Navigation Systems

Improving Container Shipment Analysis

Walker Messer, Todd Nettles, Ryan Stoner, and Alicia Sellers

May 2022

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Improving Container Shipment Analysis

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Abstract

US Army Corps of Engineers (USACE) deep-draft navigation economic analyses use assumptions about the sensitivity of vessel operations to channel modification to estimate national economic development benefits. The complexity and proprietary nature of carrier deployment decisions and loading practices adds uncertainty to USACE navigation studies. This report attempts to provide an overview of containership deployment and loading practices as it relates to USACE navigation studies to improve the quality of deep-draft economics. The report relies on trade data, vessel order books, and carrier interviews to study the impact of channel modification on vessel loading and deployment. The report makes recommendations for developing deployment and loading inputs for future economic evaluations.
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Preface

This study was conducted for the US Army Corps of Engineers, Navigation Systems Research Program, US Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), under Funding Account Code U4363796; AMSCO Code 031391. The technical monitor was Dr. Patricia DiJoseph.

The work was performed under the supervision of the Coastal Engineering Branch of the Navigation Division, ERDC-CHL. At the time of publication of this report, Ms. Lauren Dunkin was chief; Ms. Ashley Frey was division chief; and Mr. Charles E. Wiggins was the technical director for Navigation. The deputy director of ERDC-CHL was Mr. Keith Flowers, and the director was Dr. Ty V. Wamsley.

The commander of ERDC was COL Teresa A. Schlosser, and the director was Dr. David W. Pittman.
1 Introduction

1.1 Background

The US Army Engineer Research and Development Center, Navigation Systems Research Program, funded this study to address two Statements of Need (SoN): (1) 2018-1247 - Understanding how carriers make deployment decisions and (2) 2018-1255 - Percentage of Empty Containers moving on Vessels by Key Trade Routes.

SoN 2018-1247 recommends the US Army Corps of Engineers (USACE) conduct research to better understand the factors affecting vessel deployment decisions. The SoN intends the research to go beyond the “general economies of scale argument” and investigate capacity utilization and other determinants of vessel deployment.

SoN 2018-1255 recommends the USACE conduct research to improve enterprise understanding of empty box movements in relation to vessel loading at US ports. The SoN identifies multiple research tasks:

1. Identify impacts empties have on the amount of tonnage a vessel can move depending on where the vessel is in a port rotation on a trade lane.
2. Analyze variation in empty box loading between inbound and outbound transits.
3. Identify empty container types (e.g., standard, refrigerated, chemical, specialty, or other).

1.2 Objective

The objective of this study is twofold: (1) improve enterprise understanding of containership carrier deployment decisions to improve fleet forecasts for feasibility studies and (2) better understand containership loading practices (especially related to empty Twenty-Foot Equivalent Units [TEUs]) to improve deep-draft navigation plan formulation and economic analysis.

1.3 Approach

To achieve the goals of SoN 2018-1247, the research team performed a literature review of carrier deployment strategy, collected and summarized
world fleet and order book trends, and interviewed industry contacts to gain perspective on current and future vessel deployment. The study team makes recommendations for future USACE deep-draft navigation studies based on this research.

The research answers the questions of SoN 2018-1255 through a literature review, empty TEU data collection for all US containership ports, and analysis of trends in empty TEU movements over the past 10 years. The research team developed a container loading tool to assist USACE economists in estimating empty container totals given a range of vessel loading inputs.

The research concludes by describing the relationships between vessel deployments, loading practices, and channel deepening. The study team attempts to quantify the relationship between vessel deployment and loading practices and fleet change. These relationships described in this section further inform future USACE containership analyses.
2 Vessel Deployment

2.1 Containership deployment, legal parameters, and US Army Corps of Engineers (USACE) containership analysis literature review

The following literature review summarizes (1) carrier deployment practices, (2) the legal parameters of deployment, and (3) USACE containership analysis and assumptions related to vessel deployment.

2.1.1 Deployment practice and strategy

Containership carrier decisions fall into three categories: operational, tactical, and strategic (Mulder and Dekker 2016). Operational decisions occur over the short term (approximately 0–1 year) to medium term (approximately 2–5 years) and primarily focus on decisions related to cargo and vessels already under contract. For each route, carriers must make decisions related to cargo routing, disruption management, revenue management, and stowage planning. Operational decisions and their outcomes inform long-term (approximately 5–20 years), tactical planning like vessel fleet and market selection.

Tactical decisions concern the medium-term and long-term planning horizon. These decisions consist of service network design, pricing, and empty container repositioning. In general, tactical decisions concern services and fleet mix, which are constrained by what the carrier already owns or can quickly contract. Sailing speed, bunkering optimization, and schedule design decisions are iterative. These decisions must be made for every new service and reconsidered while the service is operational, therefore crossing the tactical, strategic, and operational planning levels.

Strategic decisions focus on the long term. These decisions primarily concern (1) vessel fleet size and mix and (2) market and trade selection. In theory, carriers are unconstrained by their current fleet of vessels and may procure any desired fleet mix and operate in any market in the long term. Given the length of time for vessel construction, strategic planning takes place over a 2-year minimum time horizon.

Long-term, strategic planning is not isolated from tactical and operational planning. However, the purpose of this research is to inform feasibility
studies, which can require fleet forecasts with up to 20-year planning horizons. As a result, this research primarily concerns long-term, strategic planning. This focus will provide navigation studies insight into anticipated changes in world fleet and how the future fleet will be distributed among trade routes relevant to a study area. In the literature, vessel fleet size and mix are generally referred to as the Fleet Size and Mix Problem (FSMP). Market and trade selection are identified in the literature as the Vehicle Routing Problem (VRP).

2.1.1.1 Vessel fleet size and mix

Pantuso et al. (2014) provide a comprehensive literature review of vessel fleet size and mix problems (FSMP). Of the 36 papers Pantuso et al. (2014) mention, 7 focus on the container industry.

The first mention of FSMP comes in Pesenti (1995), who proposed a heuristic methodology for purchasing and use of container ships involving feedback from all three planning levels (strategic, tactical, and operational). Sigurd et al. (2005) built on the work of Pesenti (1995) to optimize a fleet of 15 different ships on a theoretical container route between Norway and Central Europe using a heuristic branch-and-price algorithm.


Pantuso et al. (2014) further separate vessel deployment literature by constraining the FSMP decision with a fixed number and size of vessels. Bendall and Stent (2001) provided the first attempt to solve this constraint by determining the number of ships to assign to a high-speed service in a hub-and-spoke system based in Singapore. Similarly, Sambracos et al. (2003) proposed the use of a mixed integer programming (MIP) model to determine the number of small container vessels on an Aegean Sea route.

Meng and Wang (2011) developed a planning model for liner shipping companies using dynamic programming for the fleet evolution and MIP for fleet deployment. More recently, Pantuso et al. (2014) provided a hierarchical stochastic program for solving FSMP. Morch et al. (2016)
studied the role of financial performance of carrier investment in capacity expansion for a future fleet.

FSMP literature is important to understanding strategic and tactical decisions in the container industry; however, these academic models make vessel deployment decisions without many real-world constraints. Executives at container liners make fleet size and mix decisions accounting for market volatility, financial constraints, and firm-specific considerations. These agents likely conduct significantly more research and financial modeling than what is available publicly.

The given literature also focuses on optimizing fleet size and mix. This is the goal of firms in the container industry; however, fully optimized fleet size and mix are unlikely a reality for the container industry. There are knowledge gaps preventing any firm from having an optimal fleet or knowing what the optimal fleet is. As a result, the research presented in this study aims to draw from the academic literature but emphasizes actual vessel fleet data and orderbooks to make evidence-based decisions for USACE deep-draft navigation studies.

Theoretical vessel deployment is an important tool to estimate future vessel traffic, and it can serve as a starting point for fleet forecasting. However, USACE studies must incorporate port- and carrier-specific factors in planning studies to make more informed fleet forecasts.

2.1.1.2 Market and trade selection

A carrier’s goal is to maximize profits. In the case of market and trade selection, carriers look to satisfy port demand in a way that optimizes fleet utilization and economies of scale. The process of market and trade selection is a long-term, strategic decision that takes place over an annual or multi-year timeframe.

Existing literature on market and trade selection is relatively limited compared to the vessel fleet size and mix problem. There is available research on optimization of trade route selection and schedules (Lirn et al. 2004). This analysis looks at optimizing port schedules and rotations through either pendulum (back-and-forth) services, multiport services, or hub-and-spoke services where fewer calls are made to larger, hub ports that connect cargo to smaller ports in the region.
Market and trade selection determine the vessel size used and built by carriers and impact port development opportunities. Hub-and-spoke systems tend to favor larger vessels calling a small number of the world’s largest ports. Pendulum and multiport services use small-to-medium-sized containerships and call at relatively smaller ports (Notteboom and Talley 2012).

Recent work on market and trade selection is generally classified as the “Vehicle Routing Problem.” This body of work uses advanced models to optimize trade routes. A subset of this work focuses on maritime trade with a limited number of articles addressing container shipping. Recent work incorporating port draft limits into route optimization modeling is most relevant to this study (Choudhary et al. 2019; Gelareh et al. 2020). Similar research and modeling may be taking place within industry; however, it is unknown to what extent the literature lines up with actual practice. Importantly, the methodologies used in the academic literature should be able to approximate carrier actions assuming profit maximizing behavior.

