Integrating MTS Commerce Data with Multimodal Freight Transportation Performance Measures to Support MTS Maintenance Investment Decision Making

DETAILS

60 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-30815-1 | DOI 10.17226/22241

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NATIONAL COOPERATIVE FREIGHT RESEARCH PROGRAM

NCFRP REPORT 32

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Subscriber Categories
Marine Transportation • Freight Transportation • Maintenance and Preservation

Research sponsored by the Office of the Assistant Secretary for Research and Technology

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2014
www.TRB.org

NATIONAL COOPERATIVE FREIGHT RESEARCH PROGRAM

America's freight transportation system makes critical contributions to the nation's economy, security, and quality of life. The freight transportation system in the United States is a complex, decentralized, and dynamic network of private and public entities, involving all modes of transportation—trucking, rail, waterways, air, and pipelines. In recent years, the demand for freight transportation service has been increasing fueled by growth in international trade; however, bottlenecks or congestion points in the system are exposing the inadequacies of current infrastructure and operations to meet the growing demand for freight. Strategic operational and investment decisions by governments at all levels will be necessary to maintain freight system performance, and will in turn require sound technical guidance based on research.

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NCFRP REPORT 32

Project NCFRP-42
ISSN 1947-5659
ISBN 978-0-309-30815-1
Library of Congress Control Number 20144953577

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NATIONAL COOPERATIVE FREIGHT RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

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Printed in the United States of America

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AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCFRP Project 42 by the Center for Ports and Waterways at the Texas A&M Transportation Institute (TTI). Mr. C. James Kruse, Director of the Center for Ports and Waterways, was the Project Director and Principal Investigator.

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The authors wish to acknowledge the assistance of Dr. Tim Lomax, Senior Research Engineer at TTI, and Dr. David L. Schrank, Research Scientist at TTI. These gentlemen are principal authors of the *Urban Mobility Report*, published annually by TTI. The authors also wish to acknowledge the assistance provided by Dr. Kenneth Ned Mitchell, Research Civil Engineer at U.S. Army Engineer Research and Development Center Coastal and Hydraulics Laboratory in Vicksburg, Mississippi. Dr. Mitchell provided much of the data that made this study possible.

FOREWORD

By William C. Rogers
Staff Officer
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NCFRP Report 32: Integrating MTS Commerce Data with Multimodal Freight Transportation Performance Measures to Support MTS Maintenance Investment Decision Making investigates the feasibility of evaluating potential navigation operation and maintenance projects on the Marine Transportation System (MTS) not only as they relate to waterborne commerce, but also in light of the landside freight connections as well. A network optimization model is described that maximizes the multimodal system capacity by choosing the navigation maintenance projects that will either fully accommodate expected demand or provide the greatest potential throughput within overall budget constraints, taking into account the origins and destinations of the commodities that move through a regional multimodal network. Five ports are selected for analysis: Duluth, MN; Hampton Roads, VA; Huntington, WV; Plaquemines, LA; and Portland, OR.

The Marine Transportation System (MTS) consists of the nation's waterways and the connecting multimodal distribution system. The shippers who use the MTS want the system to be fast, reliable, and cost-effective. Given the vast quantities of bulk and containerized goods using the MTS, and the projected upward trend, it is vital that public agencies responsible for the separate elements of the nation's freight transportation system align their investment and maintenance activities to ensure the necessary capacity exists to efficiently move cargo through waterways, ports, and their connecting road and rail corridors. The annual maintenance dredging of the MTS is critical to the reliability of the national multimodal freight system. Rational, objective, multimodal performance indicators could help allocate limited resources across the portfolio of navigation and surface transportation projects. Such performance indicators would assist in effectively gauging which portions of the MTS are most important from a multimodal freight system perspective.

Under NCFRP Project 42, the Texas A&M Transportation Institute was asked to (1) identify, quantify, and describe the high-volume freight MTS corridors (including Great Lakes, coastal, and inland waterways) in the United States; (2) identify, quantify, and describe the intermodal connections for each of the high-volume freight corridors identified in (1); (3) develop proposed metrics and operations research methodologies for making MTS maintenance decisions that take into account the overall impact on the freight transportation system; (4) apply the operations research methodologies for making MTS maintenance investment decisions in five case studies; and (5) prepare a final report that documents the research effort, lessons learned, and suggested future research options.

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Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Integrating MTS Commerce Data with Multimodal Freight Transportation Performance Measures to Support MTS Maintenance Investment Decision Making

The Research Effort

The purpose of NCFRP Project 42 was to explore the development of an analytical framework and model for evaluating the allocation of operations and maintenance dollars to navigation projects, taking into account how those projects tie into the overall surface transportation system. However, the literature dealing with the prioritization of navigation projects suffers from the same shortcomings as transportation data repositories—it is very modal specific and does not provide a means of analyzing system effects. This research is a first step toward addressing those shortcomings.

Initially, the researchers intended to use the U.S. Army Corps of Engineers (Corps) confidential waterborne trip data file to identify specific points of interchange with the landside system (docks), as well as the FHWA confidential Freight Analysis Framework 3 (FAF3) data. After the project was initiated, these agencies determined that the researchers could not be granted access to the respective databases. Because of these limitations, the researchers developed an alternate approach using the datasets listed below. Thus, the results of this research project should be considered as a proof of concept that entities with full access to confidential data can build on to achieve their desired project evaluation objectives.

The primary datasets used in this research effort were the following:

- **Channel Portfolio Tool (CPT)** (*1*)**.** CPT accesses the dock-level, Corps-use-only tonnage database from the Institute for Water Resources (IWR) Waterborne Commerce Statistics Center (WCSC) to analyze the extent to which commercial traffic uses maintained channel depths.
- **Freight Analysis Framework 3 (FAF3) Public Data.** The FAF3 data are based on the 2007 Commodity Flow Survey (CFS) and integrate data from a variety of sources to create estimates for transported tonnage and value by origin, destination, commodity, and mode for a base year (currently 2007 to be consistent with the CFS) and forecasts, currently through 2040.
- **Federal Railroad Administration National Grade Crossing Inventory.** The U.S. DOT National Highway-Rail Crossing Inventory Program is a uniform national database of grade crossing characteristics and traffic data that can be merged with accident files.

Five port complexes were selected as case studies on which to apply the model:

- Duluth, Minnesota
- Hampton Roads (Port of Virginia), Virginia
- Huntington, West Virginia
- Plaquemines, Louisiana
- Portland, Oregon

The Port of Portland was further divided into deep draft (import/export) traffic and inland water (Columbia/Snake River) traffic. Therefore, there actually were six case studies.

For each selected port area, the researchers identified the landside corridors that tie into the waterfront origins and destinations for the primary commodity flows. Appendix C contains a description of the primary origin-destination corridors and the modal assignments for each corridor at each port. The researchers developed measures that defined the current (without project or before condition) utilization of the waterway asset and the post-project (with project or after condition) utilization of the asset, allowing for an evaluation of maintenance project activities.

For the modeling effort, the project team focused on the maximization of cargo flow based on tonnage, based on conversations with members of the NCFRP Project 42 panel. This measure could be expanded or even substituted in the model discussed in this report.

For waterways, the conceptual approach was to assume a certain loss of water depth due to lack of maintenance dredging. The researchers analyzed the commodities and tonnage that historically moved within the affected stratum at each port, and then analyzed a 10 percent, 20 percent, or 30 percent increase in that subset of the port's traffic. Initial results showed that, in many cases, the 10 percent and 20 percent levels had insignificant effects. In fact, in some cases, even a 30 percent increase in the tonnage at the affected depth caused a very small increase in the port-generated traffic relative to the total traffic in the port community. In order to simplify the analysis and make the results meaningful, the researchers chose to use only the 30 percent level for this study. Tonnage that was assigned to the affected stratum of the waterway is referred to as "project depth tonnage." Since this is the tonnage that dredging will directly affect, the objective function in the model attempts to maximize this variable.

Lock capacity/utilization is greatly dependent on available operating time and tow processing time. By improving the condition of the lock, it is possible to reduce the hours the lock is out of service and increase the capacity of the lock to move additional project depth tonnage over a given time frame. The researchers used a mathematical/statistical analysis of a number of locks performed by Oak Ridge National Laboratory (ORNL) to estimate lock capacity. Appendix D contains a detailed description of this methodology. The potential effect of a lock maintenance project was calculated by identifying the lowest annual average delay from 2000 to 2012 and using it as the target (after project) condition. The difference between the theoretical capacity of the lock based on historical data and the theoretical capacity of the lock with the optimum delay factor (target condition) was taken to be the potential tonnage increase for the lock.

For inland port waterway segments and coastal ports, the researchers used a metric based on channel depth as a utilization indicator. By examining historical average tonnage throughput at various draft levels during periods when adequate channel depth was available (as CPT does), it was possible to develop the tonnage by commodity that has historically transited in the depth stratum being affected by maintenance dredging. In the calculation of how much tonnage could be potentially added to particular waterway segments, constraints caused by water depth and lock throughput capacity (for segments with locks) were considered.

The highway corridor analysis tapped into previous and ongoing work conducted by Texas A&M Transportation Institute (TTI) through its Urban Mobility Research Program (UMRP). Based on its previous work across the country, UMRP was able to determine that any potential highway congestion effects from increased port traffic would be noticeable only in the immediate vicinity of the port.

The capacity analysis of potential rail corridors consisted of (1) identification of line segments where congestion is likely to be severe; (2) determination of the theoretical train count capacity based on methods developed in the *National Rail Freight Infrastructure Capacity and Investment Study* (*2*); (3) determination of current train counts; and (4) calculation of remaining capacity, assuming current operating parameters and track conditions.

The tonnage for each primary commodity-corridor combination was divided among the highway, rail, or water modes, based on the FAF3 data. Appendix C provides the modal assignment for the corridors associated with each port. Once the corridor modes and tonnages were established, the researchers assessed each corridor to see if there were any constraints that would prevent the tonnage increases from flowing through the corridor. Appendix E discusses the constraints.

The operations research model is built on a network using network flow techniques. For each port area, a network covering the area of interest was established. The objective of the model was to maximize the possible freight throughput served by the restored or increased system availability by first identifying lock and non-lock waterway segments/links for maintenance. In the case of dredging, the model determines dredging location and depth; in the case of locks, it determines reductions in average delay. The model then evaluates their associated combined effects on the system network including landside linkages. The freight network analysis is based on historic freight demand, as outlined above.

In order to determine a reasonable cost per unit of maintenance activity, the researchers compiled data on dredging and lock expenses at the ports and potentially constrained locks.

The flowchart shown in Figure S-1 depicts the means by which data are fed into the model and the outputs that result.

The researchers designed several scenarios to test various aspects of the model (sensitivity analysis). They used various budgeting levels and various project combinations in order to analyze the effect of different variables on the modeling results.

Findings

The most obvious issue that surfaced in this research effort is that there is a lack of the kind of data needed for developing a model that can support MTS maintenance investment decision making by being correlated between the modes and almost no accurate data on origins and destinations (in the case of publicly available data). However, combining trade literature with publicly available information from the Corps (primarily CPT data); FAF3; and regional, state, and local freight studies makes it possible to gain enough of an understanding of a port's primary trade flows to be able to provide meaningful input into the model developed for this project.

Furthermore, the metrics currently used for prioritizing maintenance and improvement expenditures are not based on post-project evaluation of the effects of such spending; rather, they are based on presumed measures of the general importance of the asset: tonnage, sustainability of the region (i.e., how much the region depends on the waterway for its economic survival), and so forth. In order for a model of the type developed under NCFRP Project 42 to have real value, there must be a way to measure the effect of maintenance projects on freight flows.

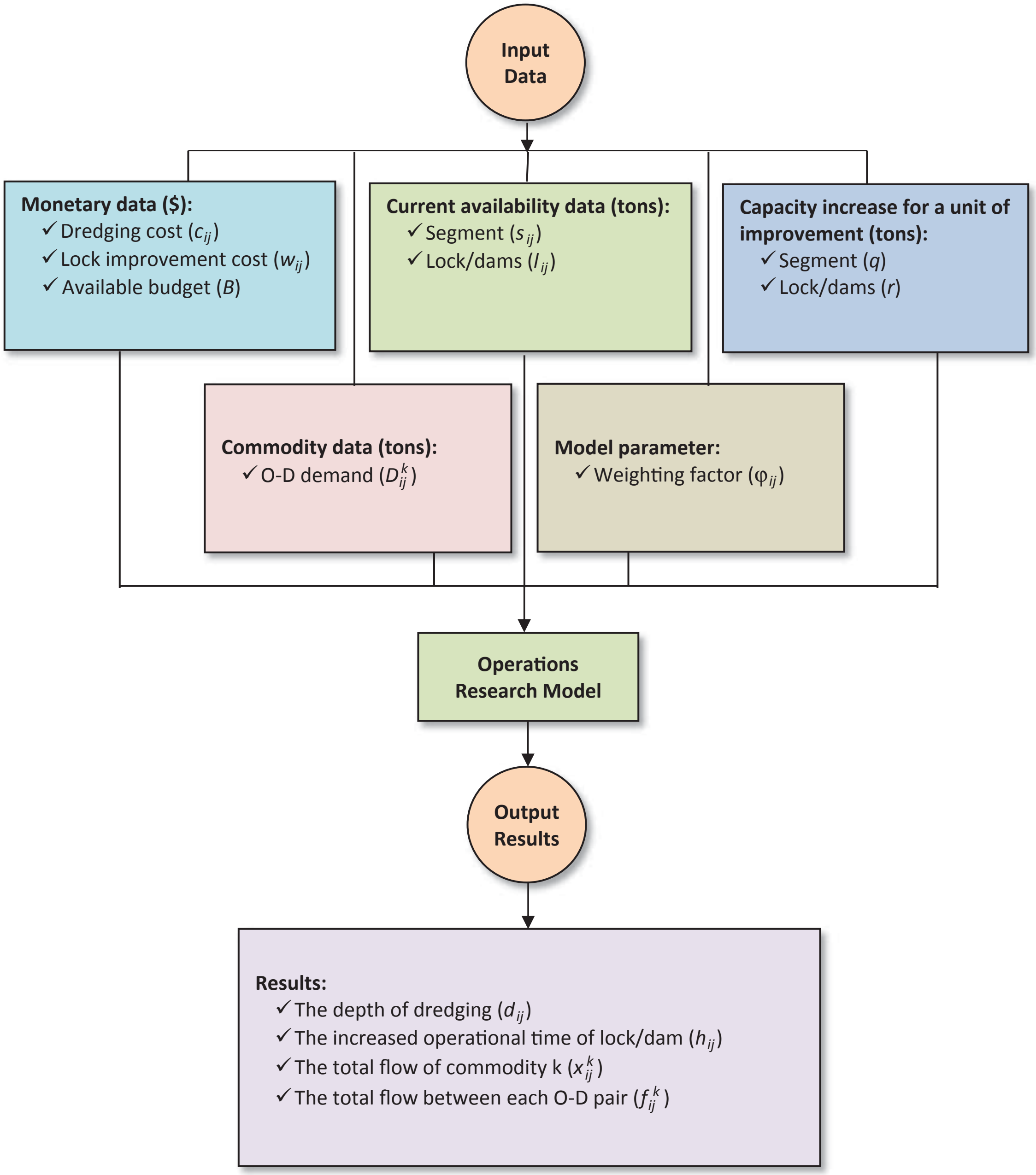

Figure S-1. Flowchart of operations research model.

Certain findings became obvious, even before running the model. They are explained in depth in the body of the report. In summary:

1. Ports vary widely in the degree to which the bottom strata of water depth are used in terms of tonnage relative to total port tonnage.
2. Highways are not at all critical in some instances, depending on the primary commodities and the mode they depend on.
3. Highway congestion caused by port truck traffic is a constraint only in the immediate vicinity of the port terminals; it does not generate city-wide or area-wide congestion.

Appendix F shows the results of the model for each of the selected dredging scenarios. In summary:

1. The improvement of only a few waterway segments could really make a difference. Improving segments that already have little tonnage throughput or are already constrained on the landside will not affect total system-wide tonnage capacity or throughput.
2. For this reason, not all eligible segments need to be fully maintained—some not at all.
3. It is possible for budgets to be set too high. Even if money is available, it might as well not be spent on segments that may not affect total tonnage throughput due to low demand or landside constraints.
4. In some cases, it's all or nothing. Decreasing the budget by just 10 percent (from 100 percent down to 90 percent) results in a zero maintenance decision. This occurs in cases where a port has only one water origin-destination corridor.
5. Locks are not a capacity constraint as long as they continue to operate as well as they have historically.

Note that the model is artificially constrained and does not incorporate all factors that may have to be considered in a real world situation. For example, shoaling effect is not considered. The model only assumes a static state, which means dredged depth will remain effective for a period of time. Additionally, system reliability often requires continuous maintenance of the waterway system so that it always has a capacity that is higher than needed in order to hedge against capacity reduction due to external unforeseen events such as weather and other incidents.

SECTION 1

Background

Marine Transportation/Surface Transportation Interface

America's Marine Transportation System (MTS) moves people and goods through U.S. ports using a system of harbor channels and waterways to reach final delivery points or make connections to highways, railways, and pipelines. In many cases, the port or marine terminal is not the true origin or final destination of the cargo. Rather, ports and marine terminals are nodes in a much larger and more complex supply chain.

The MTS enables worldwide distribution of U.S. agricultural and manufactured products. In 2011, 75.0 percent by weight and 46.9 percent by value of U.S.-international merchandise trade was transported by water, with a value of nearly $1.7 trillion (*3*). In the 10 years ending in 2009, the U.S. MTS moved 24.4 billion short tons of cargo, an average of 2.4 billion short tons annually. The activities involved in the MTS can be separated into domestic and international shipments. Of the 24.4 billion tons of cargo moved by the MTS in 2009, 60 percent (14.6 billion tons) was international and 40 percent (9.8 billion tons) was domestic (*4*). Steady gains in volumes are predicted for the next two decades. Therefore, not only must existing high-throughput corridors be properly maintained, new ones must be developed as well.

The MTS is at a crossroads. MTS infrastructure is showing signs of strain that will intensify as cargo and passenger traffic increases. Ports are in need of more capacity/resource availability and efficient throughput; inland locks are, on average, 10 years beyond their 50-year lifecycle; most coastal channels are not deep enough for the next generation of post-Panamax ships; and multimodal connections are inadequate.

In an era of increasingly difficult federal budget decisions, it is imperative to allocate investment dollars in corridors that will do the most to enhance the nation's competitiveness. Growth in the use of the MTS and projected increases in total freight volumes (including international container traffic) bring with them the demand for additional staging areas, expanded landside access, and improved logistics technologies. In short, additional infrastructure capacity is needed. What is not clear is where limited federal dollars should be spent to improve resource availability.

The federal role in managing the MTS includes public infrastructure, mobility, channels, navigational systems, charting, weather and real-time navigational information, environmental oversight, marine safety and security, and incident response. State and local agencies address the demands of the freight transportation system within their geographic boundaries. The private sector invests in, owns, or manages vessel, port, and transfer assets. A method of cataloguing system components and prioritizing possible investments to add capacity in the system is needed.

U.S. Army Corps of Engineers and Performance-Based Investment

The U.S. Army Corps of Engineers (Corps) has long been practicing rigorous performance-based investment. One of the tools developed by the Corps to assist in this mission is the Channel Portfolio Tool (CPT) (*1*). CPT helps account for both physical condition and depth utilization in prioritizing projects for operations and maintenance (O&M) funding. By focusing on the cargo at the marginal, shoal-vulnerable depths, CPT provides a more complete indication of the significance of maintenance dredging. CPT provides a means of analyzing the commercial traffic that is directly dependent upon Corps dredging activities (i.e., cargo transiting at marginal depths kept open by O&M dredging) and potentially disrupted shipments if dredging is not conducted and channel shoaling continues. CPT accesses the dock-level, Corps-use-only tonnage database from the Institute for Water Resources (IWR) Waterborne Commerce Statistics Center (WCSC) to analyze the extent to which commercial traffic uses maintained channel depths. Commodity codes are cross-referenced with the Department of Commerce (DOC) import/export figures to obtain dollar-value estimates for the cargo transiting at each 1-ft increment of maintained depth. Navigation channels and their subreaches then are ranked in terms of tons and dollar-value of cargo transiting at depths that experience shoaling.

An important premise of the approach used in the CPT is that the extent to which maintained depths are used by transiting vessels is a useful metric when attempting to prioritize navigation projects across the Corps' navigation portfolio. While tonnage totals offer an expedient way for Corps decision makers to evaluate the relative significance of navigation projects, the developers of CPT contend that incorporation of additional data such as draft and cargo value provides improved justification for maintenance dredging investments. The CPT assists decision makers with extraction and processing of pertinent data subsets from the WCSC confidential database. A limitation of CPT is that while the value of cargo may be useful for certain facets of a study, by and large it does not indicate the cost incurred when these shipments are disrupted or made less efficient.

Multimodal Freight Data and Performance Measurement

The availability of data on multimodal freight shipments in the United States and the extent to which these data capture the various ramifications and elements of multimodal transportation have a major impact on the ability to measure, evaluate, and manage the performance of the entire supply chain or to develop robust models to accurately predict multimodal freight flows in the future under varying conditions. Multimodal freight flows are captured by many standard freight data sources; however, no individual data source provides all of the commodity flow linkages associated with multimodal freight movements. The existing freight data treat each mode separately and differ in breadth and depth of coverage. Examples include the following:

- Populations or samples of populations
- Data elements included, such as revenue, tons, or 20-ft-equivalent units (TEUs)[1]
- Data field definitions, such as commodity codes such as WCSC, Standard Transportation Commodity Code (STCC), and Standard Classification of Transported Goods (SCTG)
- Level of detail, such as commodity detail and geographic detail.

NCFRP Report 10: Performance Measures for Freight Transportation addresses the metrics used by each modal system comprehensively and was consulted for this work (*5*).

Most freight movements take place through multimodal supply chains. As a result, there is a need to measure and optimize the performance of the entire multimodal system on a supply chain level. However, the available modal data are not standardized and cannot support measurement of the performance of multimodal freight transportation supply chains. New, "mode neutral" metrics that can apply to all modes or external methods to "bridge" or align the segregated modal data need to be developed and applied in order to support standardized performance measurement of the entire system. This is an important topic for future research.

Literature Review

The literature on the prioritization of navigation projects has the same shortcomings as the data repositories—it is very modal specific and does not provide a means of analyzing system effects. Only a handful of reports appear to have direct relevance to the question at hand.

Much of the modeling work is based on research done by Mitchell, Wang, and Khodakarami, in which the authors develop a model that takes into account the circumstance that one dredging project depends on other projects in the system that also are being dredged to take advantage of transportation efficiency gains derived from deeper navigable waterways (*6*). The authors test and evaluate proposed integer programming models and heuristic solution algorithms to select dredging projects for funding, while taking into account interdependent benefits. This work did not attempt to incorporate the linkage with highway or rail networks.

NCFRP Report 10: Performance Measures for Freight Transportation provides guidance on how to collect and use data for performance measurement (*5*). One important finding of the research is that measures used in the private sector have little relevance or use in the public sector and vice versa. Additionally, the number of freight-specific performance measures remains limited. The few states that include freight performance measures in their performance reporting suites typically have fewer than four freight measures. There is very little consistency across the reporting mechanisms used by the various states. The authors noted that the U.S. Maritime Administration (MARAD) listed the following as the factors that affect port efficiency the most:

- Labor efficiency (cargo moved per unit of labor)
- Land use efficiency (cargo storage per unit of land)
- Waterside access limitations
- Capacity of port road and rail connections

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[1] TEUs are the standard unit of measure for containerized traffic. A standard 40-ft container is two TEUs.

- Inland transportation availability
- Cargo handling capability

Adams and Wittwer attempted to establish performance measures for evaluating multistate projects (*7*). They arrived at the conclusion that the major hindrances to creating performance measurement tools are data availability, conformity, and reliability. Thus, it is generally impossible to correlate datasets with each other.

Most of the literature reviewed for NCFRP Project 42 dealt with the development of datasets that are important for the model that was developed and tested for this research effort (as opposed to the development of comprehensive models). Literature sources that were relied upon in the development of inputs to the model are noted during the discussion of the relevant datasets.

Modal Freight Data Repositories and Data Alignment Method

Initially, the researchers intended to use the Corps' confidential waterborne trip data file to identify specific points of interchange with the landside system (docks). However, the Corps determined that it could not make the data available to the researchers. This obstacle primarily affected the analysis of inland waterway ports. In addition to the Corps' confidential trip data files, the researchers expected to have access to the FHWA confidential Freight Analysis Framework 3 (FAF3) data at the outset of the project, as documented in the approved project work plan. After the project was initiated, however, FHWA also determined that the researchers could not be granted access to the FAF3 database. The lack of accessibility to waterborne trip data and FAF3 data, as well as to the Surface Transportation Board's confidential Carload Waybill Sample, were substantial impediments to the research project's implementation as initially defined.

It is likely that these data sources would enable a research team to perform project evaluations with a greater deal of accuracy and focus. Because these data sources were not made available for this project, the researchers developed an alternate approach, described in later sections of this report. Thus, the results of this research project should be considered as a proof of concept that entities with full access to confidential data could build on to achieve their desired project evaluation objectives.

The researchers conducted extensive research into and analysis of other, publicly available data. The following sections describe the data sources that were evaluated and how they were used in this research effort.

Waterborne Commerce Statistics Center

The Corps maintains a website via its Navigation Data Center that provides statistical information on tonnages and trip counts for each port area, among other data. All inland and intracoastal waterway trip movements at the dock origin-destination level are recorded in the confidential dataset. The public information is aggregated to the port area level and does not include any information on origin or destination docks.

Origins and destinations are especially important to the evaluation of Great Lakes and inland waterways project options. In lieu of dock-level origin-destination information for inland waterways, the Corps provided information gleaned from CPT to the research team that consisted of commodity flows, origins, and destinations at the river segment level. This necessitated a manual examination of potential loading/unloading facilities within a segment. The researchers used Google® Earth satellite images and the Corps' Port Series reports to identify individual waterfront facilities within each segment that were likely to handle the commodity in question. Once the individual facilities were identified, a determination was made as to whether the majority of overland cargo flows to/from the facilities within the segment would most likely be by truck, rail, a combination of the two, or pipeline, or whether the facility might be an end point with respect to the waterway corridor. (Because of the complexities related to assessing pipeline capacity and efficiency—and given that the primary focus of this study was the interconnection with rail and highway corridors—pipeline flows were dropped from consideration.) Using a variety of sources, the researchers then determined the most likely principal origins/destinations for respective commodities and (in the case of non-pipeline flows) the most likely highway and rail lines used.

If the confidential, dock-to-dock, seven-digit-level WCSC commodity code data were made available, the exact origin and destination facilities, tonnages, and the exact commodity would be known. The "proxy" method described above and corresponding margins of error would have been greatly reduced. In simple terms, obtaining a total by summing known elements is an accurate method. Obtaining needed detailed elements by splitting a total based on a set of assumptions is obviously a far less accurate method. The researchers initially expected to use the public FAF3 data to determine the flows into and out of the selected Great Lakes port (Duluth, Minnesota), as in the case of coastal ports. Unfortunately, the waterborne shipments on the Great Lakes were not included in the FAF3 data. However, the Corps was able to extract and aggregate data from its proprietary WCSC database that allowed the researchers to determine the primary waterborne commodity flows associated with Duluth.

Master Docks Plus Public Extract

This dataset is a listing of all waterfront facilities organized by port area and waterway. The data elements for each facility are fairly comprehensive. However, in many cases the data are dated and do not accurately reflect currently active facilities or facility infrastructures. The dates of the last update for the selected river segments range from 1991 to 2010. Indeed, facility data available for some of the segments included in the Huntington, West Virginia, case study appear to date as far back as 1991. This necessitated the type of labor-intensive analysis described under the previous section, "Waterborne Commerce Statistics Center."

Freight Analysis Framework—Version 3

The FAF3 data are based on the 2007 Commodity Flow Survey (CFS) and integrate data from a variety of sources to create estimates for transported tonnage and value by origin, destination, commodity, and mode for a base year (currently 2007 to be consistent with the CFS) and forecasts, currently through 2040.

Commodities in the public FAF3 data are classified at the two-digit level of the Standard Classification of Transported Goods (SCTG). These do not align with the Corps' two-digit WCSC classifications, so the researchers developed a cross-referencing bridge between the two systems. The commodity descriptions at the two-digit level are not always entirely compatible. Some of the commodities included in an SCTG two-digit code might not be included in the WCSC two-digit code and vice versa. Conversely, the same two-digit commodity code group may include different ranges of commodities in the different datasets. However, given that the research team had to rely strictly on public data (that are limited to the two-digit commodity code level, i.e., a group composed of several individual commodities), these inconsistencies were unavoidable. SCTG and WCSC commodity codes at the seven-digit level refer to individual commodities and correlate directly (one-to-one relationship). If the seven-digit codes were made available, there would be no need for the cross-referencing bridges or assumptions, which inherently introduce error. Appendix A shows the cross-referencing bridge and includes tables with a complete listing of FAF3 codes and Corps codes.

FAF3 domestic region level datasets and products provide information for states, state portions of large metropolitan areas, and remainders of states (RoS) as listed in Appendix B. Metropolitan areas consist of Metropolitan Statistical Areas (MSAs) or Consolidated Metropolitan Statistical Areas (CMSAs) as defined by the U.S. Office of Management and Budget (OMB). When a metropolitan area is entirely within a state or when a state's portion of a multistate metropolitan area is large enough to support the sampling procedures in the CFS, the area becomes a separate FAF3 region. Small, single-state metropolitan areas and small portions of a multistate metropolitan area are part of the state or RoS. There are 89 FAF3 regions.

Many of the origins and destinations on the inland waterways fall in the RoS regions, so FAF3 data are not useful for evaluating flows to and from relevant river segments. While statistical methods exist that allow analysts to disaggregate FAF3 data from FAF3 regions to counties or smaller areas, FHWA has not evaluated any of these methods to establish estimates of reliability or accuracy. However, for coastal ports, FAF3 data do provide a useful starting point for evaluating the domestic origins and destinations of cargo flows by mode and their most likely routing.

National Transportation Atlas Database

The National Transportation Atlas Database is a set of nationwide geographic databases of transportation facilities, transportation networks, and associated infrastructure. These datasets include spatial information for transportation modal networks and multimodal terminals, as well as the related attribute information for these features (e.g., rail and road networks).

Google Earth

Google Earth provides satellite images of the river segments that were evaluated for inland waterway commodity flows. The dates of the images range generally from the early-to-mid-1990s to the most recent 3-year period, with the greatest number of images available since 2003/2004. These images allowed the research team to identify potential origin/destination terminals on the relevant river segments, as well as historical usage patterns. These potential sites were then cross-referenced to Master Docks data or other publicly available sources to determine whether they were likely to be involved in the handling of the commodities being analyzed.

