most commodities and most countries will lie below 5 percent of c.i.f. values. Thus, the elasticity of shipping should be only 5 percent of the elasticity of demand for the product. However, they argue that for ports with considerable opportunities for substitution, elasticities would be higher.

Bennathan and Walters indicate that ports are subject to supply and demand conditions which are constantly adjusting (nearly always out of balance). This complicates pricing decisions as charging too high tariffs can reduce demand and if there is oversupply of berths, reducing tariffs can only increase demand to a point before losses occur. These problems exist for both market or planned economies and neither is more able to estimate appropriate supply and demand better than the other. They indicate marginal cost pricing of ports is most appropriate method for determining tariffs for perfect competition and indicate deviations from this will depend on the level of competition in the market. However, they indicate that effects of monopolies, monopsonies and conferences can give rise to many problems which focus on whether variations in port charges will be passed on by conferences to competitive traders which is examined in a later chapter. Another factor in port pricing is the length of term utilized for marginal costing. They indicate that shorter terms are better because supply and demand for ocean vessel transportation are generally out of balance.

Economies of scale for ports are generally split into two areas. One focuses on the economies of port location and the other on the appropriate size of those facilities. Port planners frequently calculate an optimal occupancy rate of berths by a minimizing the sum of port and ship costs (Bennathan and Walters, p. 47).

Bennathan and Walters examined port congestion theory and impacts on port pricing. They indicate tariffs are set lower in congested ports because of the high probability that increases in port prices would be reflected in increases or multiplicative increases in domestic prices for imports and lowered prices of exports. As such they are viewed as direct transfer from domestic producers and consumers to port authorities. The relevant marginal cost of shiploads reflect delay costs equal to the port cost + the own ships delay cost + additional delay costs caused to all other vessels. The required delay surcharge is calculated as the delay cost per ship multiplied by the elasticity of delay with respect to the throughput of the port. In practice the elasticity can be calculated at the port periodically or guessed at.

The structure of shipowners has an impact on congestion surcharges. Monopolists will be able to exert market power over port to extract monopoly rents. This monopolistic power is dependent on the elasticity demand and is greater for congested conditions. If no conference for a port served by multiple independent conferences is dominant, then this approaches a perfectly competitive market.

They pose several advantages of congestion pricing including: 1) The port authority gains surplus caused by demand of facilities, 2) Levies provide funds for futures expansion, 3) levies encourage efficient use of port facilities and 4) Port authority receives rent rather than other players. Disadvantages include: 1) difficulty in charging levies. 2) congestion charge may be passed on.

Another factor in port pricing is if ports factor in national interest in their decision making. Ports typically have some sort of monopoly power and as such can choose between marginal cost pricing and profit maximization for the port when establishing pricing practices.

Meersman, Vande Voorde and Vanelslander (2003) provide a more recent review of literature into port pricing. They discuss in depth the issue of marginal versus long run costs for pricing ports and indicate the literature focuses on five categories 1) cost based pricing, 2) method for cost recovery, 3) congestion pricing, 4) strategic port pricing and 5) commercial port pricing (privatized ports).

5.1.3 Modal Shares A very important parameter in port planning is the market shares of transportation mode for interior land side shipment. Harrison et al. (2000) indicates modal shares for landside movements from U.S. ports vary by port area. The West coast split (rail/truck) is 50% rail, while on the east cost the rail share is only 24%. Houston is even less, as rail accounts for only 20% of modal shares for container shipments from the port of Houston.

Important factors for modal shares for ports are double stacking of rail cars which is occurring more on the west coast as east coast railroads have a higher incidence of tunnels that do not allow for double stacking. Traffic flow at all ports is important as increases in truck shares can result in congestion problems. Other developments for trucks are the introduction/and further adoption of Long Combination Vehicles (multi container trucks or LCV's).

5.1.4 Economies of Size Economies of size in ocean container shipping has been the focus of several studies including: Cullinane and Khanna, (1999) Harrison and Figliozzi, (2001), Gao (1994) and Lim (1998). Lim provides a general discussion of impacts of increasing ship size in an effort to capture economies of scale for container ships. As shipowners increase ship sizes, rates have drop more than the drop in costs due to over building of shipowners (i.e., rather than limited shipowners building larger ships, he argues too many shipowners add larger ships beyond what industry supports). The results of firms response to economies of size is to provide a direct subsidy from shipowners to shippers and consumers.

The Tioga Group indicates an increased trend toward larger containerships. Currently, the largest containerships being delivered to shipping lines are 13000 + TEU. Expectations are for sizes to increase to 12,000 TEU for transpacific and transatlantic trades, but reach 18000 TEU for Europe/Asia trade. They indicate that as larger containerships are adopted, they are first adopted for Europe/Asia routes, then adopted for transpacific routes, then adopted for Americas/Africa or intra Asian trade routes. They also indicate that as containership sizes have increased, ship speeds are also increasing.

Gao developed a two stage model to determine optimal container fleet size minimizing capital and operational costs of containers while considering leasing options, devanning times at ports (assumes these are fixed by port, i.e., a port is able to devane containers at a fixed time continuously). The model first computes least cost flows, then linear programming model is used to adjust flows so that supply and demand of containers are equalized. He shows a couple of examples and list references that had modeled prior fleet sizes (many of which assumed fleet size was fixed and only look at optimal allocations.