### 2.1.2 Shipping laws

The International Maritime Organization (IMO) is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. Outside of national governments, which can set regulations for specific coastlines and ports of call, the IMO is the main regulatory body for international container shipping. In the IMO most recent Review of Maritime Transport (United Nations Conference on Trade and Development 2019), the primary legal and regulatory developments currently under consideration by the agency include (1) development of regulatory framework for maritime autonomous surface ships, (2) reduction of greenhouse gas emissions, (3) reduction in fraudulent ship registration, and (4) gender equality in maritime shipping. Maritime autonomous surface ship considerations are an area of interest as it relates to the future container fleet outlook; however, the most relevant regulation concerning this study are likely the IMO regulations around the reduction in greenhouse gas emissions.

Under the 2015 Paris Agreement, Article 2.2 of the Kyoto protocol specifies that parties shall pursue the limitation for reduction of greenhouse gas emissions from marine bunker fuels by working through IMO. The IMO 2020 initiative was born from this protocol. This
regulation states that as of January 2020, sulfur emissions of all maritime vessels must be limited to 0.5% mass by mass, down from 3.5% (United Nations Conference on Trade and Development 2019). This created a need for many carriers to switch fuel types or install scrubbers to reduce emissions. Carriers are primarily choosing to retrofit vessels with scrubbers, which may be lower cost in the long term compared to switching fuel types (Do 2019). In the short term, this means lower shipping capacity across all major liner services. Considering the short-term drop in spring and summer demand associated with COVID-19, this may have minimal effect on shippers. In the long term, shippers will likely consider new vessel types (e.g., liquified natural gas-powered containerships) and adjust deployment decisions and routing. This could also shorten the lifespan of the current fleet as older vessels are scrapped in place of retrofitting.

2.1.3 USACE deployment assumptions

The Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (USWRC 1983) provides the fundamentals of USACE vessel deployment methodology. The P&G instructs economists to use present data and past trends to determine future vessel fleet composition. The guidance determines that the “optimum size vessel” is not always available for charter. Instead, the economist should use a range of vessels expected to call in the with- and without-project conditions. The document recommends use of US Department of Transportation (US Maritime Administration) trade journals, trade associations, shipbuilding companies, and vessel operating companies for additional data. USACE Engineer Regulation (ER) 1105-2-100 (2000) reiterates this approach.

Institute for Water Resources (IWR) Report 10-R-4 (2010) details recommendations on USACE vessel deployment and fleet forecasting. The document offers two general approaches to determining fleet mix and size: (1) top-down approach and (2) bottom-up approach. The top-down approach generally disaggregates world or national fleet and trade forecasts to the port-level based on historical share of the world fleet and world trade. This methodology is particularly useful for long-term forecasts and capturing macroeconomic trends.

Bottom-up forecasts rely on input from shippers. Understanding the planned changes in shipping operations in terms of fleet usage and trade is
a good method to estimate short-term trends. However, these forecasts may be unreliable. Markets are volatile, and changes can be made in the shipping industry quickly.

IWR Report 10-R-4 (2010) recommends using a hybrid of the bottom-up and top-down forecast. This methodology will lead to compromises between macroeconomic forecasting and port-specific trends, but it is likely the best way to insure a reasonable estimate in line with long-term market trends. Most USACE studies rely on contracted industry forecasts to complete deep-draft navigation studies.

2.2 World fleet of containerships

USACE analysis relies on historical and existing market conditions to forecast future trends. As of 2017, world container trade totaled over 750 million TEUs, the result of 7.4% compound annual growth from 2000 through 2017 (Figure 1). Asian trade drove world container trade growth over that period, accounting for 55% of all containerized trade by 2017. The United States represents an increasingly smaller portion of total world trade, down to 7% in 2017.

![Figure 1. World container trade, 2000–2017 (World Bank).](image)

Container carriers met the growing demand for container trade with expansion of the world fleet capacity (Figure 2). From 2000 through 2017, carriers added 16.4 million TEU capacity to the world fleet. The number of vessels in the world container fleet increased to 5,154 in 2017, a net vessel count increase of nearly 2,500. Average nominal TEU capacity increased from 1,800 TEUs in 2000 to over 4,100 TEUs in 2017. During the same
period, maximum TEU size of all vessels increased from under 8,000 TEUs to 20,000 TEUs.

**Figure 2. World container fleet capacity by vessel TEU class, 2000–2017**

(Maritime Strategies, Inc.)

As of February 2019, over 5,200 container vessels were in service with 462 vessels on order (Table 1). TEU capacity of the world fleet continues to grow, particularly for vessel classes with the highest TEU capacity. As of 2019, the world order book showed 57% of all planned capacity on vessels above 14,000 TEUs. The average capacity of all vessels in service and on order is nearly 4,400 TEUs. Vessels on order will add nearly 3 million TEU capacity to the world fleet (14%). Nearly 57% of this new capacity will be from vessels with 14,000 TEU capacity and greater.

**Table 1. Containerships in service and on order, 2019 (Lloyds List February 2019).**

<table>
<thead>
<tr>
<th>TEU Size Range</th>
<th>In-Service No.</th>
<th>In-Service TEU</th>
<th>Total On-Order No.</th>
<th>Total On-Order TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2,999</td>
<td>2,869</td>
<td>4,005,394</td>
<td>284</td>
<td>533,990</td>
</tr>
<tr>
<td>3,000-4,999</td>
<td>808</td>
<td>3,331,229</td>
<td>25</td>
<td>85,488</td>
</tr>
<tr>
<td>5,000-10,999</td>
<td>1,123</td>
<td>8,395,102</td>
<td>10</td>
<td>57,700</td>
</tr>
<tr>
<td>11,000-13,999</td>
<td>209</td>
<td>2,674,403</td>
<td>51</td>
<td>598,813</td>
</tr>
<tr>
<td>14,000-17,999</td>
<td>113</td>
<td>1,660,089</td>
<td>44</td>
<td>656,938</td>
</tr>
<tr>
<td>18000+</td>
<td>90</td>
<td>1,749,942</td>
<td>48</td>
<td>1,041,738</td>
</tr>
<tr>
<td>Total</td>
<td>5,212</td>
<td>21,816,159</td>
<td>462</td>
<td>2,974,667</td>
</tr>
</tbody>
</table>
The trend toward larger vessels accelerated after 2000 and continues today. The strategy is part of carriers’ long-term strategy to capture economies of scale and maintain a competitive fleet mix. Critically, overall trade must continue to grow to realize these economies of scale. Large vessels require high utilization rates to reduce the per unit transportation costs. Today, there is a potential oversupply of vessel capacity, leading to underutilization on many large containerships. Per-unit shipping costs in this scenario are higher than on a more efficiently loaded, smaller vessel. Additionally, larger vessels can create dis-economies of scale in port due to the dockside infrastructure required by large ships.

Average containership lifespan is at least 20 to 25 years, and new vessels can take multiple years to build. This leaves carriers with a relatively fixed vessel fleet. Similarly, carriers must offer consistent services to allow customers to plan around sailing schedules and destinations. This means that carriers do not make significant changes to services more than once per year.

Competition among carriers for new-builds and overconfidence in demand growth led to the current oversupply of large containerships on routes such as Asia-Europe services. As a result, carriers must optimize their fleet by slow steaming, implementing blank sailings, and repositioning larger vessels on Asia-Europe services to relatively sub-optimal routes (e.g., transpacific, Asia-Mediterranean, and Asia-Middle East routes). As this trend continues, transpacific routes will likely see more large containerships added each year. In 2017, the London-based shipping research and consulting firm Drewry estimated that as many as 68 ships will be repositioned from Asia-Europe services (Desormeaux 2017). The transatlantic routes will also see an impact from the cascading effect; however, it will be limited on some routes by the Panama Canal size constraints.

Figure 3 presents the Organization for Economic Co-operation and Development (OECD) Container Ship Size and Port Relocation forecast for the transition of vessel sizes to transpacific routes through 2025 (International Transport Forum 2018). As shown, transpacific routes have increased average and maximum vessel size significantly between 2015 and 2020. By 2025, the OECD assumes the transpacific fleet will reflect the 2015 Far East-Europe fleet. USACE studies with transpacific traffic should consider this approximate 10-year lag when forecasting fleet transition.
2.2.1 Carrier fleet mix and size and deployment decisions

Container carriers’ objective is twofold: (1) lower shipping and inventory costs and (2) enhance services to attract more shippers. Their most critical tool is vessel deployment. The first objective led to the current emphasis on deploying larger vessels with lower unit costs. The second objective, however, can fall victim to the first. Increasing vessel size can lead to fewer overall vessel calls and route limitations caused by port capacity constraints. This sacrifices some level of service for shippers. Finding equilibrium between these two objectives requires tactical and operational changes in the short to medium-term. In the long term, carriers must consider changes to vessel fleet size and mix.

Long-term changes to the fleet size and mix take place through carriers’ decision to expand or contract fleet capacity. Carriers can purchase vessels secondhand or build them independently. Purchased vessels can be made available within months while built vessels take several years to be put into service. Alternatively, carriers can sell or scrap ships to reduce their overall fleet capacity.