U.S. DOT National Highway-Rail Crossing Inventory Program

The purpose of the U.S. DOT National Highway-Rail Crossing Inventory Program is to provide a uniform national inventory database that can be merged with accident files. The uniform dataset can then be used to analyze information for planning and implementation of crossing improvement programs by public and private agencies that are responsible for highway-rail crossing safety. Database items are generally broken into five categories: (1) location and classification information, (2) railroad information, (3) traffic control device information, (4) physical characteristics, and (5) highway information. The train counts and track characteristics can be used to analyze the level of congestion of specific track segments.

The accuracy of this dataset requires state departments of transportation to keep it current and accurate. Due to the inaccessibility of detailed data, the researchers used this information, noting that a government entity conducting the same type of research would most likely be able to acquire more recent and confidential data that would increase the accuracy of the analysis.

Other Reports/Data Sources

A number of published studies and data sources were used in assembling various parts of the data required for the detailed analysis of each port area. In most cases, these studies related to a specific port area or a methodology for extracting and evaluating data. They are noted throughout this report.

SECTION 2

Selection and Characterization of High-Volume Freight MTS Corridors in the United States

Selection of Port Areas for Analysis

The first step in developing a model that takes into account the MTS and the surface transportation system as one integrated system is to identify high-volume freight MTS corridors. By focusing on high-volume corridors, attention can be focused on projects that will have the largest potential benefit on the overall freight transportation system.

The NCFRP Project 42 researchers examined publicly available databases and other sources in order to identify seven primary MTS corridors in the United States on the Atlantic, Gulf, and West coasts; on the Great Lakes; and on the inland waterway system. The primary metric was the total tonnage carried since the focus of this study is to facilitate freight throughput; also, tonnage information is readily available and is more accurate than available cargo value estimates. A secondary concern was to achieve geographical and cargo diversity.

Using statistics from the Corps' Navigation Data Center, the researchers ranked ports across the country in three ways: (1) by dry cargo tonnage, (2) by petroleum and petroleum products tonnage, and (3) by the number of containers moved (TEUs). These rankings were then added together to form a composite score, and the port areas with the highest rankings were selected as candidates for further study. The initial list consisted of the following:

- Los Angeles/Long Beach, California
- South Louisiana, Louisiana
- Hampton Roads (Port of Virginia), Virginia
- Philadelphia, Pennsylvania
- Huntington, West Virginia
- Sabine-Neches Waterway (Beaumont, Port Arthur, and Orange), Texas
- Charleston, South Carolina

This initial list did not include a Great Lakes port while it included three ports on the East Coast. Great Lakes ports present a different set of modeling challenges compared to other ports, so it was important to modify the list to include at least one Great Lakes port. The researchers identified the Great Lakes port with the highest ranking—Duluth, Minnesota—and substituted it for Philadelphia, Pennsylvania, in order to achieve better geographical diversity. Additionally, the magnitude and complexity of the cargo flows through Los Angeles/Long Beach would have consumed a significant amount of project resources; therefore, the research team, in consultation with the NCFRP Project 42 panel, substituted Portland, Oregon, for Los Angeles/Long Beach, California. The availability of more current rail data and the connection to the Snake/Columbia River system were deciding factors in this selection. Finally, the Corps indicated that the data available in CPT for South Louisiana were inconsistent with other databases that it maintains for the same area. The Port of Plaquemines, Louisiana, has cargo and transportation characteristics similar to those of South Louisiana, although on a smaller scale, and there are fewer issues with potential inconsistencies. Therefore, the researchers substituted the Port of Plaquemines, Louisiana, for South Louisiana.

The researchers presented the list to the NCFRP Project 42 panel and discussed each port. The panel selected five ports to focus on as case studies:

- Duluth, Minnesota
- Hampton Roads (Port of Virginia), Virginia
- Huntington, West Virginia
- Plaquemines, Louisiana
- Portland, Oregon

The Port of Portland was further subdivided into deep draft (import/export) traffic and inland water (Columbia/Snake River) traffic. Therefore, even though there are five ports on the list, there are actually six case studies.

Each port area was then described in terms of certain primary physical characteristics. The primary criteria used to characterize each port include the following:

- **Type of port.** Each port was classified as an inland, coastal, or Great Lakes port. Each of these classifications embodies a unique set of modeling characteristics. For example, Great Lakes ports work within a substantially closed system, but this system includes two countries. Inland ports can handle traffic that originates at any point on the inland waterway system and connect with a wide variety of land-based transportation networks. Coastal ports are essentially end nodes in a land transportation system for purposes of this research.
- **Primary commodities.** The available Corps data reported commodity flows using two-digit commodity codes. The research team ranked commodity flows in descending order of average annual tonnages over the period 2006 to 2010 (the data from CPT that were provided to the project team) and selected the top-ranking commodities that together made up at least 80 percent of the total flows for a port.

Duluth, Minnesota (Great Lakes)

Duluth is different from the other ports included in the study because a very high percentage of its total commodity flows is outbound. In fact, for the primary commodities, the flows are entirely outbound. Additionally, Duluth tends to originate commodities destined for users located in other port cities on the Great Lakes. Therefore, its interaction with the surface transportation system primarily consists of inbound movements via rail. Table 1 shows the primary commodities at Duluth.

Although Code 44 includes "Steel Waste & Scrap" in its title, in the case of Duluth, the tonnage in this category is composed entirely of iron ore (taconite). In Duluth, a high percentage of the waterborne shipments terminate at domestic locations. Therefore, when defining the commodity flows for Duluth, it is important to look at the surface transportation flows into the port and the resulting outbound flows to other Great Lakes ports in the United States. The commodity flows for Duluth are analogous in many respects to the commodity flows described for Huntington, West Virginia.

Table 1. Primary commodity categories for Duluth, Minnesota.

Commodity Category (Code)	Average Annual Tonnage 2006–2010 (in 000s)
Coal, Lignite & Coal Coke (10)	19,825
Iron Ore and Iron & Steel Waste & Scrap (44)	15,630
Total	***35,455***
Total All Commodities	***40,721***

All tonnage figures were provided by the Corps from its CPT unless otherwise noted.

Hampton Roads, Virginia (Coastal)

Coal and containerized cargoes dominate the commodity mix for Hampton Roads. The detailed data provided by the Corps reported 90 percent of the actual total traffic. Table 2 shows the totals provided by the Corps and extrapolates them to the 100 percent level (internal and local traffic not included). The five commodity groups listed in Table 2 make up 81 percent of the total cargo flow for Hampton Roads.

An examination of the data revealed that there is virtually no coastwise activity for any of these commodity groups; therefore, Hampton Roads was considered to be the origin for imports and the destination for exports.

Huntington, West Virginia (Inland)

Huntington, West Virginia, is potentially the most complex of the candidate ports. This is because freight flows can originate and terminate on any number of waterway segments outside of the port area proper, with potential connections to highway and rail links that extend even farther. Furthermore, because the research team did not have access

Table 2. Primary commodity categories for Hampton Roads, Virginia.

Commodity Category (Code)	Average Annual Tonnage 2006–2010 (in 000s) @ 90%	@ 100%
Coal, Lignite & Coal Coke (10)	31,933	35,481
All Manufactured Equipment, Machinery and Products (70)	4,832	5,369
Sand, Gravel, Stone, Rock, Limestone, Soil, Dredged Material (43)	2,609	2,899
Other Agricultural Products; Food and Kindred Products (68)	1,932	2,147
Other Chemicals and Related Products (32)	1,762	1,958
Total	***43,068***	***47,854***
Total All Commodities	***52,946***	***58,829***

Table 3. Primary commodity categories for Huntington, West Virginia.

Commodity Category (Code)	Average Annual Tonnage 2006–2010 (in 000s)
Coal, Lignite & Coal Coke (10)	46,386
Sand, Gravel, Stone, Rock, Limestone, Soil, Dredged Material (43)	4,599
Distillate, Residual & Other Fuel Oils; Lube Oil & Greases (23)	4,159
Gasoline, Jet Fuel, Kerosene (22)	3,354
Total	***58,498***
Total All Commodities	***72,014***

to dock-level data, the data had to be managed on the basis of river segments instead of on the basis of individual dock locations. Rather than having waterway segments/links with a single dock or facility, the model is required to treat whole river segments as links with a single landside connection, which means that multiple facilities are lumped together as one. This in turn requires some generalized assumptions about the facilities in each segment that may not be entirely accurate. Using more granular data, future research efforts can build on the proposed methodology to develop a more accurate evaluation of project alternatives.

The data for calendar years 2006 to 2010 show that four commodity groups coded at the two-digit level make up over 81 percent of the total tonnage that originates, terminates, or passes through the Port of Huntington. An additional 21 groups make up the remaining 19 percent. Table 3 shows the top four commodity groups.

Coal alone accounts for 64.4 percent of the total commodity tonnage flows for Huntington.

Plaquemines, Louisiana (Dual Coastal/Inland)

Coal and grain (corn and wheat) dominate the commodity mix for Plaquemines. The detailed data provided by the Corps reflected 90 percent of the actual total traffic. Table 4 shows the totals provided by the Corps and extrapolates them to the 100 percent level (internal and local traffic not included). The seven commodity groups shown in Table 4 make up 81 percent of the total cargo flow for Plaquemines.

These commodities had significant domestic shipment volumes; therefore, each commodity has an import corridor, export corridor, domestic inbound corridor, and domestic outbound corridor. Table 4 does not include internal or coastwise shipments in the totals.

Portland, Oregon (Coastal)

Wheat exports dominate the commodity mix for Portland-Coastal. The seven commodity groups shown in Table 5 make up 82.5 percent of the total foreign trade cargo flow for Portland. Table 5 does not include internal shipments in the totals.

Portland, Oregon (Inland)

As in the case of Huntington, because the research team could not access dock-level data, the data had to be managed on the basis of river segments instead of on the basis of individual dock locations. Rather than having waterway segments/links with a single dock or facility, the model is required to treat whole river segments as links with a single landside connection, which means that multiple facilities are lumped together as one. This in turn requires some generalized assumptions about the facilities in each segment that

Table 4. Primary commodity categories for Plaquemines, Louisiana.

Commodity Category (Code)	Average Annual Tonnage 2006–2010 (in 000s) @ 90%	@ 100%
Coal, Lignite & Coal Coke (10)	10,155	11,283
Corn (63) and Wheat (62)	4,959	5,510
Crude Petroleum (21)	3,002	3,336
Petroleum Pitches, Coke, Asphalt, Naphtha and Solvents (24)	2,431	2,701
Distillate, Residual & Other Fuel Oils; Lube Oil & Greases (23)	2,079	2,310
Oilseeds (Soybean, Flaxseed and Others) (65)	2,072	2,302
Gasoline, Jet Fuel, Kerosene (22)	1,180	1,311
Total	***25,878***	***28,753***
Total All Commodities	***31,402***	***34,891***

Table 5. Primary commodity categories for Portland-Coastal.

Commodity Category (Code)	Average Annual Tonnage 2006–2010 (in 000s)
Wheat (62)	9,441
Other Chemicals and Related Products (32)	3,178
Fertilizers (31)	2,484
Gasoline, Jet Fuel, Kerosene (22)	2,182
Distillate, Residual & Other Fuel Oils; Lube Oil & Greases (23)	1,212
All Manufactured Equipment, Machinery and Products (70)	977
Primary Non-Ferrous Metal Products; Fabricated Metal Prod (54)/ Primary Iron and Steel Products (Ingots, Bars, Rods, etc.) (53)	1,129
Total	***20,603***
Total All Commodities	***24,911***

may not be entirely accurate. Using more granular data, future research efforts can build on the proposed methodology to develop a more accurate evaluation of project alternatives.

The data for calendar years 2006 to 2010 show that four commodity groups coded at the two-digit level make up over 93 percent of the total inland waterway tonnage that originates, terminates, or passes through the Port of Portland. (Forest products make up the remainder.) Table 6 shows the top four commodity groups.

Multimodal Connections for the Selected High-Volume Freight MTS Corridors

For the selected port areas, the researchers identified the landside corridors that tied into the waterfront origins and destinations for the primary commodity flows. Initially, the researchers intended to use the Corps' confidential waterborne trip data file to identify specific points of interchange with the landside system (docks). However, the Corps determined that it could not make the data available to the researchers. This obstacle primarily affected the analysis of inland waterway ports. The data from CPT that were made available by the Corps were aggregated by river segment. Nearly all of these segments included multiple facilities, any one of which could have been the origin or destination of the waterborne flow(s) (these segments are referred to as links in the description of the model). This circumstance required the researchers to treat each segment as a link with one entry/exit point for landside connections in the modeling framework, even though a segment might actually consist of multiple facilities. By examining the relevant waterfront facilities in each segment, the researchers were able to make some assumptions as to whether the landside corridor would be primarily highway, rail line, or pipeline. Because of the difficulties in assessing pipeline capacity and efficiency, and given that the primary focus of this research was the interconnection with rail and highway corridors, pipeline flows were dropped from consideration. Given a railway or highway connection, further investigation was conducted to determine the most likely rail line(s) or highway(s) used to transport the commodity to or from the waterfront facility.

The evaluation of waterfront facilities on inland waterways was conducted in a multi-phased approach. First, the researchers examined the highest volume origin-destination pairs for the highest tonnage commodities originating, terminating, or passing through the port. All of the traffic associated with these segments (not just the high-volume origin-destination flows) was tallied, and the top-ranking river segments, those that accounted for at least 80 percent of the overall cargo flows, were selected. The researchers then used Google Earth satellite images and the Corps' facility data to identify waterfront facilities in each of the selected segments that were likely to handle the commodity in question. Once these facilities were identified, an attempt was made to develop an overall characterization of the segment, i.e., a determination was made as to whether the majority of cargo flows to/from the facilities in the segment would most likely be by truck, rail, or pipeline, or whether the segment might be an end point in

Table 6. Primary commodity categories for Portland-Internal.

Commodity Category (Code)	Average Annual Tonnage 2006–2010 (in 000s)
Wheat (62)	4,444
Gasoline, Jet Fuel, Kerosene (22)	2,640
Sand, Gravel, Stone, Rock, Limestone, Soil, Dredged Material (43)	2,404
Distillate, Residual & Other Fuel Oils; Lube Oil & Greases (23)	1,976
Total	***11,464***
Total All Commodities	***12,312***

the corridor. Using a variety of sources, the researchers then determined the most likely principal origins/destinations for the commodity and (in the case of non-pipeline flows) the most likely highway and rail lines used.

Appendix C contains a description of the primary origin-destination corridors and the modal assignments for each corridor for each port. Only the ports selected for the case studies are included in the appendix, but a corridor analysis was done for each candidate port initially presented to the NCFRP Project 42 panel.

Finally, some measure of system component availability for each corridor (whether on land or water) was needed to evaluate investment options. It was assumed that a project that would enhance resource availability and tap into a highly reliable network would be preferable to a project that would tap into a highly congested or unreliable network. The goal of the measure was to define the current (without project or before condition) utilization of the asset and the post-project (improved or after condition) utilization of the asset and compare the two. Initially, the researchers defined the measure as "capacity"; however, capacity was determined to be too vague—it could be affected by time of day, season of the year, equipment choices, and other variables. A term such as "utilization" focuses on the system itself, its historic activity, and its potential usefulness to a carrier/shipper. The details of how this measure was developed are described in the section of this report titled "Utilization Metrics/Indicators."

Method of Analysis

Maintenance projects are not currently evaluated at a detailed level; rather, the objective is to maintain each navigation project at its authorized dimensions. However, given that it is unlikely that budgeted amounts will make this objective achievable any time in the foreseeable future, a system must be developed to prioritize expenditures. There are a number of metrics that could be used to prioritize the possible O&M budget items. These include cargo value, cargo quantity, economic impact on the region, availability of alternative modes of transportation, and others. The research team chose to focus on the maximization of cargo flows based on tonnage. This measure could be expanded or even substituted in the model discussed in this report.

Because there is currently no information available on how much an O&M project might affect cargo flows, the model is not able to maximize cargo throughput capability in an absolute sense; rather, it was necessary to employ a sensitivity-type analysis. The conceptual approach was to assume a certain loss of water depth due to lack of maintenance dredging. A loss of depth (draft) would not necessarily affect cargo flows in terms of total tonnage, although it would definitely affect the unit cost of the flow. Therefore, the assumption was made that loss of depth would not necessarily affect the volume of traffic. However, if the navigation project were to be restored to its authorized dimensions and remain there, it is highly probable that further shipments and investment in waterfront facilities would be made. The researchers analyzed what historically moved within affected stratum at each port and then analyzed a 10 percent, 20 percent, or 30 percent increase in that subset of the port's traffic. Initial results showed that in many cases the 10 percent and 20 percent levels had insignificant effects. In fact, in some cases even a 30 percent increase in the tonnage at the affected depth level caused a very small increase in the port's total traffic in some port communities. In order to simplify the analysis and make the results meaningful, the researchers chose to use only the 30 percent level for this research. Tonnage that is assigned to the affected stratum of the waterway is referred to as "project depth tonnage" in this research. Since this is the tonnage that dredging will directly affect, the objective function in the model attempts to maximize this variable.

The model recognizes the possibility that these potential increases could overtax the surface transportation system involved in the supply chain corridor. What follows is a step-by-step description of the method that was used to calculate the capacity of highways and railroads and the potential congestion resulting from additional tonnage generated by a potential maintenance project. Figure 1 shows a flow chart summarizing the general method of analysis.

In several cases, much of this analytical work was not necessary. The preliminary corridor analysis and historical traffic patterns indicated that either rail or highway (or both) would not be affected. This is explained in the summary of the findings for each port.

Step 1: Determine the Potential Tonnage Increase

Determine the potential increase in utilization for each port as the maximum tonnage that could be potentially added to the port's cargo volumes as a result of a project. For locks, the change in potential utilization (or theoretical capacity) is a function of the reduction in delay. While delays can be caused by unusual arrival patterns or weather conditions—and therefore cannot be eliminated—average delays are heavily influenced by down time and operational issues. For the purposes of this modeling exercise, it was assumed that delays could be cut by a certain amount with a maintenance project. For channel projects (i.e., in the case of both inland and coastal ports) potential utilization is essentially the number of additional tons that could be transported per foot dredged. As explained earlier, the projected increase in utilization is calculated by taking the tonnage that has historically transited in the depth stratum that the maintenance project will affect and then increasing that tonnage by 30 percent.

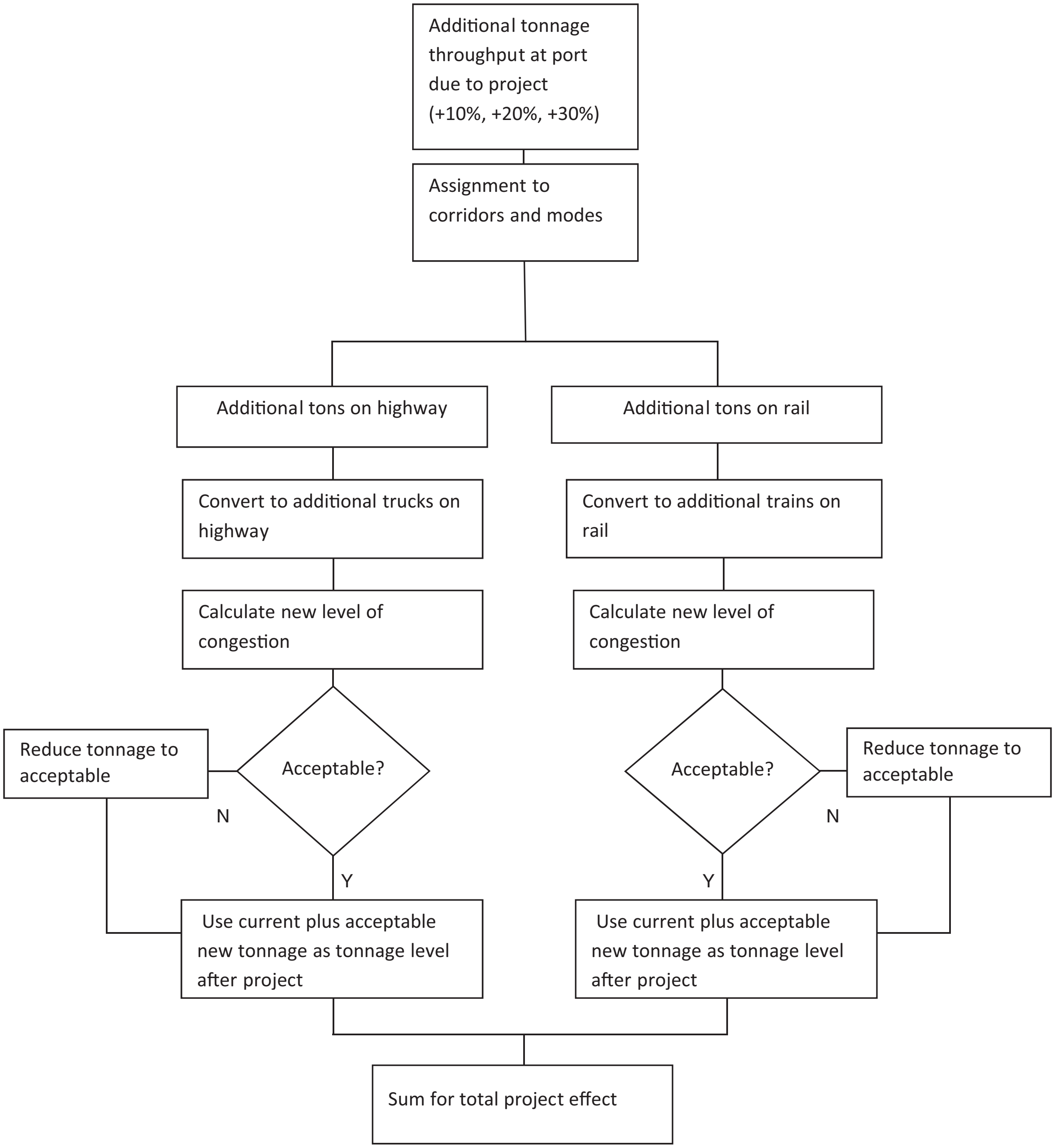

Figure 1. Overview of method for determining capacity input values for model.

Step 2: Assign Tonnage to Each Corridor and Mode

Assuming that a cargo increase will need to tap into a rail or highway corridor, the researchers used FAF3 data for 2011 to determine the percent distribution of potential tonnage by mode to/from the FAF3 area corresponding to the particular port and identify the major highway and rail corridors that transport it.

Step 3: Determine How Much of the Potential Additional Tonnage Can Be Accommodated

For the rail segments or highway segments in question, the current traffic levels and congestion levels were determined. The potential utilization of a corridor—defined as the increase in tonnage up to the point at which unacceptable congestion occurs—was then calculated. The method for determining congestion and unacceptability is described in the modal sections below. The model sets the potential tonnage increase for a corridor to the lesser of (1) potential total new tonnage or (2) total cargo flow at the point where congestion becomes unacceptable. (If the highway or rail mode has enough capacity to handle the projected cargo increase, it is essentially treated as unlimited capacity in the model.)

Utilization Metrics/Indicators

The approach used to develop utilization metrics/indicators depends on the type of system component: lock, river/channel, highway, or rail line. The following paragraphs describe the data the research team used and the corresponding methods that were employed to develop these metrics.

Locks

Capacity/Utilization

In the case of lock capacity, the constraint is not depth. Lock capacity/utilization is greatly dependent on available operating time and tow processing time. By improving the condition of the lock, it is possible to reduce the hours the lock is out of service and increase the capacity of the lock to move additional project depth tonnage over a given time frame.

The researchers conducted a thorough literature search for methodologies that have already been developed for determining lock capacity on the inland waterway system. Only two were found that appeared to be methodologically sound. In the first case, the Corps did an exhaustive analysis of lock capacities on the Ohio River as part of its "Ohio River Mainstem System Study Integrated Main Report" of 2006 (*8*). The Corps performed a series of simulations for each lock using its proprietary Waterway Analysis Model (WAM). In the second case, the Oak Ridge National Laboratory (ORNL) did a mathematical/statistical analysis of a number of locks and developed a regression equation that estimated the tonnage capacity of a lock based on historical tow sizes, tonnage throughput, and delay statistics. Appendix D contains a detailed description of this methodology.

Since the ORNL analysis used publicly available data, the researchers used the ORNL approach to calculate the capacity of a number of locks on the Ohio River and then compared the results to what the Corps calculated using WAM. After factoring out obvious anomalies (outliers) in the data (typically caused by major accidents), the results of the two were acceptably similar. Since the ORNL approach uses publicly available data and was acceptably close to the WAM results, the researchers calculated capacities using the ORNL formulas. Table 7 shows the results for the Ohio River System locks included in the corridors identified in the case studies. Table 8 shows the Columbia/Snake River locks.

Table 7. Lock utilization levels—Ohio River System (2000–2012).

Lock	Practical Capacity (Tons)	2010 Tonnage	% Utilization	2012 Tonnage	% Utilization	Peak Tonnage	Peak Year	Peak % Utilization
New Cumb	120,714	26,289	22%	31,108	26%	35,252	2002	29%
Pike	142,160	30,026	21%	31,751	22%	43,628	2002	31%
Hannibal	166,201	42,284	25%	40,389	24%	53,288	2005	32%
Willow	158,801	41,780	26%	39,786	25%	50,164	2005	32%
Belleville	183,809	44,560	24%	42,165	23%	52,888	2005	29%
Racine	151,951	45,611	30%	43,177	28%	52,275	2004	34%
Byrd	183,998	50,398	27%	48,098	26%	62,481	2005	34%
Greenup	140,903	56,443	40%	50,527	36%	71,709	2000	51%
Meldahl	142,930	57,738	40%	51,618	36%	63,809	2001	45%
Markland	156,442	57,595	37%	57,616	37%	61,401	2011	39%
McAlpine	155,429	67,660	44%	71,105	46%	73,589	2011	47%
Cannelton	152,647	67,974	45%	69,460	46%	72,305	2011	47%
Newburgh	232,639	78,302	34%	78,934	34%	81,829	2011	35%
Myers	184,744	71,501	39%	68,098	37%	75,279	2001	41%
Smithland	321,261	78,405	24%	73,447	23%	85,915	2001	27%
Monon L&D 2	37,406	14,832	40%	15,088	40%	21,733	2002	58%
Emsworth	19,970	15,326	77%	16,520	83%	23,687	2002	119%
Dashields	40,208	16,365	41%	17,897	45%	24,516	2002	61%
Montgomery	34,688	18,237	53%	18,756	54%	26,709	2002	77%
L&D 52	116,535	89,878	77%	91,401	78%	97,325	2005	84%
L&D 53	230,592	79,628	35%	76,982	33%	89,153	2000	39%

Shaded items are locks that could reach their capacity with increased tonnage from a proposed maintenance project. The corridor analysis considered these locks as potential choke points.

Table 8. Lock utilization levels—Columbia/Snake River System (2000–2012).

Lock	Practical Capacity (Tons)	2010 Tonnage	% Utilization	2012 Tonnage	% Utilization	Peak Tonnage	Peak Year	Peak % Utilization
Bonneville	23,394	8,397	36%	8,670	37%	10,614	2000	45%
The Dalles	13,225	8,025	61%	8,226	62%	10,141	2000	77%
John Day	10,319	7,368	71%	7,259	70%	9,098	2000	88%
McNary	21,652	6,244	29%	6,187	29%	8,409	2000	39%
Ice Harbor	9,195	2,887	31%	3,175	35%	4,525	2000	49%
Lower Monumental	8,232	2,554	31%	2,776	34%	4,090	2000	50%
Little Goose	8,233	2,233	27%	2,593	31%	3,059	2000	37%
Lower Granite	3,296	1,265	38%	1,510	46%	2,183	2000	66%

Shaded items are locks that could reach their capacity with increased tonnage from a proposed maintenance project. The corridor analysis considered these locks as potential choke points.

The potential effect of a lock maintenance project was calculated by identifying the lowest annual average delay from 2000 to 2012 and using it as the target (after project) condition. The difference between the theoretical capacity of the lock based on historical data and the theoretical capacity with the optimum delay factor would be the potential tonnage increase for the lock. As with highway and rail, the model compares the potential increase assigned to the corridor/lock as part of the port project analysis to the revised capacity of the lock, and the lesser of the two is taken as the actual effect of the maintenance project.

One important assumption underlies the calculation of the indicator for locks—the size and composition of tows will not change as a result of the lock project under consideration. This means that the number of barges per tow will not change from the historical average and neither will the percentage split between loaded and unloaded barges. In other words, the average throughput per lockage will remain the same.

Delays

At locks, the effect of maintenance is to reduce down time (increase operating hours) and/or reduce delays. For this study, the focus is on a reduction in delay, which increases the potential throughput at the lock. A unit of improvement is defined as one-third of the potential reduction in delays (the difference between historical average delay and optimum delay). In the case studies, up to three units of improvement are incorporated into a lock maintenance project, which amount to 100 percent of the potential reduction. For example, if the current average delay is 0.90 hours and it could potentially be reduced to 0.30 hours, the difference is 0.60 hours. One-third of 0.60 hours is 0.20; this would be one unit of improvement. If three units of improvement are achieved, the new delay will be 0.30 hours.

Channels

For inland port waterway segments and coastal ports, the researchers used a metric based on channel depth as a utilization indicator. By examining historical average tonnage throughput at various draft levels during periods when adequate channel depth was available (as CPT does), it is possible to develop the tonnage by commodity that has historically transited in the depth stratum being affected by maintenance dredging. For the purposes of this study, it was assumed that each port would silt in 3 ft before maintenance would actually be funded, with the exception of Huntington, where the assumption was 2 ft.

It was assumed that the historical tonnages would have moved on the waterway even with reduced water depth; they would just have to move in smaller barge/vessel loads, and an additional number of trips would be required to continue moving the same tonnage. The researchers made an assumption that if the waterway/channel were to be restored to its authorized dimensions and maintained there, it would be plausible to assume that additional tonnage would be attracted to the waterway. As noted earlier, this additional tonnage was termed "project depth tonnage."

A project that has silted in 3 ft (2 ft in the case of Huntington) would have zero capacity to move project depth tonnage. However, for each foot of dredging, a certain amount of project depth tonnage would be restored based on historical averages, and a 30 percent increase in tonnage moving in the newly restored stratum was added on top of that for the purposes of this analysis.

At the present time, there is no accepted methodology for determining the effect maintenance dredging (or the lack thereof) might have on tonnage throughput. It is for this reason that the Corps has selected historical tonnage and regional significance to prioritize maintenance dredging, rather than an actual analysis of potential impacts. Since there is no methodology for determining what the tonnage increase from maintenance dredging would be, the researchers initially employed a sensitivity analysis approach in which they increased the tonnage that historically moved in the affected stratum by 10, 20, and 30 percent to see how that would affect the model results. However, it became apparent early in the modeling process that in many cases, even a 30 percent increase in the potentially affected tonnage stratum was not a significant number in relation to the total tonnage each port handles. The researchers used 30 percent as the expected increase for purposes of testing the model and its indicators.

As an illustration, assume that a port has 100 million tons of traffic each year. Also, assume that 70 million tons of that traffic is project depth tonnage; it needs the maximum depth. The expected increase of 30 percent is applied to the 70 million tons, resulting in a potential increase of 21 million tons. Note that a 30 percent increase in project depth tonnage is a 21 percent increase in the port's total tonnage.