Harrison et al, reported on a study by Payer who indicated shipbuilder Germanischer Lloyd found the optimum design for containership would be 8,000 TEU based on a comparison of 40 ship designs and impact of those ships on nine round-trip alternatives. Harrison et al. indicate Payer found "1) The longer the sea leg, the greater the fuel load, which influences total cost. 2) Forming a mega-containership shuttle between two markets can reduce cost per TEU, and 3) The more ports a vessel calls on, the higher the cost per TEU. Interestingly, the maritime savings from reducing ports of call may not be sufficient to outweigh the additional costs incurred through the need to use more inland transportation to move containers to final destinations" (Harrison et al. P. 40).

Harrison and Figliozzi, (2001) construct a total cost model for container shipment as:

$$\text{Total cost} = SOC + PC + CC + LSC + IC$$

where: SOC = Ship operating costs, PC = Port costs, CC = Container costs, LSC = Landside costs, and IC = Inventory costs. They used this to evaluate total costs at sea and costs per TEU for various ship sizes.

They evaluated optimal size by minimizing total vessel operating costs. They had four main findings: 1) the larger the ship, the lower the cost per TEU mile, 2) the less time a ship remains in port, the larger it can be, 3) high fixed costs lead to larger ships, and 4) the longer the route distance between ports, the larger the optimum ship size. They note that economies of scale are significant for larger size ships when fully loaded, yet when container volumes are lesser, smaller vessels are preferred.

Cullinane and Khanna quote Pearson (1988) indicate that as ship size increases, total ship costs at sea per ton or TEU decrease. And the efficiency of a ship is closely related to total time spent on that voyage. Thus, they point to Jansson and Schneerson (1987) who indicate that with increases in ship size, "economies of ship size are enjoyed at sea and diseconomies of ship size are suffered at port." Given the current trend, companies making investments believe that economies of sea travel exceed value of diseconomies at port. Comparisons between different ship sizes are complicated by different vessel specifications, operational standards and accounting methods. Also cost data are difficult to obtain because it is commercially sensitive. This paper builds model to evaluate this tradeoff.

5.1.5 Costs Much of cost saving have been obtained from the sea portion of container movements (Notteboom). Most of container shipping costs are now comprised of the land-side movement costs - he indicates 40 to 80% of total costs for containers are for land-side movements. This has fostered moves toward strategic alliances, vertical integration, and other relationships among shipping lines and inland freight carriers.

Cullinane and Khanna estimated relationships for classes of operating costs in their examination of economies of scale for ocean vessels. They estimated several relationships between cost components and nominal TEUs (NTEU assumes 14 DWT per TEU) for a range of ocean vessel sizes.

They indicated that prior studies had estimated functional relationships between ship costs and dwt where ship costs equal $dwt^{0.67}$. They estimated a functional relationship between the initial capital cost (purchase price) for container ships and capacity where ln(Ship Price) = 4.8097 + 0.759 ln(NTEU) r^2=0.93. They assume total annual cost of repairs, maintenance, insurance, and administration is 3.5% of initial capital cost. They also assume ships are crewed by set amount dependent on capacity and crew costs calculated based on representative monthly crew expenses.

An estimated relationship was used for fuel oil consumption and brake horsepower for engines. Daily fuel oil consumption = Installed bhp * SFOC (specific fuel oil consumption) * Utilization (80%) * 24 / 1000000. Ship size elasticity of installed bhp (brake horse power) Ln(bhp) = 2.6308 + 0.967 ln (NTEU)

Mercator Transport Group indicate cost savings for an 8,000 TEU vessel on an Asia-NA trade route reduced vessel costs by $99/TEU over a 4,500 TEU vessel. A 10,000 TEU vessel would further reduce costs over 8,000 TEU vessel by $52/TEU. They suggest that container vessels will max out for US West coast at 12,000 TEU by 2020. This is due to there being increasing scale economics for ship sizes above 12,000 TEU because a change in ship technology is required. These diseconomies aren't offset till ships achieve 14,000 TEU or larger.

Harrison and Figliozzi, 2001 construct total costs for container shipment as

Total cost = SOC + PC + CC + LSC + IC

where

SOC = Ship operating costs
PC = Port costs
CC = Container costs
LSC = Landside costs, and
IC = Inventory costs.

They used this along with published elasticities for cost categories and assumptions on ships by size to evaluate allocation of total costs at sea and in port and costs per day and per TEU for various ship sizes.[6] Total operating costs per day for 1000 to 7000 TEU vessels are listed in Table 5.1.1.

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[6]When evaluating optimal ship sizes, three different optima could be utilized. These include 1) minimization of total vessel operating cost per TEU, 2) maximization of net operating surplus per TEU, 3) maximum return on capital by shipping company.

These results show that capital costs are the most important element fo cost, followed by fuel costs. The costs also vary by vessel size in each category.   The derived results suggest that the cost per day per TEU decline from $23 to $8/TEU when going from ships sized at 1000 TEU to 7000 TEUs.   Thus on a trip involving 19 days at sea, a 7000 TEU vessel would have approximately a $282/TEU advantage (according to these calculations).

These are very comparable to the results derived analytically in Wilson and Dahl 2008 using an analytical model and ACE inputs. Their results showed that the cost savings on a prototypical route would result in about a $300/TEU savings between a 7000 TEU ship vs. a 1000 TEU ship.

Table 5.1.1. Total Costs per day for Operating Cost Categories, by TEU Size

TEU	*Fuel Main Eng*	*Fuel Aux Eng*	*Capital Cost*	*Crew*	*Overhead*	*Total*	*Cost per TEU*
			$Total cost/day				
1000	1000	61	10225	1440	6946	22573	23
2000	6750	144	13939	1440	7714	29987	15
3000	9302	239	16708	1440	8203	35892	12
4000	11679	342	19001	1440	8568	41030	10
5000	13934	453	20994	1440	8862	45683	9
6000	16096	569	22777	1440	9110	49992	8
7000	18183	689	24402	1440	9325	54039	8

Source: Harrison and Figliozzi, 2001

Table 5.1.2. Allocation of Ship Operating Costs at Sea and In Port by TEU

		Allocation of Costs at Sea		
TEU	*Capital*	*Labor*	*Admin*	*Fuels*
		----Percent----		
1000	45	6	31	17
2000	46	5	26	23
3000	47	4	23	27
4000	46	4	21	29
5000	46	3	19	31
6000	46	3	18	33
7000	45	3	17	35
		Allocation of Costs in Port		
TEU	*Capital*	*Labor*	*Admin*	*Fuels*
		----Percent----		
1000	55	8	37	0
2000	60	6	33	1
3000	63	5	31	1
4000	65	5	29	1
5000	66	5	28	1
6000	67	4	27	2
7000	68	4	26	2

Source: Harrison and Figliozzi, 2001

Harrison and Figliozzi, 2001 indicate costs for other aspects of container shipping. They indicate 25% of container trade accrues transhipment costs which may range from $75 to $225 per TEU. For container costs in 2000, 50% of containers were tied to term lease agreements, 35% were fixed on master leases (containers leased for lifetime of box) and the remainder were hired. A 20 ft. box term lease rate in 1999 to 2001 ranged from $0.65/day to $0.75/day. Master leases traditionally earn a premium over term leases, and they report costs for master leases in 2001 of under $1.00/day.

Landside costs for trucks ranged from $0.20/truck mile for double stacks and $0.90/truck mile for containers (Muller, 1999). Finally, Harrison and Figliozzi, 2001 developed a model to estimate inventory costs. They indicate that inventory costs increase with increases in total trip times, value of cargo, frequency of calls, and decreases in reliability. They pose two examples, one is container with commodity valued at $30000 and another is valued at $10000. Inventory costs for the container with the higher valued commodity can vary from $20 to $30/day, while the lower valued commodity can vary from $10 to $18/day.

5.2 Interport Competition Bennathan and Walters reviewed interport competition economics. They focused on several aspects of competition including: 1) Inland competition between ports; 2) Transhipment competition; and 3) Effects of containerization. When considering inland competition, differences in congestion at ports lends to switching when hinterland is continuous between two or more ports. However, extent of switching can be affected by inland transportation costs.

They list an example of lumber where inland costs are $0.10/ton mile with $1 increase in port charges per ton only shifting drawing area 10 miles due to high cost of inland shipping. They also note that it is common for container owners to practice what they term "absorption." They define this as when there is competition between ports, the "absorption of inland transportation cost-or rather of differences in transport cost to common destinations," (p.152). This discriminates both against a particular port (reduces inland costs of competing port) and against shippers located near the favored port.

Specific attention is made by ocean carriers and alliances when setting shipping rates. They specifically consider the effects of competition from direct shipments vs. transhipment routes (shipment to one port where containers are moved from larger to smaller vessels for delivery to final port). For strategic purposes, shipping lines have in the past set direct rates to preclude transhipment options.

Finally, interport competition is affected by containerization of trade. As port volumes shift from conventional to containerized trade, ports will have reduced monopoly power and find it harder to profit or cover costs especially where there is considerable excess capacity at the port. The switch increases the average competitiveness of ports relative to competing ports, however it also increases the monopoly power of shipowners.

Other studies have examined interport competition including Blonigen and Wilson, Ng, Veldman and Buckmann,

Ng surveyed top 30 shipping lines to determine attractiveness of ports in North European Transhipment Market. Respondents were asked to assess several characteristics of attractiveness for ports and rank responses on a 0-5 scale. Then they were asked assess these factors for several specific ports and to rank these on a -3 to 3 scale. They found that factors other than monetary costs influence port attractiveness including time efficiency, location and service quality. The findings suggest that for North European ports shipping lines opinions on attractiveness are consistent with their choice of hubs. However, he argues that attractiveness and competitiveness of ports should not be confused and provides an example where other researchers assume increases in attractiveness should result in increased market shares and throughput growth. To counter this assumption, Ng presents an example from his results for the ports in Rotterdam and Hamburg which are both attractive to shipping lines, yet they service different hinterland regions, thus the two ports are not in direct competition.

Veldman and Buckmann indicate that modeling of container shipping industry is becoming highly complicated by the number of alternatives emerging on land, and at ports both from a sea-land interface, and as a sea-sea (transhipment point) interface. They model ports as node in transportation system and develop a logit model to explain market share of a port's routings for each of traffic zones or regions. Explanatory variables include transport cost, transit time, frequency of service and indicators of quality of service. They use a logit model to determine routing choice and derive a demand function. The demand function they note could be used for port traffic forecasting and for evaluation of container port projects. They applied the model to West European Container Hub Ports.

Their model estimated routing choice with respect to continental hinterland regions as a function of (change in costs, change in costs by distance from port, change in market share hub-port, change in market share hub-port by distance from port, dummies for Rail, IWT ant IWT Rotterdam-Antewerp). They further estimated routing choice with respect to overseas hinterland regions as function of (change in costs, change in costs by distance from port, change in market share hub-port).

They applied results from logit model to forecast effects comparing 1) low cost, low quality routing to high cost, high quality routing, 2) evaluates effect of change in port recovery costs of market shares of major North Sea container ports and 3) assesses market shares as a function of changes in generalized costs of project at Rotterdam. In case 2, he finds small changes in market shares of ports (3.2% Rotterdam, 1.2% Antwerp, -4.3% Bremen and -4.2% Hamburg). In case 3, they found increasing costs of using Rotterdam by Euro 27/ TEU halved container market shares for Rotterdam.

Blonigen and Wilson developed a methodology utilizing U.S. Census data to estimate port efficiencies across ports over time. Past efforts to measure port efficiencies utilized surveys, however these are limited in time and subject to views of participants which may include other factors of country in their evaluation of ports. Other efforts applied data envelopment analysis and econometric estimation of production/cost functions of ports.

They utilize import charges and through a fixed effects model estimated the portion of import charges for foreign and U.S. ports and use these as measures of port efficiencies. Components of import charges reflect 1) costs associated with loading freight and disembarking from the foreign port, 2) costs connected with transportation between ports and 3) costs associated with U.S. port arrival and unloading of freight). Fixed effects included estimated parameters for 1 and 3.

Estimated parameters for fixed effects included distance, weight and value per unit, containerization and interaction terms between containerization and weight and value per unit. Results indicated that distance, weight and value per unit were positively correlated with import charges. A 10% increase in distance would increase import charges 1.3 to 2.1%. Weight increases would increase import charges on nearly a one to one basis, while a 10% increase in value per unit would increase import charges by 5.5%. Effects for containerization were negatively correlated with import charges, though the effect was small. Interaction terms indicated effects of containerization were reduced for heavier weight products and increased for higher value products.

They estimated port efficiencies relative to Oakland and compared results from 1991-93 with 2001 to 2003. They ranked ports highest to least efficiency relative to Oakland (most negative to most positive parameter estimate). They found many West Coast and Gulf ports were ranked in upper half of list with Richmond-Petersburg most efficient. Further, Gulf ports typically improved in efficiency from earlier period to later while East Coast ports lost efficiency.

They utilized estimated effects in a gravity model to evaluate elasticities for trade volume from increases in port efficiencies. They found lower elasticities for increasing efficiencies that earlier studies. They indicate Clark et al. 2004 estimated elasticity at 25% for increase in efficiency from 25th percentile to 75th percentile, whereas, they found only a 5% elasticity. However they also indicate that product mix can have effects on their estimation procedures.

5.3 Projections and Methodologies

A range of studies employing different methodologies have been utilized to forecast container trade volumes, trade flows, shipping modes, etc. Methodologies included applying fixed growth rates over time, a more micro analysis that utilized expert opinions on longer term adjustments in major drivers along with a network analysis that forecast service calls and ship sizes based on import volumes, econometric models of mode shares, etc. Several of the published forecasts for containership trade volumes utilize proprietary data and methodologies (McGraw Hill-DRI, Global Insights, etc.). These are problematic as, methodologies are not available for review.

Sivakurmar and Bhat (2000) developed an econometric model to estimate landside shares for container shipping for two modes (rail, truck) for a Gulf Region port. Logit model of shares estimated following Papke and Wooldfridge. They used data on freight movements (Reebie Transsearch Freight Database, Transcad (county centroid distance calculations), county business patterns (census bureau), population projections, bureau of economic analysis data.

Harrison and Figliozzi (2001) developed forecasts of container flows for Gulf markets for next 20 years in 5 year increments assuming difference scenarios (pessimistic, normal and optimistic). They indicate that forecasting container demand has become too difficult, so instead they did sensitivities of expected growth rates. They assumed fixed growth rates based on historical data. The pessimistic case used 2% and 4%, normal used 4% and 7%, and optimistic used 6% and 9% growth rates. Using these growth rates, 20 year forecasts were developed and aggregated to 6 regions. Growth rates applied differentially to original flows (slower growing vs. faster growing). Their results indicate that routes to U.S. South Atlantic ports that achieve volumes significant to attract attention of lines for mega-containerships are from routes from Europe and Mediterranean Middle-East, Asia, Africa and Oceania. They found larger volumes for Carribean and Central American routes, but indicate these are serviced by smaller ships due to the low probability of being serviced through load centers and high call frequencies of smaller liner vessel schedules. For Texas gulf, they indicate that even for the most opportunistic scenario, only in period 15-20 years forward do volumes increase to numbers large enough to attract mega-containership liner service from Europe and Mediterranean routes.

The Mercator Transport Group projected future container vessel shipment activity levels (to 2020). First they reviewed historical trends from 1990 to 2004, and then estimated short term projections for 2005-2007 based on trends. Longer term projections were developed for 2008-2020 using a micro analysis. This analysis was developed based on expert opinions considering the following fundamental drivers:

1) Developments and constraints in vessel design, engineering and technology,
2) Changes in vessel capacity and operating costs
3) Capacity related conditions and constraints at major container ports (Asia and North American ports competing with San Pedro Bay (SBP) ports.
4) Changes in structure of liner industry (mergers, acquisitions, consolidations)
5) Panama Canal
6) Forecasted levels of container trade between Asia and North America (Asia to NA, for inbound, head-haul direction) (Note: they refer to Head-haul vs. back-haul portion of round trip).

They used these expert opinions to forecast firm structures (number of alliances), vessel costs and characteristics by size, service routes and capacity limits at major ports. Then they used these estimates to forecast service calls and ship sizes utilized to satisfy import volumes coming from origins on service routes to serve destinations. Ship sizes were based on service calls and import volumes to North America as import volumes exceeded export volumes by over 3:1 at SBP ports. They did sensitivities on several of the critical expert opinions impacting firm structures (alliances, Panama Canal, etc.).

They indicate impact of improvements in Panama Canal would likely shift some large container moves to U.S. East Coast from Asia, but shift smaller Panama Canal traffic (4000 TEU) to SPB. Net effect would be insignificant.

There are several large-scale efforts to make projections on container trade. These include Clarkson (2007a and 2007b), Drewry (2007) and Global Insight. Clarkson and Drewry routinely provide emirates 1-2 years forward and these are widely circulated. Their methodology is not reported but it implies it is based on macro-economic variables and/or expert judgement. The estimates by Global Insight are also widely cited and referred to in the industry, and these are longer-term.

The Global Insight analysis was presumably used by Hackett who reports forecasts of container trade through 2050 and uses these global forecasts (private estimates from DRI-WEFA) to construct estimates of constrained/unconstrained U.S. port vessel calls to 2020. He indicates that in 2000 1.2 billion tons of U.S. commodity trade moved through U.S. ports and forecast that volume will increase to 1.8 billion tons by 2020 and 2.0 billion tons by 2050. They project the shares of containerized trade to increase and the growth rate will average 2.7%/year for next 50 years. They project that China will be the source for over 2/3 of U.S. containerized trade by 2020. Tonnage growth for port areas over the next 50 years will be highest for Pacific ports (Twice that of Gulf Port growth rates), followed by Atlantic ports (halfway between Pacific and Gulf Ports) and Gulf Ports.

Container ships make the most calls on U.S. ports, generally arriving and leaving at similar capacity and generally make multiple calls at U.S. ports per trip. General cargo vessels also arrive and leave with similar capacity. Tankers and Dry Bulk vessels generally call on one port and have lesser capacity either on return trip or arriving. Containerized trade in 1995 accounted for 9.4% of traded seaborne tonnage and is predicted to increase to 25% by 2050. By 2050 container trade was projected to increase from 157 to 530 million metric tons (average of 2.7%/year).

Global Insights (formerly DRI-WEFA) forecast ocean shipping and container trade. They provide detailed short term forecast to 2008 and a more general longer term forecast to 2020. The basis of their forecasts is based on "historical trade data and the Global Insight World Trade Model." No further detail is provided. They forecast Container traffic to grow from 579 million tons to 1.1 billion tons by 2022 or from about 56 Million TEUs in 2000 to 150 Million TEUs by 2022 (Table 5.3.1). Container trade in the long term will outpace tanker and dry bulk shipping by almost 4% per year.

5.3.1 Growth Rates of Four Major Service Types - Ocean Freight				
	2000-05	*2005-10*	*2010-15*	*2015-22*
Dry Bulk	3.6%	2.6%	1.5%	1.2%
Tanker	1.2%	1.8%	1.4%	0.7%
General Cargo/Neo Bulk	3.1%	3.6%	2.8%	2.2%
Container	6.1%	4.5%	3.4%	2.8%

Source: Global Insight

Shorter term forecasts include containerized trade flows by route, both volumes and growth rates of flows. Table 5.3.2 lists export flows to North America by Export Region. The largest export region shipping to North America is NE Asia, having volumes more than 4 times the next highest region. NE Asia also has the highest growth rate for shipments to North America in 2004-2005 (15.7%-14%), declining to a 5.1% growth rate in 2008 similar to Eastern Europe (6.0%). Other export regions were forecast to have growth rates for shipments to North America in 2008 of 2% or less.

Table 5.3.2. Containerized Trade Flows to North America, by Export Region (000 TEUs)

Export Region	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***
North America	335	361	368	375	382	387
North Europe	1711	1731	1747	1765	1789	1811
NE Asia	7913	9157	10439	11690	12725	13377
SE Asia	1331	1355	1398	1442	1496	1497
ANZ	187	199	200	202	205	209
Eastern Europe	110	120	127	133	142	150
Latin America	1934	2196	2332	2410	2455	2483
Med	782	811	829	844	861	878
Middle East	71	72	74	74	76	78
Total	14374	16002	17514	18935	20131	20870

Source: Global Insight, 2005.

5.4. Spatial Optimization and Simulation Models

Various methodologies have been utilized to evaluate aspects of container shipping. Luo and Luo and Grigalunas developed a spatial-economic, multi-modal container transportation simulation model for US coastal container ports. The model is used to price elasticity of demand for port user fees. It minimizes costs and was used to estimate annual container transportation service demand for major container ports in the U.S. Costs included shipping costs by ocean, rail, truck, etc., costs for facilities use (port fees, etc.) and includes time costs. The model is constructed with a shortest path algorithm (widely applied in economic analysis and transportation engineering), as a dynamic programming problem. They assume foreign country exports to US are known and allocates demand (by weight) to states based on population (except for the northeast, where demand is allocated to counties rather than states) which is then converted to TEUs.

Gao develops a two stage model that determines optimal container fleet size to minimize capital and operational costs of containers while considering leasing options, devanning times at ports (assumes these are fixed by port, i.e., a port is able to devane containers at a fixed time continuously). His two stage model first computes least cost flows, then a linear programming model is used to adjust flows so that supply and demand of containers are equalized. He refers to other studies that have also modeled fleet sizes (many of which assumed a fixed fleet size and only look at optimal flows).

Kosior developed a model to compare total cost of ownership (economic + cash) for bulk handling system vs. container system vs. hybrid bulk/container system while considering economic costs. His model minimizes total costs which were defined as the summation of : product costs, terminal costs, inventory costs , transportation costs, material handling costs, regulatory costs, quality assurance costs, security costs, and ancillary costs; subject to: conservation of flow and stock at nodal points, carrier policies, terminal storage capacities, regulatory requirements and constraints, vehicle design limitations, and linkage constraints. He developed the model as a demand based logistical chain and mapped potential routes backward from end-user to suppliers (opposite of supply based logistical chains).

6. Summary and Implications for Design of Spatial Optimization Models

The US ACE/IWR is evaluating whether and the extent and scope of a spatial optimization model to analyze competition in the container shipping industry. Such a model would be used for making projections, and to evaluate the impacts of changes in infrastructure during the projection period. This report seeks to review other studies on container logistics and identify the current state of knowledge about port constraints and expansion possibilities and costs.

The container shipping industry is a very fast growing sector of the world economy. Concurrent has been a large number of studies convening varying aspects of this industry. These are summarized below in groups:

Trade and trends in Container shipping: This is very fast growing sector. While the growth rate has varied through time, generally it can be interpreted to be growing by about 10-11% per year. North American is a large container market, but, follows both Asia and Europe in terms of total volume. Further, container shipping is growing much fasted than shipping by other forms of ocean vessels.

Due in part to this growth, this industry is confronting many challenges. These include 1) pressures for economizing on vertical linkages; 2) port growth, congestion and competition; 3) new ports and routes; 4) changes in response to larger vessels and shipments; 5) pressure for more timely shipments; 6) and the escalation in containerization of many new commodities and products that had previously been shipped in bulk.

Market Structure and Economies of Ocean Carriers: There is growing concentration in the ocean shipping industry. The top 4 firms have about 39% of the capacity. Even though this has increased, it is still relatively competitive compared to many other industries.

There is a major trend toward increased vessel size. This has been on-going for a number of years, but for varying reasons the trend has escalated in recent years. Indeed, by 2010, the average size ship will be over 7000+ TEUs, in part to the escalation in post-Panamax ships. A major contributor to this change is the expansion of the Panama Canal which will allow vessels up to 12,000 TEUs and a draft of 15.7 meters. This contrasts with the current Canal that has a draft limit of 12 meters and a maximum capacity of about 4400 TEUs.

Port Constraints and Projects Impacting Container Shipping: It is important that many exporters in the world are gearing up for shipping in larger sized vessels, and concurrent there is a shift toward larger vessels. As a result of these changes, combined with the persistent growth in container shipments, a number of ports are becoming constrained and in need of expansion, dredging or other means to expand throughput.

In response, a number of ports or routes are in the process of expansion. Notable amongst these are the expansion of the Panama and Suez Canals, new ports at Prince Rupert and the West Coast of Mexico, and several individual projects at US ports.

Previous Studies on Container Shipping: There have been a number of studies on varying aspects of container shipping. These include studies on port expansion, pricing, economies of size and interport competition.

Projections and Methodologies: A few studies have sought to make projections on container shipments. Some of these are based on expert opinion, others based on extrapolation of trends and sensitivities. In addition to these, there are several larger-scale efforts to make projections. These include Clarkson (2007a and 2007b), Drewry (2007) and Global Insight. Clarkson and Drewry routinely provide emirates 1-2 years forward and these are widely circulated. Their methodology is not reported but it implies it is based on macro-economic variables and/or expert judgement. The estimates by Global Insight are also widely cited and referred to in the industry, and these are longer-term. They provide detailed short term forecast to 2008 and a more general longer term forecast to 2020. This is not at the port level. The basis of their forecasts is based on "historical trade data and the Global Insight World Trade Model." No further detail is provided.

Spatial Optimization and Simulation Models Several studies have developed spatial optimization models. It is important that each of these have varying forms of cost minimization and none address risk. Further, none of these explore the longer-term view of interport competition.

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Appendix: ***Detailed discussion on Specific Individual Studies***

Infrastructure Impacts of Containerships (Including Mega-Containerships) on the Texas Transport System.

Part 1.
Harrison, Robert, Miguel A. Figliozzi and C. Michael Walton. 2000. Mega-Containerships and Mega-Containerports in the Gulf of Mexico: A Literature Review and Annotated Bibliography. Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin. May.

Part 2.
Bomba, Michael and Robert Harrison. 2000. An Identification Process and Evaluation Framework for Texas Gulf Containerships. Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin. Research Report 0-1833-2. December.

Part 3.
Harrison, Robert and Miguel Figliozzi. 2001. Impacts of Containership Size, Service Routes, and Demand on Texas Gulf Ports. Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin. December.

Part 4.
Sivakurmar, Aruna and Chandra R. Bhat. 2000. Freight Modal Split Modeling: Conceptual Framework, Model Structure, and Data Sources. Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin. Research Report 0-1833-4. August.