Carriers base their fleet size and mix decision on whether to expand, contract, or maintain total capacity based on individual firm financial
conditions and cost minimization. Factors influencing this decision include current fleet maintenance cost, fuel and labor costs, commodity and construction costs for newbuilds, and other market conditions.

### 2.2.2 Container services and recent trends in vessel deployment

As of September 2019, US ports received calls from 199 liner services. The US East Coast (USEC), US West Coast (USWC), and US Gulf Coast (USGC) supported 93 services, 68 services, and 25 services, respectively. A total of 13 services called a combination of USEC, USWC, or USEC. Table 2 summarizes all liner services calling US ports in 2019. These 199 liner services form 36 individual trade lanes with US port calls. A total of 14 trade lanes call the USEC, 9 include the USWC, 6 include the USGC, and 7 include some combination of USEC, USWC, and USGC.

<table>
<thead>
<tr>
<th>Trade Lane</th>
<th>USEC</th>
<th>USWC</th>
<th>USGC</th>
<th>USEC &amp; USGC</th>
<th>USWC &amp; USEC</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>15</td>
<td>38</td>
<td>3</td>
<td>2</td>
<td>-</td>
<td>58</td>
</tr>
<tr>
<td>Caribbean/NCSA</td>
<td>43</td>
<td>1</td>
<td>15</td>
<td>1</td>
<td>-</td>
<td>60</td>
</tr>
<tr>
<td>Domestic</td>
<td>1</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>East Coast South America</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Europe-Caribbean</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Europe-Oceania</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Europe-South America</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Intra-Asia</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>Northern Europe</td>
<td>9</td>
<td>-</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Oceania</td>
<td>2</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>South America</td>
<td>-</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>West Coast South America</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Middle East/South Asia</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>South/East Africa</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>93</strong></td>
<td><strong>68</strong></td>
<td><strong>25</strong></td>
<td><strong>11</strong></td>
<td><strong>2</strong></td>
<td><strong>199</strong></td>
</tr>
</tbody>
</table>
Where possible, USACE analysis should separate results by service. Given the number of individual services, this will not always be practical, and data will be divided at the lowest level of detail necessary. Analysis will also determine at what level these trade lanes can be grouped based on observed differences in vessel loading, distance traveled, and vessel sizes used.

2.3 **USACE container analysis assumptions for channel deepening studies**

This section reviews methodologies used on the previous 19 USACE deep-draft navigation deepening studies incorporating container analysis. These studies took place between 2003 and 2020 with three studies still in draft phase. Geographical extent covers all three US coasts with eleven East Coast studies, four Gulf Coast studies, and four West Coast studies. This survey of USACE methodologies helps establish an understanding of current container analysis within the agency and identify potential areas for improvement.

2.3.1 **Survey of USACE methodology**

Loading inputs for USACE studies tend to be based on both internal USACE data and independent, contracted studies. Internal data primarily come from loading information from the Waterborne Commerce Statistics Center and the National Navigation Operation and Management Performance Evaluation and Assessment System (NNOMPEAS) tool. Studies tend to use similar utilization estimates as other studies on the same coast with some port-specific changes.

Of the 19 studies surveyed, the most common assumption used for loading changes due to channel deepening is the use of a 0.7 ft shift in the transit draft distribution per 1 ft of channel deepening. This assumption first appeared in the Charleston Harbor Deepening Study (completed in 2015). The assumption is based on IWR estimates of vessel operational changes.

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due to channel deepening. IWR estimated between 0.6 and 0.8 ft in additional vessel loading per foot of channel deepening. Charleston Harbor assumed an average of 0.7 ft of additional vessel loading. Subsequent studies that followed this methodology include Mobile Harbor, Seattle Harbor, Tacoma Harbor, Long Beach, Port of New Orleans, and Tacoma Harbor. Documentation of IWR estimate is not currently available.

The second-most common methodology for estimating vessel loading changes is to assume only the upper bound of the sailing draft distribution will shift with channel deepening. This method keeps the mean sailing draft constant but assumes the upper portion of the sailing distribution is limited by channel depth. With each foot of channel deepening, a portion of vessels at the upper bound of the sailing draft distribution increase loading by a full foot until the maximum sailing draft can be reliably reached. This methodology is used in three studies in the survey: Jacksonville Harbor, Port Everglades, and Norfolk Harbor.

One study, Savannah Harbor (Savannah District 2012), estimated the difference in loading practices between US ports with varying channel depths. The study assumed channel deepening would lead the future fleet of vessels to approximately mimic the sailing draft distribution of other similar ports in the region. For channel depths that are not available at other US Ports, the study extrapolated sailing draft distributions by estimating the rate of change in sailing drafts for each additional foot of deepening.

Other deepening studies assumed that at certain depths either a fleet transition would take place (Freeport and Wilmington) or that carriers would be able to optimize routes leading to transportation cost savings (Philadelphia). These methodologies are more port specific and require a less detailed understanding of changes in vessel loading practices.

2.3.2 Outcomes by methodology

The benefit cost analysis of each deep-draft navigation study is complex and dependent on various factors in both the benefit and cost evaluations. This section attempts to describe differences between outcomes for each vessel loading assumption. Table 3 lists the depth at which the maximum sailing draft is achieved by the design vessel and the channel depth selected (or tentatively selected) as the recommended plan.
Table 3. USACE vessel loading methodology.

<table>
<thead>
<tr>
<th>Study</th>
<th>Year of Most Recent Study</th>
<th>Draft/Final</th>
<th>Brief Description</th>
<th>Depth at which Sailing Draft Maximized</th>
<th>Selected Channel Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philadelphia</td>
<td>2003</td>
<td>Final</td>
<td>Change in route</td>
<td>N/A</td>
<td>45 ft</td>
</tr>
<tr>
<td>Freeport</td>
<td>2018</td>
<td>Final</td>
<td>Fleet transition</td>
<td>N/A</td>
<td>50 ft</td>
</tr>
<tr>
<td>Wilmington</td>
<td>2019</td>
<td>Final</td>
<td>Fleet transition</td>
<td>N/A</td>
<td>47 ft</td>
</tr>
<tr>
<td>Charleston</td>
<td>2015</td>
<td>Final</td>
<td>Benefitting class shifts sailing draft 0.7 ft</td>
<td>52 ft</td>
<td>52 ft</td>
</tr>
<tr>
<td>Mobile Harbor</td>
<td>2017</td>
<td>draft</td>
<td>Benefitting class shifts sailing draft 0.7 ft</td>
<td>N/A</td>
<td>50 ft</td>
</tr>
<tr>
<td>Seattle</td>
<td>2017</td>
<td>Final</td>
<td>Benefitting class shifts sailing draft 0.7 ft</td>
<td>57 ft</td>
<td>57 ft</td>
</tr>
<tr>
<td>Long Beach</td>
<td>2019</td>
<td>Draft</td>
<td>Benefitting class shifts sailing draft 0.7 ft</td>
<td>55 ft</td>
<td>55 ft</td>
</tr>
<tr>
<td>Port of New Orleans</td>
<td>2020</td>
<td>Draft</td>
<td>Benefitting class shifts sailing draft 0.7 ft</td>
<td>54 ft</td>
<td>50 ft</td>
</tr>
<tr>
<td>Tacoma</td>
<td>2020</td>
<td>Draft</td>
<td>Benefitting class shifts sailing draft 0.7 ft</td>
<td>57 ft</td>
<td>57 ft</td>
</tr>
<tr>
<td>Jacksonville</td>
<td>2014</td>
<td>Final</td>
<td>Mean constant, shift sailing draft upper bound</td>
<td>49 ft</td>
<td>47 ft</td>
</tr>
<tr>
<td>Port Everglades</td>
<td>2015</td>
<td>Final</td>
<td>Mean constant, shift sailing draft upper bound</td>
<td>48 ft</td>
<td>48 ft</td>
</tr>
<tr>
<td>Norfolk</td>
<td>2018</td>
<td>Final</td>
<td>Mean constant, shift sailing draft upper bound</td>
<td>55 ft</td>
<td>55 ft</td>
</tr>
<tr>
<td>Miami</td>
<td>2004</td>
<td>Final</td>
<td>N/A</td>
<td>50 ft</td>
<td>50 ft</td>
</tr>
<tr>
<td>Boston Harbor</td>
<td>2013</td>
<td>Final</td>
<td>N/A</td>
<td>48 ft</td>
<td>48 ft</td>
</tr>
<tr>
<td>Houston Ship Channel</td>
<td>2015</td>
<td>Final</td>
<td>Non-federal deepening action</td>
<td>N/A</td>
<td>45 ft</td>
</tr>
<tr>
<td>Savannah</td>
<td>2012</td>
<td>Final</td>
<td>Rate of change held constant within vessel class</td>
<td>50 ft</td>
<td>47 ft</td>
</tr>
</tbody>
</table>
The survey indicates that in eight of nine studies using sailing draft shift methodology, the recommended channel depth matches the maximum sailing draft of the design vessel. This is to say that in most cases, the benefits of adding an additional foot of channel capacity outweigh the costs of dredging. This observation holds despite differences in methodology. Both studies that shift the entire sailing draft distribution and those that hold the mean draft constant and only shift the upper bound appear to lead to similar depth recommendations.