The analysis treated each inland waterway segment that is part of an origin-destination pairing as a non-lock node—i.e., as if it were a channel of a coastal port—for purposes of determining highway and rail capacities. In other words, the selected river segments were potentially origin or destination points for a surface transportation corridor as well as origins or destinations for waterborne shipments. In the calculation of how much tonnage could be potentially added to particular waterway segments associated with each such node in the case of an inland waterway port, constraints caused by water depth and lock throughput capacity were both considered. The current theoretical availability and the projected increase resulting from any project were expressed in terms of tonnage, as explained above.

For inland port analysis (Huntington and Portland-Inland) the analysts recorded all segments and locks included in the identified corridors as well as their sequence. For each segment or lock that was analyzed, the potential additional tonnage to be gained from the project was expressed in tons per foot dredged (for segments) or tons per unit of reduction in delays (for locks).

Highways

The highway corridor analysis tapped into previous and ongoing work conducted by TTI through its Urban Mobility Research Program (UMRP) (*9*). Based on its previous work across the country, UMRP was able to determine that any potential highway congestion effects from increased port traffic would only be noticeable in the immediate vicinity of the port. The researchers established how many more trucks could be added to the arterials that link ports to Interstate or U.S. highways before congestion levels began to show dramatic deterioration.

In order to calculate the number of truck trips that would be generated by new tonnage throughput resulting from a project, the researchers assumed an average truckload of 25 tons per truck. They did not attempt to factor in backhauls, since there was no way to determine whether the truck would return directly to its origin, and if it did, what route it would follow.

Rail

The capacity analysis of potential rail corridors consisted of the following steps:

1. Define relevant rail corridors for analysis.
2. For each corridor, identify terminals and/or rail line segments where congestion is likely to be severe.
3. Determine the theoretical train count capacity of the terminal or rail line segment by using a simplified approach identified in the *National Rail Freight Infrastructure Capacity and Investment Study* prepared for the Association of American Railroads by Cambridge Systematics, Inc., in 2007 (*2*).
4. Establish current train counts for the identified terminal or rail line segment using data from the U.S. DOT National Highway-Rail Crossing Inventory Program.
5. Calculate the remaining available capacity by subtracting (4) from (3) above.
6. Using a standard train size and carload tonnage (bearing in mind the primary commodities being transported), calculate the equivalent tons of remaining available capacity.

Corridor Analysis

The tonnage for each primary commodity-corridor combination was divided among the highway, rail, or water modes, based on the FAF3 data. Appendix C provides the modal assignment for the corridors associated with each port. Once the corridor modes and tonnages were established, the researchers assessed each corridor to see if there were any constraints that would prevent the tonnage increases from flowing through the corridor. Appendix E discusses the constraints. The manner in which this information was input into the model is described next.

SECTION 3

Proposed Metrics and Operations Research Methods

Overview

Concurrently—and in coordination with—the activities described, the research team developed an operations research model for evaluating and prioritizing a set of possible projects (specifically lock and dam projects and/or dredging projects). The objective function was designed to maximize the expected total positive impact of selected potential projects on the freight transportation system as a whole.

The operations research model is built on a network using network flow techniques. The network consists of links and nodes. For each port area, a network covering the area of interest is established. The network associated with each port area consists of four different types of links (see Figures 2 and 3):

1. Numbered port segments/waterway links (═══) for inland waterway ports or the port itself for coastal and Great Lakes ports. Locks and dams are also represented by links in the theoretical network model.
2. In the case of inland ports, waterway segments/links that connect a port to other ports (▪ ▬▬▬).
3. Highways that feed freight into this waterway network or remove it (━━━).
4. Connected railroads for transporting freight out of or into the port (– – – –).

It is assumed that each of these link types has a maximum capacity and a certain level of current utilization. The objective of the model is to maximize the possible freight throughput served by the restored or increased system availability by identifying lock and non-lock waterway segments/links for maintenance. In the case of dredging, the model determines dredging location and depth; in the case of locks, it determines reductions in average delay and evaluates their associated combined effects on the system network including landside linkages. The freight network analysis is based on historic freight demand.

Definition of Terminologies

There are several terms used in the description of the model that need to be clearly defined to avoid confusion:

- **Link.** A component of infrastructure that carries a measurable volume of tonnage with a capacity that can be improved through maintenance operations. Examples of a link include: river segment(s), lock(s), ports, segments of highways, and/or segments of rail lines.
- **Node.** The connection point between two links.
- **Corridor.** The path of a particular commodity flow between an origin and destination pair. This may include highway, rail, and/or water routes that together form a corridor.

Data Needs

The following data are needed to build a sufficiently robust model:

1. Origin-destination freight demand for the selected commodity groups (in thousand tons).
2. Current utilization of highway and railroad routes and remaining throughput capacity before level of service becomes unacceptable (in tonnage).
3. A known total project budget cap.
4. Portfolios of alternative projects, each complete with budget and benefit. The benefit is the restored potential utilization at the location[2] (in tonnage).
5. Current utilization of waterway segments/links (before/without project, in tonnage).[3]

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[2] Assume multiple options of dredging or maintenance at each location are known.

[3] Restored availability from project completion is added on top of this base availability.

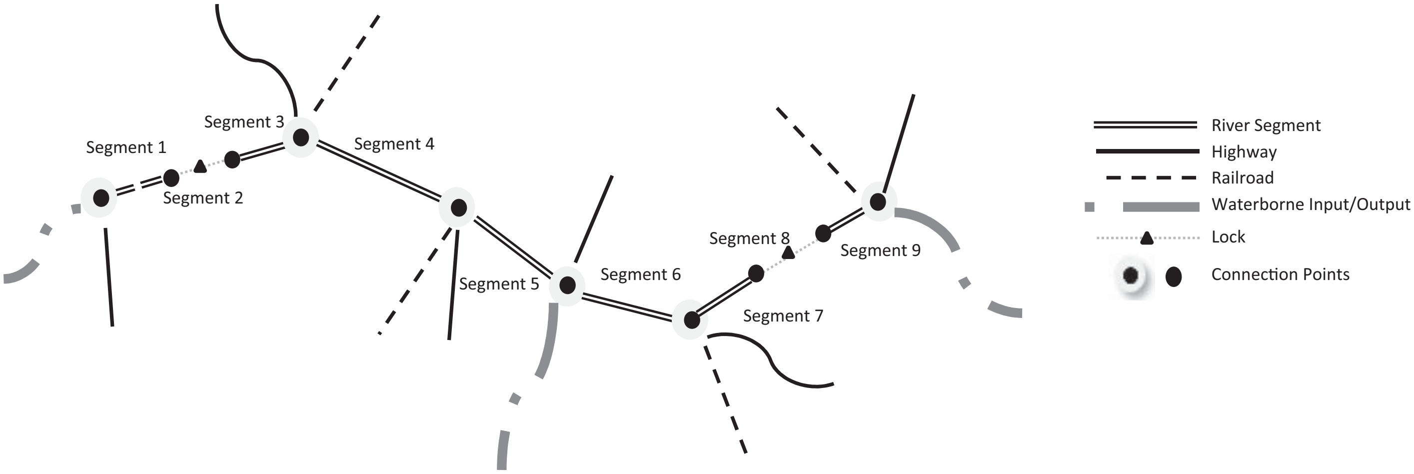

Figure 2. Abstract network representation of inland waterway port flows.

6. Current level of lock utilization (in tonnage).
7. The additional tonnage throughput due to Corps projects improvement (either waterway segments or locks, in tonnage).

Underlying Assumptions

There are two assumptions that are critical to the integrity of the model:

1. At each location (e.g., a river segment/link or a lock), only one maintenance project may be selected.
2. The lack of detail in the inland waterway trip data forces the assumption that any changes associated with a river segment will be distributed uniformly across that segment.

Assumption 1 implies that one location cannot be dredged for two depths simultaneously, which represents a logical requirement.

Inputs to the Model

Two tables were developed that provided the needed information for the modeling runs. The first table (see Table 9) provides a list of all segments that are part of selected corridor/commodity flows. For each segment, the table provides the average utilization, remaining project depth cargo capacity, increase in potential tons/year per unit of improvement, and cost per unit of improvement. A unit of improvement (or maintenance activity) consists of 1 ft of dredging for a waterway segment or one-third of the increased capacity resulting from the targeted reduction in average delay at a lock.

In order to determine a reasonable cost per unit of maintenance activity, the researchers compiled data on dredging and lock expenses at the ports and potentially constrained locks. These data were taken from the Corps' online dredging information system (*10*). These data are entered by Corps District personnel directly into the central database. Reports are posted every other Monday. There are a number of dredging-related

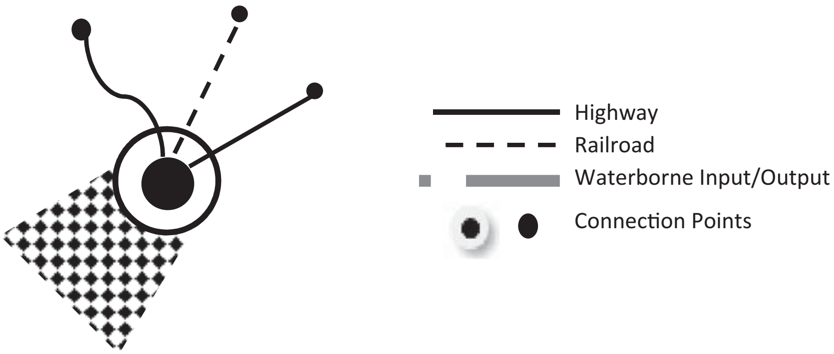

Figure 3. Abstract network representation of coastal seaport.

Table 9. Segment attributes.

Port	Segment ID	Name	Maximum Theoretical Capacity (000 tons/yr)	Average Utilization (000 tons/yr) 2006-2010	Remaining Proj Depth Cargo Capacity	Increase in Potential tons/yr per Unit of Improvement	$ Cost per Unit of Improvement
		CHANNEL SEGMENTS					
Hunt	Segment 1	Monongahela River, Pa And Wv (mile 000 To Mile 128) and Ohio River, Oh_wv_pa-lrp (Mile 000 to Mile 006)	999,999	17,877	982,122		
Hunt	Emsworth	Emsworth Lock & Dam Aux 1	24,871	18,622	6,249	3,648	705,531
Hunt	Segment 2	Ohio River, Oh_wv_pa-lrp (Mile 006 to Mile 279)	999,999	51,935	948,064		
Hunt	Segment 3	Kanawha River, Wv (Mile 00 to Mile 95)	999,999	20,066	979,933		
Hunt	Segment 4	Ohio River, Ky_oh_wv_pa-lrh (Mile 279 to Mile 317)	999,999	60,646	0	10,090	754,436
Hunt	Segment 5	Big Sandy River, Ky_wv (Mile 000 to Mile 232)	999,999	17,699	982,300		
Hunt	Segment 6	Ohio River, Il_ky_in_oh-lrl (Mile 317 to Mile 981)	999,999	88,695	0	14,757	754,436
Hunt	Segment 7	Upper Mississippi, Mo_il-mvs (Mile 000 to Mile 117)	999,999	105,764	894,235		
Hunt	Segment 8	Lower Mississippi, Ms_ar_tn-mvm (Mile 039 to Mile 954)	999,999	179,292	820,707		
HR	HR1	Entrance Channel, Va (Mile 00 to Mile 12)	999,999	57,998	942,001		
HR	HR2	Norfolk Harbor, Va (Mile 02 to Mile 19)	999,999	40,490	0	898	889,341
HR	HR3	Channel To Newport News, Va (Mile 0 to Mile 3)	999,999	17,556	0	590	562,359
Dulu	DS1	Lake Superior Spine (Mile 295 to Mile 371)	999,999	41,128	958,871		
Dulu	DS1	Superior, Wi Access	999,999	41,128	958,871		
Dulu	DS1	Duluth, Mn	999,999	41,128	0	3,748	942,828
Dulu	DS2	Lake Superior Spine (Mile 000 to Mile 294)	999,999	71,308	928,691		
Dulu	DS2	St. Mary's River (Mile 00 to Mile 63)	999,999	71,308	928,691		
Dulu	DS2	St. Mary's River Southern Access (Mile 00 to Mile 09)	999,999	71,308	928,691		
Dulu	DS3	Lake Huron Spine (Mile 242 to Mile 284)	999,999	67,880	932,119		
Dulu	DS3	Lake Huron Spine (Mile 000 to Mile 241)	999,999	7,141	992,859		
Dulu	DS4	St. Clair River	999,999	64,452	0	4,987	293,067
Dulu	DS5	Lake Michigan Spine (Mile 004 to Mile 356)	999,999	9,748	990,251		
Dulu	DS5	Burns Harbor Access	999,999	6,363	993,636		
Dulu	DS6	Burns Harbor	999,999	6,363	0	504	675,210
Plaq	PL3	Southwest Pass of the Mississippi River (Mile 00 to Mile 21)	999,999	N/A			
Plaq	PL2	Lower Mississippi, La-mvn (Mile 000 to Mile 038)	999,999	212,472	787,527		
Plaq	PL1	Lower Mississippi, La-mvn (Mile 039 to Mile 087)	999,999	84,387	0	643	18,210,964

Table 9. (Continued).

Port	Segment ID	Name	Maximum Theoretical Capacity (000 tons/yr)	Average Utilization (000 tons/yr) 2006-2010	Remaining Proj Depth Cargo Capacity	Increase in Potential tons/yr per Unit of Improvement	$ Cost per Unit of Improvement
Port In	Segment 1	Snake River, Or, Wa and Id (Mile 000 to Mile 151)	999,999	4,428	995,571		
Port In	Segment 2	Columbia above Snake River	999,999	5,899	994,100		
Port In	Segment 3	Columbia River, John Day to Snake River	999,999	7,918	992,081		
Port In	John Day	John Day Lock & Dam	10,319	7,391	2,928	608	4,919,965
Port In	Segment 4	Columbia River, Portland to John Day	999,999	9,261	0	825	200,202
Port In	Segment 5	Willamette River	999,999	1,074	998,925		
Port In	Segment 6	Columbia River below Portland	999,999	53,225	946,774		
Port In	Segment 7	Coastal South of Columbia River	999,999	N/A	N/A		
Port In	Segment 8	Coastal North of Columbia River	999,999	N/A	N/A		
Port Coas	PO1	Columbia River, Or_wa-nwp (Mile 90 to Mile 106)-Deep	999,999	27,103	0	898	4,683,100
Port Coas	PO0	Columbia River, Or_wa-nwp (Mile 00 to Mile 90)-Deep	999,999	53,225	946,774		
		RAIL SEGMENTS					
HR	**HRR1**	**NS -Norfolk International Terminal--Roanoke**	**109,500**	**24,559**	**84,941**		
HR	**HRR2**	**CSX - Newport News-Richmond**	**273,750**	**35,474**	**238,276**		
Dulu	DSR1	DMIR - Mountain Iron, MN - Duluth, MN	64,240	38,300	25,940		
Dulu	DSR2	Superior, WI - Sheridan, WY	133,700	19,825	113,875		
Port Coas	POR1	UP Line to Council Bluffs, IA thru Cascade Locks and Huntingon, OR; Rock Springs and Cheyenne, WY; North Platte, Grand Island, Omaha, NE	105,339	98,316	7,023		
Port Coas	POR2	BNSF Line to Spokane, WA thru Vancouver	116,575	116,575	0		
Port Coas	POR3	BNSF Line from Spokane, WA to Council Bluffs, IA thru Sandpoint, ID; Laurel and Warren, MT; Casper and Orin, WY	22,472	11,236	11,236		
		HIGHWAY SEGMENTS					
Port Coas	LOMB	Lombard St.	100,000	6,899	93,101		
Port Coas	MAR	Marine Drive	100,000	996	99,004		
Port Coas	I5	I-5	100,000	7,895	92,105		
Port Coas	I84	I-84	100,000	4,180	95,820		

Some datasets published by the Corps begin numbering the Ohio River in Pittsburgh and progress downstream, while others begin at the junction with the Mississippi River and progress upstream. This table starts the numbering sequence in Pittsburgh.

Blank cells indicate segments for which no maintenance activity is considered.

Dotted background indicates the actual port as opposed to segments connected to the port.

reports available on the website: advertising schedule, dredging contracts awarded, anticipated work schedule, Corps/industry dredge fleet status, long-term dredging cost analysis, number of contracts and quantity dredged, and other reports with miscellaneous information.

In any dredging or lock maintenance event, a certain amount of the expense is caused by mobilization and demobilization of the equipment, regardless of the actual amount of work involved. The researchers had no way to estimate what percentage of the cost of any given dredging event was due to mobilization or demobilization. Furthermore, the model is predicated on the ability to treat each foot or 10 percent reduction in delays as a modular function, where each unit of work costs the same as the next one. Although this is not the way contracts are actually executed, adding in a function to calculate the difference in each unit based on whether it is absorbing one-third, two-thirds, or all of the mobilization/demobilization costs would add a high degree of complexity and would not change the final result in a meaningful way. In this research, each unit was treated as a standard unit, and the cost of an event was simply the number of units times the unit cost. The resulting increase in project depth cargo capacity resulting from a unit of dredging would simply be the 30 percent increase in project depth cargo divided by three (two in the case of Huntington).

Finally, the public dataset only provides information on the quantity of cubic yards stipulated in the request for proposal; it does not provide the final quantity, nor does it indicate how that quantity was distributed across the dredged area. For instance, there is no indication of whether the quantity was a relatively deep section in a fairly small geographical area or whether the quantity was a thin layer spread over a wide geographical area. Therefore, the data that are used below are simply an attempt to arrive at dollar amounts that would be reasonable given the history of dredging in the specific area.

Duluth

Data for 5 years of dredging activity were compiled for each of the three ports that are relevant to the Duluth case study (see Table 10). The coal shipped from Duluth has the highest tonnage going to St. Clair River, Michigan. Table 11 shows its dredging history. The iron ore shipped from Duluth has the highest tonnage going to Burns Harbor, Indiana. Table 12 shows its dredging history.

Table 10. Port of Duluth dredging history (5 years).

FY	Project Name	Cubic Yards	Winning Bid
2007	Duluth-Superior, MN&WI	100,000	$1,736,425
2008	Duluth-Superior, MN&WI	190,500	$1,497,890
2009	---	---	---
2010	---	---	---
2011	DULUTH-SUPERIOR HBR MN & WI	116,000	$2,828,485

Table 11. St. Clair River dredging history (5 years).

FY	Project Name	Cubic Yards	Winning Bid
2007	---	---	---
2008	---	---	---
2009	---	---	---
2010	Channels in Lake St Clair, MI	62,500	$887,375
2011	Channels in Lake St Clair, MI*	66,000	$879,200

*Work actually done in FY 12

Table 12. Burns Harbor dredging history (5 years).

FY	Project Name	Cubic Yards	Winning Bid
2007	Burns Harbor NIPSCO* Dredging	200,000	$1,923,818
2007	Burns Waterway Dredging	131,500	$773,828
2008	---	---	---
2009	Burns Harbor NIPSCO	150,000	$2,025,629
2010	---	---	---
2011	---	---	---

*Northern Indiana Public Service Company

The researchers used the 2011 dredging event for Duluth as the standard. It seems to indicate that the cost of dredging rose significantly from 2008 to 2011. Given this rise in cost, the latest figure would be the one to use. Since this research assumes a dredging event of 3 ft, the cost of each foot of dredging would be $2,828,485 divided by 3, or $942,828.

For St. Clair, the cost for the two dredging events was very similar. The researchers used the latest event, 2011, as the standard. This resulted in a unit cost of $879,200 divided by 3, or $293,067/ft. Finally, for Burns Harbor, the researchers used the 2009 event as the standard, yielding a unit cost of $2,025,629 divided by 3, or $675,210/ft.

Hampton Roads

Table 13 shows the dredging expense data for 2007 to 2011.

The researchers needed to establish the cost of a dredging event for the Norfolk Harbor Channel and the Newport News Channel. The 2007 event was considered to be the most representative and was selected as the standard for a potential dredging event in Norfolk Harbor. This yields a unit cost of $2,668,024 divided by 3, or $889,341/ft. Data specifically for Newport News Channel were not available. The researchers used 50 percent of the 2011 event as the potential cost of a

Table 13. Hampton Roads dredging history (5 years).

FY	Project Name	Cubic Yards	Winning Bid
2007	Norfolk Harbor 50-ft Channel	506,200	$2,668,024
2008	Norfolk Harbor Channel	567,900	$1,944,000
2009	Norfolk Harbor Thimble Shoal	473,700	$2,678,090
2009	Norfolk Harbor and CI Reach	600,300	$3,691,515
2010	---	---	---
2011	Norfolk Harbor - Craney Island Reach	1,237,900	$3,374,153

Table 14. Ohio River and selected Mississippi River ports dredging history (5 years).

FY	Project Name	Cubic Yards	Winning Bid
2007	Ohio River Open (2 of 4 opt)—Louisville	1,000,000	$4,356,146
2008	Ohio River Open (3 of 4 opt)—Louisville	1,000,000	$4,587,629
2008	Mississippi River Harbors—Memphis	N/A	$9,037,409
2009	Big Sandy Harbor	200,000	$1,297,510
2009	Ohio River Open Channel (Base)—Louisville	1,000,000	$4,770,604
2009	Mississippi River Harbors—Memphis	N/A	$12,753,760
2010	**Big Sandy River Dredge**	**220,000**	**$1,508,872**
2010	Ohio River Open Channel (Op 1)—Louisville	1,000,000	$4,994,389
2010	Mississippi River Harbors—Memphis	N/A	$9,663,200
2010	Baton Rouge Harbor CY	341,168	$1,590,000
2011	Ohio River Open Channel (Op 2) LRH	1,000,000	$5,254,328
2011	Ohio River Open Chanel (Op 2)	1,000,000	$5,254,328

dredging event for Newport News. This yields a unit cost of $562,359/ft.

Huntington

As mentioned earlier, Huntington was assumed to only need 2 ft of dredging. Unfortunately, there have been no recent dredging events anywhere on the Upper Ohio that would yield real world cost data for a Huntington case scenario. However, there was a dredging event on the Big Sandy River within the selected 5-year timeframe. It was chosen as the standard event. Table 14 shows the dredging history for the upper Ohio River and the Big Sandy River.

The cost of the 2010 event on the Big Sandy River yields a unit cost of $1,508,872 divided by 2 or $754,436/ft. In order to add one degree of complexity, an additional river segment was selected as part of the potential dredging scenario for Huntington, and the same unit cost was assumed. Huntington also has one lock, Emsworth, which could potentially pose a constraint on the system. Table 15 shows the maintenance expense history for Emsworth.[4,5]

Since 2010 appears to be the most extensive maintenance project performed at this lock, it was selected as the standard. It was assumed that this work could produce a reduction in delays of 60.9 percent on the average. This yields a unit cost (cost per one-third of the potential reduction) of $2,116,593 divided by 3, or $705,531.

Plaquemines

At Plaquemines, the only dredging work that would be relevant would be dredging downstream on the Mississippi River. The problem with analyzing Plaquemines based on the dredging activity in that segment is that a much larger community of users is affected than just Plaquemines. Deep draft navigation occurs all the way up the Mississippi River to Baton Rouge, and all users up to that point are affected by dredging that takes place downstream from Plaquemines. Shippers sending commodities by barge to the lower Mississippi River may choose an alternate route if a restriction on the size of oceangoing vessels causes freight rates to rise to an unacceptable degree. In a real world situation, all of these ports would have to be treated as one entity for purposes of evaluating whether the dredging needs to be done. For purposes of testing the model in the present study, the assumption was made that any dredging that is done is done because Plaquemines needs it, even though it is a somewhat inaccurate assumption. Table 16 shows the dredging history for the Mississippi River downstream of Plaquemines.

Table 15. Emsworth lock and dam maintenance history (5 years).

FY	Project Name	Cost
2006	Emsworth – maintenance costs	$1,389,000
2007	Emsworth—nothing reported	---
2008	Emsworth—nothing reported	---
2009	Emsworth—nothing reported	---
2010	Emsworth – maintenance costs	$2,116,593
2011	Emsworth – maintenance costs	$157,800

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[4] From annual reports of the Secretary of the Army on civil works activities.

[5] Includes Emsworth, L&D 52, and John Day.

Table 16. Plaquemines dredging history (5 years)—reaches at or downriver from Plaquemines.

FY	Project Name	Cubic Yards	Winning Bid
2007	MISS RIV SWP LSD HOP 1-2007	2,300,000	$2,429,100
2007	MISS RIV SWP LSD HOP 2-2007	2,300,000	$2,684,210
2007	MISS RIV SWP LSD HOP 3-2007	2,300,000	$3,233,100
2007	MISS RIV SWP LSD HOP 4-2007	2,300,000	$2,584,500
2007	MISS RIV SWP LSD HOP 6-2007	2,300,000	$2,659,976
2007	MISS RIV SWP LSD HOP 7-2007	2,300,000	$2,659,976
2007	MISS RIV SWP LSD HOP 8-2007	2,300,000	$2,181,935
2007	MISS RV PASS A LOUTRE CY CT	4,000,000	$8,850,000
2007	MISSISSIPPI RIV SOUTH PASS	7,000,000	$18,370,000
	2007 Totals	*27,100,000*	*$45,652,797*
2008	MISS RIV SWP LSD HOP 1-2008	2,300,000	$3,075,800
2008	MISS RIV SWP LSD HOP 10-2008	2,300,000	$4,007,350
2008	MISS RIV SWP LSD HOP 11-2008	2,300,000	$5,093,120
2008	MISS RIV SWP LSD HOP 12-2008	2,300,000	$5,259,400
2008	MISS RIV SWP LSD HOP 2-2008	2,300,000	$3,500,000
2008	MISS RIV SWP LSD HOP 3-2008	2,300,000	$4,157,350
2008	MISS RIV SWP LSD HOP 4-2008	2,300,000	$4,246,900
2008	MISS RIV SWP LSD HOP 5-2008	2,300,000	$4,789,220
2008	MISS RIV SWP LSD HOP 6-2008	2,300,000	$4,585,000
2008	MISS RIV SWP LSD HOP 7-2008	2,300,000	$4,717,600
2008	MISS RIV SWP LSD HOP 8-2008	2,300,000	$3,261,000
2008	MISS RIV SWP LSD HOP 9-2008	2,300,000	$3,595,000
2008	MISS RV PASS ALOUTRE CY CT	4,000,000	$9,600,000
	2008 Totals	*31,600,000*	*$59,887,740*
2009	MISS RIV SWP LSD HOP 2-2009	6,300,000	$10,278,400
2009	MISS RIV SWP LSD CUT 1-2008	3,000,000	$11,116,326
2009	MISS RIV SWP LSD HOP 3-2009	2,300,000	$4,071,260
2009	MISS RIV SWP LSD HOP 4-2009	2,300,000	$4,188,868
2009	MISS RIV SWP LSD HOP 6-2009	3,300,000	$5,659,000
2009	MISS RIV SWP LSD HOP 7-2009	2,300,000	$4,454,320
2009	MISS RIV SWP LSD HOP 9-2009	2,300,000	$4,997,600
	2009 Totals	*21,800,000*	*$44,765,774*
2010	MISS RIV SWP LSD CUT 1-2009	2,745,396	$10,291,941
2010	MISS RIV SWP LSD HOP 1-2010	5,092,922	$12,799,420
2010	MISS RIV SWP LSD HOP 10-2010	1,308,197	$3,950,400
2010	MISS RIV SWP LSD HOP 11-2010	3,701,750	$10,340,500
2010	MISS RIV SWP LSD HOP 3-2010	1,871,098	$5,002,500
2010	MISS RIV SWP LSD HOP 4-2010	1,590,126	$6,130,825
2010	MISS RIV SWP LSD HOP 5-2010	1,428,619	$3,925,650
2010	SWP HEAD OF PASSES HDDA	8,000,000	$30,599,560
	2010 Totals	*25,738,108*	*$83,040,796*
2011	MISS RIV SWP LSD CUT 1-2010	3,241,180	$8,850,651
2011	MISS RIV SWP LSD HOP 1-2011	1,800,000	$11,381,550
2011	MISS RIV SWP LSD HOP 2-2011	1,200,000	$5,574,100
2011	MISS RIV SWP LSD HOP 4-2011	2,300,000	$5,191,800
2011	MISS RIV SWP LSD HOP 7-2011	2,619,074	$5,929,000
2011	MISS RV NO HAR LSD CT 1-2011	1,000,000	$2,890,251
	2011 Totals	*12,160,254*	*$39,817,352*
	5-Yr Average	***23,679,672***	***$54,632,891***

For the case study, the 5-year average was used as the standard. This yields a unit cost of $54,632,891 divided by 3, or $18,210,963/ft.

Portland-Coastal

Table 17 shows the 5-year dredging expense history for the deep draft portion of the Columbia River.

The totals for 2010 and 2011 are almost the same. The researchers chose 2011 as the standard, since it is the most recent. This yields a unit cost of $14,049,300 divided by 3, or $4,683,100/ft.

Portland-Inland

Table 18 shows the 5-year history for Portland-Inland.

The only active dredging reach on the Columbia/Snake River shallow draft system is in the reach between Vancouver and The Dalles. The 5-year average cost for this reach is $600,605. This yields a unit cost of $600,605 divided by 3, or $200,202/ft.

Table 17. Portland-Coastal dredging history (5 years).

FY	Project Name	Cubic Yards	Winning Bid
2007	---	---	---
2008	---	---	---
2009	---	---	---
2010	Dredge OREGON Rental	140,961	$925,130
2010	Dredge OREGON Rental	430,323	$2,096,962
2010	Dredge OREGON Rental	1,020,692	$2,246,004
2010	Dredge OREGON Rental	224,659	$512,452
2010	Dredge OREGON Rental	571,788	$1,115,336
2010	Dredge OREGON Rental	356,917	$2,364,222
2010	Dredge OREGON Rental	554,101	$1,012,846
2010	Dredge OREGON Rental	286,882	$409,961
2010	Dredge OREGON Rental	369,400	$2,302,546
	Total OREGON	*3,955,723*	*$12,985,459*
2010	Lower Columbia River Clam	84,000	$646,124
2010	Lower Columbia River Clam	92,000	$786,686
	2010 Totals	*4,131,723*	*$14,418,269*
2011	Dredge OREGON Rental	1,885,176	$11,720,900
2011	Portland Harbor Clamshell	64,000	$2,328,400
	2011 Totals	*1,949,176*	*$14,049,300*

Portland-Inland also has one lock, John Day, that could potentially pose a constraint on the system. Table 19 shows the maintenance expense history for the John Day lock and dam.

Since there has been so much maintenance activity at this site, the 5-year average was used as the standard. This yields a unit cost of $14,759,894 divided by 3 or $4,919,965 for each unit of reduction in delay.

Table 19. John Day lock and dam maintenance history (5 years).