Part 5.
Sivakumar, Aruna, Aruna Srinivasan and Chandra R. Bhat. 2001. Freight Modal Split: Estimation Results and Model Implementation. Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin. Research Report 0-1833-5. July.

This is a five part project conducted by the Center for Transportation Research, Bureau of Engineering Research, University of Texas, Austin. Part 1 is a review of literature, Part 2 develops a model to identify characteristics of ports important for use as a load center, Part 3 evaluates impacts of ship size, service routes and container demand on Texas Gulf seaports, Part 4 develops a logit model to evaluate characteristics important for determining modal splits (rail vs. truck) where results are presented in Part 5.

Luo, Meifeng. 2007. A Container Port Demand Simulation Model for US Container Ports. Department of Logistics, Hong Kong Polytechnic University, Hung Hom, Kowloon, HKSAR.

Luo, Meifeng and T.A. Grigalunas. 2003. A Spatial-Economic Multi modal Transportation Simulation Model for US Coastal Container Ports. Maritime Economics and Logistics, Vol 5(2):158-178.

These two studies appear to be similar. They developed a spatial-economic, multi-modal container transportation simulation model for US coastal container ports. The model is used to price elasticity of demand for port user fees. Cost minimization model used to estimate annual container transportation service demand for major container ports in the U.S. using a shortest path algorithm in a dynamic programing problem.

Cullinane, Kevin and Mahim Khanna. 1999. Economies of Scale in Large Container Ships. Journal of Transport Economics and Policy, Vol. 33(part 2, May):185-208.

They developed model to evaluate tradeoffs between the effects of economies of size enjoyed on the sea and diseconomies of ship size in port. They estimated elasticities for several components of operating costs for different sizes of container ships and used these to evaluate economies of size for a range of container vessels sizes.

Gao, Qiang. 1994. An Operational Approach to Container Control in Liner Shipping. *Logistics and Transportation Review*, Vol 30(3): 267-282.

Develops a two stage model that determines optimal container fleet size to minimize capital and operational costs of containers while considering leasing options, devanning times at ports (assumes these are fixed by port, i.e., a port is able to devane containers at a fixed time continuously). Two stage model first computes least cost flows, then linear programming model is used to adjust flows so that supply and demand of containers are equalized.

Brooks, Mary. 1993. International Competitiveness-Assessing and Exploring Competitive Advantage by Ocean Container Carriers. *Logistics and Transportation Review*, Vol 29(3): 278-293.

This paper analyzes container industry from an industry structure and firm strategy perspective. She utilizes a framework that looks at five competitive forces: 1) the entry of new competitors, 2) the threat of substitutes, 3) the bargaining power of buyers, 4) the bargaining power of suppliers, and 5) rivalry among competitors (Porter, 1980). Discusses each of these in context of the ocean container industry in the late 80's early 1990s.

Discusses sources of firm competitive advantages: 1) cost containment and asset utilization, 2) Services, 3) Agency Networks, 4) Access to capital, and 5) Vertical integration into Input supply. Further discusses sources of competitive disadvantages: 1)Loss of market identity and 2) service homogeneity. Goes on to discuss strategies to exploit competitive advantage: 1) Cost Leadership, 2) Focus Strategies, 3) Service Differentiation, 4) Sustaining Competitive Advantage.

Ng, Koie Yu. 2006. Assessing the Attractiveness of Port in the North European Container Transhipment Market. Maritime Economics and Logistics. Vol. 8(3, Sept):234-250.

Surveyed top 30 shipping lines to determine attractiveness of ports in North European Transhipment Market. Respondents were asked to assess several characteristics of attractiveness for ports and rank responses on a 0-5 scale. Then they were asked assess these factors for several specific ports and to rank these on a -3 to 3 scale.

Veldman, Simme J. And Ewout H. Buckmann. 2003. A Model on Container Port Competition: An Application for the West European Container Hub-Ports. *Maritime Economics and Logistics*, Vol 5(2): 3-22.

They develop a logit model to explain market share of a port's routings for each of traffic zones or regions. Explanatory variables include transport cost, transit time, frequency of service and indicators of quality of service. They use logit model to determine routing choice and derive a demand function. The demand function they note could be used for port traffic forecasting and for evaluation of container port projects. Model evaluates West European Container Hub Ports as example.

Uses results from logit model to forecast effects comparing 1) low cost, low quality routing to high cost, high quality routing, 2) evaluates effect of change in port recovery costs of market shares of major North Sea container ports and 3) assesses market shares as a function of changes in generalized costs of project at Rotterdam.

Unsure what he finds in case 1 (appears to point to another paper in summary). In case 2 finds small changes in market shares of ports (3.2% Rotterdam, 1.2% Antwerp, -4.3% Bremen and -4.2% Hamburg). In case 3, they found increasing costs of using Rotterdam by Euro 27/ TEU halved container market shares for Rotterdam.

Models ports as node in transportation system. They develop a logit model to explain market share of a port's routings for each of traffic zones or regions. Explanatory variables include transport cost, transit time, frequency of service and indicators of quality of service. They use logit model to determine routing choice and derive a demand function. The demand function they note could be used for port traffic forecasting and for evaluation of container port projects. Model evaluates West European Container Hub Ports as example

Their model estimated routing choice with respect to continental hinterland regions as a f(change in costs, change in costs by distance from port, change in market share hub-port, change in market share hub-port by distance from port, dummies for Rail, IWT ant IWT Rotterdam-Antewerp). They further estimated routing choice with respect to overseas hinterland regions as f(change in costs, change in costs by distance from port, change in market share hub-port).

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Notteboom, Theo E. 2004. Container Shipping and Ports: An Overview. Review of Network Economics, Vol. 3(2, June):86-106.

This paper reviews recent trends impacting the container shipping industry and container ports. Paper focuses on several aspects of economic theory including market structure, firm structure, strategic planning, economies of size, impacts of congestion (port, inland, etc.), interport competition, etc.

Kosior, Jake. 2004. Demand Chain Modeling Utilizing Logistical Based Costing. PhD Dissertation. Department of Mechanical and Manufacturing Engineering, University of Manitoba, Winnipeg.

Kosior reviews literature on bulk vs. container shipping trends, costs, etc. Then develops a model to compare total cost of ownership (economic + cash) for bulk handling system vs. container system vs. hybrid bulk/container system. Model was set up to minimize total costs which were defined as: product cost + terminal costs + inventory costs + transportation costs + material handling costs + regulatory costs + quality assurance costs + security costs + ancillary costs, subject to: conservation of flow and stock at nodal points, carrier policies, terminal storage capacities, regulatory requirements and constraints, vehicle design limitations, and linkage constraints.

Mercator Transport Group. 2005. Forecast of Container Vessel Specifications and Port Calls Within San Pedro Bay. Mercator Transport Group, Bellevue, WA.

This is the summary of a detailed analysis for ports of Long Beach and Los Angeles (ports located in San Pedro Bay of California) to forecast future container vessel activity levels (to 2020). Report reviews historical trends from 1990 to 2004, estimates short term impacts 2005-2007 based on trends, then develops longer term forecasts for 2008-2020 while considering fundamental drivers impacts of vessel sizes, operating costs, capacity constraints a major ports, changes in liner structures, panama canal and forecast levels of container trade.

They forecast increased consolidation in industry from current structure where 5 alliances handle 70% of capacity to 6-8 alliances handling 95%. They indicate cost savings for 8000 TEU vessel on Asia-NA trade route reduced vessel costs by $99/TEU over a 4500 TEU vessel. A 10000 TEU vessel would further reduce costs over 8000 TEU vessel by $52/TEU. Indicates that container vessels will max out for US West coast at 12000 TEU by 2020. This is due to there being increasing scale economics for ship sizes above 12000 TEU because a change in ship technology is required. These diseconomies aren't offset till ships achieve 14000 TEU or larger. Ports in Asia and NA are not expected to impede ships up to 12000 TEU. Several Asian ports can now, are developing terminals that can accommodate 10000 to 12000 TEU vessels. North American ports other than SPB that can handle these size ships include: Prince Rupert, Vancouver, Seattle, Tacoma, and Lazaro Cardenas, however all others would require improvements to rail yards and lines to handle train volumes required with these larger ships. Notes on East Coast, only Halifax and Hampton Roads have adequate channel and berth depth for 10000-12000 TEU containers. They indicate impact of Improvements in Panama Canal would likely shift some large container moves to East Coast of US from Asia, but shift smaller Panama Canal traffic (4000 TEU) to SPB. Net effect would be insignificant.

CDM on behalf of The Tioga Group. 2006. Maritime Transportation System: Trends and Outlook. Draft Report #1. October 23.

This is an outlook paper focused on the U.S. Maritime Transportation System. They report on several trends (economies of size, port trends, capacity constraints, growth in load centers, interport competition, degree of commoditization, etc.) and reports on DRI-WEFA forecasts for 2010 to 2050. DRI-WEFA indicated U.S. containerized trade has grown at an average annual rate of 6.3%, with fastest growth at Pacific Coast Ports (67.8% annually), followed by Atlantic Coast Ports (55%) and Gulf ports (5.4%). They predict slightly faster growth in near term, returning to trends from 2010 to 2050.

Global Insight. 2005. Trends in the World Economy and Trade, Third Quarter 2004 Forecast. Global Insight. http:www.globalinsight.com. January.

This document presents results of proprietary short term (to 2008) and longer term forecasts (to 2022). Forecast is for world shipping trade where container market is a sub component of world shipping trade. The forecast increases in total container trade from 56 million TEUs in 2000 to 150 million TEUs by 2022.

Kratochvil, John. 2005. Utilizing Inland Waterway, Coastal and Open Ocean Barging of Containerized Agricultural Products to Overcome Existing Service Deficiencies and Increased Transportation Costs: Part II. Oregon Department of Agriculture, Portland OR.

This study evaluates the cost of a short sea alternative serving Alaska and Hawaii from PAW ports/inland barge system. They pose this as an alternative to the increasing trend for ocean shippers to move containers to U.S. from Asia (80% capacity vs. 40% capacity for return shipments) and prefer to have empties shipped back to Asia as quick as possible to carry higher value product to the U.S. rather than shipping agricultural products to Asia. They indicate that the difference in revenue to an ocean shipper can be 3 to 5 times higher for eastbound (Asia to U.S.) shipments over westbound (U.S. to Asia) and is resulting in increased container ship sizes with larger ships moving to alternative ports.

They developed an extensive cost model of a short sea alternative serving Alaska and Hawaii utilizing Articulated Tug/Barge shipping of grains. Results indicate lower cost of operation, however, no barge operators were willing to adopt the new service. Trend is for lower movement of containers at PAW ports.