2.3.3 Recommendations for future analysis by key trade lane

The most prominent container loading methodologies (shifting the transit draft distribution by 0.7 ft and shifting only the upper bound) likely lead to consistent plan selection across USACE container studies. Future selection of methodology should depend on port-specific considerations. Shifting the entire sailing draft distribution by 0.7 ft per foot of channel deepening is meant to estimate the average increase in loading within a class. Vessels load at different sailing drafts for a variety of market and environmental reasons, this methodology is only meant to estimate average change in operations. The methodology may be best suited to studies where the design vessel or the vessel classes of interest have not transited the study channel or have infrequently called the port. In these cases, there are limited data available to estimate sailing draft distributions.

Holding mean sailing draft constant and only shifting the upper bound of the draft distribution is likely more consistent with how vessels would respond to channel deepening. However, there is uncertainty in determining what portion of the sailing draft distribution will continue shift without detailed vessel call data for the design vessel and consideration must be given to the additional cargo capacity available to carriers in each scenario. The shift of 0.7 ft for the benefiting vessel classes is considered a reasonable approach to calculating the overall efficiencies gained when analyzing a deeper channel configuration. Previous studies have also based the sailing draft distributions relying on empirical data from other US ports. This is a strong, data-based methodology. However, sailing drafts for vessels estimated to call in the future and currently calling infrequently are difficult to estimate. In the end, both methodologies can be considered appropriate for analysis.
3 Containership Loading

3.1 Variables impacting containership loading

Containership loading is based on fixed and variable loading parameters. Fixed container loading parameters include bunkerage and allowance for operations. Variable loading parameters include all other loading inputs including ballast, loaded slots, empty slots, and vacant slots. Within each loaded slot, the weight of each container also impacts vessel loading and operations. Fixed inputs are based on vessel designs. USACE forecasters have access to vessel design inputs to make assumptions about the fixed variable inputs of containership loading.

Variable inputs are often the result of port-specific analysis. Loaded TEU weights, for example, are relatively consistent by trade lane as countries’ commodity flows are relatively similar. These data are also readily available as TEU weights are monitored and reported by US Customs. Empty TEU estimates are also monitored, but trends in empty TEUs receive less consideration in USACE studies. Most studies estimate empty TEU percentages based on historical empty TEU share.

3.2 Empty Twenty-Foot Equivalent Unit (TEU)

The study uses empty TEU volume data from 1998 through 2018¹ to make observations about empty TEU movements at US Coastal Ports and identify trends for consideration in future USACE container studies. First, the study makes general observations about historical empty TEU movements at major US Ports. General trends are summarized. The study includes a survey of previously completed container studies and their assumptions related to empty TEUs. Implications for future TEU movements are added to the discussion.

3.2.1 Historical empty TEU movements

Over the 158 observations of annual TEU data at US ports with available data, average empty TEU as a percentage of total TEU volume had a

¹ Data as available through Waterborne Commerce Statistics Center.
minimum of 14% of total international TEUs, an average of 29% of total, and a maximum of 48% of total TEUs.

West Coast, East Coast, and Gulf Coast ports averaged 32%, 25%, and 26% empty TEUs as a percentage of total TEUs, respectively. The study found relatively consistent empty TEU percentage over time. The average standard deviation of average empty TEUs for all ports was 4%. No port experienced a standard deviation across the study period of more than 6% (Houston Ship Channel). This consistency indicates general support for the use of past empty TEU percentages in predicting future throughput. However, there are noticeable trends in the data, and year-to-year empty percentages and overall percentages can vary by as much as 20% for a port over 2 decades. Figure 4 shows empty TEUs as a percentage of total TEU volume for select ports.

![Figure 4. Percentage of empty TEUs by port.](image)

**3.2.2 USACE empty TEU assumptions**

USACE studies typically assume that historical empty TEU percentages are the strongest predictor of future empty TEU percentages. Of the 19 USACE container studies surveyed, 13 provided some description of empty TEU percentages used for vessel loading. All 13 of these studies extended the historical average empty TEU percentage through the study period.

Given the relatively low variation in empty TEU percentage over time at US ports, this methodology will likely lead to a relatively accurate percentage if historical trends are predictive of future empty TEU trends. However, note that empty TEU percentage is an important load factor input that can have large impacts on overall transportation cost savings.
As additional empty TEUs are loaded onto a vessel, less room is available for loaded TEUs, restricting the maximum sailing draft of a vessel and, consequently, lowering the potential for channel deepening benefits.

The regression analysis described in Section 5 indicates that for every 1% increase in the percentage of empty TEUs, average sailing draft drops by as much as 3 in., all else equal. Applying the maximum standard deviation of 6%, this could change the average potential sailing draft of vessels by nearly 1.5 ft depending on how the analyst applies historical empty TEU percentages to the forecast and load factor analysis.

Additionally, the HarborSym model limits USACE analysis to only one input for the percentage of Empty TEUs. This value applies to the percentage of total TEUs onboard that are empty versus loaded. Generally, there should be relatively low impact on the percentage of empty TEUs from one port call. In some cases, the number of empty TEUs loaded on a vessel backhaul can impact the total percentage of empty TEUs and make significant changes to a vessel’s load capacity. This could impact container analysis and total benefits. USACE should work to develop a model that allows for changes in empty TEU percentages between import and export.

3.2.3 Overview of empty TEU container trade and repositioning

Empty TEUs are the result of trade imbalance between regions within a container route. Net importers bring in more loaded containers than they can fill with exports. The US imports relatively more loaded TEUs from Asia than it can fill and send back loaded. As a result, the outbound legs of US container calls tend to have a higher percentage of empty TEUs than on the inbound legs. There is a negative relationship between the number of empty TEUs and vessel sailing draft; however, it is possible for vessels with higher empty TEU volumes to draft at deeper sailing drafts depending on the average weight of loaded containers onboard.

Empty TEU repositioning is a global logistics challenge. Container carriers seek to maximize container utilization to lower overall transportation costs. Empty containers take up landside and vessel space that could otherwise be used for more profitable, loaded containers. Figure 5 displays the US trade imbalance in terms of Loaded TEUs. As shown, the United States is a net importer of loaded TEUs. The magnitude of the trade imbalance has increased in recent years, with 2017 seeing a net import of 9.8 million TEUs. The 2017 trade imbalance leads to 9.8 million loaded TEUs entering the
United States that will not be able to be loaded for export. These empty TEUs are stored, destroyed, or sent back on backhaul. This leads to significant logistics costs for carriers and lowers port cargo capacity.

![Figure 5. US trade imbalance in TEUs.](image)

Recognizing this trend over time, USACE studies should consider the future of the trade imbalance in each port study. Empty TEU volume closely tracks the trade imbalance with an estimated correlation from 2003 through 2017 of 83% (i.e., changes in the trade imbalance account for approximately 83% of changes in empty TEU volumes). Importantly, this analysis shows that future empty TEU percentages do not necessarily track past trends, and the number of empty TEUs on backhaul transits does not perfectly follow the TEU trade imbalance. The cost of TEU production abroad and transportation cost to coastal ports also impacts the number of TEUs that are exported.

Figure 6 provides estimated total TEU trade (import and export at all US ports) and the estimated empty TEU throughput. Currently, USACE and other agencies tracking TEU volumes trade do not officially track empty TEU volumes. The following estimate of empty TEU volume is based on the difference between the total TEU trade volume estimated by the American Association of Port Authorities and the USACE Waterborne Commerce Statistic’s Center’s loaded TEU estimates.
Technological developments like foldable containers could significantly change future empty TEU percentages. These containers would reduce the onboard space used by TEUs by as much as 75% and save carriers as much as $650 per container compared to shipping a typical empty container (Press 2019). Additionally, container carriers could become more efficient in the future by incorporating sophisticated empty container repositioning tools that could reduce overall empty TEU percentages.

3.3 USACE container loading tool

The study team developed a container loading spreadsheet tool to estimate empty TEU loading given a range of vessel inputs. This section describes the methodology and required inputs for the tool. A copy of the spreadsheet can be made available by contacting the Deep Draft Navigation Center of Expertise at DDNPCX@usace.army.mil.

3.3.1 Methodology

The HarborSym Container Model Suite of Tools is the primary tool used for containership transportation costs savings analysis in USACE deep-draft navigation studies. This model converts vessel loading inputs into container vessel call lists for use in the HarborSym model. The container model suite of tools requires the user to input (1) vessel design characteristics, (2) sailing draft distributions, and (3) estimated loading
parameters. The model creates a simulated call list based on user input commodity forecasts and route group characteristics.

By manipulating the Container Model Suite of Tools loading algorithm, the study team developed a spreadsheet tool to recreate vessel call lists and estimate vessel loading parameters, including empty containers. Like the HarborSym container model, the spreadsheet tool requires (1) vessel design characteristics, (2) sailing draft distributions, and (3) estimated loading parameters. However, the spreadsheet tool allows users to quickly manipulate each input to better calibrate vessel loading parameters based on historical vessel call lists. In order, the tool requires users to input (1) a commodity forecast/throughput estimate, (2) cargo distribution by vessel class, (3) vessel loading parameters, (4) sailing draft distributions, and (5) vessel design characteristics. The tool then develops a vessel call list based on the inputs and provides a total vessel estimate by class. The following provides more detail on calculations and steps.

1. **Commodity Forecast/Throughput Estimate.** This spreadsheet tab requires the user to specify import and export volumes in metric tons. For highest accuracy, the user should input values for one route group at a time.