FY	Project Name	Cost
2007	John Day—maintenance cost	$13,083,038
2008	John Day—maintenance cost	$17,007,808
2009	John Day—maintenance cost	$14,277,859
2010	John Day—maintenance cost	$20,107,321
2011	John Day—maintenance cost	$9,323,444
	John Day Average	*$14,759,894*

Segment Table

A table was prepared to list all relevant segments for purposes of the modeling effort. These segments are grouped by mode and then by port within each mode. This table provides the model with the information necessary to determine capacity and the unit cost to increase capacity. All origin-destination flows are defined by the segments included in the flow. By examining the segments in the flow, the model is able to incorporate any possible constraints and the unit cost of any proposed maintenance activity. Table 9 was used for the model's segment input. The segments with a dotted fill in Table 9 indicate a segment containing a port complex or location where maintenance might be performed.

Many of the segments have a capacity of 999,999,000 tons per year for waterway segments or 100,000,000 for truck segments. This was just a shorthand way of telling the model that these segments have unlimited capacity and do not need to be considered as potential constraints to cargo flows. An examination of the Remaining Project Depth Cargo Capacity column will reveal which segments have the potential to constrain cargo flows.

Origin-Destination Table

An origin-destination table was prepared that contains each corridor to be analyzed. It essentially provides the segments that compose each corridor along with some freight volume information. Table 20 was used in the modeling effort. A series of explanatory notes follows Table 20.

Origin-Destination Explanatory Notes

Duluth. A high percentage, but not all, of Duluth's traffic uses the full channel depth when available. A 30 percent increase in Duluth's project cargo tonnage would result in a 27.6 percent increase in total tonnage.

Hampton Roads. Very little of Hampton Roads traffic uses the full project depth. In fact, the only cargo that uses this depth is export coal. For the other port case studies, the percentage increase in overall tonnage was used to predict the increase in corridor flows. In the case of Hampton Roads, since all of the affected tonnage is export coal and it is the only cargo that uses the full project depth, the full 30 percent increase was applied.

Huntington. The segments that were analyzed for Huntington were based on the flow patterns of the top four commodities. However, they only represent a certain percentage of these flows. These flows had to be adjusted upward to represent the total tonnage related to these four

Table 18. Portland-Inland dredging history (5 years).

FY	Project Name	Cubic Yards	Winning Bid
2007	Columbia River Between Vancouver, WA and The Dalles, OR	90,533	$412,993
2008	Columbia River Between Vancouver, WA and The Dalles, OR	72,850	$448,007
2009	Columbia River Between Vancouver, WA and The Dalles, OR	156,643	$862,752
2010	Columbia River Between Vancouver, WA and The Dalles, OR	72,510	$657,818
2011	Columbia River Between Vancouver, WA and The Dalles, OR	80,444	$621,454
	Average	*94,596*	*$600,605*

Table 20. Origin-destination table.

US Origin	US Destination	Segments (List of Numbers) along Connecting Route	Original O-D Flow	Adjustment Factor to Reach Total Tonnage	Adjusted O-D Flow	Percent Projected Increase from Project	Increase from Project	Total Demand (Current + Increase from Project)
Huntington								
Segment 1	Segment 4	Emsworth, Segment 2	6.526	1.750570513	11.424	28.0496%	3.204	14.628
Segment 1	Segment 5	Emsworth, Segment 2, Segment 4	22.722	1.750570513	39.776	28.0496%	11.157	50.933
Segment 1	Segment 6	Emsworth, Segment 2, Segment 4	1,203.568	1.750570513	2,106.931	28.0496%	590.985	2,697.916
Segment 1	Segment 8	Emsworth, Segment 2, Segment 4, Segment 6	25.913	1.750570513	45.363	28.0496%	12.724	58.087
Segment 2	Segment 4	-	217.773	1.750570513	381.227	28.0496%	106.933	488.160
Segment 2	Segment 5	Segment 4	180.100	1.750570513	315.278	28.0496%	88.434	403.712
Segment 2	Segment 6	Segment 4	6,440.566	1.750570513	11,274.665	28.0496%	3,162.497	14,437.162
Segment 2	Segment 8	Segment 4, Segment 6	233.409	1.750570513	408.599	28.0496%	114.610	523.209
Segment 3	Segment 6	Segment 4	4,463.019	1.750570513	7,812.829	28.0496%	2,191.466	10,004.295
Segment 3	Segment 8	Segment 4, Segment 6	1,720.300	1.750570513	3,011.506	28.0496%	844.715	3,856.221
Segment 4	Segment 1	Segment 2, Emsworth	2,254.283	1.750570513	3,946.281	28.0496%	1,106.915	5,053.196
Segment 4	Segment 2	-	3,304.068	1.750570513	5,784.004	28.0496%	1,622.389	7,406.393
Segment 4	Segment 5	-	3.259	1.750570513	5.705	28.0496%	1.600	7.305
Segment 4	Segment 6	-	4,056.672	1.750570513	7,101.490	28.0496%	1,991.938	9,093.428
Segment 4	Segment 8	Segment 6	445.009	1.750570513	779.020	28.0496%	218.512	997.532
Segment 5	Segment 1	Segment 4, Segment 2, Emsworth	33.863	1.750570513	59.280	28.0496%	16.628	75.908
Segment 5	Segment 2	Segment 4	1,708.117	1.750570513	2,990.179	28.0496%	838.733	3,828.912
Segment 5	Segment 4	-	0.818	1.750570513	1.432	28.0496%	0.402	1.834
Segment 5	Segment 6	-	6,199.861	1.750570513	10,853.294	28.0496%	3,044.304	13,897.598
Segment 5	Segment 7	Segment 6	0.636	1.750570513	1.113	28.0496%	0.312	1.425
Segment 5	Segment 8	Segment 6	985.161	1.750570513	1,724.594	28.0496%	483.741	2,208.335
Segment 6	Segment 1	Segment 4, Segment 2, Emsworth	1,460.607	1.750570513	2,556.896	28.0496%	717.199	3,274.095
Segment 6	Segment 2	Segment 4	1,852.364	1.750570513	3,242.694	28.0496%	909.562	4,152.256
Segment 6	Segment 3	Segment 4	1,266.594	1.750570513	2,217.262	28.0496%	621.933	2,839.195
Segment 6	Segment 4	-	108.730	1.750570513	190.340	28.0496%	53.390	243.730
Segment 6	Segment 5	-	189.945	1.750570513	332.512	28.0496%	93.268	425.780
Segment 6	Segment 6	-	11.980	1.750570513	20.972	28.0496%	5.883	26.855
Segment 6	Segment 8	-	41.089	1.750570513	71.929	28.0496%	20.176	92.105
Segment 7	Segment 2	Segment 6, Segment 4	2,280.756	1.750570513	3,992.624	28.0496%	1,119.914	5,112.538
Segment 8	Segment 2	Segment 6, Segment 4	56.682	1.750570513	99.226	28.0496%	27.832	127.058
Segment 8	Segment 5	Segment 6	363.176	1.750570513	635.765	28.0496%	178.329	814.094
Hampton Roads								
HRR1	HR1	HR2	14,498	1	14,498	30.00%	814	15,312
HRR2	HR1	HR3	9,749	1	9,749	30.00%	955	10,704
Duluth								
DSR2	DS4	DS1, DS2, DS3	8,000	1	8,000	27.60%	2,208	10,208
DSR2	DSR2	*Undefined, not port-related*	11,825	1	11,825		0	11,825
DSR1	DS6	DS1, DS2, DS5	3,675	1	3,675	27.60%	1,014	4,689
DSR1	DSR1	*Undefined, not port-related*	34,625	1	34,625		0	34,625
DS1	DS99	*(This is all other ports--no constraints)*	29,046	1	29,046	27.60%	8,017	37,063

Table 20. (Continued).

US Origin	US Destination	Segments (List of Numbers) along Connecting Route	Original O-D Flow	Adjustment Factor to Reach Total Tonnage	Adjusted O-D Flow	Percent Projected Increase from Project	Increase from Project	Total Demand (Current + Increase from Project)
Plaquemines								
PL1	PL3	PL2	31,402	1	31,402	3.10%	973	32,375
PL0	PL1		30,010	1	30,010	3.10%	930	30,940
Portland - Deep Draft								
PO0	PO1	*Moved by water. Not accounted for in our flows--insignificant*	754	1	754	10.80%	81	835
PO0	POR2	PO1	2,033	1	2,033	10.80%	220	2,253
PO0	POR3	PO1, POR2	276	1	276	10.80%	30	306
PO2	PO2	*Undefined, not port-related*	330,936	1	330,936		0	330,936
PO0	POR1	PO1	6,342	1	6,342	10.80%	685	7,027
POR1	POR1	*Undefined, not port-related*	98,316	1	98,316		0	98,316
PO0	LOMB	PO1	5,357	1	5,357	10.80%	579	5,936
PO0	MAR	PO1	774	1	774	10.80%	84	857
PO0	I5	PO1	6,130	1	6,130	10.80%	662	6,792
PO0	I84	PO1	3,245	1	3,245	10.80%	351	3,596
Portland - Shallow Draft								
Segment 1	Segment 4	Segment 3, John Day	480.262	1.330134716	638.813	23.30%	149	788
Segment 1	Segment 5	Segment 3, John Day, Segment 4	1,144.146	1.330134716	1,521.868	23.30%	355	1,876
Segment 1	Segment 6	Segment 3, John Day, Segment 4	27.527	1.330134716	36.615	23.30%	9	45
Segment 2	Segment 4	Segment 3, John Day	216.586	1.330134716	288.089	23.30%	67	355
Segment 2	Segment 5	Segment 3, John Day, Segment 4	218.683	1.330134716	290.878	23.30%	68	359
Segment 3	Segment 4	John Day	312.951	1.330134716	416.267	23.30%	97	513
Segment 3	Segment 5	John Day, Segment 4	1,034.642	1.330134716	1,376.213	23.30%	321	1,697
Segment 3	Segment 6	John Day, Segment 4	112.630	1.330134716	149.813	23.30%	35	185
Segment 4	Segment 1	John Day, Segment 3	136.033	1.330134716	180.942	23.30%	42	223
Segment 4	Segment 2	John Day, Segment 3	45.562	1.330134716	60.604	23.30%	14	75
Segment 4	Segment 3	John Day	7.359	1.330134716	9.788	23.30%	2	12
Segment 4	Segment 4	-	369.007	1.330134716	490.829	23.30%	114	605
Segment 4	Segment 5	-	240.966	1.330134716	320.517	23.30%	75	395
Segment 4	Segment 6	-	465.027	1.330134716	618.549	23.30%	144	763
Segment 4	Segment 7	Segment 6	2.374	1.330134716	3.158	23.30%	1	4
Segment 5	Segment 1	Segment 4, John Day, Segment 3	999.428	1.330134716	1,329.374	23.30%	310	1,639
Segment 5	Segment 2	Segment 4, John Day, Segment 3	321.402	1.330134716	427.508	23.30%	100	527
Segment 5	Segment 3	Segment 4, John Day	275.665	1.330134716	366.672	23.30%	85	452
Segment 5	Segment 4	-	33.156	1.330134716	44.102	23.30%	10	54
Segment 6	Segment 4	-	583.785	1.330134716	776.513	23.30%	181	957
Segment 7	Segment 4	Segment 6	30.809	1.330134716	40.980	23.30%	10	51
Segment 8	Segment 4	Segment 6	12.370	1.330134716	16.454	23.30%	4	20

commodities. One more adjustment was required to raise the total to the total for all commodities at Huntington. This resulted in an adjustment factor of 1.750571 being applied to the flows that were originally analyzed based on the selected segments. Not all of Huntington's traffic requires the full project depth, although a high percentage does. A 30 percent increase in project depth cargo for Huntington is equivalent to a 28.0 percent increase in total tonnage.

Plaquemines. Very little of the traffic at Plaquemines uses the full cargo depth. An increase of 30 percent in cargo depth tonnage is only a 3.1 percent increase overall.

Portland-Coastal. Certain assumptions were made regarding rail traffic in the Portland area. Given historical freight patterns in this area, the researchers assumed an average railcar payload of 65 tons. They further assumed an average of 100 cars per train with 40.8 percent being empty (*2*). (Western railroads have historically had an empty return ratio of 1.69, which is equivalent to 40.8 percent of the cars running empty.) This means that the average train carries 65 × 100 × (1–0.408) = 3,848 tons.

The data show that the Burlington Northern Santa Fe (BNSF) line out of Portland is already running above its theoretical capacity. Compared to other ports, shipments at the Port of Portland use the full project depth less frequently. A 30 percent increase in project depth cargo is equivalent to a 10.8 percent increase overall for international shipments.

Truck traffic for Portland was allocated to the main access arteries by using annual truck counts on those arteries. These particular routes are heavily influenced by port traffic, so the simplifying assumption was made that 100 percent of their traffic was port related.

Portland-Inland. A 30 percent increase in project depth cargo for inland waterway traffic at the Port of Portland equates to a 23.3 percent increase in overall inland waterway tonnage at the port.

Model Specifications

Background

Based on the networks shown in Figure 2 and Figure 3, commodities may need to pass through one or more locks or transit one or several segments/links of the waterway, depending on the specific origin-destinations. Therefore, if an origin-destination commodity traverses several segments/links or locks, the needed availability, or utilization level, should be provided for all the locks and river segments/links involved. Availability reduction at one lock or on one waterway segment may be the limiting factor in availability over a number of connected waterway segments/links. This consideration for network effect is specifically addressed in the proposed multimodal network flow model described in the mathematical model that follows. The flowchart shown in Figure 4 depicts how data are fed into the model and the outputs that result.

Definitions of the model parameters and variables are provided below.

Variables

The variables that are used in the model are the following:

- x_{ij}^{k}: Total commodity tonnage flow after project implementation on link (i,j) for commodity k (tons).
- f_{ij}^{k}: The tonnage accommodated on the network out of the total demand from origin i to destination j.
- d_{ij}: The depth of dredging for a river segment/link between node i and j (feet). This depth is a non-negative real number[6] that is set to a value of zero if (i,j) is a rail/highway segment.
- h_{ij}: The total increase in effective hours of lock operations due to a decrease in delays for the lock represented by link (i,j). This variable is a non-negative real number.

Parameters

The parameters used in the model are the following:

- q: The amount of increase in waterway available capacity for project depth cargo resulting from one unit increase (tons/ft) in draft due to dredging.
- r: The increase in waterway availability resulting from one unit of reduction in delay of lock operation (ton/h).
- c_{ij}: Cost of a unit depth of dredging for waterway segment/link between node i and j ($/ft).
- g_{ij}: The capacity of link (i,j) that represents loading/unloading capacity at a dock. Due to the lack of data, this parameter is set to infinity for this project.
- l_{ij}: Current availability of link (i,j) that represents a lock before a maintenance project (tons).
- s_{ij}: Current availability of segment from node i to j before a maintenance project (tons).
- w_{ij}: Cost of one unit of reduction in delay in lock operation for the lock represented by link (i,j) in the network ($/h).
- φ_{ij}: The weight for origin-destination flow from i to j. This weight may represent the distance of that flow, so that the total mileage value is maximized, or value of the commodity flows, or other economic impacts that might be relevant to the analysis.
- B: Total budget available for all maintenance projects each year ($).

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[6] This requirement can be relaxed in the model specification, but is included here for convenience of presentation.

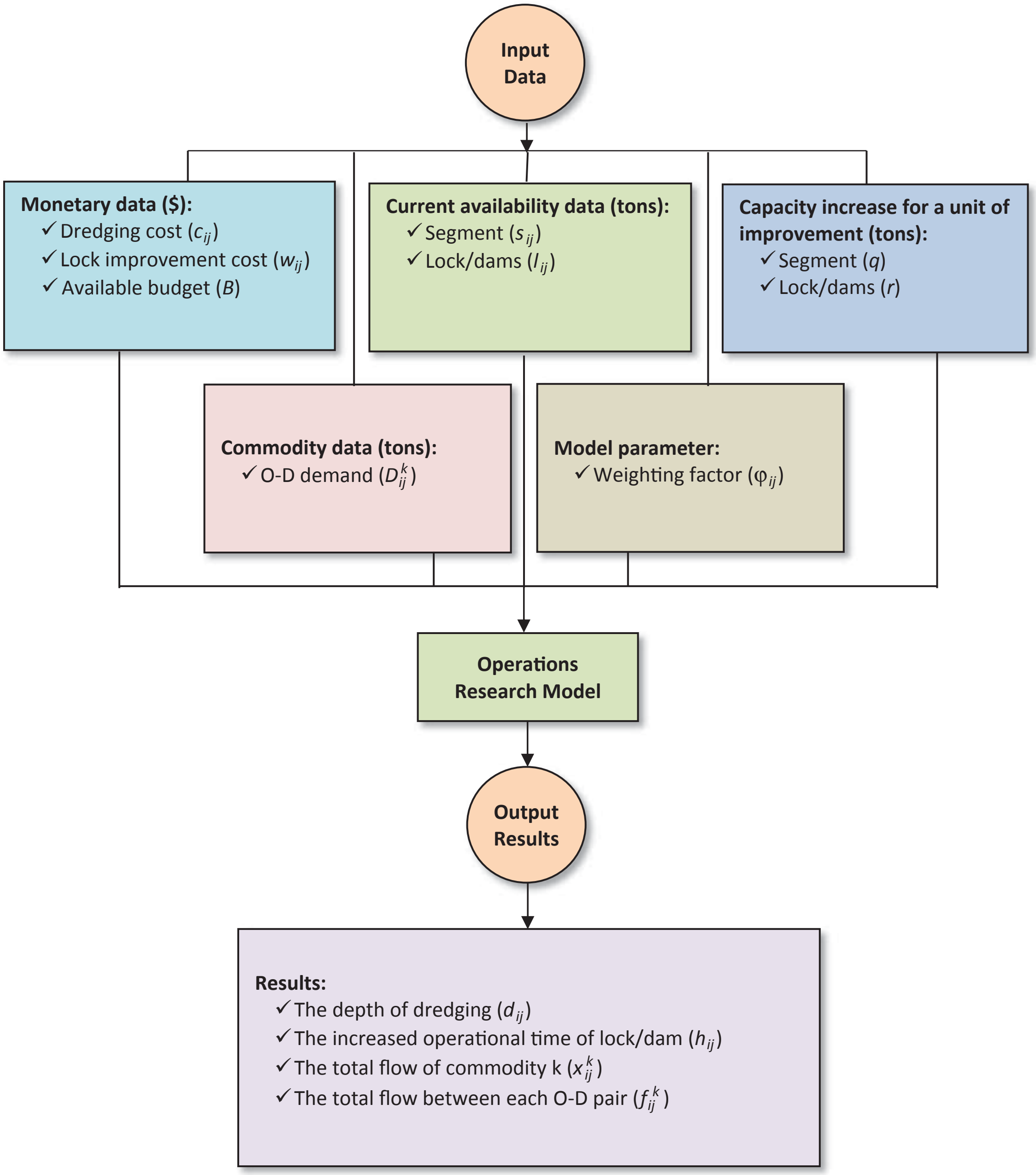

Figure 4. Flowchart of proposed operations research model.

- E: The set of links of the network including links for locks/dams and links for river segments and road and railway sections.
- L: Set of all links in the network model that represent loading and unloading operations at ports.
- OD: Set of all origin and destination pairs.
- D_{ij}^k: Demand of commodity k to be shipped from origin i to destination j (tons).
- $I(i, j)$: Set of all itineraries of freight that traverse link (i,j).

The following paragraphs present the proposed model.

Objective Function

$$Max \sum_i \sum_j \sum_k \varphi_{ij} f_{ij}^k \tag{0}$$

Subject To (s.t.)

$$\sum_k x_{ij}^k \le s_{ij} + d_{ij} \cdot q \qquad \forall (i, j) \in E \setminus E_l \tag{1}$$

$$\sum_k x_{ij}^k \le l_{ij} + h_{ij} \cdot r \qquad \forall (i, j) \in E_l \tag{2}$$

$$\sum_{i:(i,j)\in E\setminus E_l} \sum_{j} c_{ij} \cdot d_{ij} + \sum_{i:\in E_l} w_{ij} \cdot h_{ij} \leq B \tag{3}$$

$$\sum_{k} x_{ij}^{k} \leq g_{ij} \qquad \forall (i,j) \in L \tag{4}$$

$$x_{ij}^{k} = \sum_{mn\in I(i,j)} f_{mn}^{k} \qquad \forall (i,j) \in OD, k \tag{5}$$

$$f_{ij}^{k} \leq D_{ij}^{k} \qquad \forall (i,j) \in OD, k \tag{6}$$

$$x_{ij}^{k}, f_{ij}^{k} \geq 0 \qquad \forall i, j, k \tag{7}$$

$$d_{ij}, h_{ij} : Integer \qquad \forall i, j, k \tag{8}$$

The objective function maximizes the overall system benefit, i.e., maximizes the total tons of all commodity transits between all origin-destination pairs by increasing the possible flow (tonnage) between each origin-destination pair. Constraint (1) restricts the flow of all commodities over all origin-destination pairs to the availability (existing tonnage plus tonnage induced by improved conditions) for every segment. It is quite possible that just one river segment/link or lock is the bottleneck in the whole system, and improving only that lock or segment/link will create a large increase in flow over the entire system. Therefore, increasing the amount of freight over the entire system does not necessarily mean performing maintenance on all locks or waterway segments/links along the path. Constraint (1) satisfies this condition by considering the total traffic volume and the total availability of each link (whether a river segment or lock). As an example, if a tonnage increase on a path consisting of Segments/Links 1 and 2 is needed and the existing depth of Segment/Link 2 already provides enough availability to accommodate this increase, it does not need dredging; only Segment/Link 1 needs to be dredged to reach that availability over both segments/links. In this constraint, q represents the added availability to each waterway segment/link resulting from one unit of dredging (tons/ft). Based on this constraint, each waterway segment on the path should provide enough availability to accommodate the existing and the additional tonnage of commodities that transit the waterway segment/link. For the landside links (e.g., highways and rail lines), there may also be a similar capacity constraint without the term for waterway maintenance. The proposed model applies to large multimodal networks that can automatically identify bottlenecks.

Constraint (2) ensures capacity constraint from dams/locks, similar to Constraint (1). It requires the total flow through a lock/dam to be within the capacity allowed by the lock's/dam's operating hours and historical operating parameters. With this constraint, the model depicts the availability of the system not just as a function of waterway segment/link depth, but also as a function of the availability of locks/dams on the path connecting an origin to a destination.

Constraint (3) ensures that the total operating and capital cost does not exceed the budget limit. Constraint (4) restricts the output and input tonnage at dock links to the available capacity for loading and unloading at the dock. Constraint (5) connects the link volume to the accommodated itinerary volumes that traverse that link by commodity. Constraint (6) defines the accommodated origin-destination volume not to exceed the total origin-destination demand. Constraint (7) and Constraint (8) require non-negativity and integrality of variables.

The model is programmed and implemented in SAS™, calling an optimization function that has recently become available, a mixed integer linear solver of SAS. This solver uses a branch and cut algorithm to achieve the optimal solution. The formulations for the ports have 116 variables and 303 constraints, a very small-sized formulation compared with today's computational technology. The computational time ranges from 0.03 to 0.30 seconds on a desktop computer. A similar model to this one that was as developed by Mitchell, Wang, and Khodakarami (6), when applied to a large inland waterway network with 7,344 river segments, has 34,625 variables and 69,934 constraints, which takes from seven to a couple of hundred seconds to solve on a computer, depending on the required accuracy and other factors.

Scenarios Evaluated by the Model

The researchers created several scenarios designed to test various aspects of the model. Table 21 shows the potential maintenance projects that were included. The individual line items are explained in detail in the section titled "Inputs to the Model."

The researchers used various budgeting levels and various project combinations in order to analyze the effect of different variables on the modeling results. A budget level here represents a percentage of the total requested budget that would be available to fund projects in a year. Table 22 shows the scenarios that were analyzed.

Given the budget and time constraints of this project, it was not possible to do model runs for a large number of scenarios. The researchers created representative scenarios that were based on their knowledge of the characteristics of each project and that they believed would show the model's ability to produce a diversity of outcomes, thereby demonstrating its usefulness. A different set of scenarios might be just as valid. The scenarios run here are intended to highlight the model's characteristics and robustness.

Table 21. Potential case study maintenance projects.

Location	Unit Cost	Total Cost
Port of Huntington (Ohio River)	$754,436/ft	$1,508,872
Adjacent to Port of Huntington	$754,436/ft	$1,508,872
Emsworth Lock and Dam	$705,531/20.3% delay reduction	$2,116,593
Norfolk Harbor	$889,341/ft	$2,668,024
Newport News Channel	$562,359/ft	$1,687,077
Duluth Harbor	$942,828/ft	$2,828,485
St. Clair River	$293,067/ft	$879,200
Burns Harbor	$675,210/ft	$2,025,629
Mississippi River below Plaquemines	$18,210,964/ft	$54,632,891
John Day Lock and Dam	$4,919,965/9.8% delay reduction	$14,759,894
Shallow Draft above Portland (Portland-Inland)	$200,202/ft	$600,605
Portland-Deep Draft (Portland-Coastal)	$4,683,106/ft	$14,049,300
	Total possible budget	**$99,265,442**

Table 22. Scenarios analyzed.

Projects Included	Budget Amount (% of Total Possible Budget)
All Projects	**$99,265,442 (100%)**
All Projects	$79,412,354 (80%)
All Projects	$49,632,721 (50%)
All Projects minus Duluth & Hampton Roads	$49,632,721 (50%)
All Projects minus Portland	$79,412,354 (80%)
All Projects minus Plaquemines	$44,632,551 (total minus Plaquemines)

SECTION 4

Findings from the Case Studies

Generalized Findings

The most obvious issue that surfaced in this research effort is that there is a lack of the kind of data needed for developing a model that can support MTS maintenance investment decision making by being correlated between the modes and almost no accurate data on origins and destinations (in the case of publicly available data). The research team had initially hoped to be able to access both the Corps' dock-level trip data file and the confidential FAF3 file and investigate whether they might work together to answer some of the questions that remain unanswered. Although the team was not able to access these data, the researchers searched for ways to combine public data from various sources in a way that would provide relatively meaningful, if not totally accurate, information on cargo flows and the interactions between modes.

The research team believes that it found enough useful information to facilitate future investigations at a deeper level and with an expanded scope—a scope that involves the entire trade corridor. A combination of publicly available information from the Corps (primarily CPT data); FAF3; regional, state, and local freight studies; and trade literature makes it possible to gain enough of an understanding of a port's primary trade flows to be able to provide meaningful input into the model developed for this project.

There is another significant deficiency that can only be solved by the Corps. The goal of this research project was to develop a new methodology for evaluating potential O&M expenditures by a port. However, the metrics currently used for prioritizing these expenditures are not based on post-project evaluation of the effects of such spending; rather, they are based on presumed measures of the general importance of the asset: tonnage, sustainability of the region, and so forth. In order for a model of the type proposed by this research project to have real value, there must be a way to measure the effect of maintenance projects on freight flows. While this project used tonnage as the maximization metric, tonnage is not the only viable metric. The modeling approach used here can be modified to maximize (or minimize) other meaningful variables. If the proposed model were to be used for new projects, this deficiency would not exist because a detailed evaluation of traffic patterns with and without a proposed new project is typically done.

The limited geographic scope of this research does not lend itself to making generalized statements for the entire U.S. system. The case studies presented in this report are illustrative and provide a foundation for future research, but they cannot be considered definitive across a broad range of projects. Further model development with more complete data and a more comprehensive supply chain will be necessary to make recommendations on overall system performance.

Despite several limitations, the general findings from this proof-of-concept level analysis can be helpful to decision makers. It provides a framework within which to evaluate budget requests for a set of projects that are directly or indirectly tied into the surface transportation system. This framework enables an analyst to evaluate the freight flows to and from the port and determine the criticality of given corridors or pathways. This work highlights the need for and the importance of considering waterway investments within the context of multimodal systems, connections, and investments.

What the Data Show Without the Model

The data-gathering and analysis processes for this research project revealed some interesting aspects of the case study ports, even without the model:

1. **There is a wide variation in the degree to which the bottom stratum of water depth are used.** For example, CPT data revealed that 92 percent of Duluth's shipments used the bottom 3 ft of water depth. In other words, the authorized channel depth is critical to operation. Conversely, only 21 percent of the tonnage in Hampton Roads uses

Table 23. Utilization of bottom stratum of channel depth.

Port	Total Average Tonnage (Million Tons, 2006–2010)	Tonnage Using Bottom 3 Ft	Percent
Duluth	40,721	37,479	92.0%
Hampton Roads	52,946	11,362	21.5%
Plaquemines	61,412	6,429	10.5%
Portland-Deep Draft (Portland-Coastal)	24,999	8,981	35.9%
Portland-Shallow Draft (Portland-Inland)	10,633	8,249	77.6%
Huntington*	71,945	67,267	93.5%

*Only the bottom 2 ft was used for Huntington. To remove 3 ft of draft would essentially make it impossible for towboats to operate, and most traffic would shut down.

the bottom 3 ft, and only 10 percent of the tonnage at Plaquemines uses its bottom 3 ft. Table 23 provides the statistics for all case studies.

Not surprisingly, where the vessel types are more homogeneous, the depth utilization is the greatest. For example, both Portland-Shallow Draft (Portland-Inland) and Huntington have high utilization percentages (77.6 percent and 93.5 percent). Duluth had the second highest percentage and the second greatest tonnage utilization of the bottom depths. It is a port that handles a high volume of a limited number of commodities, and the vessels that transport those commodities are fairly similar in their design and operating characteristics. In future modeling efforts, it would be useful to incorporate the relative importance of the water depth that is being dredged as a metric in the prioritization process.

2. **Highways are not at all critical in some instances.** In Duluth, a high percentage of the commodities that move through the port arrive by rail and leave by water. Trucking plays almost no role in their transport. In Plaquemines, a high percentage of the traffic arrives by barge and leaves by deep draft vessel. Landside transport tends to be for very short distances; most of the cargo remains close to the water. In the case of Huntington, a high percentage of its traffic originates and terminates at waterside facilities, coal being the primary example. In Hampton Roads, the only commodity that uses the bottom 3 ft of channel depth is export coal, and this commodity arrives exclusively by rail. Of the five case study ports selected for this research project, only one (Portland) was significantly tied to its highway system.
3. **Highway congestion caused by port truck traffic is a constraint only in the immediate vicinity of the port terminals.** Prior work conducted by the UMRP at TTI revealed that even with a large increase in port throughput, once the traffic leaves the port area, it disperses quickly enough that it does not significantly affect congestion measures anywhere else. If trucking companies are selective in the routes that they travel in urban areas, and if they are able to time their urban movements outside of peak hours, the effect on traffic will be negligible.