2. **Cargo Distribution.** The user defines vessel classes based on vessel size (see tab “Vessels” for classification parameters). The user enters values for “% Total Cargo” based on cargo volume distribution by vessel class. This value is based on total cargo (import plus export). The spreadsheet automatically distributes tonnage across each vessel class based on the user-input distribution.

3. **Loading Parameters.** This tab includes all loading inputs by vessel class. The user inputs values based on available loading data. Estimated values can be pulled from the NNOMPEAS data base or other vessel call databases. The user should iteratively adjust estimates on this tab based on the accuracy of the tool’s outputs.

4. **Sailing Draft.** User-developed sailing draft cumulative distribution function by vessel class.

5. **Vessels.** Representative vessel by vessel class. The user can adjust vessel parameters based on port-specific vessel fleets and distributions.

6. **Vessel Call Worksheet.** Tool-generated vessel call list. Based on inputs from five previous tabs. The tab pulls from the sailing draft distribution to simulate vessel loading. The tab can be updated to pull new values and generate a new vessel call list.
7. *Max Vessel Estimate*. Output summary of total calls generated by class. The user should use this tab to calibrate loading inputs on previous tabs. For example, adjustments can be made to Empty TEU percentages to see if it improves accuracy of the fleet estimate.

### 3.3.2 Use

The spreadsheet tool will be useful for analysts in the early stages of study development. The tool can generate simulated call lists in a fraction of the time required for the HarborSym container tool. Additionally, the user can quickly test changes in inputs to estimate the change in vessel loading and vessel calls. It will serve to calibrate the Container Loading Tool module more efficiently within the HarborSym Model Suite of Tools (HMST).

The tool is not meant to replace the HarborSym model for evaluation of deep-draft navigation projects. It is not certified and cannot be used to generate results for decision making. Results will still need to be run through the HMST for verification and use. Figure 7 shows example inputs and outputs from the spreadsheet tool.

*Figure 7. Spreadsheet tool example setup and outputs.*
4 Carrier Survey/Interview

This section contains the feedback of numerous discussions held between USACE and two container carriers that operate in multiple world regions that currently service the US East, West, and Gulf Coasts. The perspective of the carriers is critical to USACE deep-draft navigation economic analyses. A better understanding of how these carriers make decisions for the size of the vessels in their fleet and specifications of individual vessels calling on a harbor allows for a higher level of confidence in the analysis conducted to recommend federal investment in a proposed channel modification or defend a recommendation of no additional federal investment.

The carriers were asked for their perspective on a range of topics that included timelines for operations, vessel deployment at the US national level, how channel improvements at a single harbor impact the trade lane, impacts of landside costs, their ability to adapt once a channel modification has been made, an assessment of the current US infrastructure, trends in vessel utilization, and anticipated COVID-19 Impacts.

4.1 Operation timeline for container carriers

When deciding to build a new vessel, the carriers are generally planning for a life cycle somewhere between 20 and 25+ years. The deployment plans for those vessels are deciding what world regions or ports in those regions “would be appropriate for deploying” based on 3- to 12-month schedules depending on the carrier, but the carriers are regularly making changes based on charter rates and other factors such as seasonal demand. For the US market, factors such as back-to-school and the holiday season can cause a carrier to make an adjustment to vessel deployment each year. If commercial demand is high, the carrier will attempt to use the largest vessel possible to maximize economies of scale thus resulting in the deployment of vessels with an increased carrying capacity (or TEU rating).

4.2 Vessel deployment over the next decade (2020 – 2030)

The carriers are always assessing the value of having larger vessels service their trade lanes. Globally, Asia to Northern Europe is where the world’s largest vessels are deployed. Next is Asia to the Middle East, followed by Asia to the Mediterranean. Then comes North America with vessels deployed from Asia to the West Coast, then East Coast United States. The
ship-building market goes through cycles based on the price of steel. Orders to delivery for new vessels is based on time frames that generally range from 18 to 36 months; however, some can take as long as 5 years. The world market can have significant changes during that time. Vessel deployment is based on annual evaluations. There were some minor differences amongst the carriers regarding the TEU size of the vessels that will be deployed to the United States over the coming 5 to 10 years; however, there was similar information provided on which vessel class ranges are anticipated to call on the East, West, and Gulf Coasts in the near future. Multiple carriers also mentioned that the rationale for deployment was based more on the “string level” than a coast-by-coast basis. Taking that information into account, the carriers anticipated approximately 11,500 to 13,000 TEU vessels for the US East Coast; 13,000 to 15,000 TEU vessels are anticipated to call in increasing numbers for the US West Coast; and approximately 8,500 TEUs for the Gulf Coast with possible adjustments during peak season. The difference in size of the vessel deployed is related to the fact there are more restrictions on East Coast harbors related to channel depth and air draft than West Coast harbors. While these vessels classes are anticipated to call with significant frequency over the next decade, a few carriers did express desire to add vessels up to 18,000+ TEUs when feasible, but multiple ports would have to be able to handle a vessel of that size efficiently.

4.3 Impacts of channel improvements on vessel deployment

A channel modification to a single port does not have a significant impact to the vessels deployed on an individual service. The carriers evaluate the restrictions on each of the ports that are included in a service before determining which vessels to deploy on a trade lane or individual service. Those restrictions can include the time necessary to transit from the entrance of the harbor to the dock or the need to “ride the tide” when calling on the harbor. The carriers have gathered the pertinent data on each harbor’s restrictions both domestically and along the foreign harbors that the vessel will call. The caveat to that rule would be if the channel modification being made is the limitation on the entire service. The carriers will make their decisions based on the vessels that can best accommodate the restriction on the service. The driving factor is usually imports coming to the United States and the overall need to deliver the commerce regardless of the constraint in the region.
4.4 Landside and other associated costs

US population centers are a significant factor when determining where cargo will be handled. Another factor when determining where cargo will be delivered is an evaluation into the land side capabilities of the harbor. The Port must have the ability to offload and clear terminals within a week due to weekly sailings. The carriers will evaluate the time frame necessary to remove the cargo from the vessels by assessing the number of cranes or moves per hours the cranes can make during a given time frame. There is also an evaluation of the time necessary for the cargo to be transported from land side at the harbor to the hinterland or destination of the cargo. A lack of inland capabilities to move cargo within a week can limit the size vessels calling on a harbor as well. The carriers also assess the mix between imports and exports for an individual harbor to be able to plan capacity and container movements.

Another factor is rail versus road delivery. Rail tends to the be the cheaper method of delivery when cargo is being transported to similar locations and drives the decision for the carriers when determining the first call on North America; however, road may be used when one harbor is closer to the destination than another. The total cost to transport goods to its final location, along with the time associated with handling those goods, goes into the decision-making process.

4.5 Carriers’ ability to adapt to change of a harbor

Carriers are evaluating the market every 3 to 6 months. Their operational practices are adjusted on routine basis that can occur anywhere from 3 to 12 months depending on the carrier. It is expected that any change to an existing channel footprint within the United States would take years to implement. The carriers were all in agreement that once the channel improvement was complete, the carriers would take advantage of that modification immediately.

4.6 US infrastructure needs

The carriers all mentioned that US hinterland and port infrastructure were a concern for them moving forward. According to these carriers, neither have kept pace with today’s growth and are not ready for continuing growth in the future. Specific points of interest were the ability to move cargo inland, or away from the ports to the hinterland and the West Coasts.
port’s total capacity and ability to handle increased demand. Two positives mentioned were the expansion of the Panama Canal allowing larger vessels, thereby increased cargo per call, to the East Coast from transpacific routes and the growth in Canada’s ability to handle cargo on its West Coast and transport goods to the mid-West United States.

4.7 COVID-19 Impacts to deployment decisions

This report was completed and informed by interviews taking place in the Summer of 2020. Carriers were preparing for various scenarios; however, the impacts are anticipated to be relatively temporary. The anticipated rebound of cargo growth was described as “V” to “U” shape depending on how long the global impacts of COVID are felt and an increase in consumer confidence. There was expectation that a significant demand for cargo would appear after consumer growth had been stagnant for approximately 6 months. It was anticipated that the overall base cargo volume will be lower at the beginning of 2021 but build gradually through the year. Restocking would occur, leading to slower growth afterwards. Currently, East Coast throughput volume is similar to the West Coast. East Coast growth tends to be associated with European trade lanes while West Coast growth leans heavily towards the Far East lanes. Continued growth in the future will depend on how those regions recover from the impacts to trade related to COVID-19.

The following links demonstrate ongoing recovery to international trade that has occurred in recent months.

1. https://ticotimes.net/2020/10/06/panama-canal-breaks-cargo-record-despite-pandemic-us-china-trade-war

The delta variant and supply chain issues of 2021 took place after carrier interviews and this report were completed. As expected by carriers, restocking took place leading to congestion at major US Ports. Although recovery as slowed from the Delta variant, port congestion beyond expectation continues at US Ports as of late 2021. Long-term impacts should continue to be tracked by USACE.
5 Deployment and Loading Relationships

This section provides an overview of a regression analysis testing the impact of channel depth on vessel loading and deployment. Results of the analysis are intended to provide additional context for USACE deep-draft economic analyses and improve assumptions related to the impact of channel deepening on vessel operations.

5.1 Vessel operations and channel depth

Based on the sample of US coastal ports used in this analysis, deeper ports tend to receive calls from larger vessels. This is because larger vessels tend to be used on higher-volume routes, and higher-volume routes tend to call at larger ports with capacity to handle larger ships. Figure 8 provides the average deadweight tonnage (DWT) of container vessels calling at US ports by channel depth. Based on this sample of data, each foot of channel depth is associated with an average increase in vessel size of 1,500 DWT, all else equal.

Figure 8. Container vessel size by channel depth (2007–2018).

A cursory look at transit drafts by channel depth does not indicate a strong positive relationship between channel depth and transit draft. Figure 9 provides the minimum, average, and maximum transit drafts for the ports analyzed in this analysis (see Section 5.2.1) between 2007 and 2018. The figure indicates very minor changes on the average sailing draft based on channel depth. To some extent, the highest average sailing drafts appear in the shallowest ports. The analysis presented in the next section attempts to quantify the impact of channel depth on vessel sailing drafts accounting for the range of vessel load factors and operations discussed in this study.
5.2 Regression analysis

SoN 2018-1247 identifies the need to better understand the impact of channel improvements on vessel loading and deployment. The study team compiled a dataset of vessel deployment, loading, and port calls across US coastal ports to study the impact of channel improvements. The study team’s goal was to quantify the impact of channel deepening on carrier loading decisions. The study team offers several important nuances for consideration in USACE container studies. Given the relatively short timeframe for available data, the following presents the short-term impact of channel deepening on vessel loading and deployment. Long-term impacts should be considered in future studies.

5.2.1 Data

As of 2018, 42 US coastal ports engage in significant levels of international containerized trade. Most of this cargo volume flows through a small number of large ports. In 2018, the top 5 US ports handled over 60% of all international volume, and the top 10 US ports were responsible for nearly 85% of all containerized cargo volume.

To understand the impact of channel deepening on vessel deployment and loading, the study team uses data from US coastal ports with a channel deepening between 2007 and 2018 and significant international

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1 Defined as at least 1,000 metric tons of containerized throughput tonnage.
commodity throughput. By comparing the vessel operations at deepened ports to similar ports that did not deepen, the study team makes observations about changes in deployment and vessel loading before and after channel deepening.

The analysis found five channel deepening projects at significant US container ports. Of these five deepening projects, four projects involve federal channel deepening and have data available for the time range on the USACE NNOMPEAS database. In total, the study looks at 267,811 port calls from 2007 through 2018. This dataset is further reduced to only include calls with the potential to be impacted by channel deepening (e.g., vessels with a maximum summer loadline draft below the channel depth underkeel clearance requirement and vessels loading/unloading over 100 metric tons of containerized cargo). This leaves 204,836 data points. Table 4 provides the deepening dates of each port and the number of relevant data points used in the regression for each port. Ports without deepening dates are included in the analysis as a reference to compare vessel operations at deepened ports.

<table>
<thead>
<tr>
<th>Port Name</th>
<th>Deepening Date</th>
<th>Data Time Range</th>
<th>Data Points/Port Calls</th>
<th>Relevant Data Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York-New Jersey</td>
<td>2016*</td>
<td>2010-2018</td>
<td>38,873</td>
<td>32,125</td>
</tr>
<tr>
<td>Norfolk Harbor</td>
<td>-</td>
<td>2010-2018</td>
<td>30,692</td>
<td>26,101</td>
</tr>
<tr>
<td>Port Everglades</td>
<td>-</td>
<td>2013-2018</td>
<td>17,096</td>
<td>3,317</td>
</tr>
<tr>
<td>Miami Harbor</td>
<td>2015</td>
<td>2013-2018</td>
<td>12,102</td>
<td>5,002</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>2013</td>
<td>2007-2018</td>
<td>30,651</td>
<td>24,706</td>
</tr>
<tr>
<td>Oakland</td>
<td>2010*</td>
<td>2007-2018</td>
<td>39,024</td>
<td>31,672</td>
</tr>
<tr>
<td>Seattle</td>
<td>-</td>
<td>2007-2018</td>
<td>11,359</td>
<td>9,254</td>
</tr>
<tr>
<td>Tacoma</td>
<td>-</td>
<td>2007-2018</td>
<td>7,600</td>
<td>6,633</td>
</tr>
<tr>
<td>Houston</td>
<td>2016</td>
<td>N/A</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Charleston Harbor</td>
<td>-</td>
<td>2010-2018</td>
<td>24,354</td>
<td>21,773</td>
</tr>
<tr>
<td>Savannah Harbor</td>
<td>-</td>
<td>2010-2018</td>
<td>33,823</td>
<td>27,756</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>267,811</strong></td>
<td><strong>204,836</strong></td>
</tr>
</tbody>
</table>

*deepened in phases over multiple years

Table 5 provides the number of relevant data points by year. Port calls taking place after a channel has been deepened appear in blue. Port calls from deepened channels total 49,417 data points, or 24% of the relevant data points (204,836).
### Table 5. Data points by port.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MIAMI</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2,800</td>
<td>1,936</td>
<td>1,894</td>
<td>1,920</td>
<td>1,803</td>
<td>1,749</td>
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<tr>
<td>PORT EVERGLADES</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2,764</td>
<td>2,752</td>
<td>2,407</td>
<td>3,019</td>
<td>3,011</td>
<td>3,143</td>
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<tr>
<td>NYNJ</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,794</td>
<td>4,720</td>
<td>4,184</td>
<td>4,593</td>
<td>4,528</td>
<td>4,562</td>
<td>4,429</td>
<td>3,955</td>
<td>4,108</td>
</tr>
<tr>
<td>LONG BEACH HARBOR</td>
<td>1,505</td>
<td>1,604</td>
<td>1,985</td>
<td>2,243</td>
<td>2,449</td>
<td>1,836</td>
<td>1,772</td>
<td>1,633</td>
<td>1,756</td>
<td>1,733</td>
<td>1,834</td>
<td>1,887</td>
</tr>
<tr>
<td>LOS ANGELES HARBOR</td>
<td>3,033</td>
<td>2,814</td>
<td>2,594</td>
<td>2,655</td>
<td>2,624</td>
<td>2,932</td>
<td>2,777</td>
<td>2,678</td>
<td>2,144</td>
<td>2,286</td>
<td>2,114</td>
<td>2,000</td>
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<tr>
<td>SEATTLE HARBOR</td>
<td>906</td>
<td>809</td>
<td>1,138</td>
<td>1,265</td>
<td>1,372</td>
<td>1,189</td>
<td>910</td>
<td>750</td>
<td>695</td>
<td>705</td>
<td>743</td>
<td>877</td>
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<tr>
<td>TACOMA HARBOR</td>
<td>578</td>
<td>657</td>
<td>580</td>
<td>374</td>
<td>356</td>
<td>574</td>
<td>824</td>
<td>801</td>
<td>787</td>
<td>781</td>
<td>641</td>
<td>647</td>
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<tr>
<td>CHARLESTON HARBOR</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2,429</td>
<td>2,575</td>
<td>2,738</td>
<td>2,777</td>
<td>2,825</td>
<td>3,006</td>
<td>2,752</td>
<td>2,578</td>
<td>2,674</td>
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<tr>
<td>SAVANNAH HARBOR</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,769</td>
<td>4,052</td>
<td>3,856</td>
<td>3,613</td>
<td>3,669</td>
<td>3,710</td>
<td>3,812</td>
<td>3,731</td>
<td>3,611</td>
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<tr>
<td><strong>Total</strong></td>
<td>9,637</td>
<td>9,351</td>
<td>9,721</td>
<td>23,338</td>
<td>25,398</td>
<td>24,172</td>
<td>29,681</td>
<td>28,343</td>
<td>27,184</td>
<td>28,124</td>
<td>26,464</td>
<td>26,398</td>
</tr>
</tbody>
</table>
5.2.2 General trends

Average container ship size for each port increased over the study period. This is in line with general market trends toward larger newbuilds. Figure 10 shows the average nominal TEU of all port calls included in the analysis. Across all data, average vessel nominal TEU increased from 5,400 in 2007 to 7,400 in 2018.

An initial observation of sailing drafts before and after channel deepening indicates mixed results. Los Angeles and Miami port calls increased average sailing draft for all draft ranges after channel deepening. New York-New Jersey and Oakland average sailing drafts generally remained the same or decreased after channel deepening. Table 6 summarized average transit draft by direction and vessel draft class for the relevant data points for the subject ports at each channel depth. Vessels are grouped by design draft range (e.g., “40–45” ft maximum sailing draft). Average transit draft for vessels falling into the draft range is provided (e.g., inbound vessels at Los Angeles with a maximum sailing draft between 40 ft and 45 ft had an average sailing draft of 35.5 ft).

---

1 Not all ports are included in the 2007 data. Still, average nominal TEU increased for each port.
Table 6. Average vessel draft by channel depth.