What the Model Shows

Appendix F shows the results of the model for each of the scenarios specified in Table 22. Although the model considers water, rail, and highway segments, it only makes decisions regarding the improvement of waterways through dredging and the improvement to locks/dams by reducing delays. In effect, the model treats the current state of landside transportation (railroads and highways) as a constant (constraints will not be removed). The model shows the following:

1. **Only a few segments really make a difference.** In all scenarios, many segments are not selected for improvement. Segments that pertain to landside modes are not considered in the maintenance decision. When a waterway segment or lock/dam segment that is associated with a potential maintenance project is not selected, it means that the improvement does not add any additional capacity to the system. This could be due to any of four reasons:
   - The fixed landside capacity constrains the input and output of the waterway segment.
   - There is limited demand from all origin-destination pairs that pass through the links, and there is no justification for spending additional money on maintenance.
   - The capacity of the segments is not a limiting factor in light of the origin-destination demand; therefore, spending maintenance dollars on these segments would have no effect on system-wide capacity or throughput.
   - When the budget is limited enough, there is competition between different segments for maintenance dollars; accordingly, only the segments that bring the greatest increase to system-wide capacity would be selected for funding. Typically, the zeroed segments would be selected for improvement if the budget were increased; they are not constrained by demand or landside limits. These segments can be identified in the tables shown in Appendix F; these are the segments where the magnitude of maintenance is decreasing as the budget decreases. For example, in a scenario where all the ports are included in the model, if the available budget

decreases from 80 percent to 50 percent, then the segment DS1 (Duluth-Superior, see Table 9) improvement drops from 2 ft of dredging to 1 ft of dredging.

2. **Not all eligible segments need to be fully maintained—some not at all.** The results shown in Appendix F reveal that only rarely must the entire mix of potential projects be accomplished to accommodate expected increases in demand. Furthermore, in many cases, it is not necessary to execute the full maintenance project; only a portion of the project (for example, one unit of improvement, rather than the full potential amount) is required to fully accommodate demand given system constraints. In no case was it deemed necessary to improve a lock to accommodate expected demand.
3. **It is possible for budgets to be set too high.** It is also noticeable in the results that many times, even though the system is facing a funding decrease, the results do not change unless the budget decrease becomes significant enough (say 20 percent of the total for the project). This indicates that the budget is far greater than what is needed to accommodate demand. Change occurs when the system is restricted by high demand or constrained landside capacity, and funding the segment in question would not increase throughput, since there is a landside bottleneck. In other words, improvements are allocated to segments to the degree that they enable the system to use available landside capacity or accommodate demand. Thus, even in situations where there is more money available than needed for the selected slate of improvements, the model does not call for it to be spent on further improvements due to external throughput constraints or the fact that demand is already fully accommodated. However, while the capacity of a lock may be sufficient, it is still important to be certain that the lock is not in a state of imminent failure. While it may not be important to increase a lock's capacity, it may be of critical importance to prevent its failure.
4. **In some cases, it's all or nothing.** In some instances, decreasing the budget by just 10 percent (from 100 percent to 90 percent) results in a zero maintenance decision. This occurs in cases where a port has only one water origin-destination corridor. In these cases, when a budget of less than 100 percent of the amount needed for one unit of improvement of that corridor is selected, there are no alternative courses of action.
5. **Locks are not a capacity constraint.** Neither of the locks (John Day and Emsworth) that represented possible capacity constraints was selected for maintenance under any of the scenarios. While locks may be a cause of concern in terms of efficiency, they do not appear to create important bottlenecks in the near future (assuming they continue to function adequately). As mentioned in Item 3, it is important to ensure that even a lock with sufficient capacity is not in a state of imminent failure. The point here is that locks that are operating satisfactorily do not appear to constrain freight flows.

Note that the model is artificially constrained and does not incorporate all factors that may have to be considered in a real world situation. For example, shoaling effect is not considered in the model. The model only assumes a static state, which means dredged depth will remain effective for a period of time. Additionally, system reliability often requires maintenance of the waterway system to have a capacity higher than needed capacity to hedge against capacity reduction due to weather and other incidents.

SECTION 5

Potential Future Research

The results of this research project should be considered as a proof of concept that entities with full access to confidential data can build on to achieve their desired project evaluation objectives. The full utility of this proof of concept will only be achieved if the necessary supporting data are available for analysis.

More specifically, for a model such as the one developed in this research project to be effectively deployed, there must be some means of determining the relationship between maintenance activities and the actual utilization of the asset (waterway or lock). This model assumed there would be no landside improvements to the identified origin-destination corridors. In the real world, there may be improvements to highways and rail lines occurring simultaneously with waterway/lock improvement projects. These possibilities will need to be factored into a working future-generation model.

The researchers chose the metric of tonnage throughput as the metric to be maximized. It would be instructive to include the value of the cargo in the objective function. The case may be that maximizing the throughput of the most valuable cargo would lead to an entirely different set of decisions.

APPENDIX A

Commodity Codes

Table A-1. Cross-referencing system of FAF3 codes to Corps codes.

FAF3 Code	Description	Corps Code	Description
02	Cereal grains	62 63	Wheat Corn
03	Other agricultural products	65 66	Oilseeds (soybean, flaxseed and others) Vegetable products
05 07 08 09	Meat/seafood Other foodstuffs Alcoholic beverages Tobacco products	68	Other agricultural products; food and kindred products
10 11 12 13	Monumental or building stone Natural sands Gravel and crushed stone Other nonmetallic minerals	43	Sand, gravel, stone, rock, limestone, soil, dredged material
14	Metallic ores and concentrates	44	Iron ore and iron & steel waste & scrap
15	Coal	10	Coal, lignite & coal coke
16	Crude petroleum	21	Crude petroleum
17	Gasoline	22	Gasoline, jet fuel, kerosene
18	Fuel oils	24	Distillate, residual & other fuel oils; lube oil & grease
19	Other coal and petroleum products	23	Petroleum pitches, coke, asphalt, naphtha and solvents
20 23	Basic chemicals Chemical products	32	Other chemicals and related products
22	Fertilizers	31	Fertilizers
27 28	Newsprint/paper Paper articles	42 51	Paper & allied products Pulp and waste paper
31	Nonmetallic mineral products	52	Building cement & concrete; lime; glass
32 33	Base metals Articles-base metal	53 and 54	Primary iron and steel products (ingots, bars, rods, etc.) Primary non-ferrous metal products; fabricated metal products
34 35 36 37 40	Machinery Electronics Motorized vehicles Transport equipment Miscellaneous manufacturing products	70	All manufactured equipment, machinery and products

APPENDIX B

FAF3 Regions

Table B-1. FAF3 domestic regions.

Code	FAF3 Regions*	State of FAF3 Region	State/Remainder of State which includes Part of This CMSA*	Type of Region**
19	Alabama, Remainder of State	AL		RoS
20	Alaska	AK		State
361	Albany	NY		CMSA
49	Arizona, Remainder of State	AZ		RoS
50	Arkansas	AR		State
131	Atlanta	GA	AL	CMSA
481	Austin	TX		MSA
241	Baltimore	MD		Partial CMSA
221	Baton Rouge	LA		CMSA
482	Beaumont	TX		MSA
11	Birmingham	AL		CMSA
251	Boston	MA	NH	CMSA
362	Buffalo	NY		CMSA
69	California, Remainder of State	CA		RoS
451	Charleston	SC		MSA
371	Charlotte	NC	SC	MSA
171	Chicago	IL	WI	CMSA
181	Chicago	IN	WI	
391	Cincinnati	OH	IN, KY	CMSA
392	Cleveland	OH		CMSA
89	Colorado, Remainder of State	CO		RoS
393	Columbus	OH		CMSA
99	Connecticut, Remainder of State	CT		RoS
483	Corpus Christi	TX		CMSA

(continued on next page)

Table B-1. (Continued).

Code	FAF3 Regions*	State of FAF3 Region	State/Remainder of State which includes Part of This CMSA*	Type of Region**
484	Dallas	TX		CMSA
394	Dayton	OH		CMSA
100	Delaware	DE		State
81	Denver	CO		CMSA
261	Detroit	MI		CMSA
485	El Paso	TX		MSA
129	Florida, Remainder of State	FL		RoS
139	Georgia, Remainder of State	GA		RoS
262	Grand Rapids	MI		CMSA
372	Greensboro-Winston-Salem-High Point	NC		CMSA
452	Greenville-Spartanburg	SC		CMSA
91	Hartford	CT		CMSA
159	Hawaii, Remainder of State	HI		RoS
151	Honolulu	HI		MSA
486	Houston	TX		CMSA
160	Idaho	ID		State
179	Illinois, Remainder of State	IL		RoS
189	Indiana, Remainder of State	IN		RoS
182	Indianapolis	IN		CMSA
190	Iowa	IA		State
121	Jacksonville	FL		MSA
209	Kansas, Remainder of State	KS		RoS
201	Kansas City	KS		CMSA
291	Kansas City	MO		
219	Kentucky, Remainder of State	KY		RoS
222	Lake Charles	LA		CMSA
487	Laredo	TX		MSA
321	Las Vegas	NV		CMSA
61	Los Angeles	CA		CMSA
229	Louisiana	LA		State
211	Louisville	KY	IN	CMSA
230	Maine	ME		State
249	Maryland, Remainder of State	MD		RoS
259	Massachusetts, Remainder of State	MA		RoS
471	Memphis	TN	AR, MS	MSA
122	Miami	FL		MSA
269	Michigan, Remainder of State	MI		RoS
551	Milwaukee	WI		CMSA
271	Minneapolis	MN	WI	CMSA

Table B-1. (Continued).

Code	FAF3 Regions*	State of FAF3 Region	State/Remainder of State which includes Part of This CMSA*	Type of Region**
279	Minnesota, Remainder of State	MN		RoS
280	Mississippi	MS		State
299	Missouri, Remainder of State	MO		RoS
12	Mobile	AL		CMSA
300	Montana	MT		State
472	Nashville	TN		CMSA
310	Nebraska	NE		State
329	Nevada, Remainder of State	NV		RoS
330	New Hampshire	NH		State
349	New Jersey, Remainder of State	NJ		RoS
350	New Mexico	NM		State
223	New Orleans	LA		CMSA
92	New York	CT	PA	CMSA
341	New York	NJ	PA	
363	New York	NY	PA	
369	New York, Remainder of State	NY		RoS
512	Norfolk	VA	NC	MSA
379	North Carolina, Remainder of State	NC		RoS
380	North Dakota	ND		State
399	Ohio, Remainder of State	OH		RoS
409	Oklahoma, Remainder of State	OK		RoS
401	Oklahoma City	OK		CMSA
419	Oregon, Remainder of State	OR		RoS
123	Orlando	FL		CMSA
429	Pennsylvania, Remainder of State	PA		RoS
342	Philadelphia	NJ	DE, MD	CMSA
421	Philadelphia	PA	DE, MD	
41	Phoenix	AZ		MSA
422	Pittsburgh	PA		CMSA
411	Portland	OR	WA	MSA
373	Raleigh-Durham	NC		CMSA
440	Rhode Island***	RI		State
511	Richmond	VA		MSA
364	Rochester	NY		CMSA
62	Sacramento	CA	NV	CMSA
491	Salt Lake City	UT		CMSA
488	San Antonio	TX		MSA
63	San Diego	CA		MSA
64	San Francisco	CA		CMSA
132	Savannah	GA		CMSA

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Table B-1. (Continued).

Code	FAF3 Regions*	State of FAF3 Region	State/Remainder of State which includes Part of This CMSA*	Type of Region**
531	Seattle	WA		CMSA
459	South Carolina, Remainder of State	SC		RoS
460	South Dakota	SD		State
172	St. Louis	IL		CMSA
292	St. Louis	MO		
124	Tampa	FL		MSA
479	Tennessee, Remainder of State	TN		RoS
489	Texas, Remainder of State	TX		RoS
42	Tucson	AZ		MSA
402	Tulsa	OK		CMSA
499	Utah, Remainder of State	UT		RoS
500	Vermont	VT		State
519	Virginia, Remainder of State	VA		RoS
539	Washington, Remainder of State	WA		RoS
513	Washington	VA	WV	CMSA
111	Washington	DC	WV	
242	Washington	MD		
540	West Virginia	WV		State
559	Wisconsin, Remainder of State	WI		RoS
560	Wyoming	WY		State

* Many CMSA boundaries cross more than one state. Major subareas of a CMSA are defined as separate FAF3 regions, one for each state. Small subareas of a CMSA are included with the State or Rest of State region identified in this field.
**Type of Region codes:

CMSA: Census-defined Consolidated Metropolitan Statistical Area
MSA: Census-defined Metropolitan Statistical Area
RoS: Rest of State-everything in a state that is not included in a CMSA or MSA
State: State that does not include a CMSA or MSA

*** Rhode Island state is also Providence CMSA

APPENDIX C

Origin-Destination Corridors and Modal Assignment at Selected Ports

The description of each port's freight flows is broken into two parts: (1) the description of the most important origin-destination corridors and (2) the modal assignments for these corridors. For easier reading, all tonnages in the modal assignment parts are stated in thousands; therefore, a number such as "753" indicates 753,000.

Duluth, MN (Great Lakes)

Duluth Origin-Destination Corridors

There were no FAF3 data available for waterborne shipments into or out of the port of Duluth. However, the Corps was able to provide a breakdown of the tonnages and values for the primary waterborne corridors between Duluth and other U.S. Great Lakes ports. Tables C-1 through C-4 summarize these corridors.

Duluth Modal Assignments by Corridor

Table C-5 is a copy of Table 1 in the main body of this report that showed the commodity flow statistics for Duluth for easy reference.

For the surface transportation segments, iron ore is 100 percent transported by rail on the Mountain Iron-Duluth rail segment; coal is 100 percent transported by rail on the Staples-Duluth segment. A very high percentage of the 38,300 tons of iron ore produced in Minnesota in 2010 was transported by rail on the Duluth, Missabe, and Iron Range Railway (DM&IR), so the researchers assigned 100 percent of iron ore traffic to this segment. Figure C-1 shows the relevant rail segments.

A complete analysis of the waterborne traffic network to which Duluth/Superior is connected was beyond the scope of this study. In order to show how the model would work, the researchers developed a case in which Burns Harbor and/or St. Clair would need dredging in addition to Duluth/Superior for the tonnage increases to occur. The researchers used the numbers provided by the Corps to allocate waterborne flows to Duluth-Burns Harbor and Duluth-St. Clair River. All other flows were allocated to a fictitious "all other ports" segment with the assumption that no ports other than Burns and St. Clair would present constraints. Figure C-2 shows the relevant waterway segments. There were no relevant highway segments for Duluth.

Hampton Roads, VA (Coastal)

Hampton Roads Origin-Destination Corridors

Using FAF3 data, the researchers summarized the primary corridors for these commodities. As it turns out, CPT data indicate that the only commodity using the bottom 3 ft of water depth is export coal. Therefore, while the total cargo mix is very diverse and geographically dispersed, the model focused exclusively on export coal, making Hampton Roads one of the simpler port communities to evaluate. Table C-6 and Table C-7 summarize the coal movements.

A brief description of the other commodities handled at Hampton Roads can be found in the body of the report.

Hampton Roads Modal Assignments by Corridor

In the case of Hampton Roads, the researchers discovered that the only cargo flow that used the 47–50 ft stratum of the ship channel was export coal. Coal is delivered to the port exclusively by rail.

The average export coal tonnages at Newport News and Norfolk Harbor were used to allocate the coal tonnages to the two servicing railroads: CSX and Norfolk Southern. It was assumed that all export coal would be moved by rail and that the proportion of coal shipped out of each of the two terminal areas would be similar to the proportion of coal transported by each of the

Table C-1. Inbound coal for shipment from Duluth, MN (FAF3 data).

[48.1% of all Waterborne Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
Wyoming	45.9%	Rail	100%
Montana	45.8%	Rail	100%
All Others (95 entries)	8.3%		

Table C-2. Outbound coal shipped from Duluth, MN (Corps data).

[48.1% of all Waterborne Commodity Flows]			
Domestic Origin	**% of Total**	**Mode**	**Modal Share**
St. Clair River, MI	58.4%	Water	100%
North Marquette, MI	11.8%	Water	100%
Monroe, MI	7.4%	Water	100%
Muskegon Harbor, MI	6.0%	Water	100%
All Others (13 entries)	16.4%		

Table C-3. Inbound iron ore for shipment from Duluth, MN (FAF3 data).

[38.3% of all Waterborne Commodity Flows—100.0% of FAF3 data sampled]			
Domestic Origin	**% of Sample Total**	**Mode**	**Modal Share**
Remainder of Minnesota	100.0%	Rail Multi	59% 41%

Table C-4. Outbound iron ore shipped from Duluth, MN (Corps data).

[38.3 % of all Waterborne Commodity Flows]			
Domestic Origin	**% of Total**	**Mode**	**Modal Share**
Burns Harbor, IN	33.5%	Water	100%
Indiana Harbor, IN	19.0%	Water	100%
Detroit River, MI	14.7%	Water	100%
Gary, IN	13.4%	Water	100%
All Others (9 entries)	19.4%		

Table C-5. Commodity tonnage—Duluth.

Commodity Category (Code)	Average Annual Tonnage 2006–2010 (in 000s)
Coal, Lignite & Coal Coke (10)	19,825
Iron Ore and Iron & Steel Waste & Scrap (44)	15,630
Total	***35,455***
Total All Commodities	***40,721***

two railroads because each terminal is served by only one of the two railroads. Figure C-3 shows the relevant rail segments.

For the waterborne segments, the researchers simply divided the tonnage coming into and out of Hampton Roads between Norfolk Harbor and Newport News Channel based on historical data from Waterborne Commerce Statistics (*11*). The effect of increased tonnage was factored in by taking the total potential increase and dividing it between the two port areas based on their share of coal shipments for the period of 2006 to 2010. Figure C-4 shows the relevant waterway segments.

There were no relevant highway segments for Hampton Roads.

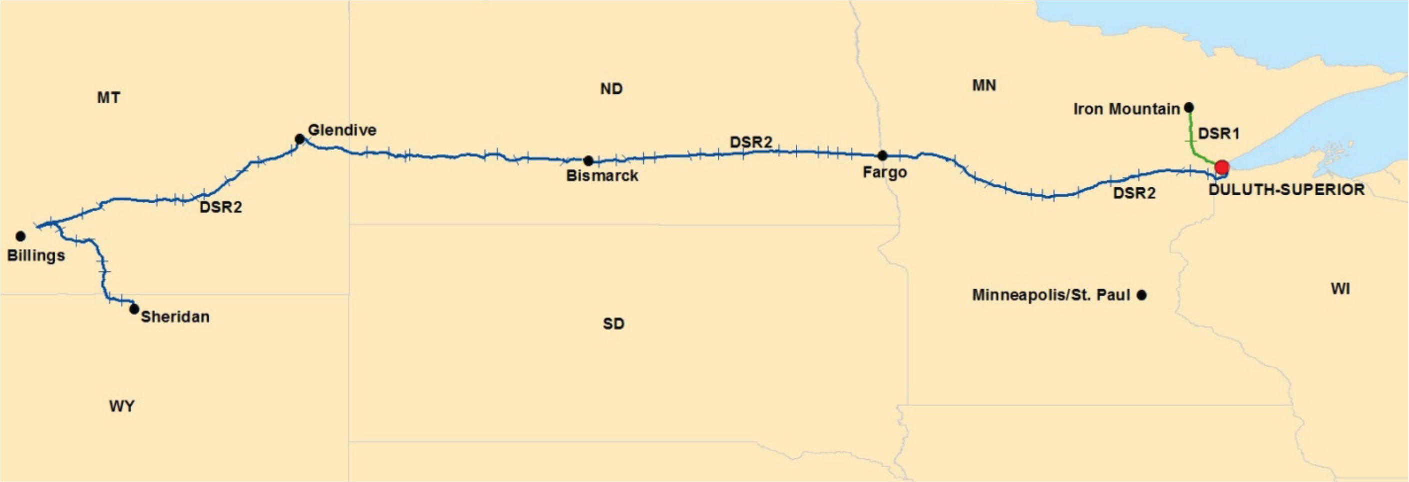

Figure C-1. Rail segments for Duluth, MN.

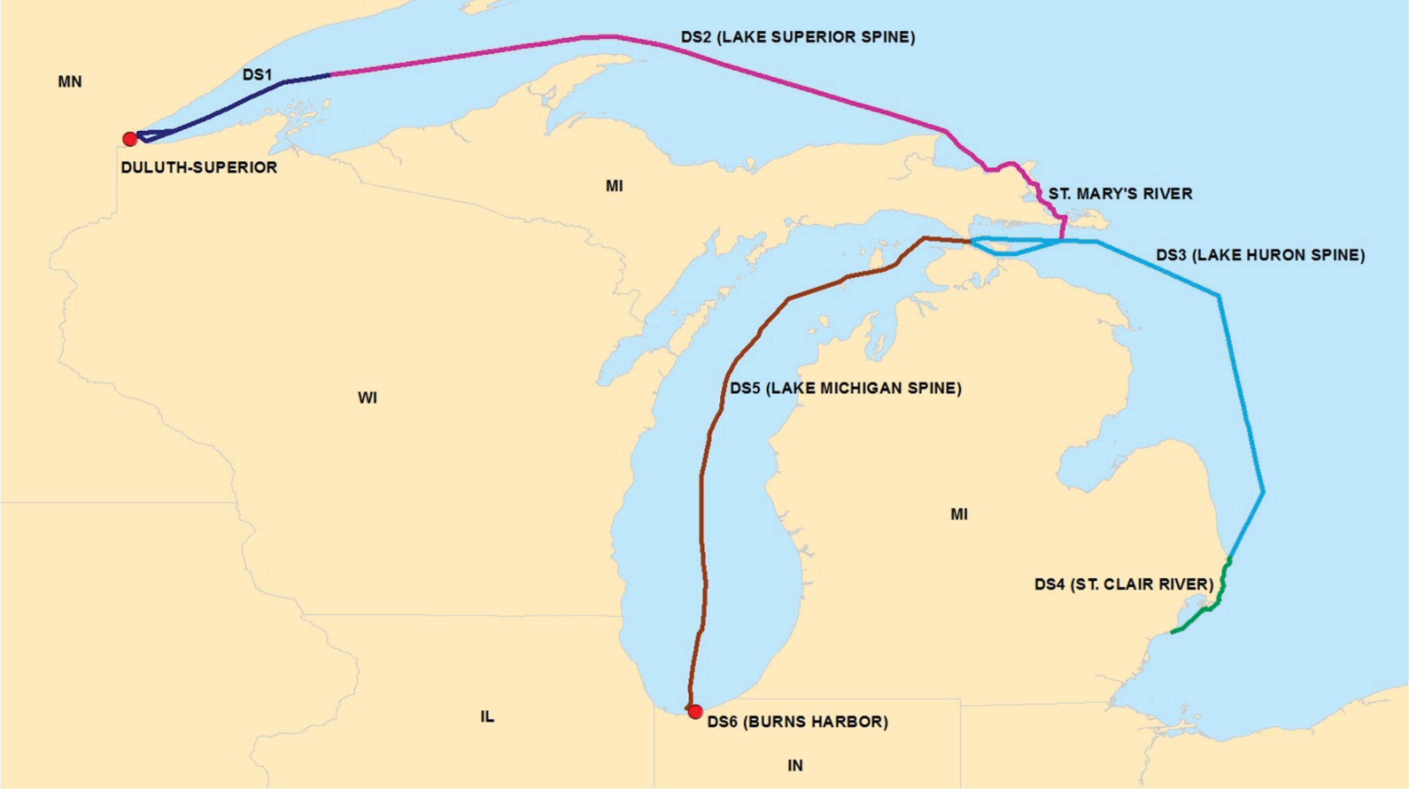

Figure C-2. Waterway segments for Duluth, MN.

Table C-6. Coal imports for Hampton Roads, VA.

[2.4% of all Commodity Flows]			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
Richmond VA MSA	100%	Rail	100%

Table C-7. Coal exports for Hampton Roads, VA.

[59.9% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
Norfolk VA-NC MSA (VA Part)	100%	Rail	100%

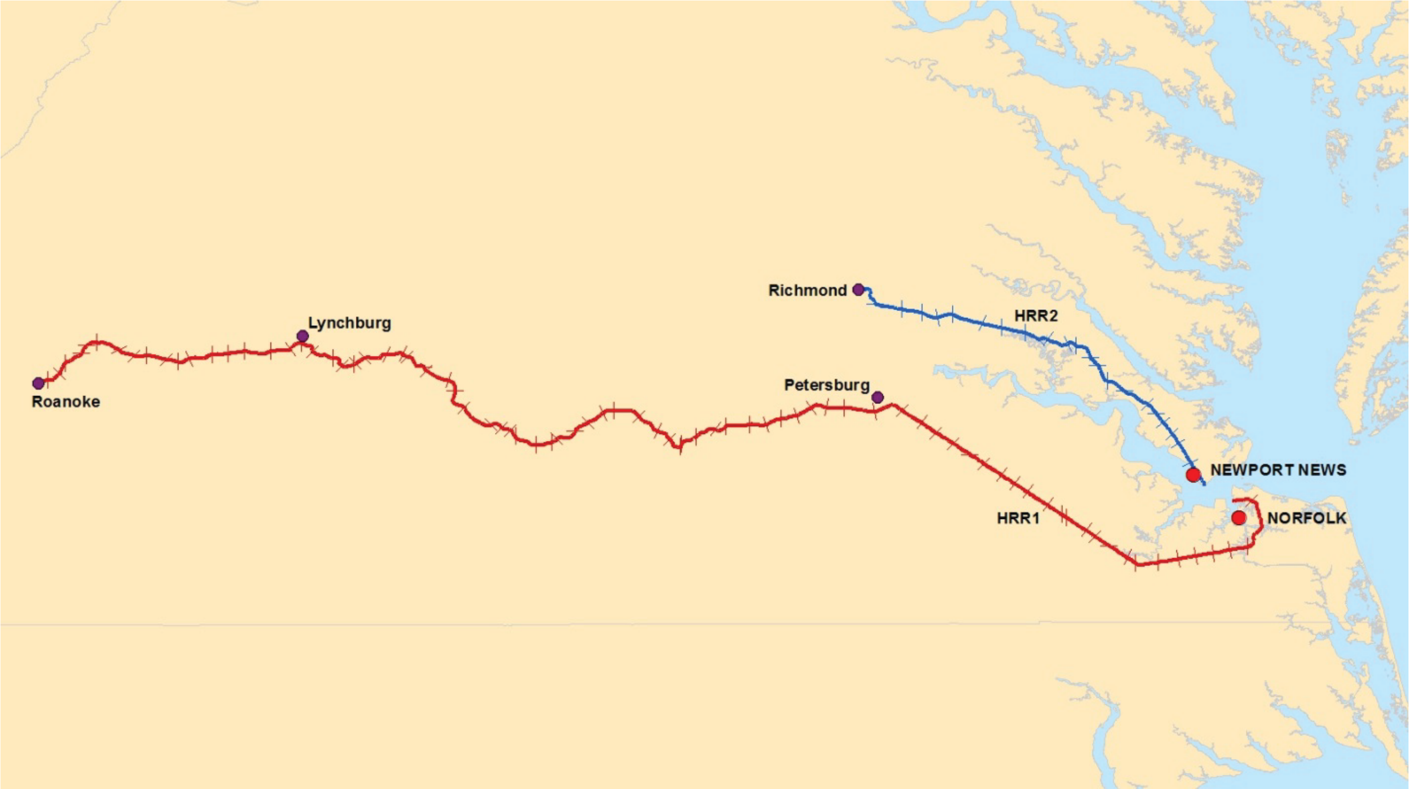

Figure C-3. Rail segments for Hampton Roads, VA.

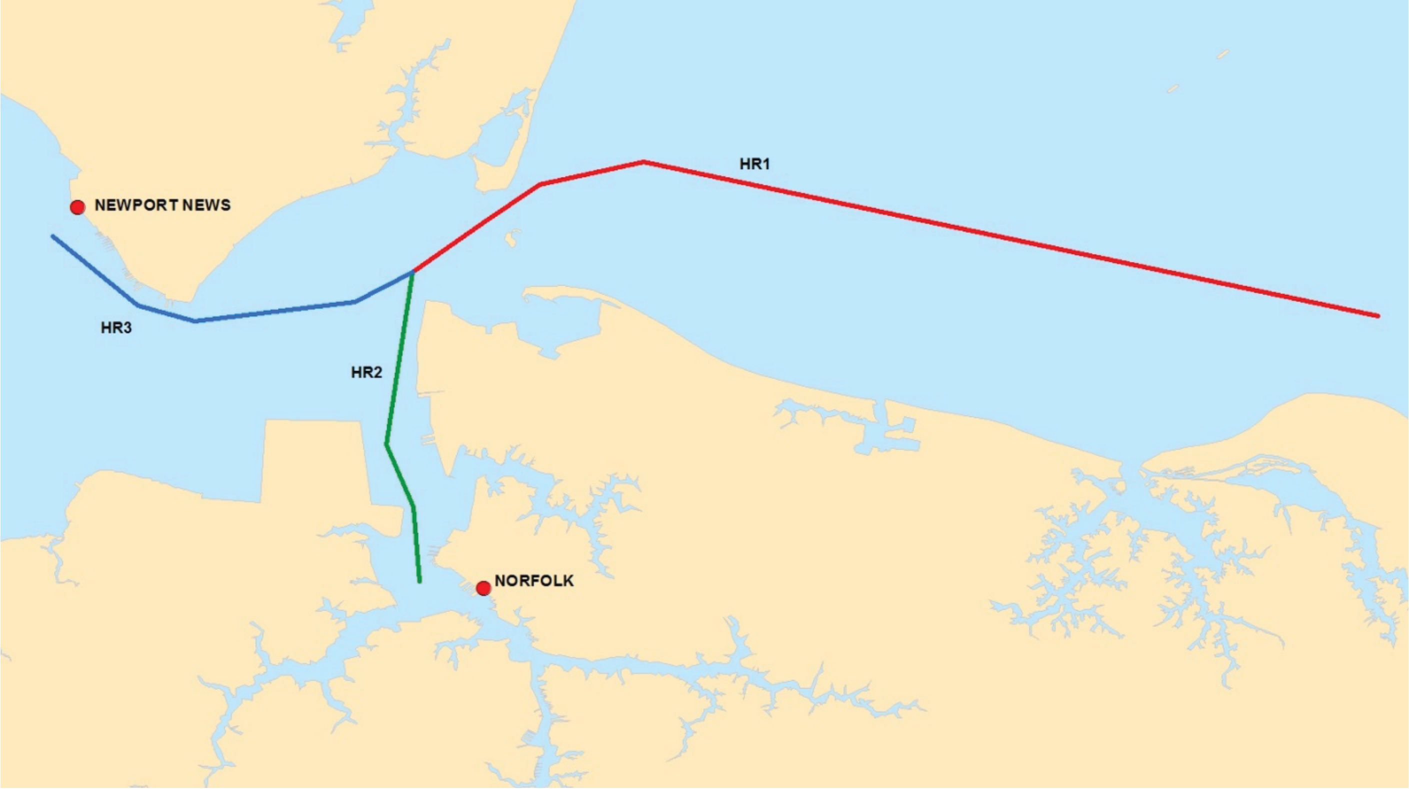

Figure C-4. Waterway segments for Hampton Roads, VA.