<table>
<thead>
<tr>
<th>Port</th>
<th>Direction</th>
<th>Channel Depth (ft)</th>
<th>Vessel Draft Range (ft)</th>
<th>40-45</th>
<th>45-50</th>
<th>50-55</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles</td>
<td>Inbound</td>
<td>45</td>
<td>35.5</td>
<td>37.2</td>
<td>40.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>53</td>
<td>35.6</td>
<td>38.8</td>
<td>40.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outbound</td>
<td>45</td>
<td>34.0</td>
<td>34.6</td>
<td>38.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>53</td>
<td>34.5</td>
<td>36.4</td>
<td>38.7</td>
<td></td>
</tr>
<tr>
<td>Miami</td>
<td>Inbound</td>
<td>44</td>
<td>34.5</td>
<td>32.5</td>
<td>35.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>36.1</td>
<td>38.5</td>
<td>39.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outbound</td>
<td>44</td>
<td>34.1</td>
<td>32.3</td>
<td>35.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>35.8</td>
<td>38.3</td>
<td>39.4</td>
<td></td>
</tr>
<tr>
<td>New York-New Jersey</td>
<td>Inbound</td>
<td>40</td>
<td>37.6</td>
<td>41.0</td>
<td>45.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>45</td>
<td>36.7</td>
<td>41.9</td>
<td>45.2</td>
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<tr>
<td></td>
<td></td>
<td>50</td>
<td>36.6</td>
<td>41.1</td>
<td>41.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outbound</td>
<td>40</td>
<td>37.4</td>
<td>40.2</td>
<td>44.8</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>45</td>
<td>36.2</td>
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<td>50</td>
<td>35.8</td>
<td>40.0</td>
<td>41.0</td>
<td></td>
</tr>
<tr>
<td>Oakland</td>
<td>Inbound</td>
<td>46</td>
<td>34.3</td>
<td>35.0</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>32.8</td>
<td>34.7</td>
<td>36.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outbound</td>
<td>46</td>
<td>34.3</td>
<td>35.1</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>33.0</td>
<td>34.8</td>
<td>37.3</td>
<td></td>
</tr>
</tbody>
</table>

5.2.3 Assumptions

The study attempts to observe the impact of channel deepening on vessel loading and deployment through regression analysis. The study makes the following assumptions about how channel deepening will impact vessel loading and deployment:

- Vessel operators seek to maximize profit by loading vessels with as much cargo per trip as possible.
- Vessel loading is dependent on unique vessel characteristics, market forces, and maritime infrastructure (i.e., channel depth and landside capacity).
- Channel deepening allows vessels to load more cargo each trip, leading to deeper sailing drafts, higher vessel utilization, and fewer overall port calls required.
The following data are available to serve as a response variable in the regression analysis:

- Transit Draft: vessel transit draft as reported by Waterborne Commerce Statistics Center through the NNOMPEAS tool.
- Tons Unloaded/Discharged: total metric tons unloaded on import or loaded on export.
- Vessel Utilization: total tonnage onboard divided by total vessel capacity.
- Cargo Share: total tonnage (un)loaded divided by total tonnage onboard (as estimated by NNOMPEAS).

The analysis assumes that transit draft and tons (un)loaded are the best response variables for use in this study. Utilization and cargo share are estimated values determined by other values within the dataset. This creates potential modeling issues. Table 7 shows the results of simple regression modeling showing the correlation between channel depth and each potential response variable (ton (un)loaded, transit draft, utilization, and cargo share. The results show channel depth has the highest predictive capability for “Tons (un)loaded” and “utilization.” In this simple regression model, channel depth has only a minor impact on vessel operations overall. In the case of transit draft and utilization, the relationship is negative.

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Coefficient of Channel Depth</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton (un)loaded</td>
<td>480.44</td>
<td>0.0354</td>
</tr>
<tr>
<td>Transit Draft</td>
<td>-0.0760</td>
<td>0.0056</td>
</tr>
<tr>
<td>Utilization</td>
<td>-0.0082</td>
<td>0.0465</td>
</tr>
<tr>
<td>Cargo Share</td>
<td>0.0090</td>
<td>0.0312</td>
</tr>
</tbody>
</table>

5.2.4 Regression analysis

The following regression analysis focuses on the impact of channel depth on vessel sailing draft. The regression analysis attempts to isolate the channel depth impact by controlling for vessel size and characteristics, market forces, and service-specific vessel loading.

The available data for each vessel call for use in the regression analysis include the following predictor variables:
• **Federal Channel Depth:** based on NOAA charts and USACE survey data.
• **Transit Direction:** inbound or outbound
• **Waterway/Port:** Name of Port
• **Dock:** Name of Dock
• **Distance to Origin/Destination:** sea distance from/to prior/next port of call
• **Average Weight per TEU:** average metric tonnage for each TEU loaded/unloaded
• **Vessel Deadweight Tons:** total vessel Deadweight tonnage
• **Vessel Maximum Summer Loadline Draft:** maximum vessel design sailing draft
• **Vessel Nominal TEU Capacity:** total count of onboard slots for TEUs
• **Service (based on origin/destination):** 102 unique liner routes developed for this study based on prior and next port call regions.
• **Annual Calls in service:** number of calls to specific port of similar service route (as determined by “service” name above)
• **Average Annual % Empty TEUs:** Percentage of total annual TEU throughput that are empty. Data retrieved from USACE studies and Port Authority websites for relevant years
• **Average Annual Container Spot Rates:** The average annual spot rate for vessels on similar trade routes retrieved from UNCTAD Maritime reports.

First, a backward stepwise selection was run to identify the best subsets of continuous predictive variables. Table 8 outlines possible predictive variable sets and their $R^2$ values. Continuous predictive variables alone do not appear to be strong predictors of transit draft. Channel depth is the most selected predictor in this exercise.
The study team then ran a simplified regression using only categorical predictors to test the importance of port, coast (Atlantic/Pacific), liner service, dock, and direction. The regression resulted in an $R^2$ of 16.83% with port, service, and direction being relatively stronger predictors of transit draft than coast and dock. Table 9 presents the results of the analysis. As shown, port name, service, and direction were all significant predictors of transit draft. The regression $R^2$ estimates that 16.83% of the variation in transit draft can be explained by these predictors. Dock was not a significant predictor in this case and was removed from the analysis.

<table>
<thead>
<tr>
<th>Variables</th>
<th>$R^2$</th>
<th>Channel Depth</th>
<th>Origin/Destination Distance</th>
<th>Average Weight per TEU</th>
<th>Vessel DWT</th>
<th>Vessel MXSLD</th>
<th>Vessel Nominal TEU Capacity</th>
<th>Annual Service Count</th>
<th>Empty TEU Percentage</th>
<th>Spot Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>X</td>
<td>X</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
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<tr>
<td>6</td>
<td>12.3</td>
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<td></td>
</tr>
<tr>
<td>8</td>
<td>12.5</td>
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<td>X X</td>
<td>X X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>12.4</td>
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<td>X X</td>
<td>X X</td>
<td>X</td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>12.5</td>
<td>X X</td>
<td></td>
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<td>X X</td>
<td>X X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Finally, the study team runs an analysis including both categorical and continuous predictors. Table 10 shows the results from the regression, excluding variables that were eliminated for lack of significance\(^1\). The interaction variable “CHANNELXMXSLLD” was also included in the regression to account for the potential for the impact of channel depth to depend on a vessel’s sailing draft (i.e., vessels with deeper maximum sailing drafts are more likely to realize benefits of channel deepening than shallower drafting vessels). The regression results indicate the impact of channel depth is sensitive to vessel draft. However, the R\(^2\) of this model is approximately 24\%, indicating relatively weak predictive power.

---

\(^1\) The variable “service” was significant but was removed from the regression as it did not improve the predictive ability of the model and was highly correlated to several other variables.
Table 10. Regression analysis results.

Based on the analysis presented in Table 10, vessels calling US ports tend to load only slightly deeper at ports with additional channel depth, all else equal. Table 11 estimates the impact on loading of one additional foot of channel depth by vessel MXSLLD based on the results of the regression analysis. The highest observed change in vessel transit draft would be for Ultra Large Container Vessels (ULCVs) with sailing drafts up to 52.5 ft. These vessels would load an additional inch per each foot of channel deepening under this model. The impact on smaller vessels is lower.
Table 11. Channel deepening impact of sailing drafts.

<table>
<thead>
<tr>
<th>Vessel MXSLLD</th>
<th>Additional Sailing Draft (ft)</th>
<th>Additional Sailing Draft (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>-0.010</td>
<td>-0.1</td>
</tr>
<tr>
<td>45</td>
<td>0.038</td>
<td>0.5</td>
</tr>
<tr>
<td>46</td>
<td>0.047</td>
<td>0.6</td>
</tr>
<tr>
<td>47</td>
<td>0.057</td>
<td>0.7</td>
</tr>
<tr>
<td>48</td>
<td>0.066</td>
<td>0.8</td>
</tr>
<tr>
<td>49</td>
<td>0.076</td>
<td>0.9</td>
</tr>
<tr>
<td>50</td>
<td>0.085</td>
<td>1.0</td>
</tr>
<tr>
<td>51</td>
<td>0.095</td>
<td>1.1</td>
</tr>
<tr>
<td>52.5</td>
<td>0.109</td>
<td>1.3</td>
</tr>
</tbody>
</table>

To further test the channel deepening impact on vessel loading, the study team uses the same predictive variables to test the overall impact of channel deepening on the total tonnage loaded and unloaded at a port. The rationale for this impact follows the same logic as the previous regression: greater channel depths should lead to carriers loading more tonnage on each trip leading to deeper average sailing drafts. The results of the regression analysis indicate a small, positive impact on tonnage (un)loaded in each port call because of channel deepening. Table 12 summarizes results using tons unloaded/loaded as the dependent variable. The R² of this analysis is only approximately 3%, indicating very low predictive power of the model.
Table 12. Channel deepening impact on tons (un)loaded regression analysis.