Huntington, WV (Inland)

Huntington Origin-Destination Corridors

The researchers examined the top origin-destination waterway segment pairs in terms of tonnage. They totaled all of the tonnage handled by those waterway segments—not just tonnage included in the top origin-destination flows, but all of the tonnage that moved through these waterway segments—until the segment set included at least 80 percent of the tonnage associated with the Port of Huntington (origins in the port, destinations in the port, and traffic passing through the port).[7] Twenty-three river segments were selected as a result of this analysis for coal. The researchers performed a thorough examination of the 23 river segments and identified approximately 212 docks located at approximately 170 different facilities on these segments that could have handled any of the four selected commodities. The researchers identified 102 coal docks. The remainder could handle one of the remaining three commodities or a combination of two or more of the four commodities. While this project relies on the facilities data described earlier, a close inspection of the dataset revealed inconsistencies between *Port Series*[8] report information and port facility spreadsheet information, particularly when applicable *Port Series* reports are more dated. Google Earth imaging also suggests some limited inconsistencies between information contained in Corps' datasets and actual facility usage.

The researchers conducted a similar analysis of the other three major commodity categories: sand and gravel; distillate/fuel oil; and gasoline, jet fuel, and kerosene. With all four commodities, a total of 30 segments were identified as origins or destinations on the waterway. The fact that only seven new segments were added with the additional three commodities illustrates the dominant position of coal in the tonnage figures and the high level of industrialization along the river. Table C-8 lists the segments.

Table C-8. Origin-destination river segments for Huntington.

CPT Segment Number	CPT River Segment Description	Approximate Geography
200367	Monongahela River, PA and WV (Mile 016 to Mile 128)	From Grays Landing Lock and Dam to Maxwell Lock and Dam
200380	Monongahela River, PA and WV (Mile 016 to Mile 128)	Lock and Dam 3 to mouth of Youghiogheny River (McKeesport, PA)
200728	Ohio River, OH WV PA-LRP (Mile 808 to Mile 981)	Chester, WV, to New Cumberland Lock and Dam
200729	Ohio River, OH WV PA-LRP (Mile 808 to Mile 981)	New Cumberland Lock and Dam to Pike Island Lock and Dam
200730	Ohio River, OH WV PA-LRP (Mile 808 to Mile 981)	Pike Island Lock and Dam to point downstream of Clarington, OH
200739	Ohio River, OH WV PA-LRP (Mile 808 to Mile 981)	Hannibal Locks and Dam to Willow Island Locks and Dam
200800	Ohio River, KY OH WV PA-LRH (Mile 796 to Mile 807)	Junction with Muskingum River at Marietta, OH, to junction with Little Kanawha River at Parkersburg, WV
200900	Ohio River, KY OH WV PA-LRH (Mile 715 to Mile 795)	Mouth of Kanawha River to Racine Locks and Dam
201010	Ohio River, KY OH WV PA-LRH (Mile 664 to Mile 714)	Huntington, WV, to Gallipolis Locks and Dam
201020	Ohio River, KY OH WV PA-LRH (Mile 664 to Mile 714)	Huntington, WV, to Mouth of Big Sandy River
201120	Ohio River, KY OH WV PA-LRH (Mile 512 to Mile 663)	Greenup Lock and Dam to Concord, KY
201129	Ohio River, KY OH WV PA-LRH (Mile 512 to Mile 663)	Concord, KY, to Meldahl Lock and Dam
201130	Ohio River, KY OH WV PA-LRH (Mile 512 to Mile 663)	Meldahl Lock and Dam to point just upstream of New Richmond, OH
201140	Ohio River, KY OH WV PA-LRH (Mile 512 to Mile 663)	Point just upstream of New Richmond, OH, to Mouth of Licking River (Cincinnati, OH)
201210	Ohio River, IL KY IN OH-LRL (Mile 435 To Mile 511)	Lawrenceburg, IN, to location upstream (WNW) of Hamilton, KY
201219	Ohio River, IL KY IN OH-LRL (Mile 435 to Mile 511)	Location upstream (WNW) of Hamilton, KY, to Markland Locks and Dam

(continued on next page)

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[7] The actual percentage was 84.3 percent.

[8] This report series was discontinued by the Corps during the execution of the research project. The U. S. Army Corps of Engineers Navigation Data Center used to produce *Port Series* report books that described the physical and intermodal (infrastructure) characteristics of the coastal, Great Lakes, and inland ports of the United States. That information is now published in the Master Docks dataset. This dataset was available at http://www.navigationdatacenter.us/ports/data/mdplus_public_extract.zip as of February 19, 2014.

Table C-8. (Continued).

CPT Segment Number	CPT River Segment Description	Approximate Geography
201220	Ohio River, IL KY IN OH-LRL (Mile 435 to Mile 511)	Markland Locks and Dam to mouth of Kentucky River (Carrollton, KY)
201230	Ohio River, IL KY IN OH-LRL (Mile 435 to Mile 511)	Mouth of Licking River (Cincinnati, OH) to Lawrenceburg, IN
201310	Ohio River, IL KY IN OH-LRL (Mile 196 to Mile 434)	Mouth of Kentucky River (Carrollton, KY) to downtown Louisville, KY
201330	Ohio River, IL KY IN OH-LRL (Mile 196 to Mile 434)	West side of downtown Louisville, KY to Leavenworth, IN
201349	Ohio River, IL KY IN OH-LRL (Mile 196 to Mile 434)	Lewisport, KY, to Newburgh Lock and Dam
201710	Ohio River, IL KY-MVS (Mile 000 to Mile 043)	Lock and Dam 52 to just upstream of Joppa, IL
201919	Kanawha River, WV (Mile 00 to Mile 58)	Winfield, WV to confluence with Ohio River
202020	Big Sandy River, KY WV (Mile 000 to Mile 232)	All of Big Sandy River
212917	Kanawha River, WV (Mile 59 to Mile 95)	London Locks and Dam to Longacre, WV
212918	Kanawha River, WV (Mile 59 to Mile 95)	London Locks and Dam to Marmet Locks and Dam
222120	Upper Mississippi, MO IL-MVS (Mile 000 to Mile 117)	From point just downstream of Chester, IL, to mouth of Ohio River
221920	Upper Mississippi, MO IL-MVS (Mile 118 to Mile 195)	From south of St. Louis to junction with Kaskaskia River
235180	Lower Mississippi, LA-MVN (Mile 107 to Mile 227)	From Garyville, LA, to Jefferson, LA, just downstream of Highway 90 Bridge
271500	Lower Mississippi, LA-MVN (Mile 039 to Mile 087)	From Algiers Canal to Freeport Sulphur Canal

After a thorough examination of these segments, the researchers determined that many of the segments could be combined into consolidated segments while still maintaining the origin-destination flows of the various commodities. This was done by consolidating segments based on their geographical position relative to proposed maintenance projects. This made the model simpler to execute and understand. Table C-9 shows how the consolidated segments were formed.

Huntington Modal Assignments by Corridor

There are no significant rail or highway flows associated with the waterborne cargo for Huntington. A very high percentage of the shipments take place between waterfront facilities. While there is rail traffic through the area, there did not appear to be any significant rail flows for any waterborne origins or destination associated with the segments included in the analysis. A detailed examination of the segments indicated that in a high percentage of cases, the origin/destination site was the actual origin or final destination of the product in its transported state (prior to consumption or transformation).

Waterborne flows were allocated based on a detailed analysis of trip data provided by the Corps. The researchers developed segment flows and then extrapolated those numbers to reach a tonnage amount equal to the total tonnage for Huntington. Figure C-5 shows the relevant waterway segments.

Table C-9. Consolidated river segments for Huntington.

Super Segment	CPT Segments
Segment 1 (Monongahela River)	200367 200380
Segment 2 (Upper Ohio River)	200728 200729 200730 200739 200800 200900
Segment 3 (Kanawha River)	212917 212918 201919
Segment 4 (Ohio River—Huntington)	201010 201020
Segment 5 (Big Sandy River)	202020
Segment 6 (Lower Ohio River)	201120 201129 201130 201140 201210 201219 201220 210230 201310 201330 210349 201710
Segment 7 (Upper Mississippi River)	221920 222120
Segment 8 (Lower Mississippi River)	235180 271500

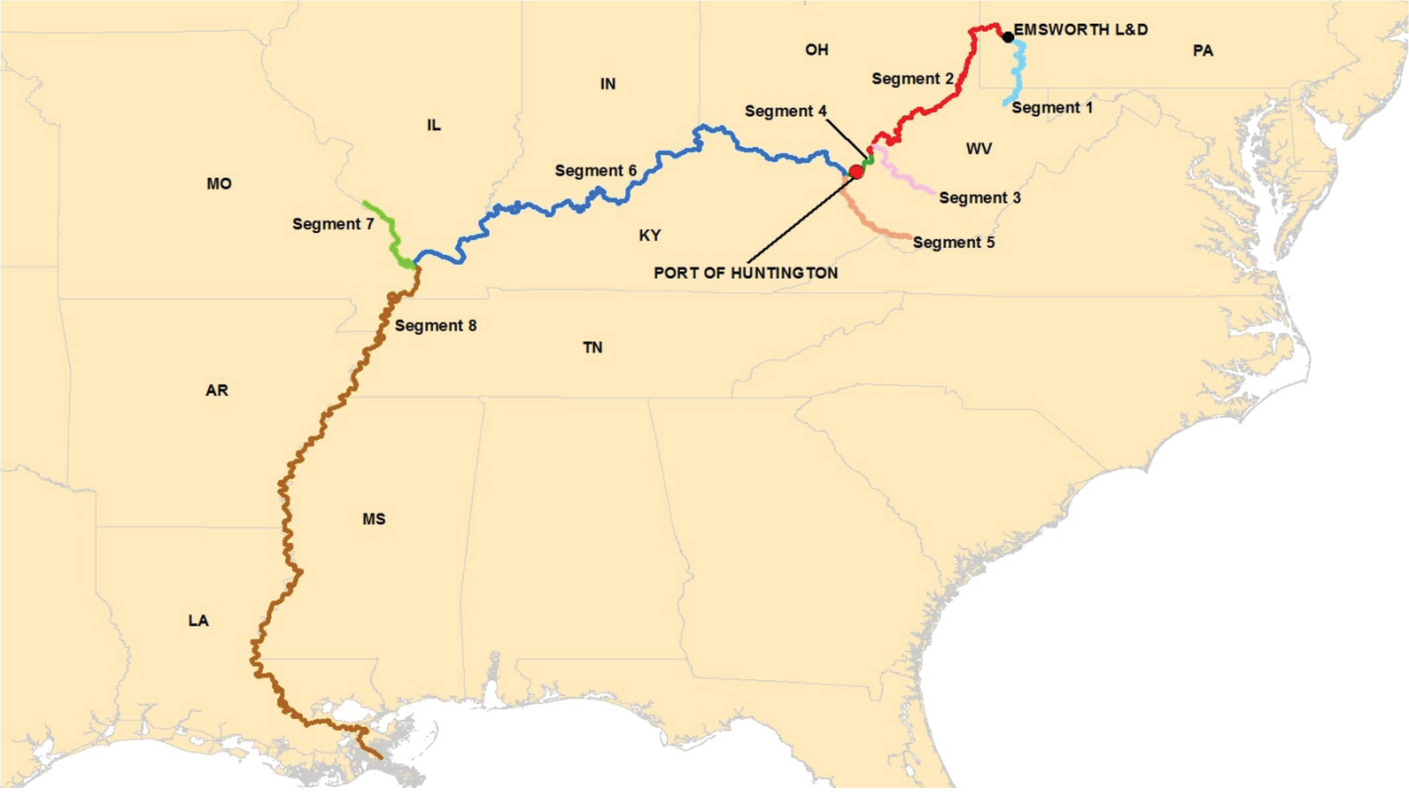

Figure C-5. Waterway segments for Huntington, WV.

Plaquemines, LA (Dual Coastal/Inland)

Plaquemines Origin-Destination Corridors

The tables below that report domestic cargo flows show a percentage based on all commodity flows in the table. Although domestic cargo flows are not shown in the summary totals provided in Table 4 (of the main report) in the introductory descriptions of the case study ports, the percentages in all of the following tables are expressed as a percentage of the Table 4 total tonnage in order to allow the reader to evaluate the relative volume of cargo included in the tables. Using FAF3 data, the researchers summarized the primary corridors for these commodities. Tables C-10 through C-28 summarize these corridors.

There were no corn and wheat imports for Plaquemines, Louisiana.

Crude exports are negligible for Plaquemines.

There are negligible oilseed imports for Plaquemines, Louisiana.

Table C-10. Coal imports for Plaquemines, LA.

[2.6% of all Commodity Flows]*			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
Raleigh-Durham NC CMSA	45.0%	Multi Truck	78% 22%
Tampa FL MSA	25.0%	Multi Water	78% 19%
Atlanta GA-AL CMSA (GA Part)	20.0%	Rail	88%
All Others (3 entries)	10.0%		

*The Corps and FAF data did not agree on the distribution of coal with regard to imports, exports, and coastwise shipments. The Corps reported significant coastwise shipments where FAF had none. The researchers split coastwise shipments into imports/exports using the percentages for total coal for purposes of computing this number.

Table C-11. Coal exports for Plaquemines, LA.

[11.0% of all Commodity Flows]*			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New York NY-NJ-CT-PA CMSA (CT Part)	79.8%	Other/Unknown Multi	72% 21%
Baltimore MD MSA	5.3%	Truck Rail	64% 32%
All Others (9 entries)	14.9%		

*The Corps and FAF data did not agree on the distribution of coal with regard to imports, exports, and coastwise shipments. The Corps reported significant coastwise shipments where FAF had none. The researchers split coastwise shipments into imports/exports using the percentages for total coal for purposes of computing this number.

Table C-12. Corn and wheat exports for Plaquemines, LA.

[15.8% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
Remainder of Illinois	30.4%	Water Rail	65% 19%
Minneapolis-St. Paul MN-WI CMSA (MN Part)	18.6%	Water	100%
Miami FL MSA	8.4%	Multi Water	55% 38%
Remainder of Missouri	6.5%	Water	100%
New Orleans LA CMSA	6.2%	Water Rail Truck	52% 26% 16%
St. Louis MO-IL CMSA (MO Part)	5.4%	Water	100%
Kansas City MO-KS CMSA (KS Part)	4.2%	Rail Water	69% 25%
New York NY-NJ-CT-PA CMSA (CT Part)	3.8%	Other/Unknown Multi	76% 22%
All Others (37 entries)	16.5%		

Table C-13. Crude oil imports for Plaquemines, LA.

[9.5% of all Commodity Flows]			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	88.1%	Unknown	84%
All Others (3 entries)	11.9%		

Table C-14. Crude oil domestic inbound for Plaquemines, LA.

[Total Domestic: 6.6% of all Commodity Flows]			
Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	67.8%	Water	100%
Houston TX CMSA	16.9%	Water	100%
All Others (39 entries)	15.3%		

Table C-15. Crude oil domestic outbound for Plaquemines, LA.

[Total Domestic: 6.6% of all Commodity Flows]			
Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	97.2%	Water	100%
All Others (23 entries)	2.8%		

Table C-16. Asphalt imports for Plaquemines, LA.

[0.0% of all Commodity Flows]*			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
Houston TX CMSA	56.9%	Pipeline	66%
		Multi	24%
Baton Rouge LA CMSA	9.8%	Pipeline	52%
		Water	45%
New Orleans LA CMSA	9.2%	Water	66%
		Pipeline	21%
Remainder of Kentucky	6.0%	Water	80%
All Others (42 entries)	18.1%		

*The Corps did not report any asphalt imports, whereas FAF3 reported a small amount. The FAF3 commodity flows are shown for the sake of completeness, even though they are a small number and were not reported by the Corps.

Table C-17. Asphalt exports for Plaquemines, LA.

[6.4% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	82.9%	Water	67%
		Pipeline	20%
All Others (12 entries)	17.1%		

Table C-18. Asphalt domestic inbound for Plaquemines, LA.

[Total Domestic: 7.3% of all Commodity Flows]			
Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
Chicago IL-IN-WI CMSA (IL Part)	50.0%	Water	100%
New Orleans LA CMSA	36.5%	Water	100%
All Others (6 entries)	13.5%		

Table C-19. Asphalt domestic outbound for Plaquemines, LA.

[Total Domestic: 7.3% of all Commodity Flows]			
Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	52.3%	Water	100%
Lake Charles LA CMSA	15.9%		
Houston TX CMSA	12.0%		
All Others (9 entries)	19.8%		

Table C-20. Fuel oil imports for Plaquemines, LA.

[3.2% of all Commodity Flows]			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	95.1%	Pipeline	43%
		Water	34%
		Multi	12%
All Others (5 entries)	4.9%		

Table C-21. Fuel oil exports for Plaquemines, LA.

[1.8% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	99.6%	Pipeline	43%
		Water	34%
		Multi	13%
All Others (2 entries)	0.4%		

Table C-22. Fuel oil domestic inbound for Plaquemines, LA.

[Total Domestic: 10.3% of all Commodity Flows]			
Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	44.1%	Water	100%
Remainder of Louisiana	37.6%	Water	100%
All Others (3 entries)	18.3%		

Table C-23. Fuel oil domestic outbound for Plaquemines, LA.

[Total Domestic: 10.3% of all Commodity Flows]			
Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	60.1%	Water	100%
Beaumont TX MSA	12.9%	Water	100%
Houston TX CMSA	7.0%	Water	100%
All Others (23 entries)	20.0%		

Table C-24. Oilseed exports for Plaquemines, LA.

[6.6% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
Minneapolis-St. Paul MN-WI CMSA (MN Part)	18.0%	Water	100%
Remainder of Illinois	15.9%	Water Rail	75% 19%
St. Louis MO-IL CMSA (MO Part)	15.8%	Water	95%
New York NY-NJ-CT-PA CMSA (NY Part)	13.3%	Truck	96%
New Orleans LA CMSA	7.1%	Truck Water	43% 38%
Memphis TN-MS-AR MSA (TN Part)	5.2%	Multi	83%
Kansas City MO-KS CMSA (KS Part)	3.8%	Rail Truck	67% 31%
Mississippi	3.4%	Water	92%
All Others (62 entries)	17.5%		

Table C-25. Oilseed domestic inbound for Plaquemines, LA.

[Total Domestic: 5.5% of all Commodity Flows]			
Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
Mississippi	18.2%	Water	100%
Remainder of Missouri	13.3%	Water	100%
Arkansas	13.0%	Water	100%
Remainder of Illinois	12.2%	Water	100%
Iowa	11.4%	Water	100%
St. Louis MO-IL CMSA (MO Part)	8.1%	Water	100%
Memphis TN-MS-AR MSA (TN Part)	6.4%	Water	100%
All Others (6 entries)	17.4%		

Table C-26. Gasoline imports for Plaquemines, LA.

[0.0% of all Commodity Flows]*			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	62.7%	Pipeline Truck Water	52% 25% 23%
Houston TX CMSA	34.1%	Pipeline Multi Water	40% 38% 22%
All Others (34 entries)	3.2%		

*The Corps did not report any gasoline imports, whereas FAF3 reported a small amount. The FAF3 commodity flows are shown for the sake of completeness, even though they are a small number and were not reported by the Corps.

Table C-27. Gasoline exports for Plaquemines, LA.

[1.5% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	100%	Pipeline Truck Water	52% 25% 23%

Table C-28. Gasoline domestic outbound for Plaquemines, LA.

[Total Domestic: 4.0% of all Commodity Flows]			
Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
New Orleans LA CMSA	44.2%	Water	100%
Tampa FL MSA	21.8%	Water	100%
Houston TX CMSA	19.3%	Water	100%
All Others (3 entries)	14.7%		

Plaquemines Modal Assignments by Corridor

In developing the original modal breakdown based on the FAF3 data, the researchers had to use the New Orleans MSA because there was nothing explicitly for Plaquemines in the FAF3 dataset. This showed a high percentage of flows by water, with significant amounts of tonnage taking place by rail and truck in certain instances. However, a close examination of the Port of Plaquemines, its surrounding infrastructure, and its historical freight flows indicates that very little moves into or out of Plaquemines by truck or rail. It is almost entirely a transfer point between inland waterway barges and deep sea vessels or direct shipments into and out of waterside facilities.

Given this background, the researchers assigned all traffic into and out of Plaquemines to the water mode. The researchers simply divided the tonnage between internal traffic (Mississippi River) and deep sea traffic (Gulf of Mexico). Figure C-6 shows the relevant waterway segments.

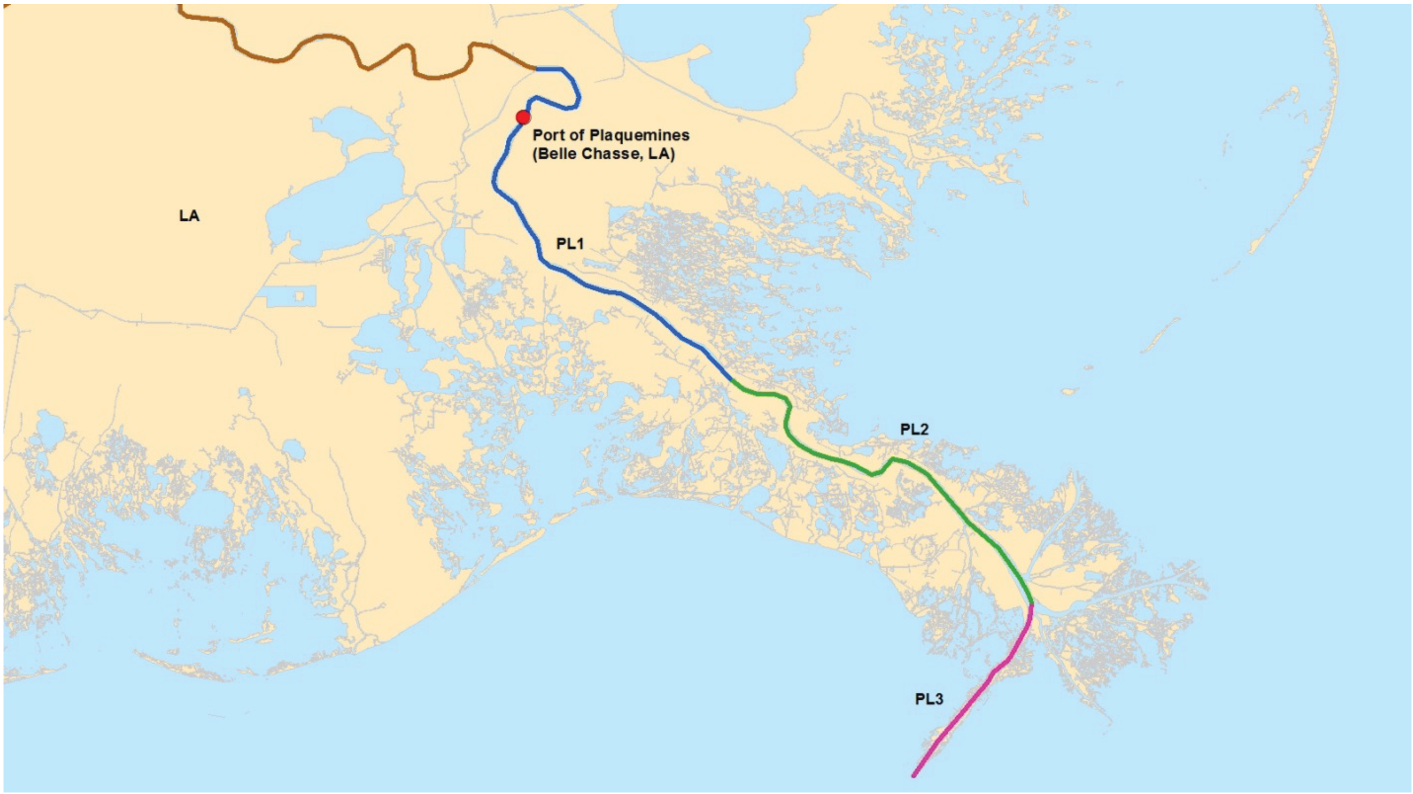

Figure C-6. Waterway segments for Plaquemines, LA.

Portland, OR (Coastal)

Portland (Coastal) Origin-Destination Corridors

Using FAF3 data, the researchers summarized the primary corridors for the highest volume commodities. Tables C-29 through C-38 summarize these corridors. There were no wheat imports for Portland, Oregon.

There were no gasoline exports for Portland, OR. Fuel oil exports were negligible. Manufactured exports were negligible.

Portland (Coastal) Modal Assignments by Corridor

The modal allocations for Portland were very detailed and complex. Table C-39 is a copy of Table 5 (from the main report) that provides the control totals that were used to accomplish the modal allocations.

The FAF3 "% of all commodity flows," shown in the first line of Tables C-40 through C-49 (37.9 percent in Table C-40), only accounts for 70.3 percent of the total tonnage flows in FAF for Coastal, Imports, and Exports—the "Total All Commodities" value of 24,911 thousand tons shown in Table C-39.

Table C-29. Wheat exports for Portland, OR.

[37.9% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
Portland OR-WA MSA (OR Part)	24.0%	Other/ Unknown	97%
Philadelphia PA-NJ-DE-MD CMSA (NJ Part)	18.8%	Other/ Unknown	92%
Remainder of Washington	16.6%	Rail Truck	52% 35%
Los Angeles CA CMSA	12.5%	Rail Multi Water	51% 27% 20%
Minneapolis-St. Paul MN-WI CMSA (MN Part)	10.5%	Multi Rail Water	47% 31% 19%
All Others (19 entries)	17.5%		

Table C-30. Chemical imports for Portland, OR.

[2.0% of all Commodity Flows]			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
Montana	51.3%	Truck	90%
Remainder of Washington	20.4%	Truck	92%
Idaho	8.2%	Truck	100%
All Others (47 entries)	20.0%		

Table C-31. Chemical exports for Portland, OR.

[10.8% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
Remainder of Washington	77.9%	Truck	91%
Los Angeles CA CMSA	8.4%	Multi Truck	51% 49%
All Others (23 entries)	13.7%		

Table C-32. Fertilizer imports for Portland, OR.

[0.8% of all Commodity Flows]			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
Idaho	63.5%	Rail	97%
Philadelphia PA-NJ-DE-MD CMSA (PA Part)	18.9%	Rail Truck	73% 24%
All Others (7 entries)	17.6%		

Table C-33. Fertilizer exports for Portland, OR.

[9.2% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
Portland OR-WA MSA (OR Part)	55.5%	Truck	100%
Remainder of Oregon	17.2%	Truck	100%
Remainder of Washington	10.8%	Multi Truck	68% 32%
All Others (10 entries)	16.5%		

Table C-34. Gasoline imports for Portland, OR.

[0.9% of all Commodity Flows]			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
Houston TX CMSA	52.7%	Truck	100%
Portland OR-WA MSA (OR Part)	43.4%	Truck	100%
All Others (18 entries)	3.9%		

Table C-35. Fuel oil imports for Portland, OR.

[0.2% of all Commodity Flows]			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
Portland OR-WA MSA (OR Part)	74.9%	Truck	100%
Remainder of Oregon	11.2%	Truck	100%
All Others (18 entries)	13.9%		

Table C-36. Manufactured imports for Portland, OR.

[3.9% of all Commodity Flows]			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
Los Angeles CA CMSA	78.1%	Truck	99%
Portland OR-WA MSA (OR Part)	13.7%	Truck	94%
All Others (85 entries)	8.3%		

Table C-37. Iron and steel imports for Portland, OR.

[4.1% of all Commodity Flows]			
Domestic Destination	**% of FAF3 Total**	**Mode**	**Modal Share**
Portland OR-WA MSA (OR Part)	62.7%	Truck	84%
Remainder of Oregon	19.5%	Truck Rail	54% 45%
All Others (71 entries)	17.8%		

Table C-38. Iron and steel exports for Portland, OR.

[0.5% of all Commodity Flows]			
Domestic Origin	**% of FAF3 Total**	**Mode**	**Modal Share**
San Francisco CA CMSA	24.9%	Truck	97%
Portland OR-WA MSA (OR Part)	18.2%	Truck	88%
Los Angeles CA CMSA	11.9%	Truck Rail	52% 41%
Memphis TN-MS-AR MSA (TN Part)	7.4%	Multi	92%
Birmingham AL CMSA	7.4%	Multi	95%
New York NY-NJ-CT-PA CMSA (CT Part)	7.2%	Multi	88%
Miami FL MSA	6.1%	Truck	94%
All Others (71 entries)	16.9%		

Table C-39. Commodity tonnages for Portland-Coastal.

Commodity Category (Code)	Average Annual Tonnage 2006–2010 (in 000s)
Wheat (62)	9,441
Other Chemicals and Related Products (32)	3,178
Fertilizers (31)	2,484
Gasoline, Jet Fuel, Kerosene (22)	2,182
Distillate, Residual & Other Fuel Oils; Lube Oil & Greases (23)	1,212
All Manufactured Equipment, Machinery and Products (70)	977
Primary Non-Ferrous Metal Products; Fabricated Metal Products (54)/ Primary Iron and Steel Products (Ingots, Bars, Rods, etc.) (53)	1,129
Total	***20,603***
Total All Commodities	***24,911***

In order to account for all tonnage, the percentages listed in the column labeled "% of FAF3 Total" had to be inflated. The inflated percentage is shown following the original percentage in the column labeled "Adjusted % of FAF3 Total." This, of course, assumes that the extrapolated tonnage would have the same corridor and modal distribution as the FAF3 tonnage.

Also, the last row in each table, labeled "All Others," is assumed to follow roughly the same patterns as all of the other cargo does. It is further assumed that even if the assignments are in error, the absolute values are small enough that they will not influence the final outcomes. The "All Other" statistics are rolled up into the designated corridors in each table.

For grain, the total rail split should be roughly 70 percent Union Pacific Railroad (UP) and 30 percent BNSF Railway Co. (BNSF). The distribution of rail traffic for grain export from Portland, Oregon, is based on the railroads' access to the port and the dedicated port facilities of the railroads. UP has three access lines into the general port area while BNSF has only one access line into the city of Portland. UP has five large rail terminal yards in or near the port while BNSF has only two yards in the port area on the Oregon side of the Columbia River. In other words, UP has 71 percent of the rail yard infrastructure (five out of seven). The total rail access to Portland is four lines; of these, UP has three. This equates to UP having 75 percent of the existing rail lines into the port area. Based on the access availability between UP and BNSF and the three extra rail yards UP possesses, the research team determined that 70 percent of the traffic must be handled by UP. UP handles a high percentage of chemical and fertilizer shipments in the Portland area, so 100 percent of these shipments were assigned to UP.

In order to facilitate the analysis, modal shares shown in Appendix C only include the shares that would account for at least 80 percent of the total corridor traffic, according to FAF3. Given that this is anywhere between 80 and 100 percent of each corridor's reported tonnage, the researchers assigned any tonnage not accounted for to the listed modes in proportion to each mode's share of the total. Therefore, in Tables 40 through 50, the modal shares account for 100 percent of each corridor's traffic. The relevant rail segments for Portland-Coastal are shown in Figure C-7 and Figure C-8. Figure C-9 shows the relevant waterway segments. Figure C-10 shows the relevant highway segments.

In Table C-40, there are 13,430 tons, 100 percent of which is coming into the port for export. Based on expert knowledge

Table C-40. Wheat exports for Portland, OR.