Table 13 estimates the total impact of channel deepening on total tonnage loaded/unloaded at US ports for each additional foot in channel depth. Like the impact on sailing draft, the largest impact is for deeper draft vessels with ULCVs potentially (un)loading as much as 700 additional metric tons of cargo on each transit. Based on a typical tons per inch immersion rating between 300 and 400, this confirms the 1 to 2 in. additional sailing draft from the regression analysis presented in Table 14.
The study team also tested the importance of time on the impact of channel depth on vessel sailing draft. A time variable would indicate a delay between channel deepening and carrier changes in vessel loading and practices. The reasoning for this delay would reflect carriers’ inability to immediately change vessel operating practices. Loading practices are dependent on previous and next port channel depths and vessels deployment. Changes in vessel loading are unlikely to be instantaneous. The results indicate a relatively low, negative impact on sailing draft. As a result, the study team does not estimate significant change in sailing draft over the study period. This applies to a 1-year lag and a 2-year lag. The results below show the results of a 2-year lag. The coefficient indicates that sailing drafts stay relatively constant after channel deepening.

**Table 13. Channel depth impact on tons (un)loaded by vessel MXSLLD.**

<table>
<thead>
<tr>
<th>Vessel MXSLLD</th>
<th>Additional Tonnage (Un)Loaded per Trip</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>-565</td>
</tr>
<tr>
<td>45</td>
<td>-55</td>
</tr>
<tr>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td>47</td>
<td>149</td>
</tr>
<tr>
<td>48</td>
<td>251</td>
</tr>
<tr>
<td>49</td>
<td>353</td>
</tr>
<tr>
<td>50</td>
<td>455</td>
</tr>
<tr>
<td>51</td>
<td>557</td>
</tr>
<tr>
<td>52.5</td>
<td>710</td>
</tr>
</tbody>
</table>
Table 14. Regression analysis with lag variable.

```r
Call:
  lm(formula = data$ActualTransitDraft.ft. ~ data$Channel.Depth +
  data$Avg.WeightPer.TEU.mt. + data$Vessel.DWT..mt. + data$Vessel.MXSLLD..ft. +
  data$TEUS..Nominal + data$Annual.Service.Count + data$Empty.TEU +
  data$Spot.Rates + data$Port2 + data$Direction + data$Draft.Class +
  data$ChannelXMXSLLD + data$lag2)

Residuals:
     Min      1Q  Median      3Q     Max
-17.3076 -2.1852  0.0667  2.2995 21.7443

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)           7.986e+01  6.102e+00  13.089  < 2e-16 ***
data$Channel.Depth   -3.867e-01  3.681e-02  -10.506  < 2e-16 ***
data$Avg.WeightPer.TEU.mt. -7.435e-03  3.862e-03  -1.925   0.05422 .
data$Vessel.MXSLLD..ft. -2.281e-01  3.938e-02  -5.798  6.72e-09 ***
data$TEUS..Nominal     1.734e-03  1.387e-04   12.499  < 2e-16 ***
data$Empty.TEU         -2.753e-01  8.996e-02  -3.060   0.00221 **
data$Spot.Rates        2.123e-04  1.521e-05   13.943  < 2e-16 ***
data$Port2Long Beach  -1.135e-04  4.257e-05  -2.665   0.00769 **
data$Port2Los Angeles -7.097e-02  3.860e-02  -1.839   0.06595 .
data$Port2Miami        1.145e+00  6.077e-02   18.840  < 2e-16 ***
data$Port2New York-New Jersey  3.250e+00  3.769e-02  86.233  < 2e-16 ***
data$Port2Norfolk      3.956e-01  4.134e-02   9.569  < 2e-16 ***
data$Port2Oakland     -1.379e+00  3.932e-02  -35.065  < 2e-16 ***
data$Port2Port Everglades  -7.151e-01  7.118e-02  -10.046  < 2e-16 ***
data$Port2Savannah     1.013e+00  3.426e-02   29.576  < 2e-16 ***
data$Port2Seattle     -4.114e+00  6.265e-02  -66.099  < 2e-16 ***
data$Port2Tacoma       9.430e-03  5.626e-02   0.168   0.86689

data$DirectionOutbound -2.550e-01  2.002e-02  -12.742  < 2e-16 ***
data$Draft.Class40-45   1.679e+00  5.490e-02   30.583  < 2e-16 ***
data$Draft.Class45-50   2.840e+00  7.351e-02   38.630  < 2e-16 ***
data$Draft.Class50-55   4.156e+00  1.094e-01  37.998  < 2e-16 ***
data$ChannelXMXSLLD    9.458e-03  8.192e-04   11.546  < 2e-16 ***
data$lag2              -1.927e-02  2.911e-03   -6.618  3.64e-11 ***

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 3.468 on 169652 degrees of freedom
(25346 observations deleted due to missingness)
Multiple R-squared:  0.2375,  Adjusted R-squared:  0.2374
F-statistic: 2202 on 24 and 169652 DF,  p-value: < 2.2e-16
```
6 Conclusions and Recommendations for Future Work

6.1 Conclusions

The analysis presented in Section 5.2.4 indicates a relatively weak correlation between channel deepening and vessel transit drafts based on the available data and time frame. Specific ports, vessels size, and route groups tend to be better predictors of vessel transit drafts than channel depth alone. This result holds true when accounting for vessel size and characteristics, market forces, and service-specific vessel loading.

These results indicate a need to further consider the correlation between channel deepening and vessel sailing draft in USACE navigation studies. The available data do not provide support for the assumption that vessels tend to draft 0.7 ft deeper for each foot of channel deepening. However, the study is also not able to improve on that assumption using the available data.

Interpretation of these results should consider the relatively short timeframe with data available: of the ports included in the analysis, the average amount of time since deepening is just over 5 years. USACE considers 50-year planning horizons during which time vessel operations may change to optimize channel use. Over a longer time, the change in vessel sailing draft and loading practices may still support the 0.7 ft shift assumption. Additionally, the response to channel deepening may be different in the future as more, large vessels call US ports.

Regarding empty TEU considerations, this analysis identifies the input for empty TEU percentages in navigation studies is among the most important factors in determining vessel sailing draft. The analysis confirms empty TEU percentages remain relatively stable over time by trade lane. However, market trends lead to notable changes in the long term. Effort should be made to improving the studies’ ability to accurately model empty TEU percentages. Specifically, efforts should be made to allow unique inputs for import and export vessel transits in USACE navigation models.

The results of the study indicate a need to continue to track these data to improve enterprise understanding of the relationship between channel
deepening and vessel operations. Additionally, the analysis points to the uniqueness of individual ports. USACE analysis should account for port-specific changes in estimating the impact of channel deepening. As discussed in Section 4, pilot rules, services, and port capacity are more likely to create limitations on vessel sailing draft before channel depth becomes a constraint.

6.2 Recommendations for future work

SoN 2018-1247 recommends an investigation into the factors affecting vessel deployment decisions. This study attempted to provide context and data to improve enterprise understanding of carrier deployment decisions. This study primarily addressed the underlying factors impacting vessel deployment decisions at US coasts through carrier interviews and regression analysis. The study primarily uses internal data sources and data publicly available for US ports. Importantly, vessel deployment is impacted by international container ship markets. USACE should work to gain more recent industry data on vessel deployment and order books to maintain a database that can be used on all USACE navigation studies. Future analysis should build on this study through updating USACE container deployment assumptions and considering trends from international ports.

SoN 2018-1255 recommends research to improve the understanding of empty box movements in relation to vessel loading at US ports. This study has improved enterprise understanding of empty TEU loading and developed a tool to help analysts estimate empty TEU percentages of cargo onboard vessels. This will be useful for USACE deep-draft navigation studies moving forward. Future analysis should try to improve the USACE ability to forecast empty TEU movements. This analysis attempts to quantify the relationship between the trade deficit and empty TEU movements; however, the importance of empty TEU assumptions creates the need for a more comprehensive method. Additionally, this study did not address box size or reefer units. This can vary widely by trade route and can impact vessel loading assumptions for USACE studies.
References


Acronyms and Abbreviations

DWT  Deadweight tonnage
FSMP  Fleet size and mix problem
IMO  International Maritime Organization
IWR  Institute for Water Resources
MIP  Mixed integer programming
NNOMPEAS  National Navigation Operation and Management Performance Evaluation and Assessment System
OECD  Organization for Economic Co-operation and Development
SoN  Statement of Need
TEU  Twenty-Foot Equivalent Unit
ULCV  Ultra Large Containerships
USACE  US Army Corps of Engineers
USEC  US East Coast
USGC  US Gulf Coast
USWC  US West Coast
VRP  Vehicle Routing Problem
# Improving Container Shipment Analysis

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**Seattle, WA 98134**

This report attempts to provide an overview of containership deployment and loading practices as it relates to USACE navigation studies to improve the quality of deep-draft economics. The report relies on trade data, vessel order books, and carrier interviews to study the impact of channel modification on vessel loading and deployment. The report makes recommendations for developing deployment and loading inputs for future economic evaluations.