[37.9% of all Commodity Flows] (53.9%)						
Domestic Origin	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
Portland OR-WA MSA (OR Part)	24.0%	29.1%	Other/ Unknown (Truck)	100%	3838[a]	
Philadelphia PA-NJ-DE-MD CMSA (NJ Part)	18.8%	22.8%	Other/ Unknown (Rail)	100%	2791[b]	POR1
					276	POR2/ POR3
Remainder of Washington	16.6%	20.1%	Rail	60%	1620	POR2
			Truck	40%	1080	
Los Angeles CA CMSA	12.5%	15.2%	Rail	52%	1633	POR1
			Multi	28%		
			Water	20%	408	
Minneapolis-St. Paul MN-WI CMSA (MN Part)	10.5%	12.8%	Multi	48%	963	POR1
			Rail	32%		
					413	POR2
			Water	20%	408	
All Others (19 entries)	17.5%	0%				
TOTAL					**13,430**	

[a] Rounding error was applied here.

[b] With the special assignments noted in the text, POR1 originally receives 4740 and POR2 receives 2950 for a 62/38 split, but it should be 70/30 (5387/2309). The Phil split was adjusted to make it work.

Table C-41. Chemical combined for Portland, OR.

[2.0% of all Commodity Flows] (2.8%)						
Domestic Destination	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
Montana	51.3%	64.2%	Truck	100%	455	
Remainder of Washington	20.4%	25.5%	Truck	100%	181	
Idaho	8.2%	10.3%	Truck	100%	73	
All Others (47 entries)	20.0%	0%			709	

Truck tons = 709 tons

Table C-42. Chemical exports for Portland, OR.

[10.8% of all Commodity Flows] (15.4%)						
Domestic Origin	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
Remainder of Washington	77.9%	90.3%	Truck	100%	3455	
Los Angeles CA CMSA	8.4%	9.7%	Multi (Rail)	51%	189	POR1
			Truck	49%	182	
All Others (23 entries)	13.7%	0%			3826	

Truck tons = 3,637

Table C-43. Fertilizer imports for Portland, OR.

[0.8% of all Commodity Flows] (1.1%)						
Domestic Destination	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
Idaho	63.5%	77.1%	Rail	100%	219	POR 1
Philadelphia PA-NJ-DE-MD CMSA (PA Part)	18.9%	22.9%	Rail	75%	48	POR 1
			Truck	25%	16	
All Others (7 entries)	17.6%	0%			283	

Truck tons = 16

Table C-44. Fertilizer exports for Portland, OR.

[9.2% of all Commodity Flows] (13.1%)						
Domestic Origin	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
Portland OR-WA MSA (OR Part)	55.5%	66.5%	Truck	100%	2168	
Remainder of Oregon	17.2%	20.6%	Truck	100%	671	
Remainder of Washington	10.8%	12.9%	Multi (Rail)	68%	286	POR1
			Truck	32%	135	
All Others (10 entries)	16.5%	0%			3260	

Truck tons = 2,974

Table C-45. Gasoline imports for Portland, OR.

[0.9% of all Commodity Flows] (1.3%)						
Domestic Destination	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
Houston TX CMSA	52.7%	54.8%	Truck	100%	175	
Portland OR-WA MSA (OR Part)	43.4%	45.2%	Truck	100%	144	
All Others (18 entries)	3.9%	0%			319	

Truck tons = 319

Table C-46. Fuel oil imports for Portland, OR.

[0.2% of all Commodity Flows] (0.3%)						
Domestic Destination	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
Portland OR-WA MSA (OR Part)	74.9%	87.0%	Truck	100%	61	
Remainder of Oregon	11.2%	13.0%	Truck	100%	9	
All Others (18 entries)	13.9%	0%			70	

Truck tons = 70

Table C-47. Manufactured imports for Portland, OR.

[3.9% of all Commodity Flows] (5.5%)						
Domestic Destination	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
Los Angeles CA CMSA	78.1%	85.2%	Truck	100%	1178	
Portland OR-WA MSA (OR Part)	13.7%	14.8%	Truck	100%	205	
All Others (85 entries)	8.3%	0%			1383	

Truck tons = 1,383

of commodity flows in the northwest, the "Other/Unknown" tonnages in this table were assigned to rail with the exception of "Other/Unknown" appearing in a Portland-Portland corridor; these were assigned to truck. After all the necessary adjustments, rail shipments accounted for 7,696 tons, 57.3 percent of the total. Truck shipments accounted for 4,983 tons (37.1 percent), and water accounted for 751 tons (5.6 percent) of the total.

Rail shipments are handled by Union Pacific (UP) and Burlington Northern Santa Fe (BNSF) railroads. Tonnages were assigned based on the routes and the railroad that would be expected to carry wheat on that route. Seventy percent of the rail traffic was assigned to UP, 5,387 tons. This was assigned to segment POR1. Thirty percent of the rail shipments were assigned to BNSF, 2,309 tons, and this was assigned to segment POR2. (The "Remainder of Washington" is considered to be Spokane and was assigned 100 percent to BNSF.) The final split for wheat was: UP: 5,387 tons, BNSF: 2,309 tons, trucks: 4,983 tons, and water: 751 tons.

In Table C-42, the "Multi" mode is assigned to Rail. Because the commodity flow is chemicals, this would be 100 percent UP.

In Table C-44, the "Multi" mode is assigned to Rail. Because the commodity flow is fertilizer, this would be 100 percent UP.

There were no gasoline exports. There were no fuel oil exports. There were no manufactured exports.

In Table C-49, the "Multi" mode is assigned to Rail. Because of the points of origin, this would be 100 percent UP.

Table C-48. Iron and steel imports for Portland, OR.

[4.1% of all Commodity Flows] (5.8%)						
Domestic Destination	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
Portland OR-WA MSA (OR Part)	62.7%	76.3%	Truck	100%	1108	
Remainder of Oregon	19.5%	23.7%	Truck	55%	189	POR1
			Rail	45%	155	
All Others (71 entries)	17.8%	0%			1452	

Truck tons = 1,297

Table C-49. Iron and steel exports for Portland, OR.

[0.5% of all Commodity Flows] (0.7%)						
Domestic Origin	**% of FAF3 Total**	**Adjusted % of FAF3 Total**	**Mode**	**Modal Share**	**Tonnage**	**Rail Segment**
San Francisco CA CMSA	24.9%	30.0%	Truck	100%	53	
Portland OR-WA MSA (OR Part)	18.2%	21.9%	Truck	100%	38	
Los Angeles CA CMSA	11.9%	14.3%	Truck	56%	14	POR1
			Rail	44%	11	
Memphis TN-MS-AR MSA (TN Part)	7.4%	8.9%	Multi (Rail)	100%	16	POR1
Birmingham AL CMSA	7.4%	8.9%	Multi (Rail)	100%	16	POR1
New York NY-NJ-CT-PA CMSA (CT Part)	7.2%	8.7%	Multi (Rail)	100%	15	POR1
Miami FL MSA	6.1%	7.3%	Truck	100%	13	
All Others (71 entries)	16.9%				176	

Truck tons = 118

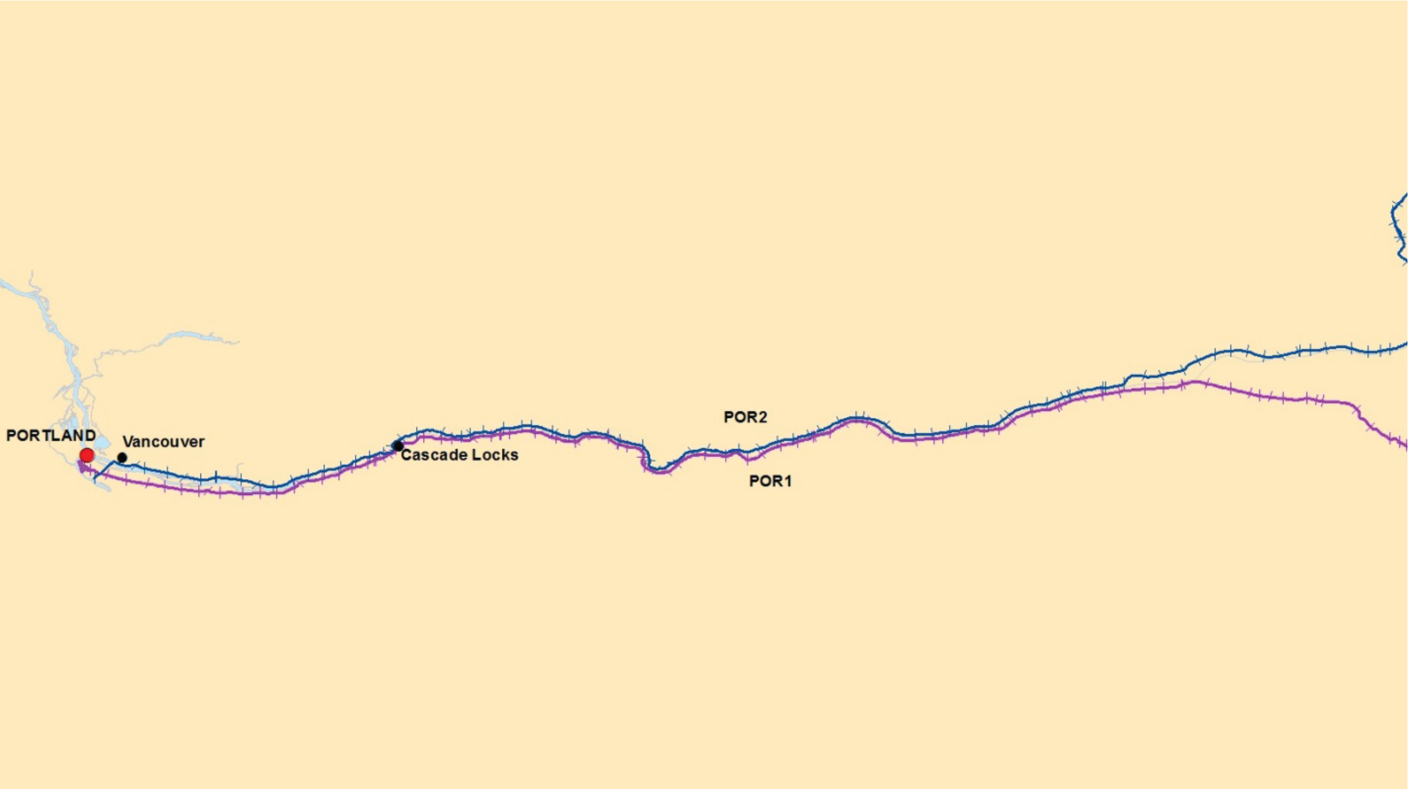

Figure C-7. Rail segments for Portland, OR—Columbia River portion.

Figure C-8. Rail segments for Portland, OR—complete.

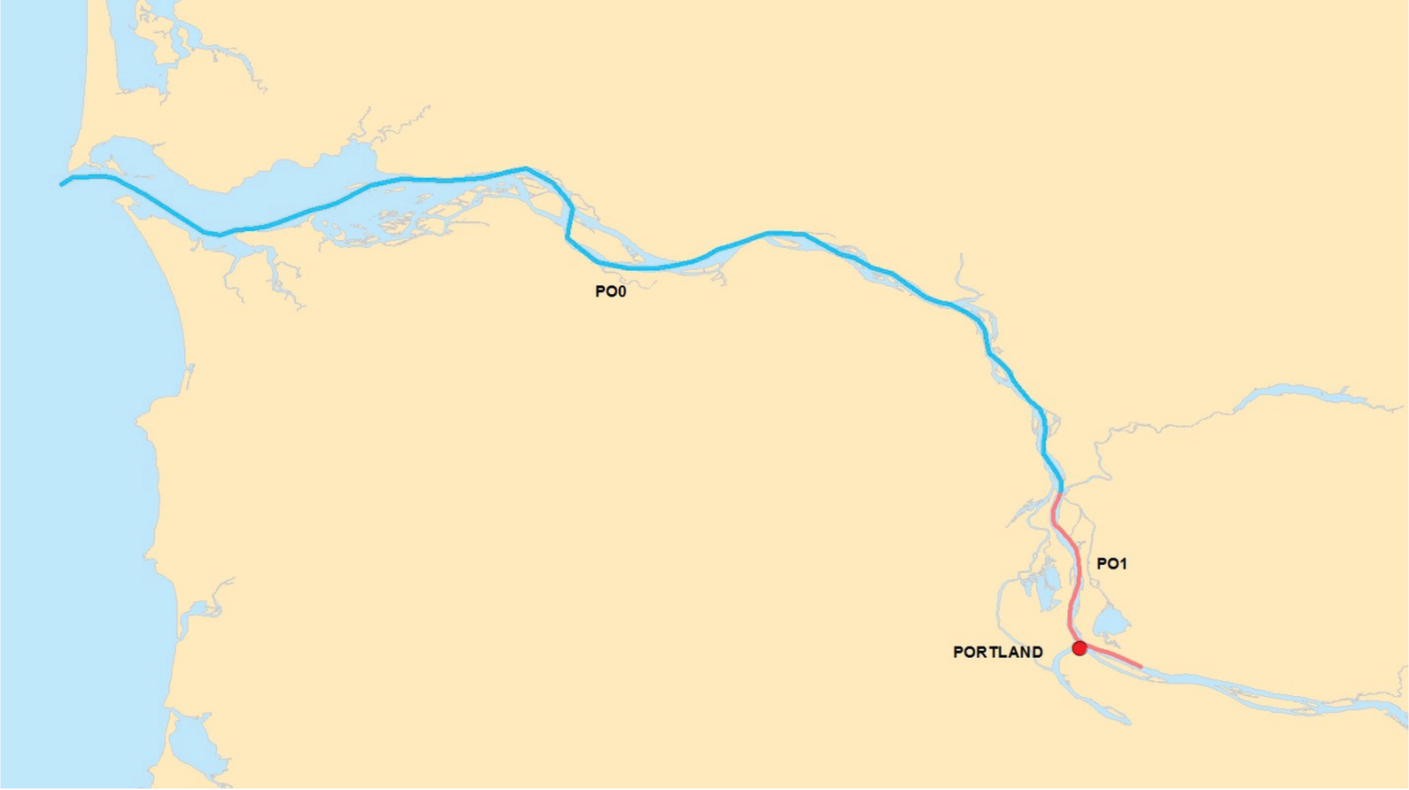

Figure C-9. Waterway segments for Portland, OR–coastal.

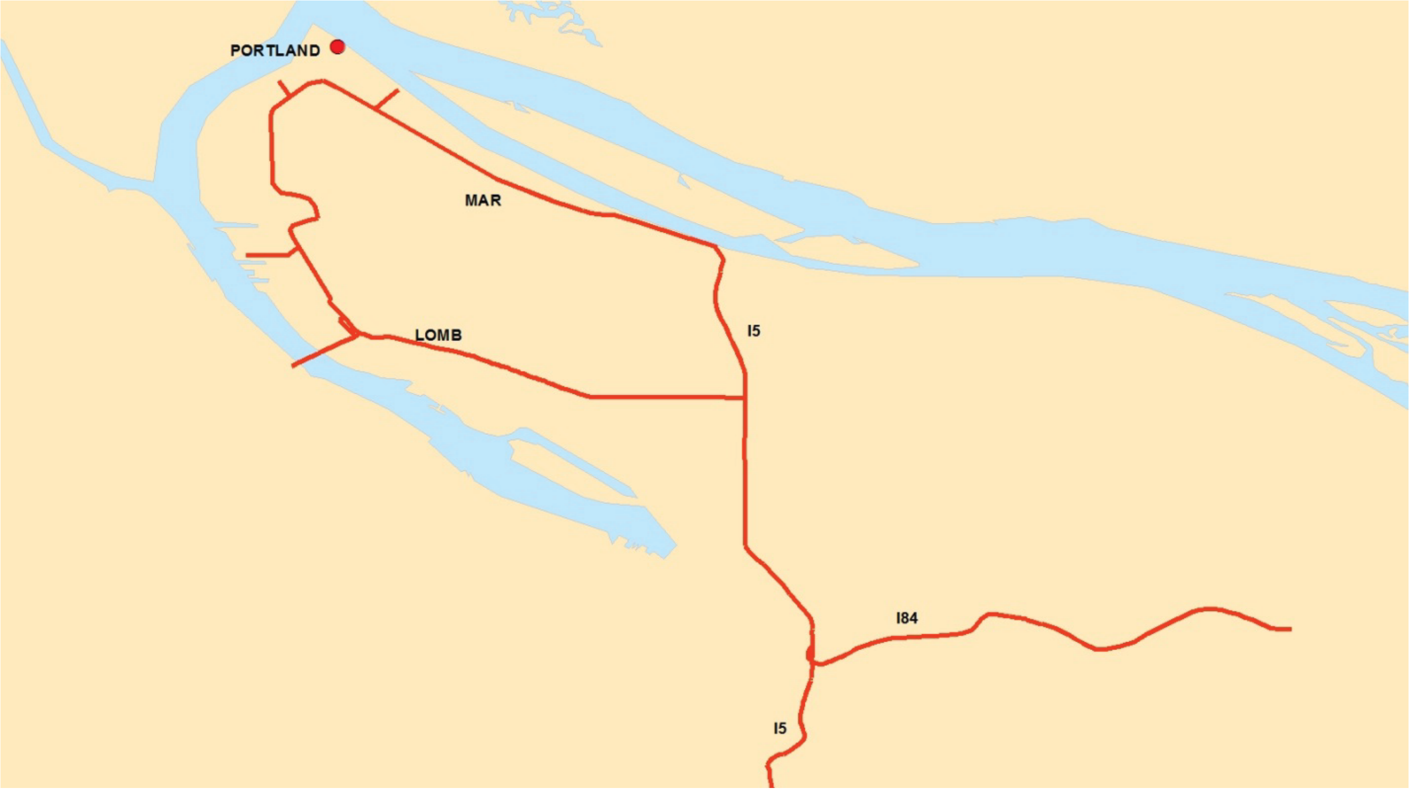

Figure C-10. Highway segments for Portland, OR.

Table C-50 provides the final modal breakdown for Portland-Coastal cargo.

An examination of the port area revealed that the truck traffic to and from the main terminals (especially Terminal 6) are serviced by four main arteries. The tonnage assigned to the truck mode for Portland-Coastal was distributed across these four routes using annual average daily truck counts. The total number of trucks was calculated by dividing total truck tonnage by 25 tons, and this number was then distributed according to existing truck traffic levels on each link.

Table C-50. Summary of modal assignments for Portland-Coastal.

Rail Tons	Truck Tons	Water Tons	Rail Assignment	
			POR1	POR2
7696	4983	751	5387	2309
0	709	0		
189	3637	0	189	
267	16	0	267	
286	2974	0	286	
0	319	0		
0	70	0		
0	1383	0		
155	1297	0	155	
58	118	0	58	
Total 8651	**15506**	**751**	**Total 6342**	**2309**
Total Rail/Truck/Water		**24,908**		

Rounding error of -3

Of all the case studies, this is the only one where highways are involved in moving significant amounts of project depth cargo. The researchers analyzed the main highway corridors in Portland to see if additional project depth cargo would cause severe congestion.

Congestion on any specific route in a large metropolitan region, no matter how much the travel times increase or how much higher the passenger or freight volume, will always be a small portion of the regional total. The key aspect with significant freight corridors is the increase in travel time and the decrease in travel time reliability along the route. Congestion will increase with higher volume more rapidly in corridors that already see stop-and-go speeds. Corridors that already have more traffic volume than can be handled efficiently suffer even more when there is additional volume on the route; not only does more passenger and freight movement join the congestion, but traffic speeds decline for everyone. Congestion effects will be particularly large in the peak travel periods, especially if freight has no alternative mode or route.

Figure C-11 illustrates that the effects of doubling total port tonnage throughput will most likely have a relatively insignificant effect on total delay over the corridors in the vicinity of the port during typical terminal operating hours of 6 a.m. to 7 p.m. While the curve moves up slightly, the shape of the curve does not undergo a significant change, that is, the traffic levels are not pushing congestion into an extreme increase.

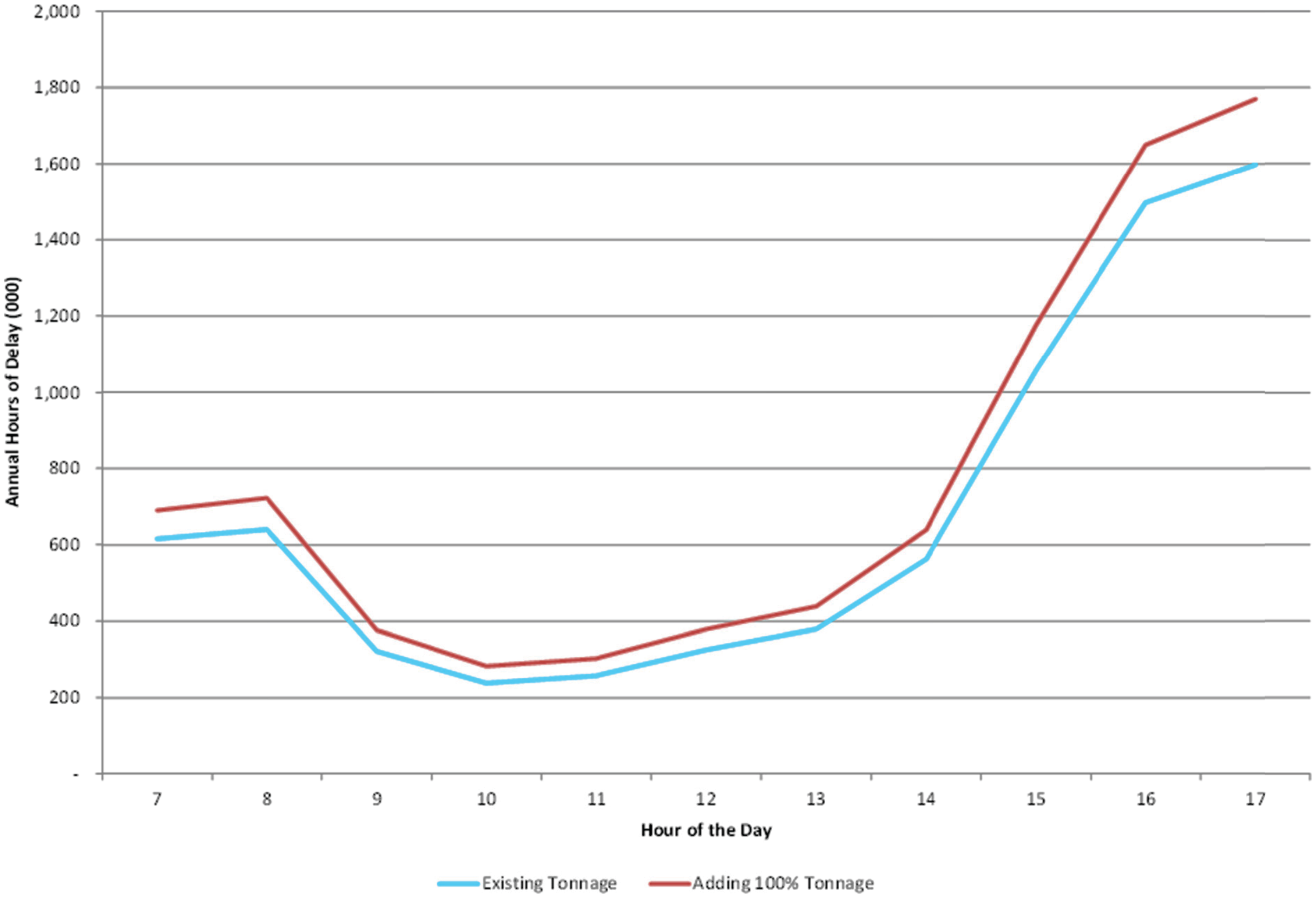

Figure C-11. Port of Portland—hours of delay from existing and 100 percent additional tonnage.

Table C-51. Origin-destination river segments for Portland-Inland.

CPT Segment Number	CPT River Segment Description	Approximate Geography
857220	Richmond Harbor, CA	San Francisco Bay Area
849700	Clearwater River, ID (Mile 0 to Mile 2)	From east side of Lewiston, ID, to junction with Snake River on west side
848750	Snake River, OR WA and ID (Mile 000 to Mile 146)	From Ice Harbor Lock and Dam to junction with Columbia River at Burbank, WA
848719	Snake River, OR WA and ID (Mile 000 to Mile 146)	From Lower Granite Lock and Dam to Little Goose Lock and Dam
848709	Snake River, OR WA and ID (Mile 000 to Mile 146)	From junction with Snake River at Lewiston, ID, to Lower Granite Lock and Dam
848610	Columbia River, OR WA-NWS (Mile 326 to Mile 329)	From Highway 395 bridge in Pasco, WA, to south side of Pasco
848518	Columbia River, OR WA-NWP (Mile 290 to Mile 325)	From junction with Snake River at Burbank, WA, to point downstream from Wallula, WA
848320	Columbia River, OR WA-NWP (Mile 192 to Mile 290)	From point downstream from Wishram, WA, to The Dalles Lock and Dam
848309	Columbia River, OR WA-NWP (Mile 192 to Mile 290)	From Umatilla, WA, to John Day Lock and Dam
848219	Columbia River, OR WA-NWP (Mile 107 to Mile 192)	From Hood River, OR, to Bonneville Lock and Dam
848210	Columbia River, OR WA-NWP (Mile 107 to Mile 192)	From the Dalles Lock and Dam to Hood River, OR
848100	Columbia River, OR WA-NWP (Mile 106)	From just downstream of I-5 in Portland, OR, to junction with Oregon Slough
847800	Columbia River, OR WA-NWP (Mile 102 to Mile 105)	From junction with Oregon Slough to junction with Willamette River
847620	Willamette River, OR (Mile 014 to Mile 162)	From West Linn, OR, to Toe Island
847500	Willamette River, OR (Mile 004 to Mile 013)	From Toe Island to junction with Multnomah Channel
847100	Oregon Slough, OR (Mile 0 to Mile 4)	All of Oregon Slough
846500	Columbia River, OR WA-NWP (Mile 050 to Mile 068)	From junction with Cowlitz River to junction with Clatskanie River
841900	Other Puget Sound Area Ports, WA	Puget Sound, WA

Portland, OR (Inland)

Portland (Inland) Origin-Destination Corridors

Portland-Inland was analyzed identically to Huntington, West Virginia. The network for Portland is not as extensive as the network for Huntington, and there is no single commodity that dominates Portland-Inland tonnage as coal does for Huntington, West Virginia. After analyzing the highest volume commodity groups, 18 segments were selected for analysis. Those segments are listed in Table C-51.

After a thorough examination of these segments, the researchers determined that many of the segments could be combined into consolidated segments while still maintaining the origin-destination flows of the various commodities. This was done by consolidating segments based on their geographical position relative to proposed maintenance projects. This made the model simpler to execute and understand. Table C-52 shows how the consolidated segments were formed.

Table C-52. Consolidated river segments for Portland-Inland.

Super Segment	CPT Segments
Segment 1 (Snake and Clearwater Rivers)	849700 848709 848719 848750
Segment 2 (Columbia River above Snake River)	848610
Segment 3 (Columbia River—John Day to Snake River)	848518 848309 848320
Segment 4 (Columbia River—Willamette River to John Day)	848210 848219 848100 847800
Segment 5 (Willamette River)	847620 847500
Segment 6 (Lower Columbia River)	847100 846500
Segment 7 (Coast below Columbia River)	857220
Segment 8 (Coast above Columba River)	841900

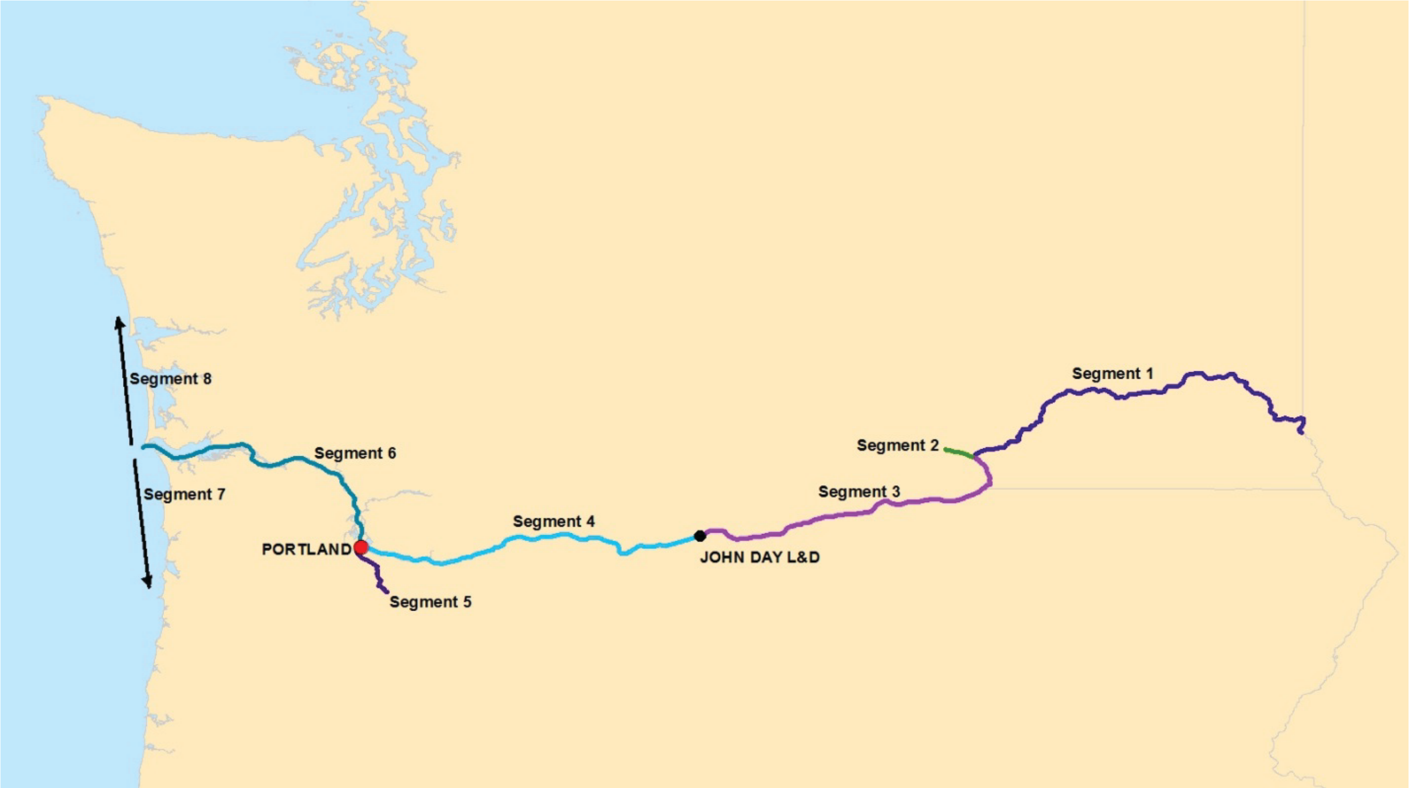

Figure C-12. Waterway segments for Portland, OR–Inland.

Portland (Inland) Modal Assignments by Corridor

As in the case of Huntington, there are no significant rail or highway flows associated with the waterborne cargo for Huntington. Much of the cargo is originally delivered to the river terminal via a short truck haul. There is no urban traffic to contend with and only minor congestion issues, so highway segments were not included in the analysis. A very high percentage of the shipments moves directly to waterfront facilities in Portland for eventual export. Waterborne flows were allocated based on a detailed analysis of trip data provided by the Corps. Researchers developed segment flows using CPT data and then extrapolated those numbers to reach a tonnage amount equal to the total tonnage for Portland-Inland. Figure C-12 shows the relevant waterway segments.

APPENDIX D[9]

Lock Capacity Calculation

In an attempt to estimate the capacity of the inland waterway system on a link-by-link basis, we developed a process using monthly historical traffic and delay data to estimate the delay as a function of traffic and then to define a capacity for each lock. The process was designed to be easily replicated across all of the locks in the system using a small dataset and limited computation.

We used one year (2008) of monthly data for the 193 locks reporting through the Army Corps of Engineers Lock Performance Monitoring System (LPMS) and the Operations and Maintenance of Navigation Information (OMNI) system. Of these locks, we had no lockage data for 18 locks, leaving 175 locks reporting at least some data. Another 14 had limited data (less than 1 lockage per day for each active month). Locks are built in different sizes based on anticipated traffic and tow sizes. Many of the smaller rivers or upper reaches of rivers have chambers 600 ft long or shorter. Busier sections have 1200 ft long chambers. Many locks have a main chamber and an auxiliary chamber. If the auxiliary is smaller than the main chamber, it is often used primarily for recreational traffic allowing the main chamber to process the large commercial tows. The auxiliary also acts as a backup if the main is closed for maintenance or repair. A few locks have twin chambers and use both for commercial traffic. We also gathered data on the physical characteristics of each of the locks: location, length, width, number of chambers.

A theoretical bound on capacity (in terms or tows processed) could be estimated by dividing the available processing time by the average processing time for a vessel. This number is almost meaningless, however, since we are dealing with a system where tows arrive at random times and shippers do not have limitless patience for delay. Instead, we need to estimate the traffic that can reasonably be expected to endure the delay transiting the lock. Delay can be directly translated to cost for waterway shippers. At some level of traffic, adding additional tows will cause the average delay to exceed the time and cost threshold of some shippers, and these shippers will no longer find the waterway a cost effective transportation alternative. They will move their goods by other modes (rail, highway) or possibly they will not have a profitable transportation alternative and not make the movement at all. A full analysis of this economic tradeoff requires an economic equilibrium model with detailed costs for each shipment. As an alternative, we attempted to estimate the delay shippers would endure by observing their shipping patterns at various locks. We calculated the hours per Kiloton transiting each lock (delay and processing time) assuming the movements were in average tow sizes for that lock. Thus, for each lock we calculated the current Level of Service (LOS) as:

$$(\text{Average Delay} + \text{Average Processing})/\text{Average Tow Size}$$

Plotting the distribution of these values (see Figure D-1) shows that they cluster around 0.2 and drop off sharply at about 0.8. In fact, 90 percent of the locks have an LOS less than or equal to 0.8. The 0.8 value appeared to represent the maximum delay most tows were willing to endure at a lock. Assuming a 0.8 LOS value, we calculated a MAXDELAY value for each lock using the lock's processing time and average tow size. Given the MAXDELAY value, we estimated each lock's capacity as the traffic that can be accommodated with the expected delay equal to MAXDELAY using the transit delay functions derived below. The 17 locks that currently have an LOS above 0.8 are assumed to be at capacity currently. Any additional demand for traffic through those locks is assumed to be offset by the loss of existing traffic.

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[9] The methodology employed to calculate the theoretical capacity of locks was borrowed from an unpublished paper titled "Using Historic Data to Estimate Capacity of the U.S. Inland Waterway System," prepared by M. R. Hilliard, D. P. Vogt, and M. S. Schultze for the Center for Transportation Analysis at Oak Ridge National Laboratory. An abridged version of that paper with minimal editing is presented in Appendix D. This abridged version is used with permission. This material has not been edited by TRB.

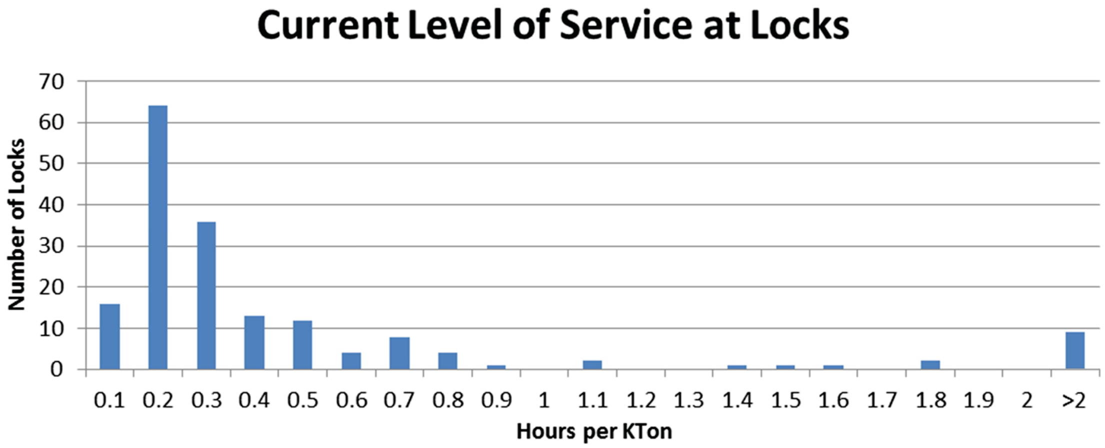

Figure D-1. The distribution of the level of service (hrs/kton) for 174 locks calculated for 2008 traffic.

We approached the development of delay curves (the functional relationship between traffic level and delay) on two parallel tracks: a queuing model and a regression model. In both cases the goal was to use the monthly traffic data at the locks to estimate delay at any given level of traffic. Combining a delay curve with a MAXDELAY then defines a maximum endurable traffic level, which we call capacity.

The queuing approach assumed that the equations for estimating the delay in an M/G/1 queuing system could be applied to the lock operations. The M/G/1 queue refers to a system with exponentially distributed inter-arrival times, a random service time governed by any reasonable distribution, and a single server. The standard form of the delay (wait time) as a function of traffic level is the Pollaczek-Khinchin formula. It appears in several versions, but the one most useful for this analysis was:

$$W = \frac{1}{\mu}\frac{\rho}{(1-\rho)}\frac{(1+c^2)}{2} \qquad (1)$$

Where

μ = service rate (tows locked per hour when busy)
c = conditional variance of the service time
ρ = ratio of arrival rate to service rate (between 0 and 1)

Attempting to fit the monthly data to this form was difficult. We did not have the individual lockage times to generate the c value, and attempting to estimate it from the monthly means or working backwards from the average waiting time and service times to estimate a value for c did not produce reasonable values for many locks.

The M/G/1 queuing model has fundamental assumptions about the system. In particular, the service time is assumed to be independent of the queue length. This assumption is probably not true for the lockage process. There are efficiencies in processing several tows in a row. Also, lockage times are not independent. Since weather and flow conditions affect lockages, the processing time for a tow is likely to be correlated to the previous tow's processing time. The loss of these assumptions means that the theoretical model can be far from the actual system's performance. In many cases, estimating the parameters for the queuing model produced delay estimates considerably higher than the observed delay. This overestimation of delay created some estimates of capacity less than the current traffic levels. We needed another approach to provide an estimate using a limited dataset.

The second approach was to consider each month at each lock as an observation and to develop a formula for the relationship between traffic levels and delay using a regression approach. The lock data were aggregated based on lock size and the presence of an auxiliary chamber. The main chambers of the majority of locks fall into one of two standard lengths, 640 ft or 1200 ft. These two classes had sufficient data and produced reasonable results for the regression using a log-log form. For the 640 ft locks, the equation was:

$$Log(Delay) = 2.1483 * Log(TowsPerDay) + Intercept \qquad (2)$$

For each individual lock, the intercept was chosen such that the curve goes through the annual average point for that lock.

The other large cluster of locks has 1200 ft main chambers. The regression for this set of locks produced a slope of 1.682. Once again, the intercept for each lock was calculated from the annual averages. All locks under 1200 ft were modeled with the 640 ft equation, and the rest of the locks were modeled with the 1200 ft equation.

For this effort, the goal of the development of transit curves is not to estimate the delay under all traffic levels. The final goal was to estimate the traffic level that gives the delay identified as the MAXDELAY. By substituting MAXDELAY

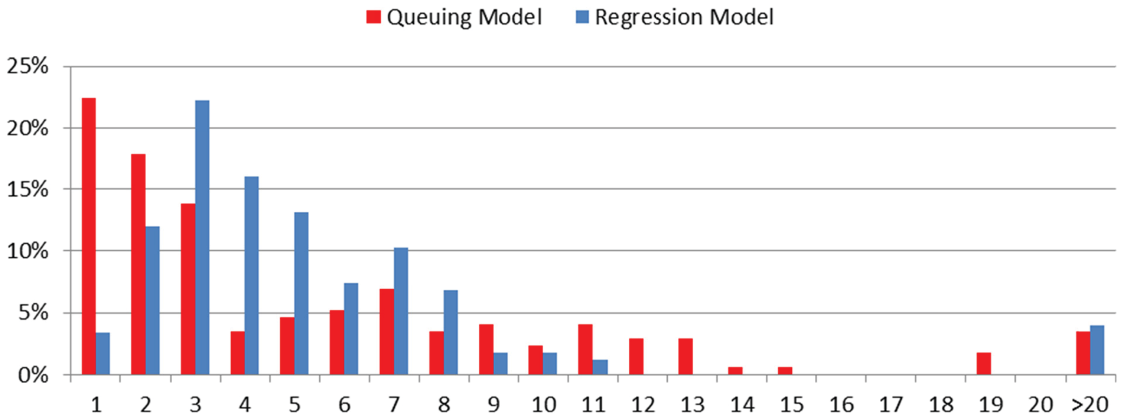

Figure D-2. Ratio of estimated capacity to current traffic under two models (175 locks).

for each lock into its transit equation and solving for the TowPerDay variable, we were able to generate an estimate of the capacity in terms of annual traffic.

Comparing the capacity traffic and the current traffic provides a first level check of the estimates. Figure D-2 shows the distribution of the ratio of the estimated capacity to the current traffic level based on the queuing-based approach and the regression approach. The queuing approach produced a large number of estimates showing locks already at or above capacity (ratio less than or equal to 1). While many locks may be congested, it does not seem reasonable to argue that many are already at capacity. The regression approach seemed to produce a more reasonable estimate relative to current traffic with a median of 3.7 and only a few ratios less than 1. A few locks have less than one tow per day with the current shipping patterns. The capacity estimates are based on the physical limitations, and though they are not large values, the ratio can exceed 20.

There are a number of opportunities to improve the regression approach. Analyzing several years data on individual lockages would allow the data to be averaged in smaller time units (days or weeks) providing a larger dataset and a wider range of delays and traffic intensities. Also, other functional forms could be tested. Clearly, if the arrival rate equals or exceeds the processing rate, delay eventually becomes infinite. In queuing terms, the queue “explodes.” While the log-log form provides a reasonable fit for the monthly data and moderate traffic levels, it does not have an asymptote to model the extreme high values of the relationship. Thus, at extremely high traffic levels we know the model is underestimating delay.

Conclusions

The typical approach to establishing the relationship between traffic and delay at a lock (and estimating capacity) is to develop and run detailed simulations of the lock operations at various levels of demand. The timing for lock operations (vessels entering the chamber, opening and closing gates, filling and emptying the chamber, etc.) is estimated using distributions based on historical data. These results are then used to estimate delay at any level of traffic. This process requires a great deal of data and a large number of simulation runs. The effort often consumes weeks or months of time. The resulting curve is not necessarily guaranteed to coincide with any one historical year. This approach is a first attempt at a simplified analysis for the system as a whole. While we would still consider the results preliminary, the overall approach seems promising for further study.

APPENDIX E

Analysis of Constraints

Notes on Rail Capacity Approach

As explained in the section "Utilization Metrics/Indicators" in the main body of *NCFRP Report 32*, the rail capacity analysis was based on work done by Cambridge Systematics for the American Association of Railroads (AAR) (*2*). The analysis essentially makes capacity a function of the traffic management system and the number of tracks. The types of traffic management system are the following:

- **Centralized Traffic Control (CTC).** This system consists of a centralized train dispatcher's office that controls railroad interlockings and traffic flows in portions of the rail system designated as CTC territory. A train may occupy a main track in CTC territory if it has been permitted to do so by signal indication. This means that a train may enter a CTC track from another track, or move within the CTC territory, on signal indication alone. A signal indicating it is safe to proceed is also the authority to proceed. A CTC track can be used for traffic in both directions, although one direction may be preferred in daily operations. There is a set of rules governing train entry into CTC territory where a signal is not provided (say, from a spur) and to get trains moving in case of signal failure.
- **Automatic Block Signaling (ABS).** This system consists of a series of signals that divide a railway line into a series of sections, or blocks. The system controls the movement of trains between the blocks using automatic signals. ABS operation is designed to allow trains operating in the same direction to follow each other in a safe manner without risk of rear end collision.
- **Track Warrant Control (TWC).** Track warrants are systematized permissions used on some railroad lines to authorize a train's use of the main line. Dispatchers issue these permissions to train crews instead of using signals. The crews receive track warrants by radio, phone, or electronic transmission from a dispatcher.

Each system has a unique set of operating characteristics that defines the maximum number of trains that can be expected to operate over a given track segment. For this study, the maximum number of trains for a given segment was set as shown in Table E-1.

Notes on Highway Capacity Approach

Consultation with TTI's Urban Mobility Program personnel revealed that even very large increases in truck traffic from port-related activity would only be statistically noticeable within a few miles of the port. Once the truck traffic leaves the port area, it disperses rapidly, and it is such a small percentage of the overall vehicle count that it has almost no effect on average delays. In the case of Portland (the only case study in which highways were a significant issue), the worst-case scenario indicates a possible 1.7 percent increase in delay times on the network of principal roadways in the metro area. Any highway analysis taken at any of the case study ports only focused on the immediate vicinity of the port.

Duluth

Duluth waterborne shipments tend to use the maximum water depth available. An increase of 30 percent of the tonnage that has historically moved in the deepest 3 ft would amount to an increase of 27.5 percent of total tonnage. Since coal and taconite are not the only commodities moved at these depths (although they certainly dominate the flows), the 27.5 percent increase is used as the projected increase in flows based on total tonnage handled at the port.

Landside, all of the potential project depth tonnage increases would be carried by rail. There are two major rail corridors that are relevant to the analysis. One runs from the iron ore (taconite) mines north of the Duluth-Superior metropolitan area to the port. This rail corridor is operated by the Duluth,

Table E-1. Maximum number of trains per day by traffic control system.

System	1 Track	2 Tracks
CTC	30	75
ABS	18	53
TWC	16	N/A

Missabe and Iron Range Railway (DM&IR). The other carries coal from the Powder River Basin to the port. That line is owned and operated by BNSF.

A standard taconite unit train is defined as a 100-car train with 110 tons per car, for a total of 11,000 tons per shipment. The most constrained point for the DM&IR is at the Shelton, Minnesota, stop. This is a single TWC track. Since TWC segments with one track have a capacity of 16 trains per day, the theoretical capacity is 16 × 11,000 tons × 365 days or 64,240,000 tons per year. This corridor currently experiences volumes of approximately 38,000,000 per year. This means the current tonnage could increase by 69 percent before reaching the theoretical limit. This corridor is not considered to be constrained in the model.

A standard coal train is defined as 110 cars at 111 tons per car. The most constricted point on the BNSF line is at the Beach, North Dakota, stop. This is a CTC segment with one track and two sidings, which means it should be able to handle a maximum of 32 trains per day (30 on the track and 2 on sidings). This stop is currently experiencing 27 trains per day; the unused capacity is 5 trains per day. This is a potential increase of 18.5 percent in volume before the theoretical capacity is reached and could constrain potential increases in cargo volumes.

For the purposes of this study, researchers also assumed that Burns Harbor, Indiana, and St. Clair, Michigan, would need to be dredged 3 ft. This loss of depth would affect the amount of coal and iron ore that has historically been destined for these two ports, as it would if Duluth (the origination point) lost depth. It was assumed that no other destination port would present a constraint.

Hampton Roads

The only commodity that would be affected by maintenance dredging at Hampton Roads is export coal. No other commodity has historically used the deepest 3 ft of water. Since this is the only commodity affected by maintenance dredging, a 30 percent increase in project depth tonnage would be reflected by a 30 percent increase in coal tonnage. Since this is moved entirely by rail, rail is the only potential landside constraint.

There are essentially two major coal exporting facilities at Hampton Roads: one at Newport News and the other on the Norfolk Channel. Norfolk handles about 60 percent of the total coal tonnage, and Newport News 40 percent. CSX is the primary railroad into Newport News and Norfolk Southern (NS) is the primary railroad into Norfolk. These coal trains are assumed to consist of 100 cars at 100 tons per car, or 10,000 tons per train.

For CSX, the most likely constrained point is Richmond, Virginia. This is a CTC segment with two tracks, which indicates a theoretical capacity of 75 trains per day. This would equate to 75 × 10,000 × 365, or 273,750,000 tons per year. Currently, 26 trains a day use this segment. This indicates an unused capacity of 178,850,000 tons per year. Since this is several multiples of annual coal traffic through Hampton Roads, a 30 percent increase would not result in constraint on this segment.

For NS, the most likely constrained point is Pamplin, Virginia. This segment is a CTC segment with one track, which would indicate a capacity of 30 trains per day. This equates to 30 × 10,000 × 365, or 109,500,000 tons per year. Currently, 18 trains a day are transiting this segment, leaving a capacity of 12 additional trains per day. This amounts to unused capacity of 43,800,000 tons. A 30 percent increase in coal tonnage (30 percent of 35.5 million tons) would not consume more than approximately 24 percent of this capacity, so this rail line is also unlikely to constrain traffic.

Huntington

Based on FAF3 data and the information the Corps provided, there was no indication of any significant rail or highway flows linked to the cargo movements associated with Huntington. The only potential constraint on Huntington is found at Emsworth Lock and Dam and Lock and Dam 52. A potential increase of 30 percent in project depth cargo for Huntington would not cause either one of these structures to experience a substantial increase in capacity utilization. However, these structures were included in the model as potential constraints.

Plaquemines

Plaquemines has insignificant interfaces with the highway or rail modes, and there are no locks that would constrain traffic to the port. Therefore, landside and lock constraints were not considered in the analysis of Plaquemines traffic. A 30 percent increase in project depth tonnage for Plaquemines would only result in a 3.1 percent increase in total tonnage. This indicates that only a small fraction of shipments at Plaquemines actually rely on the full depth for their movements.

Portland-Coastal

There are significant interfaces with both the rail and highway systems at Portland. The vessel fleet calling at Portland does not rely heavily on the availability of maximum project depth. An increase of 30 percent of project depth cargo would equate to a 10.8 percent increase in overall tonnage. The corridor analysis for Portland had to be based on overall tonnage due to a lack of available granularity in the data. Therefore, all flows were projected to increase by 10.8 percent based on current traffic figures.

There are two major railroads serving Portland: UP and BNSF. BNSF tends to carry freight to the north and east, while UP tends to operate to the south and southeast of Portland. The assignment of tonnages to the two railroads was explained in Appendix C. BNSF is currently operating at the theoretical capacity of their line out of Portland. Therefore, the model shows zero unused capacity for this railroad.

Trains serving Portland tend to carry a mix of commodities and empty cars. The theoretical capacity for UP is based on CTC with two tracks available, for a total of 75 trains per day. A fully loaded 110-car train with 100 tons per car could carry 11,000 tons. This would yield an annual capacity of 75 × 11,000 × 365, or 301,125,000 tons. However, trains in the northwest area tend to have 40.8 percent empty cars, and the average car load is only 65 tons (*2*). This would mean that a standard train would be carrying ((1–0.408) × 100) × 65, or 3,848 tons per train.

The most likely constraint on the UP line occurs at Rock Springs, Wyoming. This is a CTC segment with two tracks, which would indicate a capacity of 75 trains per day. There are currently 70 trains per day on this segment, so the remaining capacity is 5 trains per day. A 30 percent increase in project depth traffic for Portland would only result in an increase of less than 700,000 tons on this line, so it appears that it is not a significant constraint for Portland.

There are no data concerning truck freight shipments in the vicinity of the Port of Portland. Researchers identified four major highway routes into and out of the port: Lombard Street, Marine Drive, I-5, and I-84. TTI's Urban Mobility Program was able to make data available on daily truck counts for these roadways. These truck counts were assumed to consist of port-related freight traffic. Using earlier-cited statistics, a 30 percent increase in project depth cargo would result in an increase of 10.8 percent in truck-related traffic. The truck counts were inflated by 10.8 percent to reflect the potential increase in project depth cargo. These inflated truck counts were then fed into the delay model.

In order to calculate the congestion associated with additional truck traffic on area roadways, researchers used the road network to produce the *Urban Mobility Report* (*9*), which matches traffic volumes from the FHWA's Highway Performance Monitoring System with speed data from INRIX™ to generate traffic congestion statistics for over 100 urban areas across the United States. This roadway network has traffic conditions for the average week of the year for each stretch of roadway within urban areas. Researchers added the 10.8 percent additional trucks between 6:00 a.m. and 7:00 p.m. (the time when the port facilities or supporting operations are open for business) onto the roadway network. The additional traffic volumes would cause deterioration in the speeds when traffic conditions were already in congested conditions and would send conditions closer to congested operations if the current situation was uncongested. This deterioration function is based on a relationship between traffic volume per lane and speed that has been used for years in the *Urban Mobility Report.* Several assumptions were made to perform the calculations:

- Each additional truck uses the roadway capacity of three passenger cars (passenger car equivalent, or PCE = 3).
- Existing traffic volumes (excluding the additional truck traffic) on the road network continue to travel at the same time and on the same facility regardless of the new truck traffic.
- The additional truck traffic uses the entire length of the identified affected corridors within the urban area as if the new traffic is using these corridors to exit the urban area.

One would expect that if traffic volumes are expected to push congestion toward an intolerable situation, that increases in delay would show an exponential increase as the volume approaches the congestion barrier. However, even with a 200 percent increase in port-related truck traffic (as opposed to 10.8 percent), the model shows no significant increase in the rate of growth in delays. This would indicate that trucking is not a constraint for the movement of additional tonnage for Portland.

APPENDIX F

Model Results

The various scenarios evaluated by the model are presented in Table 22 in the body of the report. That table is reproduced here as Table F-1 for easy reference.

The model maximizes the throughput of the new project depth cargo, subject to congestion and budget constraints. The first three scenarios are all part of one model run where the budget is continually adjusted downward. The last three scenarios were each the focus of a model run. In these cases, the total budget was set at the budget amount for that scenario. Several subsets of each of the six scenarios were created by taking various percentages of the scenario budget (reducing the budget). The downward adjustments were done in order to see at what budget level the project mix would show a significant change.

When discussing the model results, the term “total demand” is used. This term denotes the new project depth tonnage that could possibly be generated if all projects pertaining to the ports being modeled were constructed. This demand is listed on a segment-by-segment basis in the “Increase from Project” column in the origin-destination table (see Table 20 in the main body of this report). Tables F-2 through F-6 present the results of these model runs.

Scenarios 1 and 2: All Ports Included, Total Budget of $99,265,442 or $79,412,354

Scenarios 1 and 2 produced exactly the same results. The segments shown in Table F-2 are selected by the model in each case. This project mix accommodates 39.7 million tons of 40.0 million tons (99 percent) of total demand.

The model shows that spending the full budget amount will not produce any additional benefit over spending just 50 percent of the budget ($49,915,341/$99,265,442) in Scenario 1 and 63 percent of the budget ($49,915,341/$79,412,354) for Scenario 2, based on projected demand levels.

Scenario 3: All Ports Included, Total Budget of $49,632,721

In Scenario 3 the project mix begins to change. The segments shown in Table F-3 are selected by the model. This project mix accommodates 39.2 million tons of 40.0 million tons (98 percent) of total demand.

The model shows that 97 percent of the budget ($48,297,303/$49,632,721) should be spent, based on projected demand levels. At this budget level, the available budget has begun to cut into the optimum project mix from Scenarios 1 and 2. Both of those scenarios required a budget greater that Scenario 3’s budget. Even so, 98 percent of the demand is still met.

Scenario 4: Duluth and Hampton Roads Are Excluded, Total Budget of $49,632,721

The segments shown in Table F-4 are selected by the model under this scenario. This project mix accommodates 26.7 million tons of 27.0 million tons (99 percent) of total demand.

The total demand for this scenario drops to 27.0 million tons since Duluth and Hampton Roads are not included. The model shows that 86 percent of the budget ($42,814,101/$49,632,721) should be spent, based on projected demand levels, even though this budget is only half of the original budget in Scenario 1.

Scenario 5: Portland Is Excluded, Total Budget of $79,412,354

The segments shown in Table F-5 are selected by the model under this scenario. This project mix accommodates 100 percent of total demand (35.1 million tons).

The total demand for all of the ports minus Portland is 35.1 million tons. The projects selected in Table F-5 can fully

Table F-1. Scenarios analyzed.

Projects Included	Budget Amount
All Projects	**$99,265,442 (100%)**
All Projects	$79,412,354 (80%)
All Projects	$49,632,721 (50%)
All Projects minus Duluth & Hampton Roads	$49,632,721 (50%)
All Projects minus Portland	$79,412,354 (80%)
All Projects minus Plaquemines	$44,632,551 (total minus Plaquemines)

Table F-2. Segment improvements selected for Scenarios 1 and 2.

Port	Segment	Units of Improvement*	Expenditure
Huntington	Segment 4	1	$754,436
Huntington	Segment 6	1	$754,436
Hampton Roads	HR2	1	$889,341
Hampton Roads	HR3	2	$1,064,718
Duluth	DS1	3	$2,828,485
Duluth	DS4	1	$293,067
Duluth	DS6	3	$2,025,629
Plaquemines	PL1	2	$36,421,927
Portland-Inland	Segment 4	1	$200,202
Portland-Coastal	PO1	1	$ 4,683,100
		Total	**$49,915,341**

*Unit of Improvement for waterway segments is 1 ft of dredging; for locks, it is the maintenance necessary to reduce the average delay at a lock by one-third of the total potential reduction in delay.

Table F-3. Segment improvements selected for Scenario 3.

Port	Segment	Units of Improvement*	Expenditure
Huntington	Segment 4	1	$754,436
Huntington	Segment 6	1	$754,436
Hampton Roads	HR2	1	$889,341
Hampton Roads	HR3	2	$1,064,718
Duluth	DS1	2	$1,885,656
Duluth	DS4	1	$293,067
Duluth	DS6	2	$1,350,420
Plaquemines	PL1	2	$36,421,927
Portland-Inland	Segment 4	1	$200,202
Portland-Coastal	PO1	1	$ 4,683,100
		Total	**$48,297,303**

*Unit of Improvement for waterway segments is 1 ft of dredging; for locks, it is the maintenance necessary to reduce the average delay at a lock by one-third of the total potential reduction in delay.

Table F-4. Segment improvements selected for Scenario 4.

Port	Segment	Units of Improvement*	Expenditure
Huntington	Segment 4	1	$754,436
Huntington	Segment 6	1	$754,436
Plaquemines	PL1	2	$36,421,927
Portland-Inland	Segment 4	1	$200,202
Portland-Coastal	PO1	1	$4,683,100
		Total	**$42,814,101**

*Unit of Improvement for waterway segments is 1 ft of dredging; for locks, it is the maintenance necessary to reduce the average delay at a lock by one-third of the total potential reduction in delay

Table F-5. Segment improvements selected for Scenario 5.

Port	Segment	Units of Improvement*	Expenditure
Huntington	Segment 4	1	$754,436
Huntington	Segment 6	1	$754,436
Hampton Roads	HR2	1	$889,341
Hampton Roads	HR3	2	$1,064,718
Duluth	DS1	3	$2,828,485
Duluth	DS4	1	$293,067
Duluth	DS6	3	$2,025,629
Plaquemines	PL1	2	$36,421,927
		Total	**$45,032,039**

*Unit of Improvement for waterway segments is 1 ft of dredging; for locks, it is the maintenance necessary to reduce the average delay at a lock by one-third of the total potential reduction in delay.

accommodate the demand. Only 57 percent ($45,032,039/ $79,412,354) of the budget is required to do so.

Scenario 6: Plaquemines Is Excluded, Total Budget of $44,632,551

The segments shown in Table F-6 are selected by the model under this scenario. This project mix accommodates 37.8 million tons of 38.1 million tons (99 percent) of total demand.

Table F-6. Segment improvements selected for Scenario 6.

Port	Segment	Units of Improvement*	Expenditure
Huntington	Segment 4	1	$754,436
Huntington	Segment 6	1	$754,436
Hampton Roads	HR2	1	$889,341
Hampton Roads	HR3	2	$1,064,718
Duluth	DS1	3	$2,828,485
Duluth	DS4	1	$293,067
Duluth	DS6	3	$2,025,629
Portland-Inland	Segment 4	1	$200,202
Portland-Coastal	PO1	1	$4,683,100
		Total	**$13,493,414**

*Unit of Improvement for waterway segments is 1 ft of dredging; for locks,it is the maintenance necessary to reduce the average delay at a lock by one-third of the total potential reduction in delay.

The expected demand for all the ports minus Plaquemines is 38.1 million tons. The project mix selected in Table F-6 can accommodate 99 percent of total demand, yet only 30 percent of the budget ($13,493,414/$44,632,551) is required to do so. At first glance, this would seem to indicate that Plaquemines is a relatively expensive port to maintain for the expected growth in cargo that would result, but dredging the river below Plaquemines could affect ports all the way up to Baton Rouge, and it could also affect the decisions of shippers in the upper Mississippi region. A more comprehensive approach is needed in this instance, where the potential increases in project depth cargo are calculated for all potentially affected ports.

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List of Acronyms, Abbreviations, and Initialisms

AAR	Association of American Railroads
ABS	Automatic block signaling
BNSF	Burlington Northern Santa Fe
CFS	Commodity Flow Survey
CMSA	Consolidated Metropolitan Statistical Area
Corps	U.S. Army Corps of Engineers
CPT	Channel Portfolio Tool
CTC	Centralized traffic control
DM&IR	Duluth, Missabe, and Iron Range Railway
DOC	Department of Commerce
FAF3	Freight Analysis Framework (Version 3)
IWR	Institute for Water Resources
MARAD	U.S. Maritime Administration
MSA	Metropolitan Statistical Area
MTS	Marine Transportation System
NIPSCO	Northern Indiana Public Service Company
NS	Norfolk Southern
O&M	Operations and maintenance
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
PCE	Passenger car equivalent
RoS	Remainders of states
SCTG	Standard Classification of Transported Goods
STCC	Standard Transportation Commodity Code
TEU	20-ft equivalent units
TTI	Texas A&M Transportation Institute
TWC	Track warrant control
UMRP	Urban Mobility Research Program
UP	Union Pacific
WAM	Waterway Analysis Model
WCSC	Waterborne Commerce Statistics Center

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation