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Navigation Systems Research Program

Marine Transportation System Performance Measures Research

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Abstract

Performance measures for the marine transportation system (MTS) span many operational categories including economic benefits, capacity and reliability, safety and security, environmental stewardship, and resilience. The measures of greatest interest to any one group of stakeholders depend upon their underlying values and goals; however, some measures have been identified by expert groups as fundamental to understanding MTS operations. Within the United States, multiple Federal agencies have a role in maintaining and regulating the MTS. This has resulted in compartmentalized authorities and data collection efforts, unintentionally limiting the access to and utility of multiple data sets. The research presented in this technical report provides historical context for the development of performance measures for Federally managed MTS infrastructure, identifies authoritative data sources (or relevant proxies) for performance measures of interest, and provides extracted data that allows for assessment of performance over time. This work lays the foundation for examining MTS performance as an interconnected system and within a larger intermodal supply chain network. The final section suggests using observed data to develop models that explore a wide range of future scenarios and provide insight into potential effects on MTS performance.

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Preface

This study was conducted for the U.S. Army Corps of Engineers under the Navigation Systems Research Program, Work Unit 33143, "Navigation Transportation System." The program manager was Charles E. Wiggins (CEERD-HZ-T).

The work was performed by the Coastal Engineering Branch of the Navigation Division (CEERD-HNC), U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication, Tanya Beck was Chief, CEERD-HNC; Jacqueline Pettway was Chief, CEERD-HFH; and W. Jeff Lillycrop, CEERD-HX-T, was the Technical Director for Navigation. The Director of ERDC-CHL was José E. Sánchez.

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The Commander of ERDC was COL Bryan S. Green, and the Director was Dr. Jeffery P. Holland.

Executive Summary

The U.S. marine transportation system (MTS) is a diverse compilation of public and private assets that ranges from supertankers to forklifts, from navigation buoys to massive navigation locks. An accurate assessment of any system that spans such a broad temporal and geographic range is complicated by the need for multiple data types and sources to answer the deceptively simple question, "how is the MTS performing?" To organize this effort, major indicators with nationally available data were identified in the following five categories: Economic Benefits, Capacity and Reliability, Safety and Security, Environmental Stewardship, and Resilience. A summary of these initial performance measures is presented below.

Performance Measure	Status and Historical Context
Total value and tonnage of international trade moved by MTS	During the recent economic downturn, the value of cargo moved by the MTS dropped but has since surpassed 2007 levels. Since 2007, export tonnage has increased while import tonnage has decreased by almost one-third.
Income and disbursement of Harbor Maintenance and Inland Waterways Trust Funds	Harbor Maintenance Trust Fund (HMTF) revenues have exceeded disbursements for over 15 years; Inland Waterways Trust Fund (IWTF) disbursements exceeded revenues for most of past decade.
Producer Price Index (PPI) for transportation modes	Waterborne transportation-related prices are rising at rate similar to truck transport prices.
Number of jobs in marine transportation industries, direct employment	MTS employment declined during the economic downturn of 2008 to 2010 but is returning to pre-downturn levels for 10 states with the highest reported MTS employment.
Inland waterway shipping barge freight rates	Seasonal cyclical prices exhibited less variability from 2010 to 2014 when compared to 2005 to 2010.
Navigation lock closures, hours and number of closures, unscheduled and scheduled	1993 to 2013 saw an overall increasing trend in navigation lock closures.
NOAA PORTS instrumentation availability at 59 high-tonnage USACE projects	Over half of 59 high-tonnage USACE projects (handling 95% of waterborne tonnage) have this instrumentation available.
Quarterly travel time estimates for key waterway segments	With AIS-archived data, these reports can now be generated at a variety of spatial scales, development ongoing.

Federal channels at project depth according to USACE eHydro	Program implementation is underway across USACE and will provide timely regional information.
Number of commercial vessel accidents (collisions, allisions, groundings)	No significant change from 2002 to 2011; recent years have unresolved cases that obscure annual totals.
Number of commercial mariner and passenger casualties (personal injuries, deaths)	No significant change from 2002 to 2011; recent years have unresolved cases that obscure annual totals.
U.S. Coast Guard incident investigations	No significant change from 2002 to 2011; recent years have unresolved cases that obscure annual totals.
U.S. petroleum-based fuel sales to the maritime industry	Sales appear to have peaked in approximately 1999; by 2012, volumes dropped to levels last seen in the 1980s.
Vessel pollution incidents (petroleum and other types)	Slight downward trend from 2002 to 2011; recent years have unresolved cases that obscure annual totals.
Amount of dredged material reclaimed for beneficial use	Since 2008, beneficial reuse for beach nourishment has been relatively steady, but wetland nourishment has declined.
Number of reported whale strikes by vessels	Available records indicate little change from 2007 to 2010; experts believe events are significantly under-reported.
Physical condition ratings of USACE-owned critical coastal navigation infrastructure	The most common rating given was “B”; very few pieces of infrastructure received an “F” rating.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
hectares	1.0 E+04	square meters
knots	0.5144444	meters per second
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second

1 Introduction

1.1 Background: The U.S. Marine Transportation System (MTS)

MTS performance measures, key elements:

- Performance goal
- Quantifiable measure that relates to goal
- Authoritative data used to calculate measure of interest

Measurement should be based on data that is collected regularly over time; this allows for transparent analysis of progress towards goals.

The U.S. MTS encompasses both the Nation's navigable waterways and the infrastructure that facilitates the movement of people and goods to, from, and along these waterways. The MTS encompasses waterside features such as navigable channels in rivers and lakes, marinas, commercial ports, and infrastructure such as navigation locks (U.S. Department of Transportation, Maritime Administration 2013). As part of a larger multimodal transportation system, the MTS is connected to landside features such as intermodal connector roads, railways, and the interstate highway system (U.S. Department of Transportation, Maritime Administration 2013). The MTS is a physically expansive system, connecting inland ports in America's center to the edges of the U.S. Exclusive Economic Zone (EEZ) through approximately 25,000 miles of commercially navigable channels and hundreds of ports (U.S. Committee on the Marine Transportation System 2008).

Within the United States, the MTS can be divided into subsystems based on the predominant vessel types. One system consists of shallow-draft navigable inland rivers and waterways like the Gulf Intracoastal Waterway with commercial users largely engaged in long-haul, bulk-freight movements (Committee for a Study of the Federal Role in the Marine Transportation System 2004). The Great Lakes and Saint Lawrence Seaway connect to both the inland and the ocean systems but can be considered a subsystem of their own. The Great Lakes in particular have many deep-draft vessels that stay entirely within the Great Lakes due to depth and width restrictions along the Seaway. The other MTS subsystem is made up of coastal ports and channels that serve vessels engaged in coastwise, international, or transoceanic trade. All ports are nodes for the MTS network and the larger land-transportation network that includes America's highways, railroads, and pipelines. Ports are more than a part of the MTS; by definition, they are intermodal hubs that integrate waterborne transportation with all other major freight transportation systems (Committee for a Study of the Federal Role in the Marine Transportation System 2004).

The MTS exists for the benefit of its users, both direct and indirect. The population of direct users includes commercial vessel operators, port operators, the fishing community, marine service industries, and government entities such as state natural resource agencies and the military. Indirect users include any U.S. consumer or industry that buys or sells goods that travel on the MTS (U.S. Committee on the Marine Transportation System 2008). MTS users employ vessels to move goods worth billions of dollars through the global supply chain between foreign and domestic seaports to their final destination. Seasonal patterns in shipping closely track oscillations in U.S. retailers' inventories and sales (Chambers 2012). All users are affected by MTS performance, but the immediacy of that interest can vary widely. For example, shipments of imported merchandise in anticipation of holiday sales in the United States happen long before that merchandise is actually stocked on retail shelves, but delays at critical time points can disappoint both retailers and consumers. Other shipments such as bulk commodities like road salt are not typically as time sensitive as consumer retail products, but road salt shipments can take on an extra urgency when winter storms deplete supplies and municipalities are looking to rapidly restock (Kilgannon and Santora 2014). Despite its recognized criticality to the national economy, the value of the MTS can easily be overlooked by the public since much of the physical infrastructure is removed from the daily lives of most Americans. Even ports associated with major metropolitan areas can seem separate from the urban fabric of a city because they are set apart for reasons such as logistical convenience, the result of land-use patterns or real-estate prices, or resident concerns about impacts of commercial activities on quality of life. Every year the MTS contributes over $200 billion in port sector Federal, state, and local taxes while supporting more than 13 million jobs (U.S. Department of Transportation, Maritime Administration 2013). The contribution from waterborne shipping-associated activities to the U.S. Gross Domestic Product (GDP) is over $645 billion annually (U.S. Department of Transportation, Maritime Administration 2013).

Although functioning, the MTS is beginning to show signs of capacity limitations and the effects of aging infrastructure. In 2005, the U.S. Department of Transportation (USDOT) reported to Congress that commercial operations in port areas were raising concerns about freight-related transportation capacity limits, such as the availability of cargo staging areas in the face of increasing cargo volumes, port rail infrastructure and intermodal connectivity, landside access to ports and improved highway signage, channel and port dredging, and the availability of financing to upgrade and expand infrastructure (U.S. Department of Transportation, Maritime Administration 2005). These concerns from the business community have not diminished in the past decade. Making improvements on any one of these issues requires long-term planning and investment in infrastructure. In 2005, possible solutions were complicated by the multiple mission requirements from 17 Federal agencies responsible for maritime decision making (U.S. Department of Transportation, Maritime Administration 2005). As of the year 2014, this number has increased to 23 Federal agencies or offices (U.S. Committee on the Marine Transportation System 2014) with a defined interest in marine transportation-related decisions. While the number of groups interested in maritime affairs has increased, so too has the ability to gather relevant data, produce precise maps showing where issues intersect, develop computational models, and use these tools to develop solutions to transportation challenges.

1.2 Objective

The MTS has numerous stakeholders, but there is no unified set of national MTS performance goals. This project is working to identify and assess how well critical aspects of the MTS are functioning across the Nation so that all parties can have the same baseline information. The next step is a broader discussion across the MTS community about setting National goals for the MTS and then developing a strategy to achieve a desired level of performance.

The purpose of this technical report is threefold:

1. To provide context for the development of MTS performance measures
2. To identify, document, and support progress towards better technological integration of existing MTS-related data sources that can be used to inform performance measures
3. To present a series of related questions that would benefit from an operational intermodal freight network model and could leverage ongoing

research by agencies and organizations with an interest in MTS performance.

1.3 Approach

The research approach used for this project had three main elements: consultation with subject matter experts, web-based research, and consequent analysis of discovered data. Input from subject matter experts in fields relevant to marine transportation was used to develop an initial list of potential performance measures. Subject matter experts were drawn from multiple fields including infrastructure, economics, navigation, engineering, and life sciences. Experts were also queried for their knowledge of existing data sets relevant to suggested performance measures. Research to identify and acquire publicly available datasets relevant to MTS performance was primarily conducted through online search queries and direct inquiries to Federal agency contacts. Background on the history of performance measurement efforts related to the MTS was gathered from legislative databases and nongovernment publications.

Multiple quantitative datasets were assembled during the course of this research. These datasets were analyzed for their continuity, spatial coverage, and overall relevance to understanding the performance of the U.S. MTS. Datasets that were deemed relevant for inclusion are presented graphically throughout this technical report. The sources of publicly available datasets that informed the performance measures used in this report are described in the Appendix.

2 Definition of Performance Measure

"Performance indicators help participants to understand strengths and weaknesses within their organizations and institutions. They also help assist in identifying measures that can be implemented to counteract undesirable developments."

Performance Indicators for Inland Waterways Transport: User Guideline (PIANC Inland Navigation Commission, Working Group 32 2010)

Measures, indicators, metrics—these words are often used interchangeably, but the desired result is the same, to understand how elements are functioning within a larger complex system such as an international supply chain. In general, a performance measure provides information about progress towards a goal. Detailed descriptions of performance measure characteristics have been defined in previous studies. For example, in a report on freeway operations performance measurement, Brydia et al. (2007) stated that well-designed performance measures should be the following.

- Reflective of the end result, the measure should help determine if a goal is being met
- Simple, understandable, unambiguous, accepted, and meaningful to the customer
- Responsive or sensitive to the data being measured
- Appropriate temporal and geographic scales

For example, the performance measures for the MTS should be applicable nationally. An ideal MTS performance measure would be collected locally, using the same method across all sites, so that state, regional, and National summaries could be easily compiled for comparison.

Brydia et al. (2007) distinguish between **output measures** and **outcome-based measures**. Output-based measures identify information about the **use** of resources (Brydia et al. 2007). Examples of MTS-related output measures can include number of containers unloaded at a port, amount of sediment removed from a channel, or vessel inspections completed by regulators. Outcome-based measures identify **how well** an organization is meeting stated goals and objectives; these types of measures are often more relevant to the general public (Brydia et al. 2007). Examples of MTS outcome measures include number of vessel accidents, average tons per vessel transported through a channel, and average travel time between two ports. Both output- and outcome-based measures are necessary to evaluate a system; they work in tandem to support analysis of how a system structure is contributing to its functional goals.

Output and outcome measures can serve more than one purpose depending on the user group. One prominent MTS user group is the World Association for Waterborne Transport Infrastructure (PIANC), the leading nonpolitical and nonprofit forum for international experts and transportation professionals on technical, economic, and environmental issues related to waterborne transportation infrastructure. PIANC has expressed support for MTS performance measures as useful to their members. The PIANC Inland Navigation Commission, Working Group 32 (WG 32)—Performance Indicators for Inland Waterways Transport (PIANC Inland Navigation Commission, Working Group 32 et al. 2010), identified three general purposes for performance measures. Those purposes are as follows:

- Operational - To manage and control, helping answer the question:
  - What is the present state of our business?
- Informational - To provide and find information, helping answer the question:
  - How do we appear to our users?
- Referential - To compare and improve, helping answer the questions:
  - What can we learn from others?
  - What can we learn from our own performance?

If one measure can be used for multiple purposes, then assembling and publishing such information should take a higher priority. For example, *fuel use* is a single performance measure with relevance for operations (cost of running equipment), information (air emissions associated with operations) while also serving a reference purpose (tracking changes over time). This example demonstrates how a single measure can be both output related and outcome related depending on the context.

One group using a well-defined performance measure is Transport Canada, an official Canadian transportation agency. Transport Canada has developed a system that tracks the performance of multiple transportation modes operating within a single freight corridor; this performance is measured as the time it takes a shipping container to complete each predefined segment of the journey. Transport Canada tracks the travel time of a shipping container moving from ports overseas to destinations within Canada or through Canada into the United States via Canadian ports and truck or rail lines. This travel time measure is known as *fluidity* because it reveals how well shipments are *flowing* through different segments along a route by using time as the performance measure. Development of the Canadian fluidity index was motivated by a desire to improve the competitiveness of containerized imports through Canadian ports. The Canadian fluidity index relies on data-sharing partnerships between the Canadian Government and private sector freight carriers who report transit times for different modal segments (ocean voyage, port dwell time, drayage, truck transit, rail transit, shipment via inland waterways) (Transport Canada 2012). Establishing data-sharing partnerships with private companies doing business in Canada required legally binding commitments from the Canadian government to protect proprietary data about commercial shipping. Securing agreements and putting the proper data collection procedures in place took multiple years. With data acquisition and sharing infrastructure now in place, the resulting evidence is being used by Canadian provincial governments to identify specific delay points, such as on-grade road and rail crossings, for investments to upgrade infrastructure (Tardif 2014).

"The very act of gathering, synthesizing, and analyzing such information and relating it to performance should prompt more critical thinking about the scope and effect of Federal involvement in the MTS."

The Marine Transportation System and the Federal Role: Measuring Performance, Targeting Improvement (Committee for a Study of the Federal Role in the Marine Transportation System 2004)

3 Why Maritime Transportation System (MTS) Performance Measures?

Performance measurement is a useful process to evaluate the relationship between inputs and outputs within the structure of a specific system and subsequently identify areas of possible improvement. The MTS is spatially expansive and fragmented in terms of operations and ownership but is a system of interest to many parties. In the United States, there are Federal agencies that provide public data on parts of the MTS, but standardized, nation-wide information on private assets is not freely available and so was not included in this project. Despite certain informational opacities, this research is bringing together publically available pieces of data to present a shared baseline of MTS performance that can be evaluated over time. The anticipated uses are described below.

3.1 Performance measures to support goal setting

Federal agencies and their policy makers receive advice from many parties on desirable levels of funding and changes to Federal programs and policies. However, they often lack evidence-based information and analyses to support and coordinate the decisions required. Decision makers at all levels need to know how well the MTS is functioning to meet the demands of commerce, safety, environmental protection, and National security. They also need a means for identifying shared goals, assessing progress toward achieving them, and planning concerted actions to further this progress (Committee for a Study of the Federal Role in the Marine Transportation System 2004). A unifying set of national goals for the MTS does not currently exist. However, the USDOT supports a "full integration of a strengthened marine mode into the national intermodal system... The ultimate goal is to deliver a marine transportation system that enhances the efficiency, productivity, and capacity of our nation's intermodal transportation system." (U.S. Department of Transportation, Maritime Administration 2005). Without accurate data about performance, there will be no way to know if the MTS is operating in the most productive and efficient way. Information gathering about current operating conditions must proceed in order to develop a common baseline picture.

Other parties have written extensively on this need for a shared understanding of the MTS. To that point, the Committee for a Study of the Federal Role in the MTS (2004), organized by the Transportation Research

Board of the National Academies, found that "strengthening of the information and analytic bases for Federal decisions relating to the MTS is urgently needed. Federal program expenditures on individual components of the MTS are large, and each expenditure must be justified in its own right." The scale of investments in MTS-associated infrastructure can vary widely. Channel dredging, port facility upgrades, or improved intermodal connections are often funded by private entities or states. At the other end of the cost scale are capital-intensive and large-scale constructions projects such as navigation lock rehabilitation or replacement. These financial realities underscore the fact that MTS infrastructure is a long-term investment, with long-term benefits, and should be viewed accordingly.

3.2 Performance measures for multiple stakeholders

Multiple stakeholders, including private business entities, regulatory bodies, and communities that live near the water, are interested in aspects of MTS performance. These varied user groups are often interested in the same measure but for different purposes. For example, a financial performance measure such as port-associated revenues could be used by private business to consider potential expansion opportunities, a regulatory body for compliance inspection purposes, and a local community for understanding the tax revenue that a port brings to a municipality. A measure such as air-quality impacts from MTS operations could be of interest to companies who want to reduce emissions and vessel operating costs, regulatory agencies involved in emissions testing, and communities concerned about the effects of local air quality on their health.

In cases where stakeholders work together to improve specific aspects of MTS performance, all parties need reliable data to craft effective solutions. Recently, public, private, and nonprofit stakeholders in Houston, TX, worked together to secure Federal funding to replace commercial tugboat engines with newer, cleaner engines that significantly reduce diesel emissions (Environmental Defense Fund 2014). Replacing engines instead of rebuilding them (a regular maintenance technique) allowed for the incorporation of new emission control technology. Achieving this success required trusted data on vessel age, engine age and type, vessel fuel use, engine emissions, grant funding opportunities, and waterway use patterns for vessels in the Houston area (Environmental Defense Fund 2014). Partners in this effort included the Houston-Galveston Area Council, Port of Houston Authority, multiple towing companies, and the Environmental

Defense Fund. Replicating this kind of success in more locations will require mutually trusted data and dedicated partnerships.

3.3 Performance measures for system-wide analysis

Administrative agencies and private entities seek and collect information that supports their activities and missions. While these mission areas might include aspects of marine transportation, the level of knowledge within a single administrative silo is unlikely to span all MTS-relevant areas. There is a growing recognition that this partitioning of knowledge is not supportive of systems-level thinking. The ramifications of this partitioning are illustrated in the following quotation from a Transportation Research Board (TRB) report:

> Federal responsibilities in the MTS are fragmented among several congressional committees and administering agencies. The resulting dispersion of program authorizations, budgeting, and funding has led to fragmentation in the information collected and analyzed by the Federal Government on the performance, conditions, and needs of the system. Each agency has come to rely on different sets of information and analytical tools to inform its decisions. For the most part, this information is not coordinated in a way that allows for Federal funding and investment priorities to be examined with regard to national interests or across the Federal agencies with relevant responsibilities. The result is that no single entity has the responsibility to gather and analyze information on system performance and needs or the ability to act on this information in a comprehensive way. (Committee for a Study of the Federal Role in the Marine Transportation System 2004)

As a counter to this habit of partitioning, this current project brings together information that is already publicly available but which might not be readily apparent to all interested MTS stakeholders. These data on the MTS reflect the fact that it is an intricate system tied to, but existing independent of, any single agency mission.

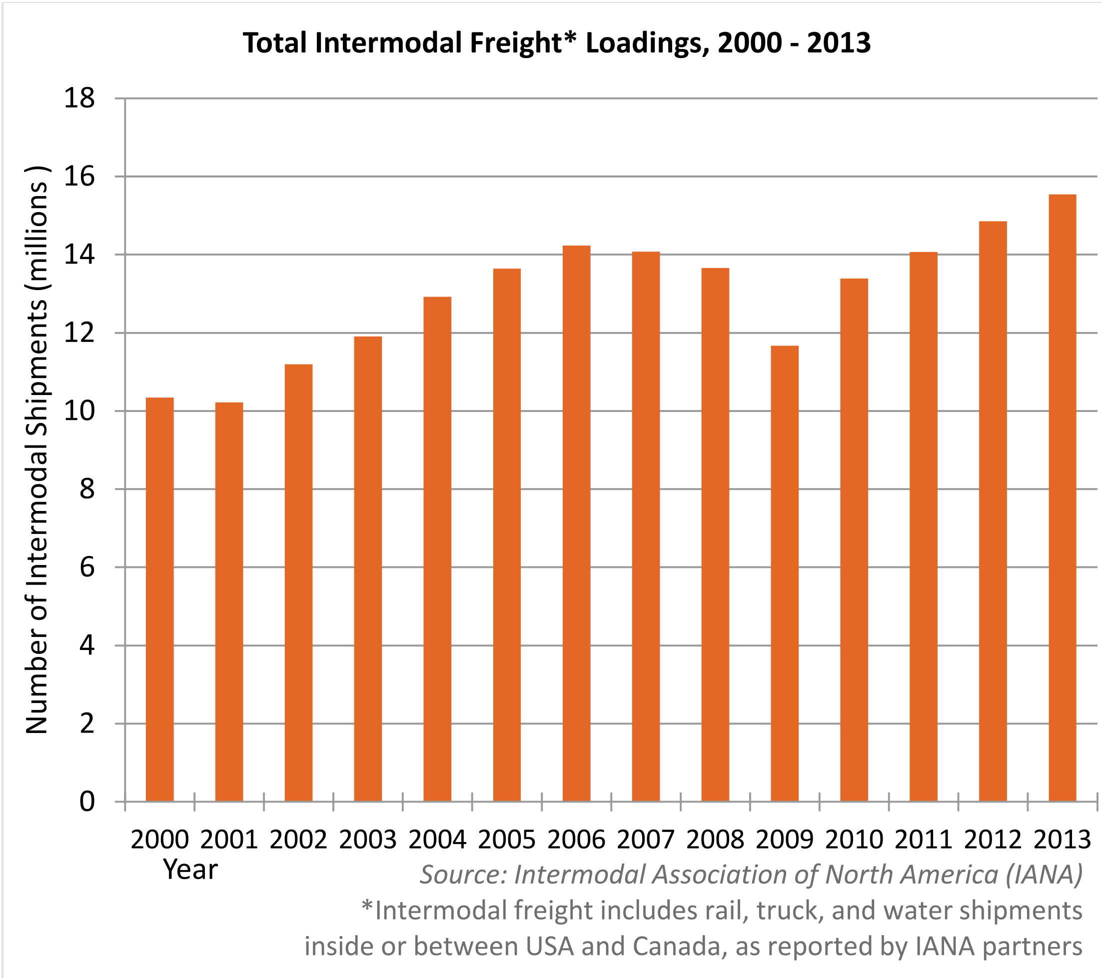
As written by the TRB, "a comprehensive effort to integrate and analyze this information in support of Federal decisions across agencies and for the MTS as a whole is needed" (Committee for a Study of the Federal Role in the Marine Transportation System 2004). MTS professionals who participated in the 2010 conference organized by the U.S. Committee on the

Marine Transportation System (CMTS) and TRB, *Transforming the Marine Transportation System: A Vision for Research and Development* (U.S. Committee on the Marine Transportation System 2011), voiced support for the development of performance measures for individual MTS components and the system as a whole, supported by the creation of "a data integration framework for accessing, sharing, and disseminating data" based on existing programs such as the Integrated Ocean Observing System (IOOS) and the National Coastal Mapping Program (NCMP) (U.S. Committee on the Marine Transportation System 2011). The assemblage and transparent presentation of data on current aspects of MTS operations is a starting point on the journey to meet that need.

3.4 Recognizing the MTS as part of an intermodal freight system

With the perspective that the MTS is part of a much larger intermodal and interconnected freight system, it rapidly becomes apparent that performance measures that can translate across transportation modes will be most useful. "Historically, transportation planning, funding and operation have been made by each transportation mode (i.e., highway, air, rail, and marine). Since the U.S. transportation system is now at capacity in many places, freight and passenger transportation issues need to be addressed from a system-wide perspective in order to maximize solutions."(U.S. Department of Transportation, Maritime Administration 2005) Current Federal infrastructure funding processes are not organized to consider multiple modes at once. At present "the U.S. does not focus on intermodal improvements when planning for long-term highway infrastructure projects. At the same time, railroad infrastructure, which is similarly capital-intensive and time-consuming, is totally funded through the private capital investment of railroad companies"(U.S. Department of Transportation, Maritime Administration 2005). The importance of intermodal considerations is evident from the growth in intermodal shipments as reported by the Intermodal Association of North America, shown in Figure 1 (Intermodal Association of North America 2014).

Figure 1. Intermodal freight loadings, 2000–2013. Source: Intermodal Association of North America (2014).



Despite differences in infrastructure asset types and ownership structures, there are lessons to be learned from performance measures used by other modes. For example, the American Association of Railroads maintains a website where seven U.S. Class I railroads voluntarily report weekly performance measures specific to the rail industry: cars on line, train speed, and terminal dwell time (Association of American Railroads 2014). These class I railroads (BNSF Railway Company; CSX Transportation, Inc.; Grand Trunk Corp [including U.S. affiliates of Canadian National Railway]; Kansas City Southern Railway Company; Norfolk Southern Combined Railroad Subsidiaries; Soo Line Corp [including U.S. affiliates of Canadian Pacific Railway]; and Union Pacific Railroad Company) each had operating revenues of over $450,000,000 in 2012 dollars, and in combination they represent a major portion of U.S. railroad capacity (U.S. Surface Transportation Board 2014). The Federal Highway Administration produces an annual *Conditions and Performance Report* that includes both output measures (e.g., highway spending) and outcome measures (e.g., highway safety, pavement condition) (U.S. Department of Transportation, Federal Highway Administration and Federal Transit Administration 2014). The mix of public and private MTS assets makes a parallel effort difficult but not impossible. A Federal report from 2005 asserted that within academic and scientific literature there was no widespread agreement on an approach to measuring the efficiency of a port as a link in the logistics chain (U.S. Department of Transportation, Maritime Administration 2005). While there are measures for the length of time cargo sits in a port before being transferred to another mode, multiple factors influence these times, which may skew an accurate interpretation of port efficiency.

Discussions in the Advisory Committee on the Supply Chain Competitiveness (ACSCC) (U.S. Department of Commerce, International Trade Administration 2014) and the National Freight Advisory Council (NFAC) (U.S. Department of Transportation, National Freight Advisory Committee 2014) have given voice to the broad support that well-performing freight infrastructure has in the country. Several high-profile events in 2011 focused a spotlight on the fragility of global supply chains, notably severe flooding in Thailand and a tsunami and subsequent power shortages in Japan (Lohr 2011; Fuller 2011). These events highlighted the need to improve the resiliency of global supply chains, and freight networks upon which global commerce depends, in the face of existing and emerging hazards. The domestic system is in no less need of coordinated attention. This renewed focus on the intermodal freight system and the smooth functioning of supply chains lends support for the development of MTS performance measures.

> "The MTS does not exist in isolation, but is instead inseparable from landside transportation systems that move billions of tons of freight each year throughout the country."
>
> *Diagnosing the MTS: Measuring Performance and Targeting Improvement, 26–28 June 2012* (U.S. Committee on Marine Transportation System 2013)

3.5 Performance measures for investment decisions

Maintaining and improving MTS infrastructure to support efficient freight movement is challenging given the physical and financial scale and scope of projects. The Government Accountability Office (GAO) identified the following key barriers that U.S. Army Corps of Engineers (USACE) and USDOT face with regards to infrastructure maintenance (U.S. Government Accountability Office 2012):

1. Both USACE and the USDOT are faced with more demands for maintenance and improvement than available Federal funding allows.
2. Lack of a system-wide strategy for prioritizing MTS investments, although steps have been taken to prioritize projects within individual agency budgets (U.S. Government Accountability Office 2012).

While performance measurement alone will not solve the problems identified by the GAO, offering transparency on the state of important MTS components can support project prioritization within the funding process of agencies. Within USACE, the water resource project suitability can be evaluated according to National Economic Development (NED) principles (U.S. Army Corps of Engineers) and National Ecosystem Restoration (NER) benefits (U.S. Army Corps of Engineers 2015a). The overarching framework for NED and NER assessments comes from interagency Principles, Requirements and Guidelines (PR&G) that have recently been updated through the White House Council on Environmental Quality for the first time since 1983 (White House Council on Environmental Quality 2014). These PR&G are currently in the process of being incorporated into guidance documents for multiple Federal agencies involved in water resources planning; Federal agency investments will continue to be based on a broad suite of considerations including safety, national security, and environmental priorities.

3.6 Performance measurement benefits from open data

Ready access to data is vital for accurate performance measures across a system as complex as the MTS. For Federal agencies with a role in the MTS, making data available is simply the first step in contributing to a truly transparent evaluation process. *Presidential Executive Order 13642* released on 9 May 2013 directs offices in the Executive Branch to make open data and machine readable data the new default for government information (Obama 2013). *Open data* is the practice of regularly releasing data in widely accessible file formats through a website. Machine readable data refers to specific computer file formats that are used most often in conjunction with web services. Machine readable files are especially useful for third parties because they facilitate automation and processing of data. The promotion of open and machine readable data across Federal agencies will enhance the ability to develop targeted performance measures over time. By gaining access to the different streams of information that will flow into the public domain as a regular part of agency missions, there will be greater opportunity to combine disparate types of data to increase their informational power.

System-wide data collection must be designed to evaluate MTS needs

"For the most part [MTS] databases are disconnected from one another and are designed to meet specific legislative and program requirements.… Much of the information gathered by industry and government on system performance and needs is based on narrowly construed surveys of users, which do not provide a complete and objective assessment. The absence of system-wide performance data and the lack of efforts to bring such information together have hindered evaluation of the critical needs facing the marine transportation sector."

The Marine Transportation System and the Federal Role: Measuring Performance, Targeting Improvement (Committee for a Study of the Federal Role in the Marine Transportation System 2004)

4 Domestic and International Support for MTS Performance Measures

Interest in MTS performance measures is reflective of a larger trend towards outcome measurement for government programs in general. Calls for performance measurement and management are spreading through the public sector; there is national legislation to support the development and publication of transportation performance measures and multiple Federal agency initiatives on the topic. The increased use of automated data acquisition and sharing technologies in the private sector accentuates the need for adoption of similar practices in the public sector. Recent recommendations from marine transportation industry professionals on this topic are summarized in this chapter.

4.1 2010 Committee on the Marine Transportation System-Transportation Research Board (CMTS-TRB) conference proceedings: Recommendations

In 2010 CMTS and the TRB hosted their first joint conference: "Transforming the Marine Transportation System: A Vision for Research and Development." The conference proceedings were combined with other recommendations and released as the *Strategic Action Plan for Research and Development in the Marine Transportation System* (U.S. Committee on the Marine Transportation System 2011). One of the primary R&D focus areas identified in the *Strategic Action Plan* was the development of "MTS performance metrics that assess the national freight movement system in a systemic way"(U.S. Committee on the Marine Transportation System 2011). Recommended research topics related to this focus area are listed below.

- Create an MTS-wide data access and sharing capability
- Create a framework and system-wide performance metrics
- Address technological gaps for a systems approach to national freight movement
- Create a model of supply-chain dependencies
- Create tools and capabilities for a holistic approach to global freight movement.

These recommendations reflect the awareness of the MTS as part of a multimodal freight network and the subsequent need to work across modes to improve overall system functioning. While progress has been made in understanding how different transportation modes interact to move freight around the United States, the ability to have a fine-grained understanding of how specific shipments flow through the intermodal network is still under development.

4.2 2012 CMTS-TRB conference proceedings: Recommendations

In 2012, the TRB and CMTS co-hosted their second conference on marine technology research and development. Participants in that conference, "Diagnosing the Marine Transportation System: Measuring Performance and Targeting Improvement," sought to identify research areas that would support the development of intermodally appropriate performance measures for the MTS (U.S. Committee on the Marine Transportation System 2013). One objective was to develop a framework to measure MTS performance within the context of supply chains and the freight system. The conference proceedings make recommendations for developing MTS performance measures (U.S. Committee on the Marine Transportation System 2013), listed below.

- Explicitly state goals and priorities in a national document, to provide guidance to all involved
- Design measures that reflect goal outcomes
- Develop a comprehensive inventory for existing data
- Automate data collection and reporting as much as possible
- Include a time element in measurements to maximize their utility
- Develop modal neutral measures, such as a reliability parameter or level of service index
- Use a spatially grounded *corridor-based* approach for developing intermodal measures
- Employ data visualization tools for communications and analysis.

The recommendations listed above, developed by practitioners in the field, illustrate the variety of outstanding needs for performance measures research. Although this is a broad topic with multiple possible approaches, the projects and products described throughout this report represent progress towards the ultimate goal of a well-informed and widely shared understanding of the MTS.

4.3 MAP-21 legislation: Goals and products

In 2012 the U.S. Congress passed, and the President signed, the *Moving Ahead for Progress in the 21st Century Act* (P.L. 112–141), known as MAP-21 (Rep. John Mica (R-FL7) 2012) (*H.R. 4348* 2012). MAP-21 identified multiple transportation system needs and identified new responsibilities for Federal agencies, primarily the USDOT. The outline below identifies some of these new responsibilities.

- Assessment of the condition and performance of the national freight network
- Development of an initial national freight strategic plan and supporting strategies for the following focus areas:
  - improve freight intermodal connectivity
  - improve economic efficiency of the national freight network
  - reduce environmental impacts of freight movement on the national freight network
  - incorporate concepts of performance, innovation, competition, and accountability into the operation and maintenance of a national freight network
- Development or improvement of tools, to support an outcome-oriented, performance-based approach to evaluate proposed freight-related and other transportation projects. Such tools should support these abilities:
  - consider safety, economic competitiveness, environmental sustainability, and system condition in the project selection process
  - assist in making transportation investment decisions through improved use of transportation-related model data elements that support a broad range of evaluation methods and techniques
- Consideration of improvements to existing freight-flow data collection efforts that could reduce identified freight data gaps and deficiencies and help improve forecasts of freight transportation demand

The language used in the MAP-21 Act demonstrates a forward-thinking and holistic view of transportation system needs. Indeed, within this Act, Congress declared, “it is in the vital interest of the United States… to ensure accountability and link performance outcomes to investment decisions.”(Rep. John Mica (R-FL7) 2012) (*H.R. 4348* 2012). The MAP-21 priority areas identified by the USDOT for their condition and performance report are listed below.

1. Enhancing economic efficiency, productivity, and competitiveness
2. Reducing congestion
3. Improving safety, security, and resilience
4. Improving sate of good repair
5. Using advanced technology, innovation, performance management, competition, and accountability
6. Reducing adverse environmental and community impacts (U.S. Department of Transportation, National Freight Advisory Committee 2014).

The USDOT is charged with reporting on condition and performance categories outlined in the MAP-21 legislation in a Report to Congress by 2015.

4.4 International consensus on the need for navigation performance measures

PIANC's international recommendations are issued through reports written by Working Groups on matters of relevance identified by Technical Commissions (PIANC). In 2010, the PIANC Inland Navigation Commission Working Group 32 (WG 32) recognized that there was no transnational *commonly accepted and system wide* set of performance measures for the inland navigation system (PIANC Inland Navigation Commission, Working Group 32 et al. 2010). This prompted PIANC WG 32 (comprised of inland navigation operations experts) to develop a set of performances measures to use in evaluating the performance of inland waterways with respect to transportation functions; this list was published in *Report 111: Performance Indicators for Inland Waterways Transport* (PIANC Inland Navigation Commission, Working Group 32 et al. 2010). The nine thematic areas of performance measurement described by PIANC WG 32 in *Report 111* are listed below (PIANC Inland Navigation Commission, Working Group 32 et al. 2010).

1. Infrastructure
2. Ports
3. Environment
4. Fleet and vehicles
5. Cargo and passengers
6. Information and communication
7. Economic development
8. Safety
9. Security

The stated goal of PIANC WG 32 in carrying out this work was to "improve efficiency and overall performance" of inland transportation navigation systems through improved understanding within organizations that develop, operate, maintain, and manage inland waterways for the purposes of navigation (PIANC Inland Navigation Commission, Working Group 32 et al. 2010). Specific elements of these goals are to "enable a common basis of comparable data, guarantee transparency in reporting, enable time feedback for users, and induce a long-term continuous improvement process" (PIANC Inland Navigation Commission, Working Group 32 et al. 2010). Included in this report was a one-page template to describe each performance measure. The PIANC template served as the basis for the one-page summaries included in Appendix A (an example is shown in Table 1).

Table 1. Performance measures summary table. Modified from an original figure by PIANC Inland Navigation Commission, Working Group 32 (2010).

Category	Category of Performance Measure
Measure	*Name of Specific Measure*
Source	*Name of organization or agency in charge of distributing data*
Description	*Explanation of the source of the performance measure data, how it is collected, and other relevant details.*
Website	*URL for data source, as of 2014*
Regulatory / Legislative Driver	*Why this data is already being collected*
Unit	*The unit of measure use (e.g., dollars, hours, ton-miles, kilograms)*
Collection Frequency	*Frequency of data collection (e.g., minutes, weekly, quarterly, yearly)*
Reporting Frequency	*How often this data is released/reported by the collecting organization (e.g., continuously, weekly, monthly, yearly)*
Geographic Scope	*Geographic reach of indicator, e.g., national, regional, state, project, port, or a combination of multiple sites*
Objective	*The larger performance goal that this measure supports*
Application Value	*Does this performance measure directly support Operations (present state), Information (for all stakeholders), or Reference (for longer-term learning and improvement) use*
Comment	*Informative comments if needed; may be left blank*

The performance measures information reported as part of the first phase of this project is aimed at a general audience; associated descriptive information has been edited for clarity.

5 MTS Performance Measures Categories and Examples

The previous chapters provided the theoretical and operational rationale for developing MTS performance measures. This chapter describes the current list of performance measures within each category and provides a graphic representation for measures that had data that were both sufficiently vetted and publicly available as of January 2015. The measures described in this chapter should be recognized as the first step in a longer research process that will continue to identify and refine MTS performance measures. Existing information gaps and ideas for future research are discussed in section 8.

5.1 Performance measures categories

The first phase of this research is focusing on MTS-specific performance measures, with a focus towards folding those measures in to a larger body of research that can include network modeling and scenario exploration. The categories used to group performance measures together for this project are the following.

- Economic Benefits to the Nation
- Capacity and Reliability
- Safety and Security
- Environmental Stewardship
- Resilience

These organizational categories align well with other major performance measurement efforts, including the themes developed by the PIANC Working Group 32 (PIANC Inland Navigation Commission, Working Group 32 et al. 2010) and the USDOT MAP-21 priority areas listed in the previous section. Note that this phase of research does not focus on the performance of individual private assets (e.g., vessel emissions, port efficiency) because of confidentiality issues commonly associated with such data and difficulty in making appropriate national aggregations. The list of MTS categories targeted for data acquisition and performance measure development in the first round of this project is as follows.

Economic Benefits to the Nation

- Total value and tonnage of international trade moved by the MTS
- Income and disbursement of Harbor Maintenance and Inland Waterways Trust Funds
- Producer Price Index (PPI)
- Number of jobs in marine transportation industries, direct employment in 10 states
- Inland waterway shipping barge freight rates
- Federal agency budgets for MTS administration and research and development

Capacity and Reliability

- Navigation lock closures, hours and number of closures, unscheduled and scheduled
- NOAA PORTS instrumentation availability at 59 high-tonnage USACE navigation projects
- Quarterly travel-time estimates for key waterway segments
- Degree of channel width/depth utilization for major waterways
- Federal ship channels at project depth according to USACE eHydro observations

Safety and Security

- Number of commercial vessel accidents (collisions, allisions, groundings)
- Number of commercial mariner and passenger casualties (personal injuries, deaths)
- U.S. Coast Guard incident investigations

Environmental Stewardship

- Petroleum-based fuel use by the maritime industry (diesel fuel, residual fuel)
- Vessel pollution incidents (petroleum and other types)
- Amount of dredged material reclaimed for beneficial use
- Number of reported whale strikes by vessels

Resilience

- Physical condition ratings of critical coastal navigation infrastructure

When transportation data are valued by multiple stakeholders, that recognition lends support for continued data collection and dissemination. This relates to one of the biggest challenges faced by researchers—data continuity over time. Without regular data collection, changes in performance cannot readily be quantified. The ability to quantify historical performance of transportation assets is crucial when multiple major infrastructure investment options are competing for funding. Data discovery is an ongoing process as sources for historical and current data are continuously being developed and released to the public. This section contains examples of performance measures for which data are readily available at the time of writing. These measures should be regarded as preliminary products of ongoing research that are open to further refinement.

5.2 Economic Benefits to the Nation

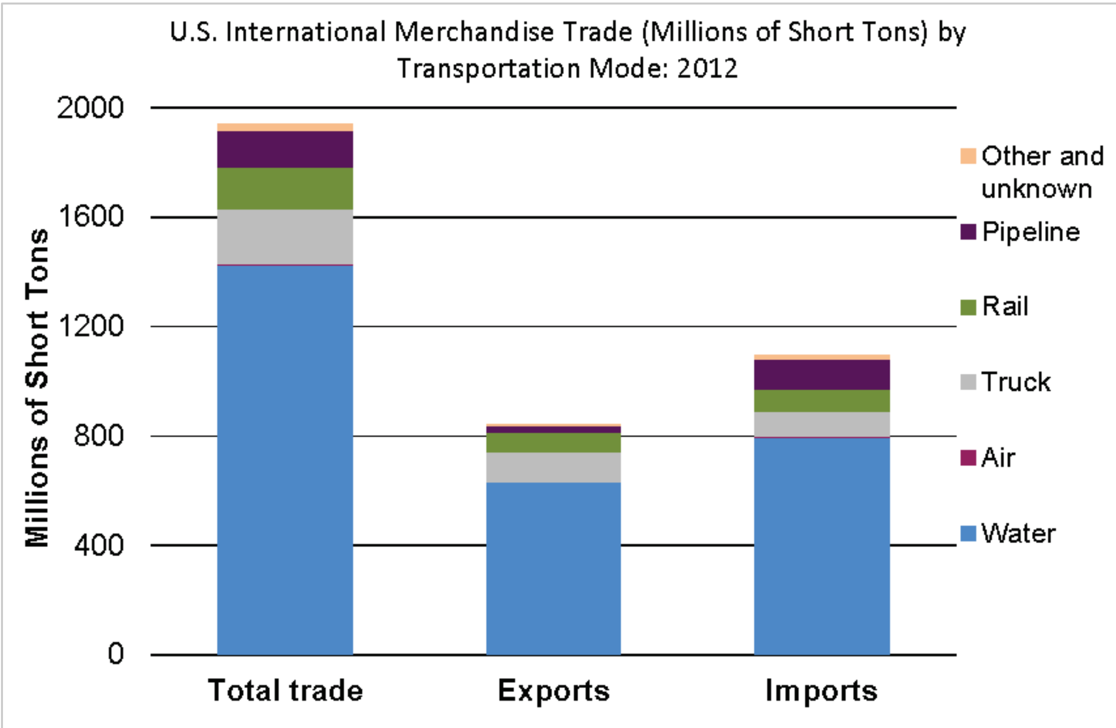
The MTS functions through a mix of public and private assets, inclusive economic performance measures should reflect that reality. As discussed earlier in this report, MTS infrastructure involves many capital-intensive components, so understanding the status of available funding streams is of interest to many stakeholders. Additionally, monitoring the financial performance and employment levels of MTS-associated industries provides insight into overall industry health and the economic benefits that result from a robust MTS. While the level of employment in MTS industries is one indicator of demand, it does not support a specific performance goal in this transportation sector.

5.2.1 Total value and tonnage of international trade moved by the MTS

The significance of the MTS international trade can be assessed in multiple ways; the two most common are total dollar value of cargo and total tonnage (shipping weight) of cargo moved. Figure 2 shows water was the transportation mode for almost 47% of U.S. international trade value (including exports and imports). In comparison, air and truck accounted for 24% and 17%, respectively, of the total trade value in 2012. In 2012, a majority of U.S. imports (52%) moved by water, with less total value moving by air (22%), truck (14%), rail (almost 5%), or by pipeline (3%) (U.S. Department of Commerce, U.S. Census Bureau 2014). The value of individual cargo, however, only tells part of the story. Total tonnage is an important indicator since many raw materials used at the start of many supply chains fall into the category of high-weight but low-value shipments. Figure 3 shows that over 73% of the total U.S. international trade tonnage moved by water in 2012. In comparison, air moved less than 1% of total tonnage while rail moved 8% and truck 10% in 2012. Almost 75% of U.S. exports and slightly over 72% of U.S. imports (measured in short tons) moved via water in 2012.

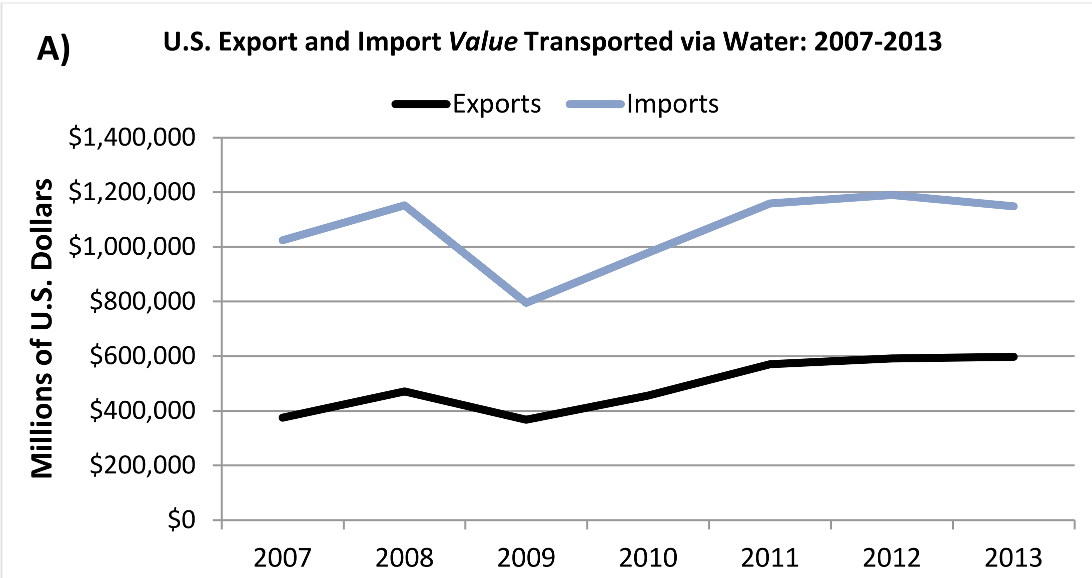
Figure 2. U.S. international merchandise trade (billions of dollars) by transportation mode: 2012. Source: U.S. Census Bureau, Foreign Trade Division (2015) and U.S. Department of Transportation, Bureau of Transportation Statistics (2014).

Figure 3. U.S. international merchandise trade (millions of short tons) by transportation mode: 2012. Source: U.S. Census Bureau, Foreign Trade Division (2015) and U.S. Department of Transportation, Bureau of Transportation Statistics (2014). (Note: 1 short ton = 2,000 pounds.)



Multiple sources of information were needed to create Figures 2 and 3. These public sources were the *FT920 – U.S. Merchandise Trade: Selected Highlights* (for total, water and air data, published by U.S. Department of Commerce, U.S. Census Bureau, Foreign Trade Division [U.S. Census Bureau, Foreign Trade Division 2015]) and the *Freight Facts and Figures 2013* report (for truck, rail, pipeline, and other and unknown data, utilizing multiple sources within USDOT) (U.S. Department of Transportation 2014). The nuance involved in assessing the contribution of the MTS to international trade will continue to require multiple sources with different data contributions. As Figure 4 shows, it is important to consider the historical importance of MTS utilization for international trade.

Figure 4. A) U.S. export and import value transported via water: 2007-2013; B) U.S. export and import shipping weight transported via water: 2007-2013. Source: U.S. Department of Commerce; U.S. Census Bureau; Foreign Trade Division (2015); tables 1, 4, or 6.



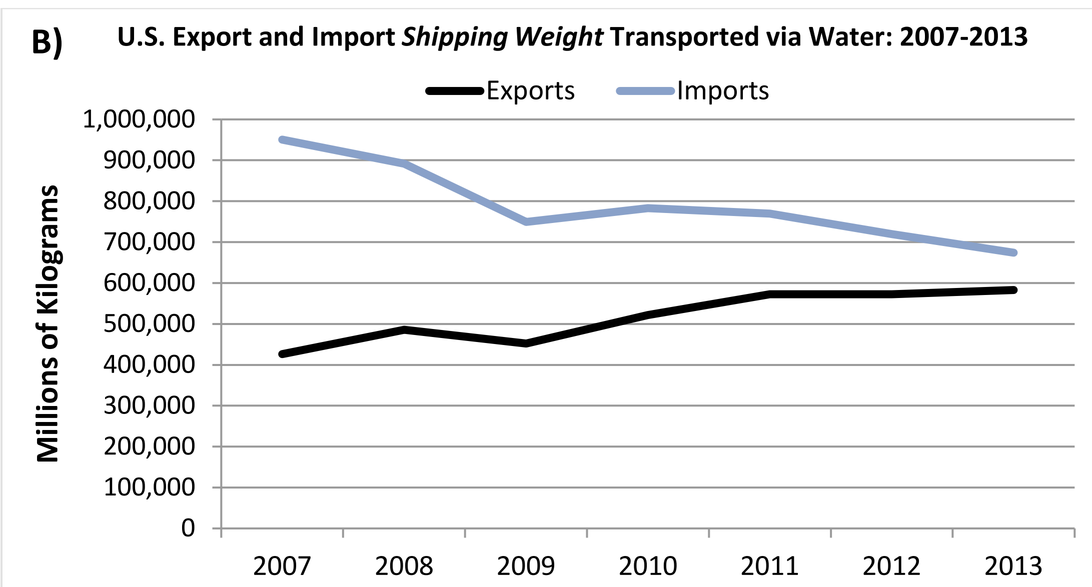


Figure 4A shows the U.S. export and import value moved by water while figure 4B shows U.S. export and import shipping weight moved by water (U.S. Census Bureau, Foreign Trade Division 2015). These two graphs clearly show the effects of the economic recession spanning December 2007 to June 2009 and the temporary decrease in international trade that accompanied the recession (National Bureau of Economic Research, Inc. 2010). Since 2009, both the value and shipping weight of U.S. exports moved by water have been growing. The value of U.S. imports moved by water has returned to pre-recession levels, but the total shipping weight of U.S. imports moved by water continues to decline.

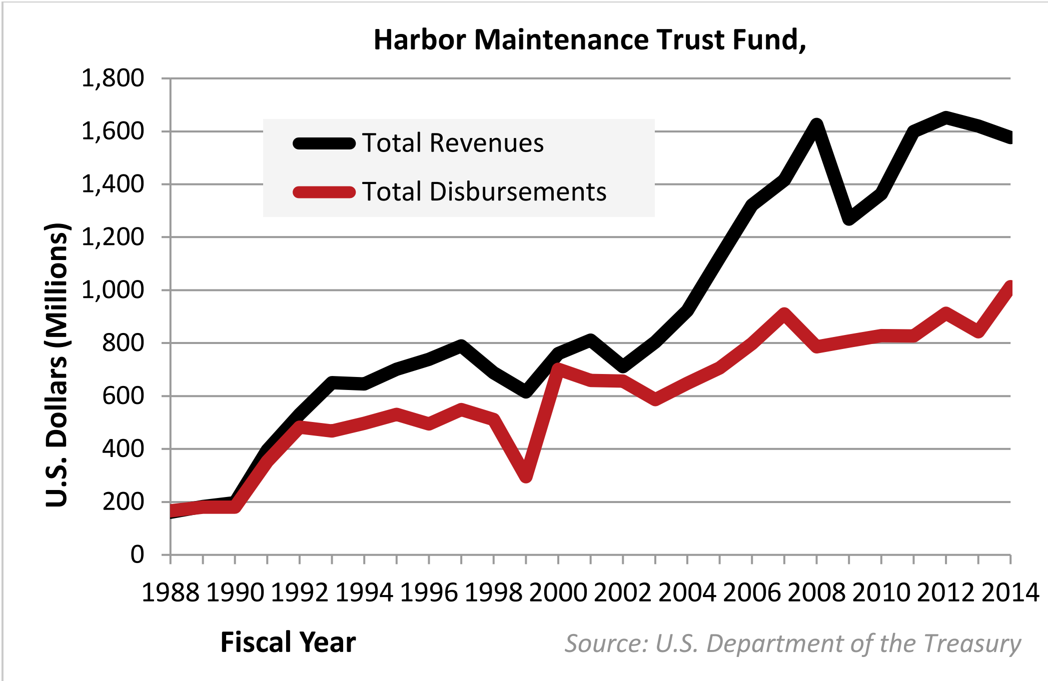
5.2.2 Federal financial measures

The GAO estimated that total Federal expenditures on the MTS averaged $3.9 billion per year between 1999 and 2001 (U.S. General Accounting Office 2002). The construction, operation, and maintenance of navigation infrastructure accounted for approximately 45% of the total MTS-related Federal expenditures, or approximately $1.75 billion per year (U.S. General Accounting Office 2002). Fees charged to commercial users of inland waterways (approximately $90 million per year) and harbors (approximately $750 million per year) cover approximately half the Federal outlay on infrastructure. In 2002, GAO estimated that approximately 25% of total Federal expenditures on the MTS was derived from user fees (Committee for a Study of the Federal Role in the Marine Transportation System 2004; U.S. General Accounting Office 2002). Arguably, all of the Federal expenditures on the MTS are to provide a safe and well-functioning system that supports the U.S. economy.

5.2.2.1 Harbor Maintenance Trust Fund

One financial performance measure of interest is the balance of the Harbor Maintenance Trust Fund (HMTF) administered by the U.S. Department of the Treasury (U.S. Department of the Treasury 2015a). The Harbor Maintenance Tax and the HMTF were established in 1986; the tax is a 0.125% ad valorem fee on the value of commercial cargo loaded or unloaded on vessels using federally maintained harbor projects; this fee applies to most imports, foreign trade cargo, passengers not aboard ferries, and certain domestic shipments (U.S. Army Corps of Engineers 2007). Monies from the HMTF are available to reimburse eligible operations and maintenance (O&M) expenses associated with commercial navigation infrastructure maintenance and channel dredging, except along fuel-taxed inland waterways (U.S. Army Corps of Engineers 2007). Figure 5 presents the total annual revenues and disbursements for the HMTF from 1988 to 2014. As the figure indicates, HMTF revenues have long exceeded disbursements to eligible Federal agencies.

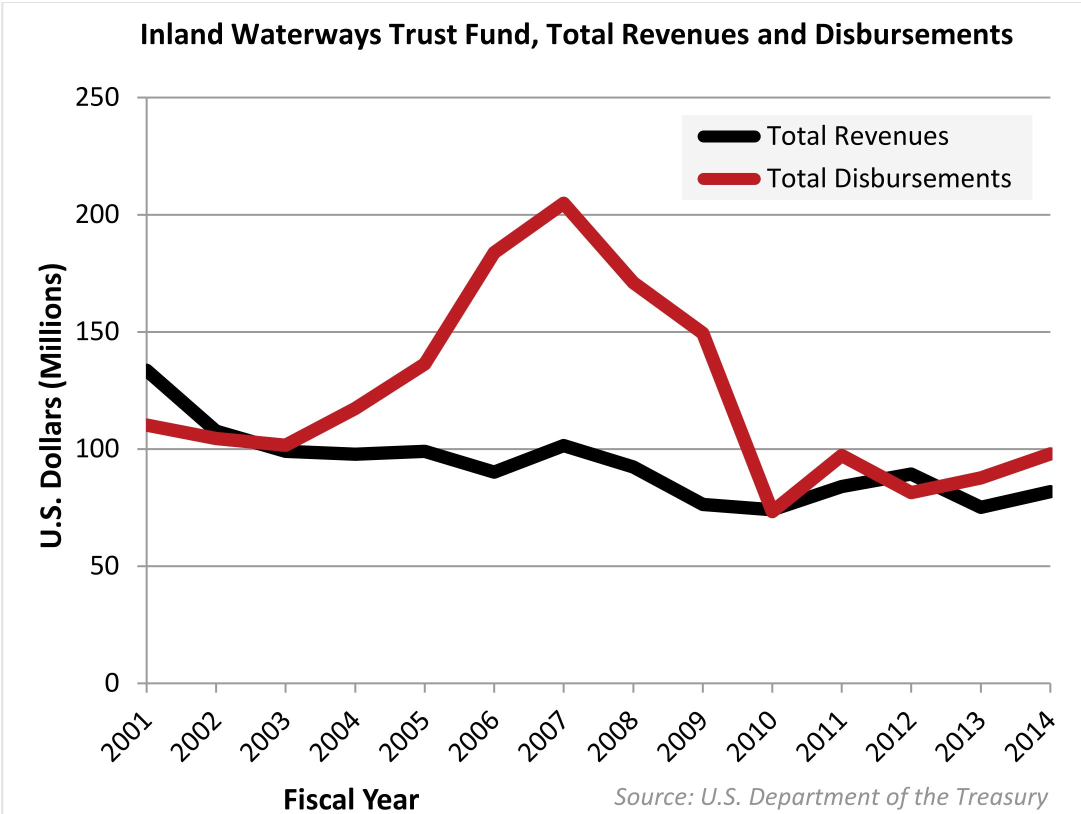
Figure 5. Harbor Maintenance Trust Fund revenues and disbursements, fiscal years 1988–2014. Source: U.S. Department of the Treasury (2015a).



5.2.2.2 Inland Waterway Trust Fund

The Inland Waterways Trust Fund (IWTF) was established in 1978 to provide funding for major construction and rehabilitation of navigation projects on inland and intracoastal waterways, it is administered by the U.S. Department of the Treasury (U.S. Department of the Treasury 2015b). The IWTF is funded by a fuel tax on commercial towing companies that operate on the inland and intracoastal waterways; the tax rate has not risen since 1995 and currently stands at 20 cents per gallon (U.S. Army Corps of Engineers, Louisville District 2014). As shown in Figure 6, between 2002 and 2009, disbursements from the IWTF exceeded revenues. The Olmstead Locks and Dam project currently claims most funds. Due to the limited availability of IWTF monies to provide cost-share support to other inland navigation projects, alternative funding options are being explored by many parties (U.S. Army Corps of Engineers, Louisville District 2014).

Figure 6. Inland Waterways Trust Fund, total revenues and disbursements, fiscal years 2001– 2014. Source: U.S. Department of the Treasury (2015b).



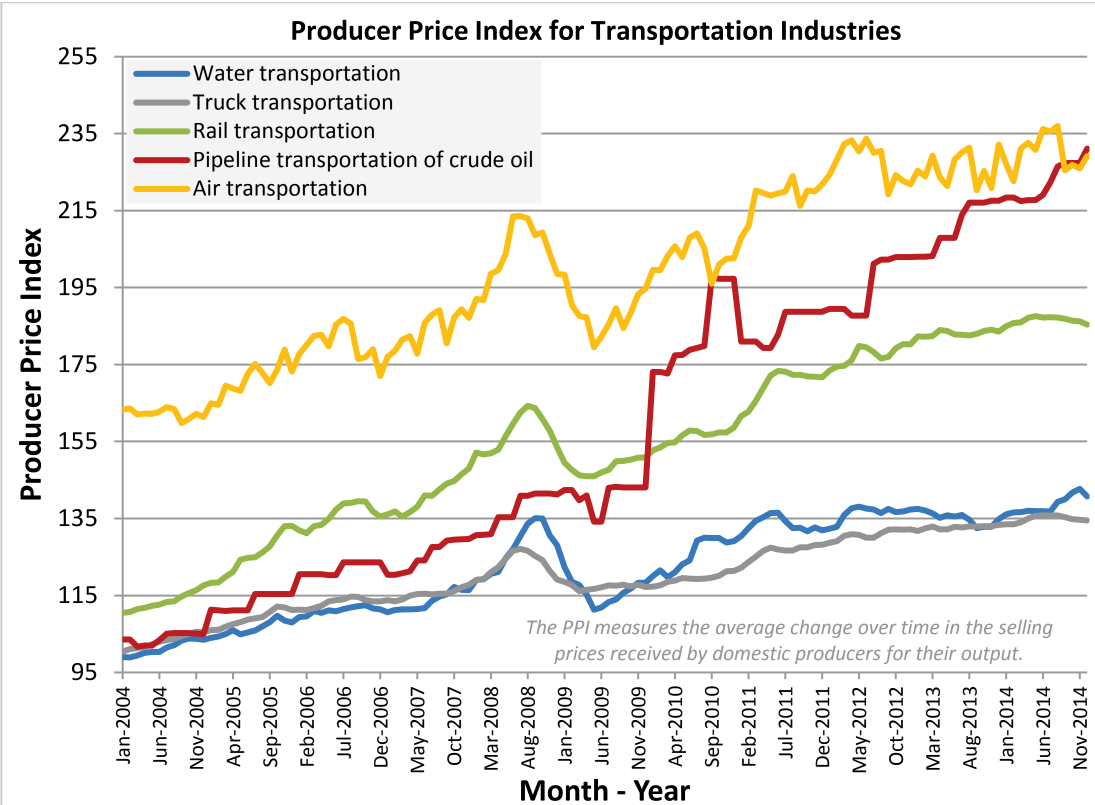
5.2.3 Private industry financial measures

Other financially relevant performance measures include the number of people employed in MTS industries, the performance of companies whose business involves the MTS (including research and development), and prices for MTS-related services such as shipments by barge.

5.2.4 Producer Price Index (PPI)

The Producer Price Index (PPI) reported by the U.S. Department of Labor, Bureau of Labor Statistics (BLS), measures the average change over time in the selling prices received by domestic producers for their output (Bureau of Labor Statistics 2014a). Price data from companies of all sizes are collected from surveys administered via mail, fax, and the Internet. Figure 7 shows how the selling price for water transportation services (blue line) has changed in relation to the selling prices for other transportation mode services such as truck and rail. Because the PPI compares changes in prices over time, as opposed to the actual dollar value of a service, it is an appropriate measure for intermodal price comparisons. Figure 7 shows that the price of waterborne transportation service has not increased as fast as other modes over the past 10 years.

Figure 7. Producer Price Index for transportation industries (air, water, truck, rail, pipeline), January 2005 to May 2014. Source: U.S. Department of Labor, Bureau of Labor Statistics (2014).

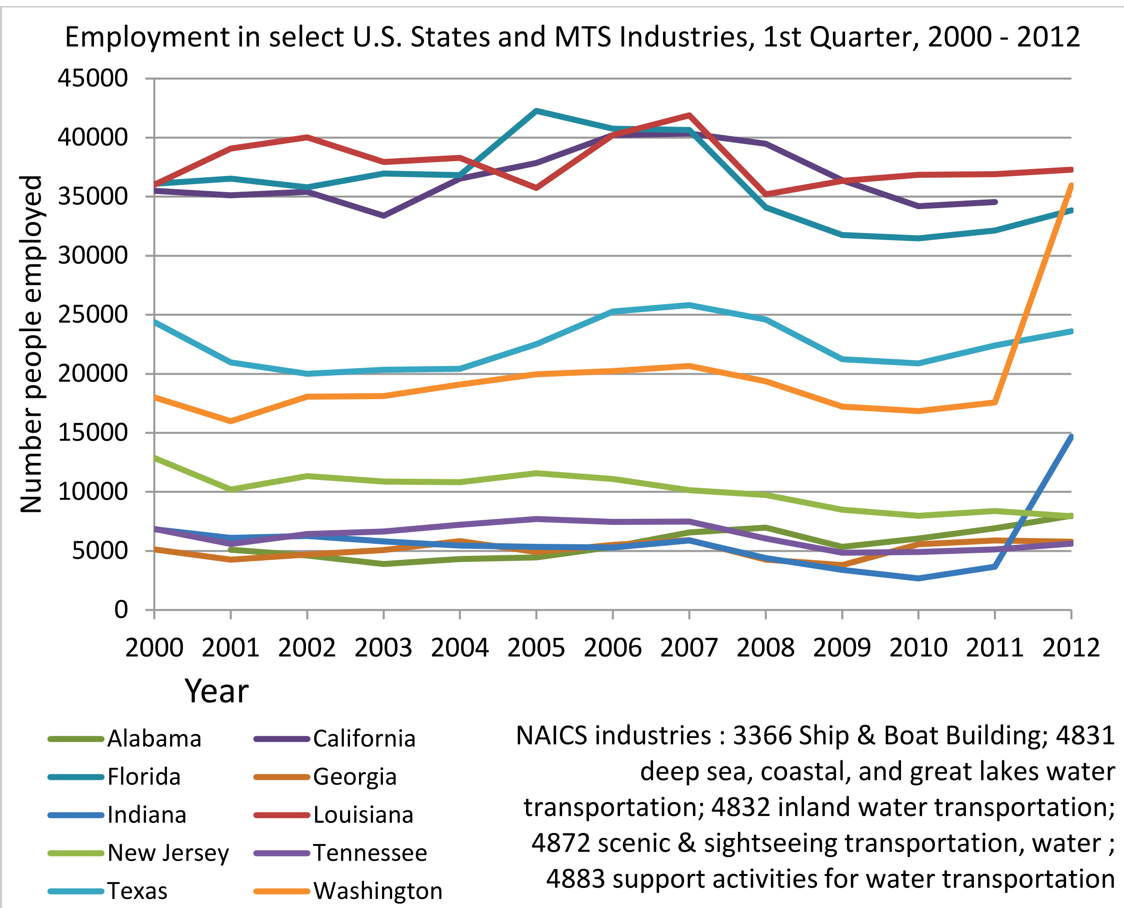


5.2.5 Direct employment in MTS industries

One indicator of the economic benefits derived from MTS is the number of people directly employed in MTS-related industries. The U.S. Census measures employment across all business categories (organized via the North American Industrial Classification System [NAICS]) every 5 years, most recently in 2012. Employment in the Water Transportation sector (NAICS code 483) was fairly stable in 2007 and 2012, with the total number of employees reported as 75,997 and 70,014 respectively (U.S. Census Bureau 2014). Expanding the range of MTS industries to include the categories of “ship and boat building” (3366), “scenic and sightseeing transportation, water” (4872), and “support activities for water transportation” (4883) brings the 2012 count of paid employees in these four NAICS categories to 232,665 (U.S. Census Bureau 2014). Note that this number does not include related industry groups such as marine insurance carriers or heavy construction that might perform work in aquatic environments.

A more frequent measure of employment in MTS industries is captured through the Census' Quarterly Workforce Indicators, voluntarily reported by individual states. The U.S. Census collects quarterly workforce indicator reports voluntarily submitted by individual states that provide data on sectoral employment within a state. MTS-related employment includes areas such as ship and boat building, on-water sightseeing, and water transportation support activities. Not all states report quarterly workforce indicator data. First-quarter employment numbers from 2000 to 2012 for selected states that rank highly in MTS employment are shown in Figure 8.

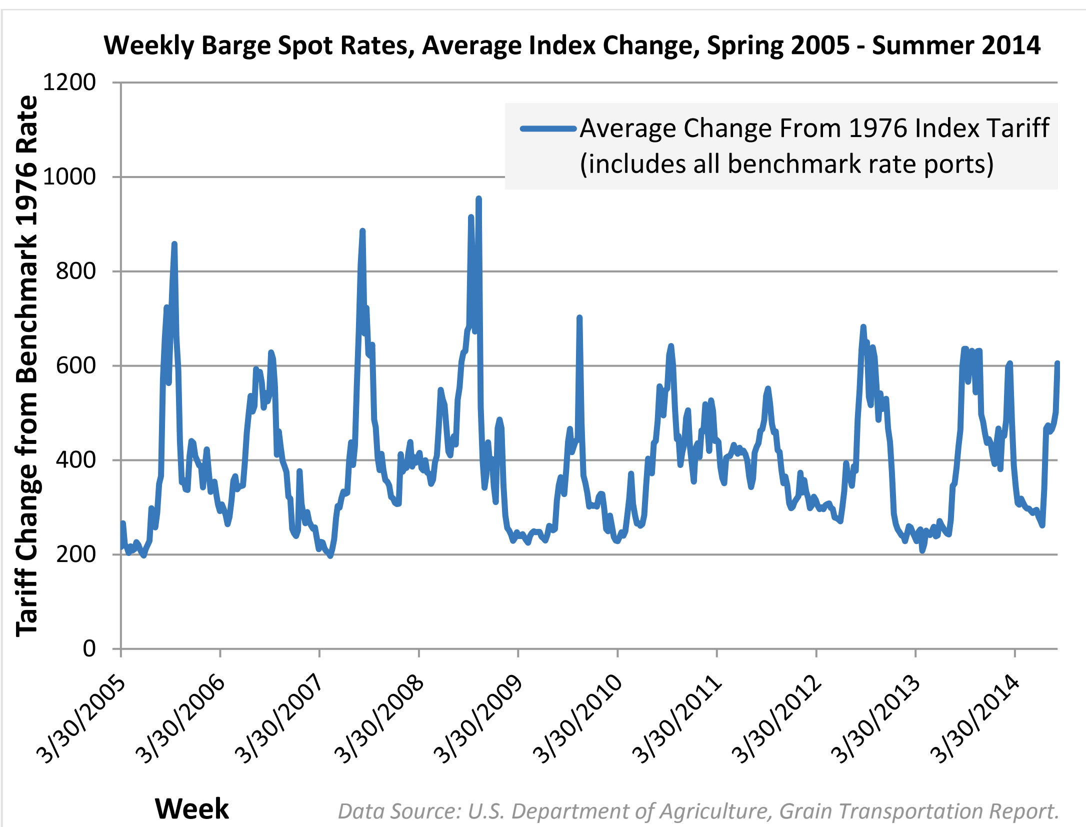
Figure 8. Employment in selected U.S. states and MTS Industries, first quarter of 2000 to 2012. Source: U.S. Census Bureau, Quarterly Workforce Indicators. Data aggregated from individual state-reported totals (U.S. Census Bureau 2015).



5.2.6 Inland waterway shipping barge freight rates

Multiple barge companies operate along the Mississippi River and its tributaries. Many of these companies are privately owned and do not have to disclose financial performance data; however, weekly barge spot freight rates for bulk grain and grain products give an indication of the demand for barge services. Figure 9 shows the average change for barge freight spot rates for all shipping areas from spring 2005 through summer 2014. The baseline index used for these calculations is the 1976 benchmark tariff, which varies according to distance from the mouth of the Mississippi River (U.S. Department of Agriculture, Agricultural Marketing Service 2014). These rates are published by the U.S. Department of Agriculture (USDA) and demonstrate the seasonal nature of grain transportation demand. The benchmark rate ports actually encompass multiple local ports in the regions around St. Paul, MN; Rock Island, IL; St. Louis, MO; Meredosia, IL; Cincinnati, OH; Louisville, KY; and Cairo, IL (U.S. Department of Agriculture, Agricultural Marketing Service 2014).

Figure 9. Change in weekly barge spot freight rates for southbound shipments originating in areas along the Mississippi River, Spring 2005 to Summer 2014. Source: U.S. Department of Agriculture, Agricultural Marketing Service (2014).



5.2.7 Federal agency budgets for MTS administration and research and development

Another financial indicator for the level of Federal involvement in the MTS is the annual budget for MTS-related expenditures by Federal agencies, including marine-focused research and development. Marine-focused research spans a wide variety of areas including infrastructure improvements to locks and dams, operations research for improved freight flows, the ecosystem services provided by marine habitat preservation, and advanced vessel technologies and materials. Research in this area is ongoing.

5.3 Capacity and reliability performance measures

Capacity and reliability are key concerns for commercial shippers in any transportation mode; all parties want to know when a shipment will arrive so that they can plan supply chain activities accordingly. Once a maritime shipment arrives at port, the speed and smoothness of cargo offloading and transfer to other modes is influenced by factors such as berth availability, cargo handling equipment at the port, and labor availability. Port infrastructure and labor availability is largely under the control of local businesses and port authorities; data associated with these measures are not typically made freely available to the public and are not considered in this report.

Accidents are another factor that can lead to waterway closures and impact vessel movements and reliability in the short term. As vessels are notified of waterway closures, they must adjust their operations accordingly; however, there is no national standardized reporting of the duration of waterway closures due to accidents. Statistics regarding the total number of accidents and investigations by the USCG are available and are referred to in section 5.4 on safety and security; those records do contain location information that could be queried to perform further spatial analyses.

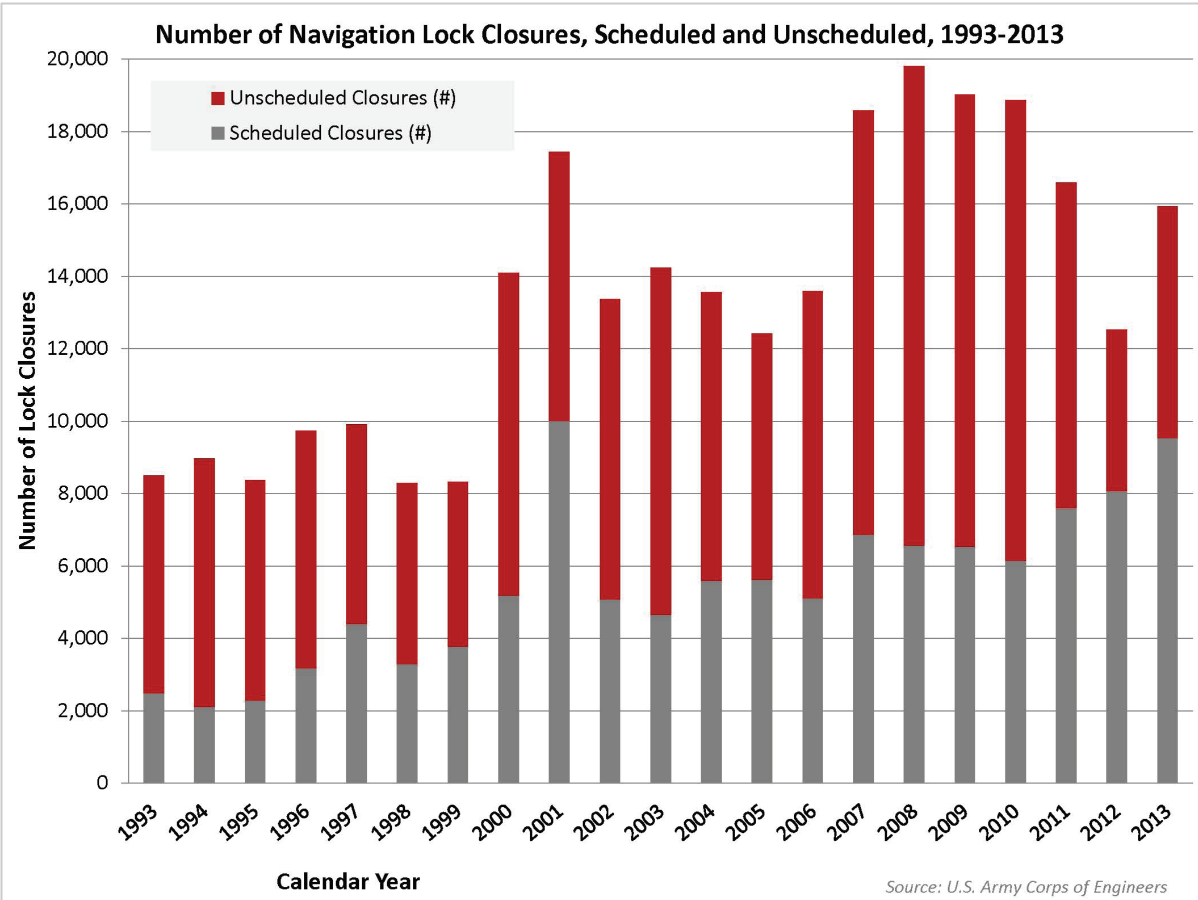
For the inland waterway system in particular, river operating conditions and the availability of navigation locks are two influences on capacity and reliability estimates. Operators at select sites can use the Lock Operations Management Application (LOMA) to adjust operations based on oncoming traffic, visible through the use of automatic identification system (AIS) signals. LOMA data can be made available to other USACE systems and be archived for future analysis (Tetreault 2011). Additional information on lock traffic comes from the Lock Performance Monitoring System (LPMS) (U.S. Army Corps of Engineers 2014a). The public-facing LPMS website makes data available through web services. Data on navigation lock number and hours of closures derived from the LPMS are aggregated and published by the USACE, Navigation Data Center.

Local infrastructure condition reports are useful measures that can be aggregated along corridors or regions of interest to analyze asset performance. For the MTS, navigation channels are a critical asset for both coastal and inland waters. Federally authorized navigation channels have regular hydrographic surveys to document their depth and width; these surveys generate a wealth of information about channels, including shoaling rates. The results of these surveys are currently published in a variety of formats by individual USACE Districts in the form of Channel Conditions Reports. This historical reporting method does not allow for efficient compilation of the number of channels at *full depth, half width*, currently only reported annually. In the near future, the implementation of the eHydro program by all USACE Districts will automate channel condition reporting and allow for streamlined access to data on channel availability through an online toolkit (U.S. Army Corps of Engineers, Engineer Research and Development Center 2013). The ability to combine recent channel condition data with environmental parameters such as river levels can provide further insights into operational improvements

5.3.1 Unscheduled and scheduled lock downtime

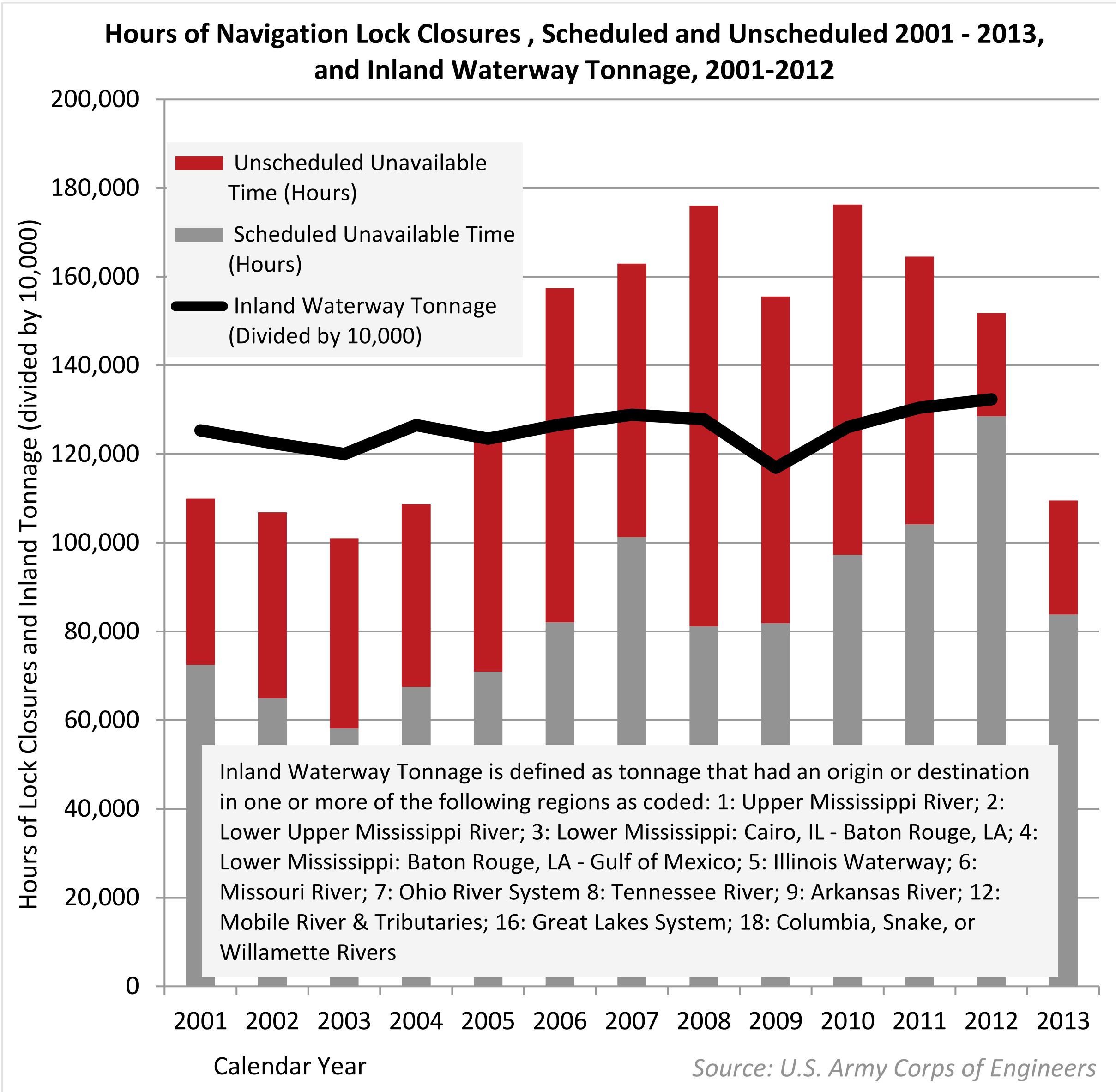
The USACE Navigation Data Center publishes data on navigation lock operations and performance (U.S. Army Corps of Engineers 2015d). Figure 10 presents information on the number of times that navigation locks were unavailable due to scheduled or unscheduled closures. This measure gives an overall indication of reliability for navigation infrastructure components that are dispersed over a large part of the inland waterway system. Scheduled lock closures are advertised in advance, allowing commercial shippers time to adjust their O&M activities to be coordinated for maximum benefit. Unscheduled closures can result from accidents, weather, or emergency maintenance needs, all of which can impact commercial movements on the water.

Figure 10. Number of navigation lock closures, scheduled and unscheduled, 1993–2013. Source: U.S. Army Corps of Engineers (2015d).



Vessels plying inland waters often, but not always, have to pass through navigation locks as they travel from origin to destination. When these navigation locks must close, the closures are categorized as *scheduled* or *unscheduled*. There is concern that unscheduled closures could be disruptive enough to shippers that they would be motivated to reroute their cargo using other methods such as road or rail that promise a different level of reliability. However, as shown in Figure 11, there does not seem to be a pronounced relationship between the overall number of lock closure hours and annual tonnage that has an origin or destination within an inland waterway region (U.S. Army Corps of Engineers 2014d, 2015d). There may be important regional patterns and impacts that are not visible with this national-level summary but could be revealed through a more detailed analysis. In addition, waterway closures for other reasons not related to lock operations may affect shipping operations.

Figure 11. Hours of navigation lock closures, scheduled and unscheduled, 2001–2013, and annual inland waterway tonnage (divided by 10,000) from 2001–2012. Source: U.S. Army Corps of Engineers (2013a, 2015d).

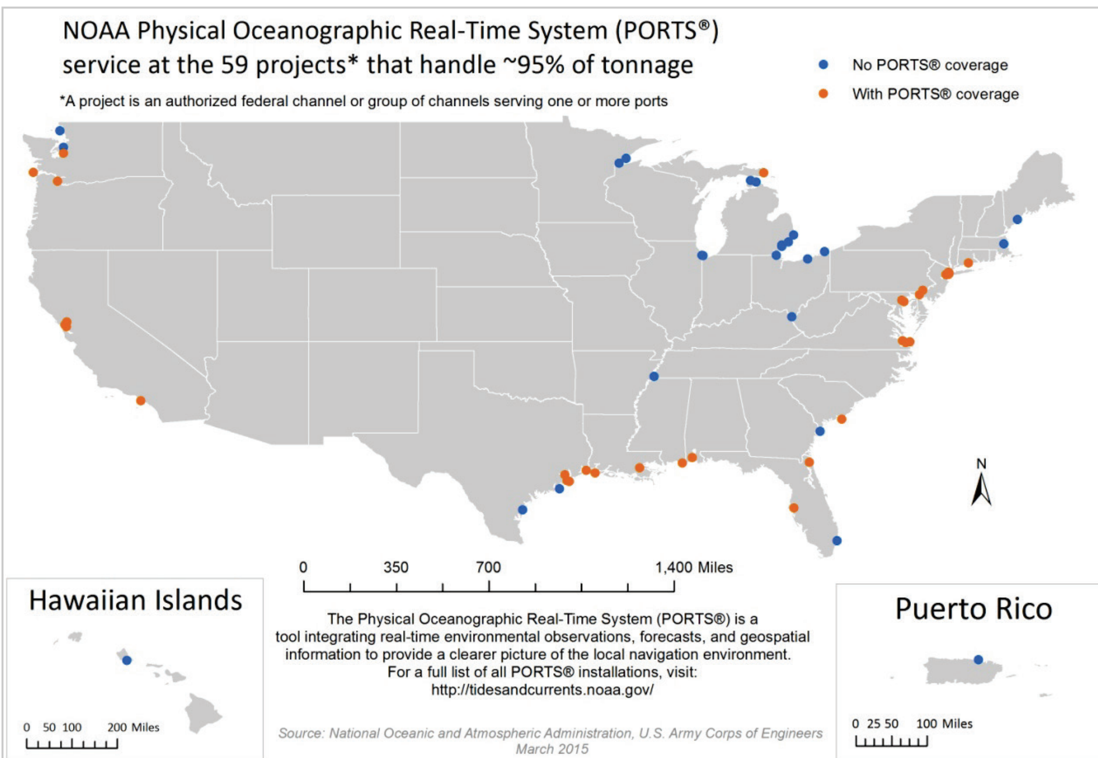


5.3.2 National Oceanic and Atmospheric Administration (NOAA), Physical Oceanographic Real-Time System (PORTS), instrumentation availability at 59 high-tonnage USACE navigation projects

Capacity and reliability are improved if mariners have access to accurate data about navigation conditions. The National Oceanic and Atmospheric Administration (NOAA), Physical Oceanographic Real-Time System (PORTS) provides real-time oceanographic data and other navigation products to promote safe and efficient navigation in U.S. waters (National

Oceanic and Atmospheric Administration 2013b). Multiple analyses of the economic benefits of PORTS systems are available, including case studies from around the United States (National Oceanic and Atmospheric Administration 2013c). One measure of performance in this category is the number of the 59 highest-use USACE-maintained navigation projects with NOAA PORTS instrumentation installed, shown in Figure 12. These 59 USACE navigation projects consist of channels that handle approximately 95% of U.S. waterborne cargo by value or volume; as of early 2015, there are 24 PORTS installations covering 35 of the 59 high-tonnage USACE projects.

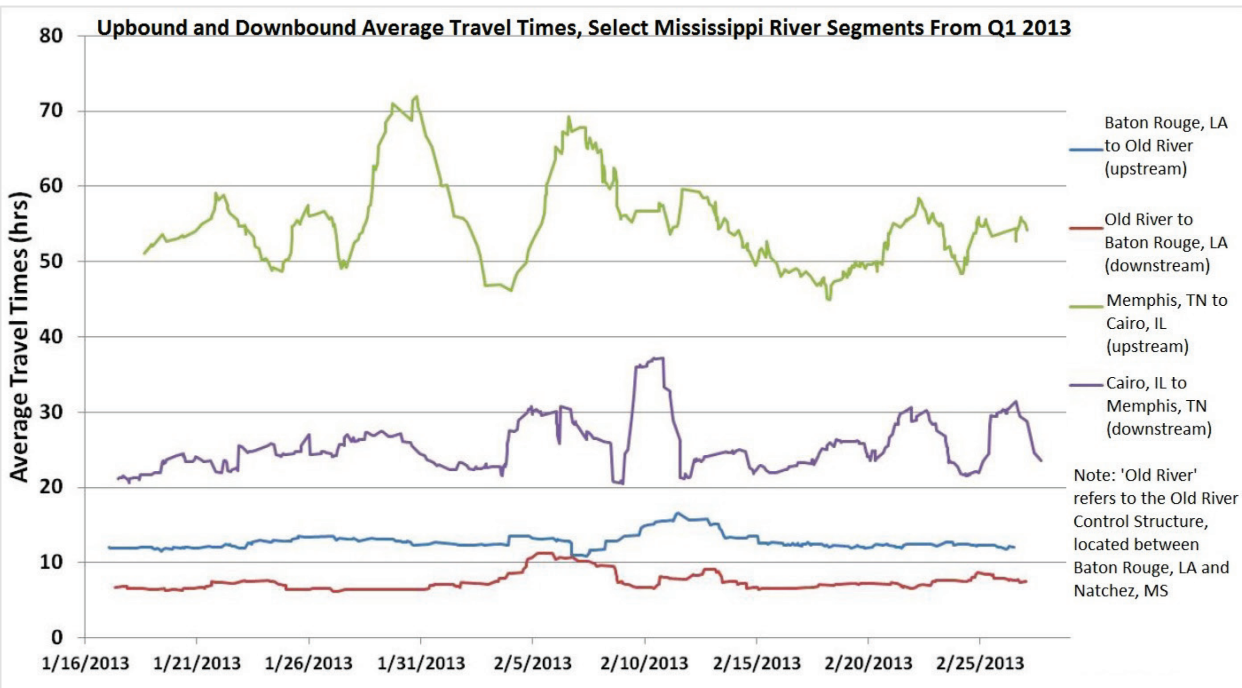
Figure 12. NOAA PORTS instrumentation availability *at* 59 high-tonnage USACE navigation projects. Source: National Oceanic and Atmospheric Administration (2013b), U.S. Army Corps of Engineers (2013a).



5.3.2.1 Quarterly travel time estimates for select waterway segments

Being able to reliably plan the duration of a journey between two places is an important component of a reliable system. For inland waterways it is now possible to calculate the duration of a vessel's journey between two ports using archived data from the U.S. Coast Guard (USCG). The performance of a waterway segment, as it relates to commercial navigation interests, can be analyzed through this performance measure. Travel time estimates typically require large numbers of data points under a variety of normal operating conditions. There must also be specified segments (origin-destination pairs) over which vessel travel time is measured. Segments that see relatively few vehicles will require longer observation periods to generate enough observations to calculate useful average travel times; depending on the network segment, this observation period might span anywhere from 1 week to 1 year. Figure 13 shows average observed travel times for two waterway segments, for vessels heading upstream (upbound) and vessels moving downstream (downbound). Generating travel time estimates based on direction of travel is important for waterways because of the effect of water flow on vessel speed.

Figure 13. 20-point rolling average observed travel times between Baton Rouge, LA, and Old River Control structure and Memphis, TN, and Cairo, IL. Upbound and downbound vessels during a 6-week period in early 2013. 521 unique vessels (modified from Mitchell and Scully 2014).



Since the MTS does not exist in isolation from other parts of the transportation system, a multimodal application of any performance measure would be especially useful. Travel time estimates and travel time reliability are measures that can be used across transportation modes. Travel time is an outcome-based measure which is widely understood since people deal with the concept on a daily basis. Travel time reliability takes a longer term perspective because it includes consideration of the potential for delays in arrival time, or rather, obstructions to the fluid flow along a certain path. Chapter 6 provides more detail on the status of waterway travel time research efforts.

After a disruption, first-phase recovery efforts typically focus on restoring system functions (utility systems, transportation, and communication). Pre-event planning and preparation can never remove all risk, but identifying minimum and desired levels of service from engineered systems sets a baseline for recovery. For transportation networks, progress towards recovery can be assessed by a return to pre-incident or normal travel times since this is indicative of both network condition and fuel availability. For the MTS, evaluating the resiliency of a system post event will require the use of pre-event travel time data. Data for this performance measure will thus contribute to a greater understanding in two categories, Capacity and Resilience (discussed further in section 5.6).

5.3.2.2 Federal ship channels at project depth according to USACE eHydro observations

The eHydro program is being implemented across USACE District offices. Once in place, it will allow for the automatic updating of channel condition information based on the most recent field surveys of channels (U.S. Army Corps of Engineers, Engineer Research and Development Center 2013). This will allow local, regional, and national summaries of channel availability and calculation of the difference from Federally authorized channel dimensions.

5.4 Safety and security performance measures

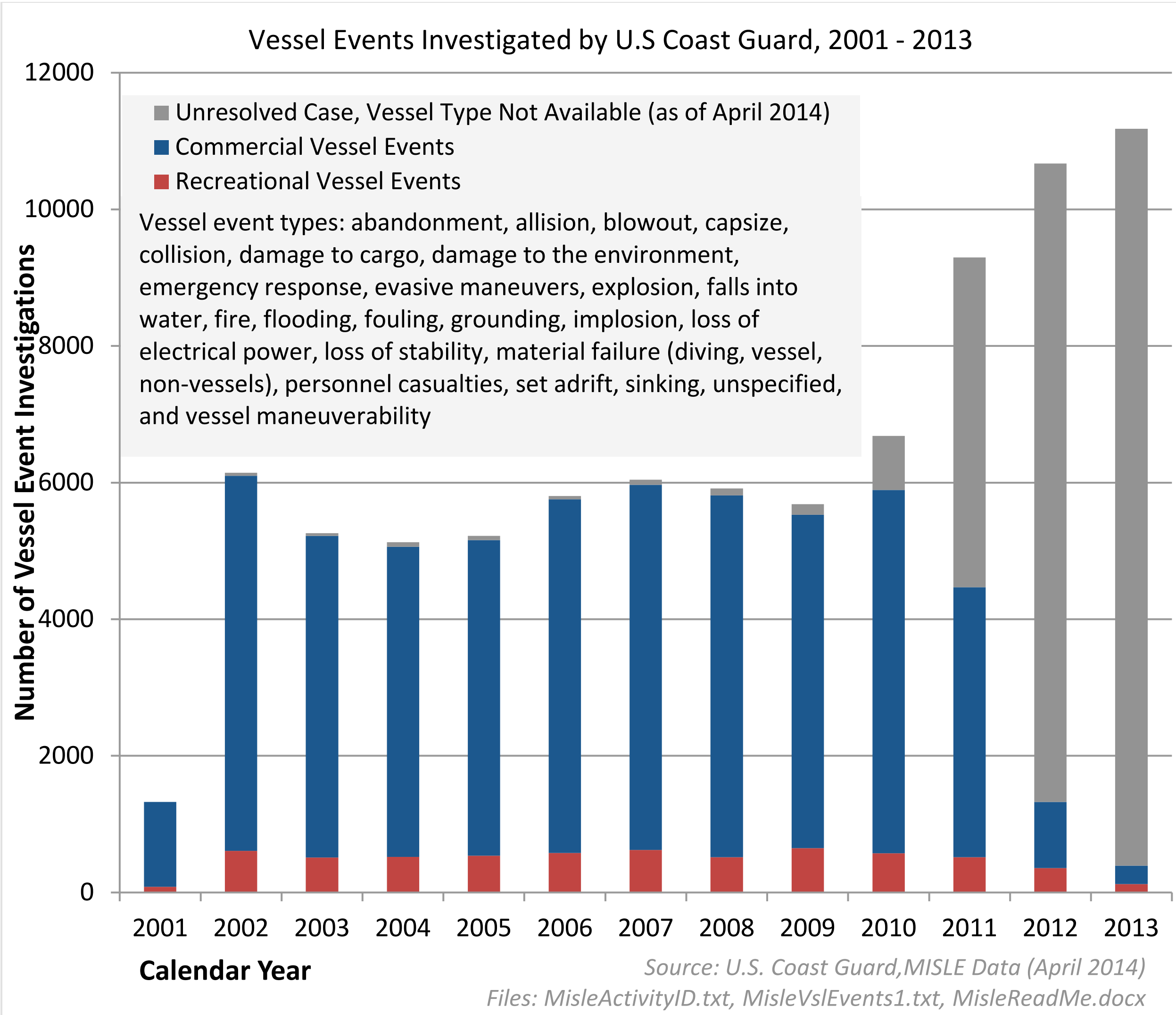
The safe operation of vessels transiting the Nation's waterways is of central importance to all MTS stakeholders. Maritime safety and security has multiple facets, from the operation of vessels to the inspection of cargo entering the United States. There are very few public data sources for elements related to national MTS security, none of which provide a comprehensive picture for long-term assessment purposes. Inspection of offloaded cargo is the responsibility of Customs and Border Protection (CBP), but limited public data about inspections and seizures is available in CBP annual reports. The scale of work conducted by CBP is significant; on a typical day in 2012, CBP admitted over 50,000 passengers and crew arriving by sea and over 60,000 shipping containers via truck, rail, and sea (U.S. Customs and Border Protection 2012). Performance measures for MTS security procedures and security compliance costs were not developed for this report.

Within the Department of Homeland Security, the USCG is the primary agency in charge of on-water safety and investigates the vast majority of reported marine-related accidents involving commercial vessels. Specific types of marine accidents may alternatively be investigated by the National Transportation Safety Board (NTSB), including those involving U.S. flagged vessels outside of U.S. waters (National Transportation Safety Board 2015). As of February 2015, the NTSB had listed 140 reports in the Marine Accident Reports database dating back to the year 1996 (National Transportation Safety Board 2015). Due to the limited size of the NTSB Marine Accident Reports database, the first phase of this research has focused on records from the USCG to develop performance measures in this category. No authoritative database exists to record and report maritime near-misses in the United States, but any near-miss incident can be confidentially reported to the international Mariners' Alerting and Reporting Scheme (The Nautical Institute 2015). The ability to capture and share data on "incident precursors" or near-misses would provide greater insight into MTS operational safety.

5.4.1 Number of vessel events investigated by USCG (collisions, allisions, groundings, etc.)

Commercial vessel accidents (more formally referred to as *events*) can have many contributing factors such as bad weather, mechanical failure, and human error. There are also many types of vessel accidents, from allisions to groundings. The USCG responds to and investigates accidents on waterways. The publicly available details of these investigations can be downloaded through the USCG Homeport website under the topic area "Marine Casualty and Pollution Data for Researchers," within the Marine Information for Safety and Law Enforcement (MISLE) files (U.S. Coast Guard 2014a). Figure 14 shows the number of reported vessel accidents from 2001 to 2013. The total number of accidents was fairly stable from 2002 to 2010; the apparent increase is driven by the large number of unresolved investigations for which details are not yet available. For unresolved investigations, the USCG only releases the number of cases; these are listed in the MisleReadMe.docx file associated with each release of updated MISLE files. While the MISLE files contain information relevant to the overall safety of marine operations, at present they are most useful for historical analysis due to the delay time between event occurrence, investigation resolution, and data publication.

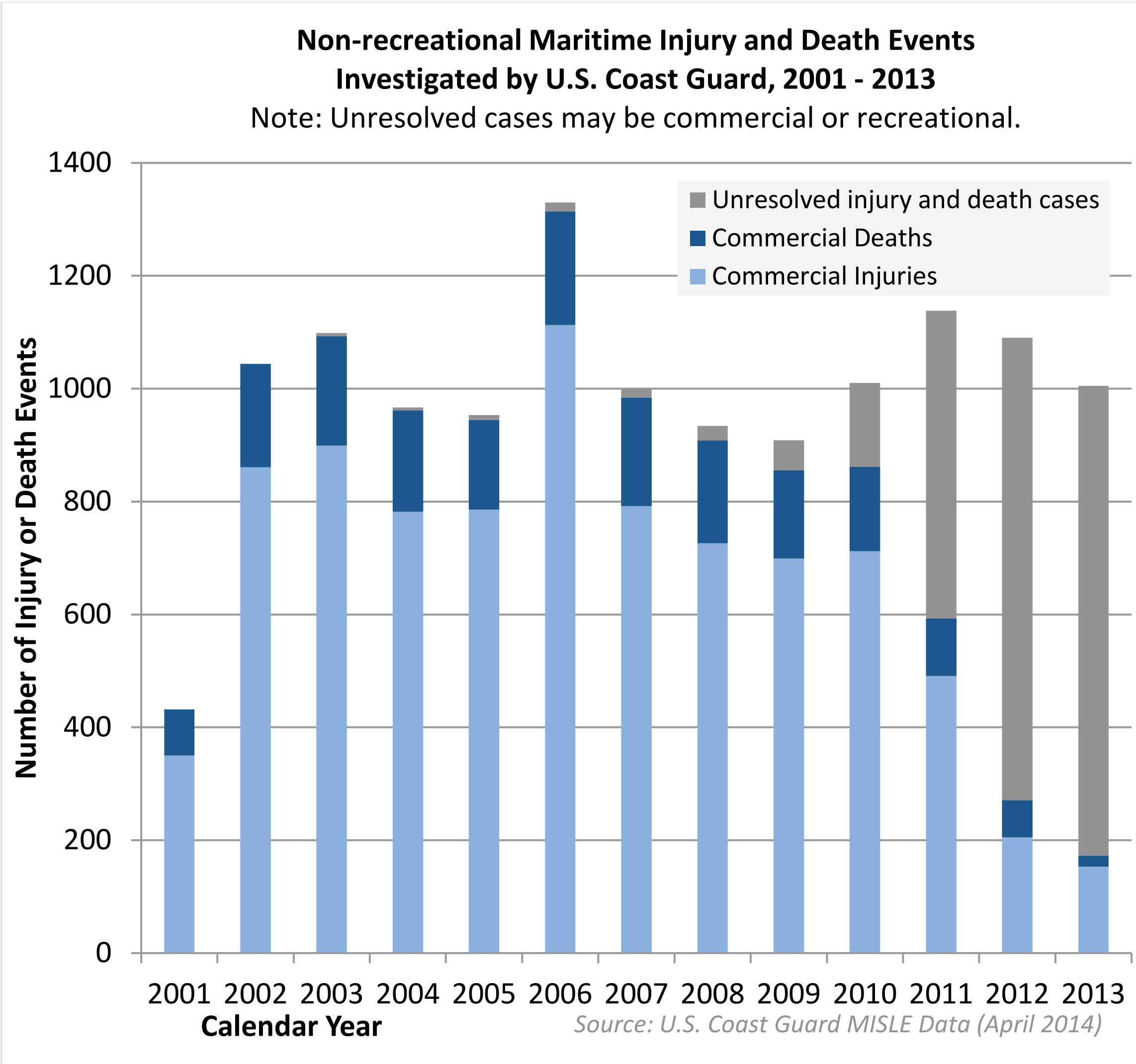
Figure 14. Number of vessel events investigated by USCG, 2001–2013. Source: U.S. Coast Guard (2014a), MISLE Data (April 2014).



5.4.2 Number of commercial mariner and passenger deaths and injuries

One performance measure of safety is the number of accidents that take place on the water. The USCG collects information on mariner casualties and fatalities for commercial and recreational vessels as they are reported (U.S. Coast Guard 2014a). Due to the high percentage of recreational vessel accidents associated with alcohol use, rather than with infrastructure deficiencies or commercial freight movement activity, this research measure does not include recreational vessel incidents. Historical safety information on casualties associated with commercial operations is shown in Figure 15.

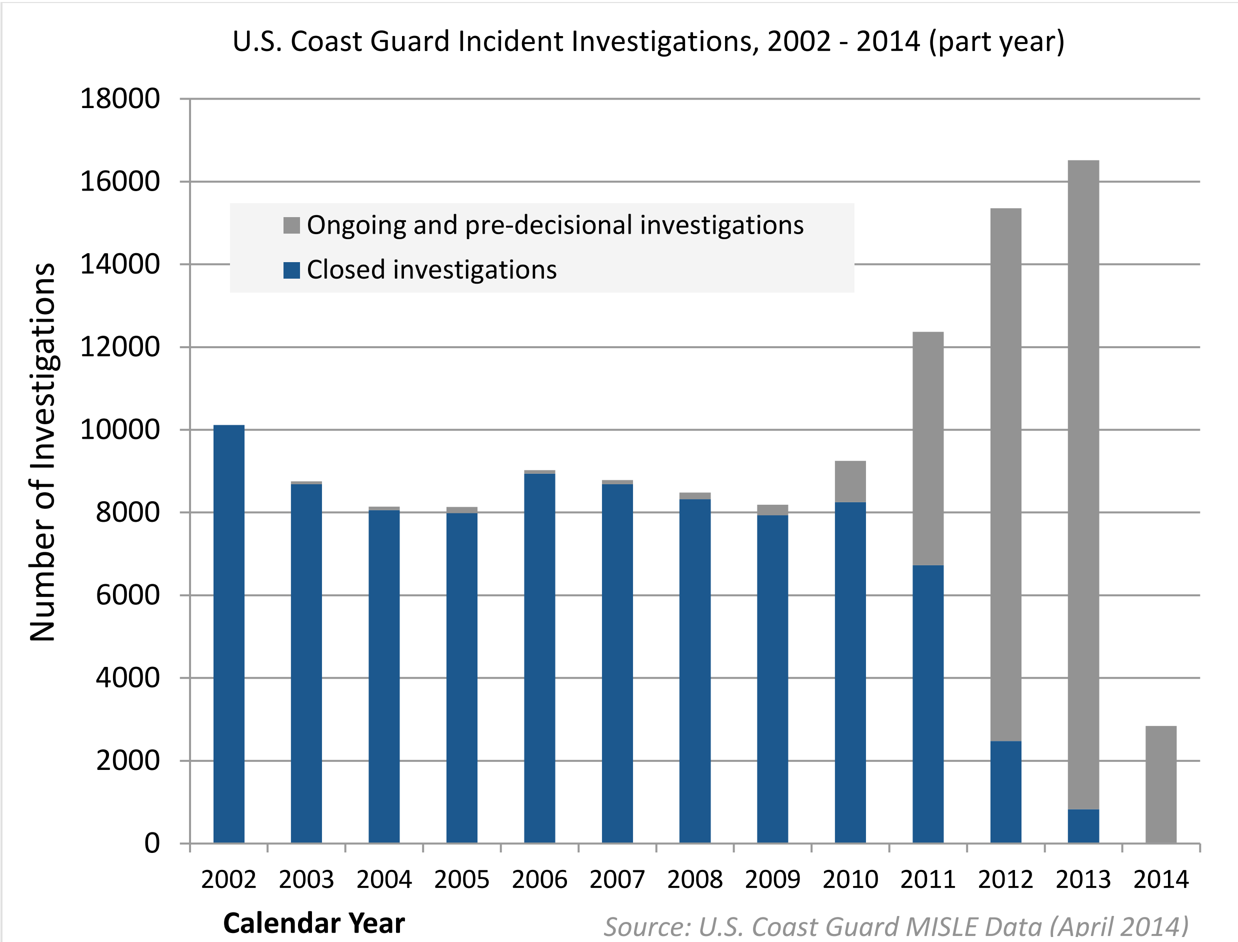
Figure 15. Marine casualties associated with commercial operations, 2001–2013. Source: U.S. Coast Guard (2014a), MISLE Data (April 2014).



5.4.3 Maritime incident investigations

The USCG has authority to investigate maritime-associated incidents, including vessel grounds, accidents at sea, and maritime casualties. Information about these investigations is released periodically (approximately annually) through the USCG Homeport website (U.S. Coast Guard 2014a). What is not included in the public data file from USCG is the total or estimated total number of incidents or the number of incidents that cannot be investigated due to funding or personnel constraints. Figure 16 shows that the decade of 2002–2011 saw a fairly stable number of investigations closed every year. It is not clear whether the large number of ongoing investigations (shown in grey) will result in a significant change to that pattern.

Figure 16. Number of USCG incident investigations, 2002–2014 (part year). Source: U.S. Coast Guard (2014a), MISLE Data (April 2014).



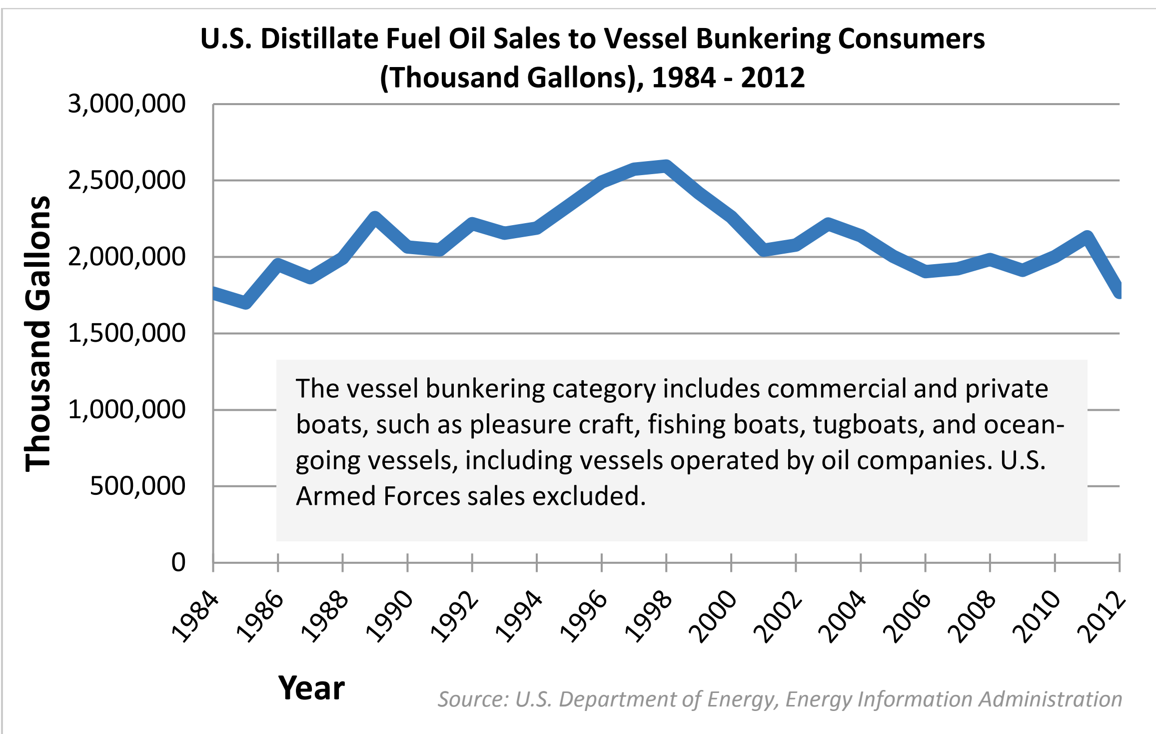
5.5 Environmental stewardship performance measures

Like all transportation modes, MTS infrastructure and operations affect the environment. Negative impacts from MTS operations include air emissions from vehicles, point-source discharges, nonpoint-source runoff, marine debris, and the movement of potentially invasive plant and animal species on ship hulls and in ballast water (U.S. Committee on the Marine Transportation System 2008). However, the productive re-use of dredged material to restore wetlands or other habitats is of interest to multiple MTS stakeholders. Sharing MTS-related environmental measures was recommended by the CMTS in 2008. The CMTS identified multiple recommendations for ways to protect the environmental health of communities and ecosystems, including "work collaboratively to foster the collection of data and information that will underpin environmental impact assessments and decision-making in MTS planning and development" (U.S. Committee on the Marine Transportation System 2008).

5.5.1.1 Petroleum-based fuel use by the maritime industry

An environmental stewardship performance measure with broad interest is the amount of fuel being used by vessels within the MTS. This information can be found through the Department of Energy, Energy Information Administration (EIA) (U.S. Department of Energy 2013). Annual data on petroleum fuels sales to vessel bunkering consumers are available at the national level. Research into available relevant spatially disaggregated data about petroleum fuel sales is ongoing. Figure 17 shows a downward trend in fuel use since the late 1990s; however, it is not clear from this dataset alone whether that trend is the result of increased engine efficiency, reduced shipping demand, a switch to other fuel types, increased fuel purchases at foreign ports, or other factors. Understanding the underlying factors that are driving changes in fuel consumption will require combining usage data with other operationally relevant data sets.

Figure 17. U.S. distillate fuel oil sales to vessel bunkering consumers. Source: U.S. Department of Energy, Energy Information Administration (2013).

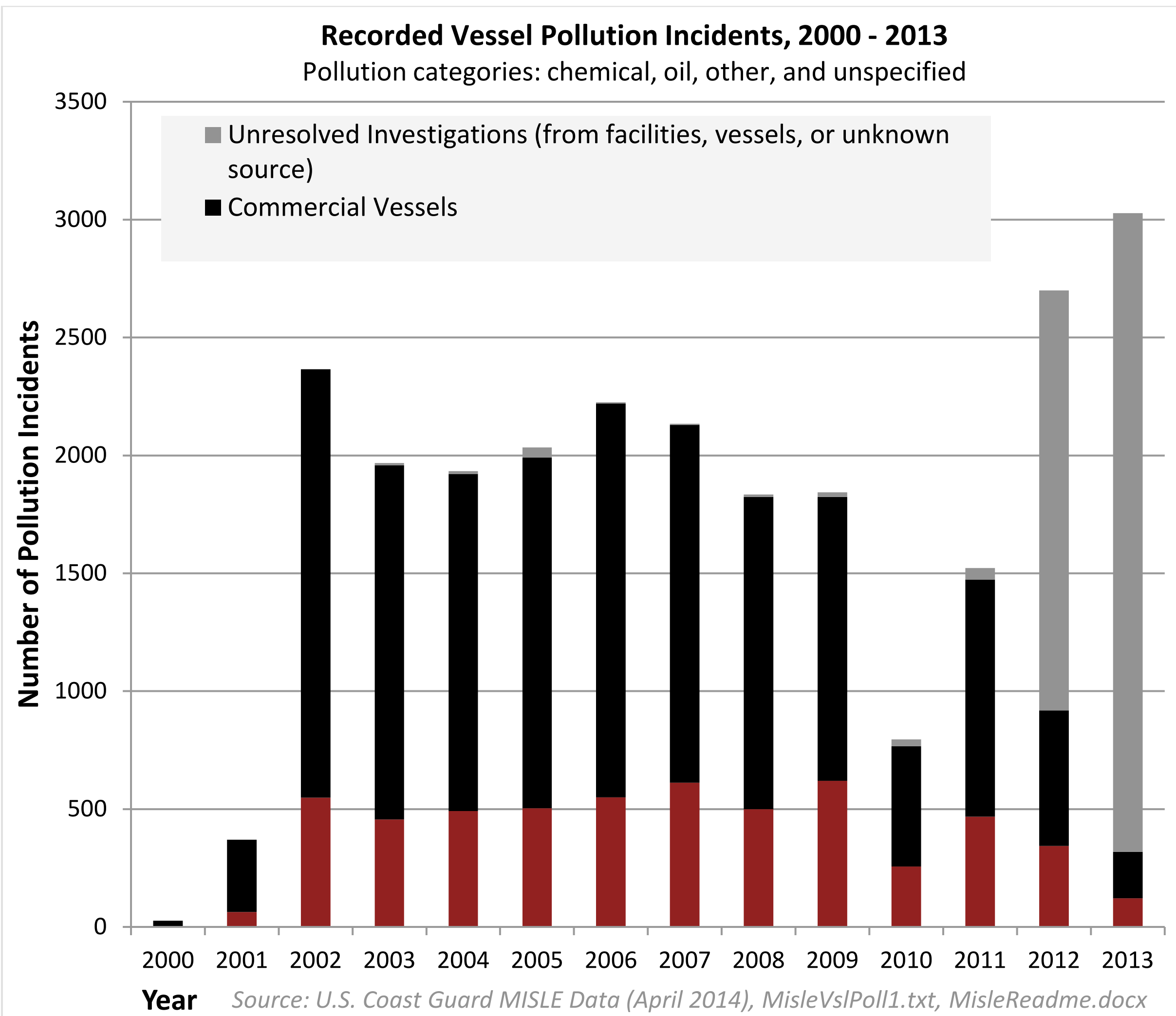


5.5.1.2 Vessel pollution incidents (petroleum and other types)

The USCG investigates and records pollution incidents associated with vessels. Pollution incidents are broadly classified as oil, chemical, other, or unspecified. Greater detail about each pollution incident is available in the

MISLE files available for public download (U.S. Coast Guard 2014a). Pollution incidents have been associated with a wide variety of vessel types, including recreational, commercial fishing, and bulk tankers. While there are four main categories of pollutants (chemical, oil, other, and unspecified), the vast majority of recorded pollution incidents are associated with oil pollution. USCG records for the number of vessel pollution incidents between 2000 and 2013 are shown in Figure 18. Figure 18 does not include pollution incidents that are associated with maritime facilities; those incidents are recorded separately by the USCG.

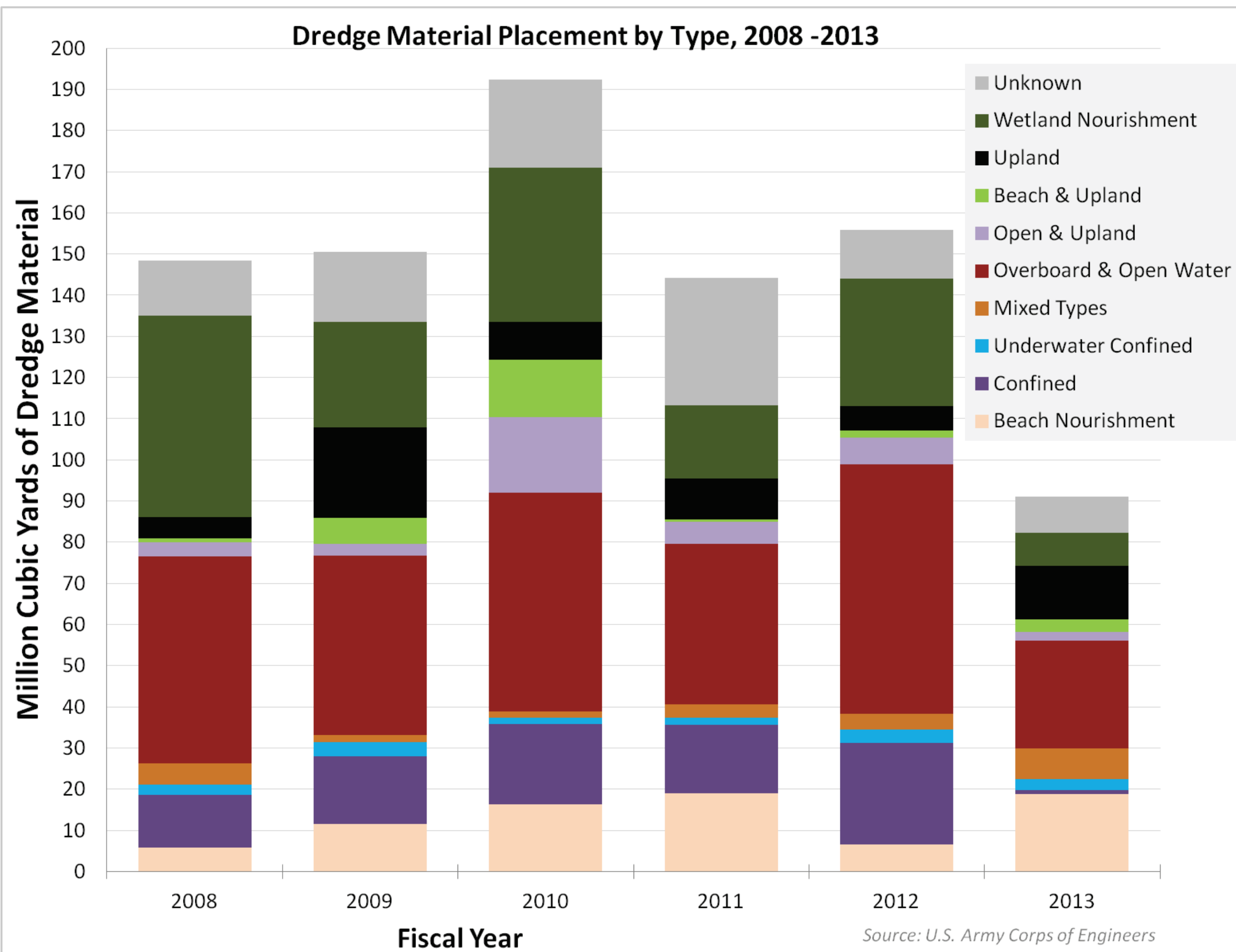
Figure 18. Recorded vessel pollution incidents, 2000–2013. Source: U.S. Coast Guard (2014a), MISLE Data File (April 2014).



5.5.1.3 Amount of dredged material reclaimed for beneficial uses

The beneficial re-use of material dredged to maintain navigation channels is of interest to multiple stakeholders. The capability to re-use dredge material depends on multiple factors such as sediment type, location of dredging activity, and overall cost to move the sediment to a site for re-use. In some cases a nonFederal partner contributes funds to cover any difference in placement costs between the least-cost method and the desired location. These kinds of partnerships can produce valuable benefits such as habitat creation or storm protection, but they require extra planning and financial management. Recent data on dredge material placement type and volume of sediment placed from USACE projects is shown in Figure 19 (U.S. Army Corps of Engineers 2015c).

Figure 19. Dredge material placement methods and volume, 2008–2013. Source: U.S. Army Corps of Engineers (2015c).



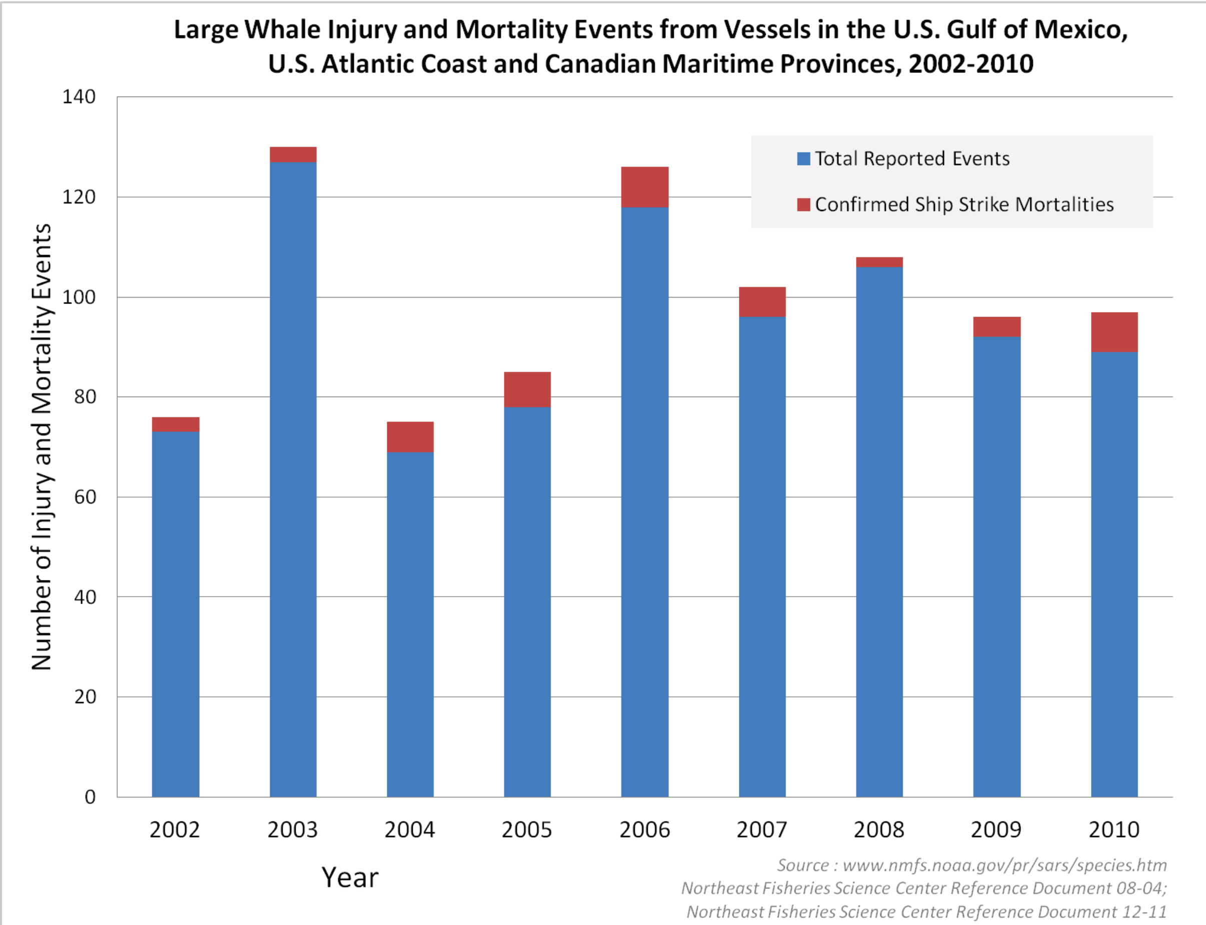
Environmental assessment reports with relevance to the MTS include the National Coastal Condition Report series, published by the U.S. Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency 2012a,b). "These reports, which contain data on water and sediment quality, biota, habitat, and ecosystem integrity that are summarized into indices of the overall condition of the nation's navigable waters and coastlines. The indices in the report are intended to provide benchmarks for monitoring changes in coastal conditions over time and an overall assessment of the need for Federal attention in improving coastal conditions" (Committee for a Study of the Federal Role in the Marine Transportation System 2004). While incredibly valuable as national level summaries, it is not immediately apparent how to down scale the findings of these high-level reports to enact change at the local level. However, since local and regional data contributed to the National Coastal Condition Report, one ongoing research track is to work with EPA collaborators to locate and share these detailed data sets at the most disaggregated level possible.

5.5.1.4 Number of reported whale strikes by vessels

Marine mammals have been granted special protection under the *Marine Mammal Protection Act* and the *Endangered Species Act* (National Oceanic and Atmospheric Administration 2013a). In addition to legal protections, some sections of U.S. waters have enacted permanent or seasonal operational changes for vessels that pass through areas where interaction with certain types of marine mammals is likely. Despite efforts to reduce interactions, there continue to be collisions between vessels and marine mammals, most notably with multiple species of large whales such as the North Atlantic Right Whale. Information about the number and location of these incidents, when available, is collected by the NOAA Office of Protected Resources; available data is shown in Figure 20.

Due to the nature of whale-vessel interactions, it is likely that many ship strikes go either unnoticed or unreported. Not all ship strikes are immediately fatal; animals can be discovered later with evidence of such interactions, which may or may not be directly linked with mortality events.

Figure 20. Large-whale injury events and mortalities reported for the U.S. Gulf Coast, U.S. Atlantic Coast, and Canadian Maritime Provinces, 2002–2010. Source: National Oceanic and Atmospheric Administration (2013a).



"The economic health of the MTS and the natural health of the Nation's ocean, coastal, and freshwater ecosystems must co-exist in a way that supports transportation while protecting and sustaining human health and the environment. The MTS intersects with, and is in close proximity to, sensitive and valuable natural resources, including wetlands, estuaries, drinking water sources, recreational waters, watersheds, critical habitats, fisheries, coral reefs, and marine life habitats."

Strategic Action Plan for Research and Development in the Marine Transportation System (U.S. Committee on the Marine Transportation System 2011)

5.6 Resilience performance measures

Resilience is considered to have four elements that describe how a system, or group of systems, responds to a challenge: prepare, resist, recover, and adapt (Rosati et al. 2015; U.S. Committee on the Marine Transportation System 2015). Any area challenged by a disturbance event such as a major storm contains a mix of social systems, ecological systems, and engineered systems. The level of resilience for any of these systems is not a static measure; it changes over time in response to growth, decay, natural changes, and human interventions. Resilience research literature has ample examples of hypothetical scenarios based on historical conditions (Park et al. 2013; Omer et al. 2012), but how do these translate into useful, actionable, performance measures of future resilience? An example of a regional-to-national evaluation for ecological resilience is the U.S. EPA's *National Coastal Condition Report IV,* a summary of key ecological health indices combined to give an overall condition of U.S. coastal areas (U.S. Environmental Protection Agency 2012a, 2012b). Although attention grabbing, nationally aggregated grades do not necessarily provide guidance that is specific enough to prompt actionable investment decisions at the regional or project level. Identifying opportunities for resilience improvement requires measurement at a local scale.

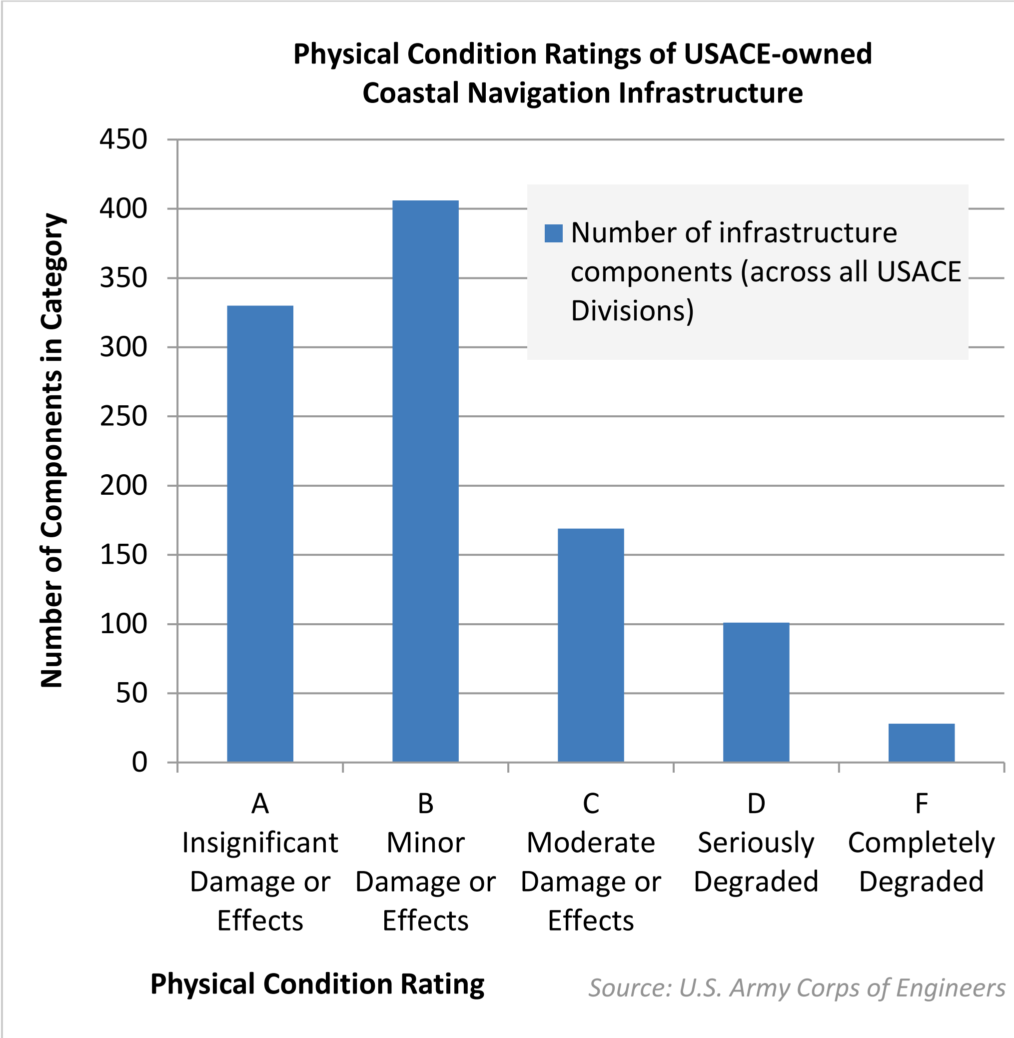
The value of aggregate measures of resilience components on a regional or national scale is that they draw attention to issues that underpin system resilience and encourage local or state officials to look at their own communities since resilience is ultimately location and event specific. One example of an aggregate measure related to resilience is the American Society of Civil Engineers annual *Report Card for America's Infrastructure*, which gave an overall grade of D+ to American infrastructure in 2013 (American Society of Civil Engineers 2013). In the case of engineering systems, an evaluation of resilience would include elements such as the state/condition and functional performance of physical infrastructure.

A resilience assessment for a single piece of infrastructure would likely incorporate the condition of the structure, the current level of function, and the type of challenge it is expected to withstand. For example, a dam structure is designed to supply a known amount of resistance force in order to perform the function of holding back a certain amount of water, with a margin of safety included in the design. If that dam structure shows evidence of deterioration, such as multiple cracks in the concrete, this can indicate loss of structural integrity. Excessive deterioration of structural integrity can reduce the functionality of the dam, causing it to leak. Under challenging conditions like a severe flood, this combination of reduced structural integrity and extra strain could lead to catastrophic failure. Assessing resilience is not an easy task. The task becomes manageable by constraining a world of infinite possible scenarios down to those that are both within the realm of possibility and of high enough concern. Since the limits of living human memory do not encompass all likely natural scenarios, it is important to use historical and geological evidence to define the full suite of possible hazard events that a structure is likely to face during its service life.

5.6.1.1 Physical condition ratings of critical coastal navigation infrastructure

Coastal navigation infrastructure includes features such as piers, groins, jetties, dikes, breakwaters, and revetments. Structures owned and maintained by USACE have been rated on their physical condition according to standard engineering criteria. This national inventory includes hundreds of structures of varying size and physical complexity. Note that physical assessments are not the same as functional assessments. It is possible for a damaged structure to retain some level of function, but not always. Some types of structural deterioration can be more detrimental than others, and deferred maintenance on these issues could end up increasing repair costs in the long run. Figure 21 shows the physical condition rating of USACE-owned coastal navigation infrastructure, aggregated by grade class (i.e., B, B-, and B+ ratings are all shown in the B column) (U.S. Army Corps of Engineers 2013b).

Figure 21. Physical condition ratings of USACE-owned coastal navigation infrastructure components, 2013. Source: U.S. Army Corps of Engineers (2013b), Asset Management Database (beta).



Other resilience performance measures are being explored for future development. These include design time vs. actual time for travel through navigation locks, further delineation of the causes of unscheduled lock closures (e.g., weather conditions), and physical conditions vs. functional performance for certain types of fixed structures (e.g., rubble mounds). For large systems such as navigation networks, resilience is unlikely to be reduced to a single measurement, but a relevant suite of measures through time will provide important insight into infrastructure performance under a variety of conditions.

6 Vessel Travel Time Statistics

Vessel travel time statistics, such as mean and standard deviation, can be applied to analyze MTS performance over time at the local, regional, and National level. Examples of such analysis include identifying segments of the MTS that are points of congestion (i.e., bottlenecks) or have fluctuations in vessel travel times.

6.1 Background: Travel time estimates benefits realized for roadway users

Travel time estimates are calculated for different modes of transport, including waterways and roadways. Previous research has demonstrated the benefits of providing roadway users, such as commuters and trucking companies, with trip travel time estimates and delay information. In a study conducted by Wunderlich et al. (2001), it was shown that the provision of advanced traveler information services (ATIS) improved on-time reliability, reduced the amount of time wasted by arriving too early, and reduced driver stress (Wunderlich et al. 2001). In a study conducted by Toledo and Beinhaker (2006), the provision of ATIS resulted in travel time savings of up to 14% (Toledo and Beinhaker 2006). In addition, the Federal Highway Administration (FHWA) has published material explaining the usefulness of calculating travel time reliability for roads since it affects many people every day. “Travel time reliability reflects the consistency or dependability in the travel time estimates, i.e., how likely the estimates are to reflect the actual travel time of a vehicle” (U.S. Department of Transportation, Federal Highway Administration et al. 2006). Roadway travel time estimates can be used for route choice selection or pickup and delivery scheduling for trucking companies transporting time-sensitive freight. Roadway travel times are also used by state Departments of Transportation to monitor traffic conditions, as inputs for travel demand models, and for system analysis. By also providing travel time estimates for the MTS, these or similar benefits may also be realized by users of the MTS.

6.1.1 Vessel travel time data source: Automatic identification system (AIS) data

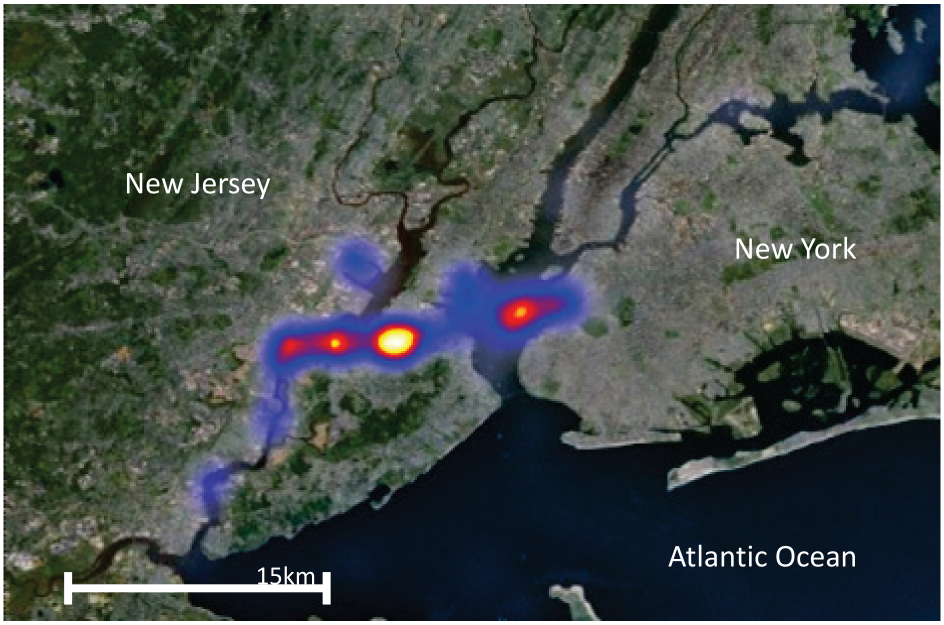
The source and collection of vessel position data was described in previous research by Mitchell and Scully (2014):

> The United States Coast Guard (USCG) maintains the Nationwide Automatic Identification System (NAIS) (http://www.uscg.mil/acquisition/nais/) to collect real-time traffic monitoring data on vessels operating in U.S. territorial waters. Transceivers onboard the vessels broadcast the AIS signal containing position, heading, speed, and other identifying information to shore-based towers with a reporting interval of only a few seconds for vessels underway…. In addition to the live picture of waterway traffic conditions provided by the AIS technology, vessel reports are archived for several years from time of receipt, resulting in an enormous volume of data concerning vessel utilization patterns and trends in coastal and inland waterways (Mitchell and Scully 2014).

Thus, each time a vessel transmits information via AIS, a record of the transmission is archived.

Records from different vessels or from a single vessel over a given time period can be analyzed to reconstruct vessel paths, estimate travel times or speeds between points of interest, and calculate dwell times at ports or anchorages. For example, AIS records for vessels traveling on the East River near the Throgs Neck Bridge in the New York metropolitan area for the month of January 2013 were received from the USCG. These records included the location of each vessel every 5 minutes during the month. Note the number of records per vessel can be requested at intervals as short as 6 seconds; however, the number of records per vessel to manage then increases. A relative density plot (also known as a *heatmap*) of the vessels' locations was created that shows the areas in which the vessels spent the most time. The resulting vessel AIS signal densities (high-density in yellow, low-density in blue to gray) are shown in Figure 22.

Figure 22. Relative density plot of AIS position reports around New York, NY, during January 2013.



This type of analysis can be adjusted to areas of different size, such as small-scale analysis of an individual waterway or large-scale analysis of entire regions.

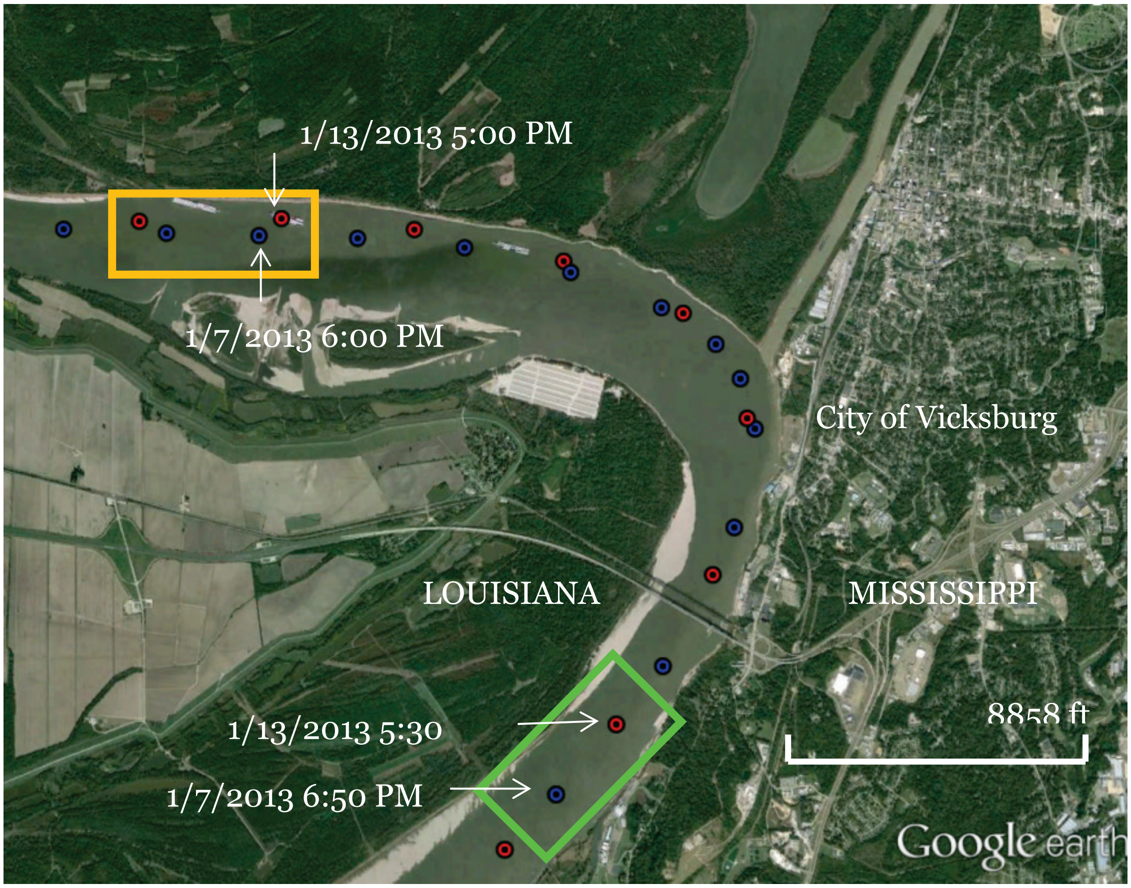
6.2 Methodology to calculate travel time statistics

AIS data is applied to determine vessel travel time statistics. For example, to calculate the travel time of a vessel from an origin to a destination, the AIS records for the vessel at the origin and the destination are analyzed to determine when the vessel departed the origin and when it arrived at the destination; the difference between the departure time and the arrival time is the estimated travel time. To calculate the dwell time of a vessel (i.e., the time a vessel spends at a location or within a specified area, such as a port), its AIS records from that one location are analyzed. The time stamp of the record from when the vessel first entered the location is compared to the time stamp of the record from when the vessel is no longer is in the location, to estimate the dwell time. The individual vessel travel times or dwell times can then be compared to those of other vessels to determine values for travel time statistics such as average and standard deviation.

The method to estimate the travel time of vessels for a river segment is illustrated in Figure 23. The figure shows a segment of the Mississippi River near Vicksburg, MS. The downstream direction of travel is considered in this example. The origin of the study segment is denoted with a yellow rectangle, and the destination is denoted with a green rectangle. The AIS position reports of two different vessels traveling the same river segment on two different days are mapped. The locations corresponding to the AIS reports for a vessel that traveled on 7 January 2013 are indicated with blue circles, and the locations corresponding to the AIS reports for a vessel that traveled on 13 January 2013 are shown with red circles. Note the recorded positions are discrete and are transmitted at time intervals, not specific distance intervals. Thus, the position reports for the two vessels are at different locations and have different spacing. For this example, the reports were requested at a 5-minute interval.

The travel times of the two vessels are estimated. For the vessel that traveled on 7 January 2013 (blue circles), its last record before it departed the origin had a timestamp of 6:00 p.m., and its first record after it arrived at the destination had a timestamp of 6:50 p.m. Thus, its travel time for this river segment is estimated to be 50 minutes. Likewise, for the vessel that traveled on 13 January 2013 (red circles), its last record before it departed the origin had a timestamp of 5:00 p.m., and its first record after it arrived at the destination had a timestamp of 5:30 p.m. Thus, its travel time is estimated to be 30 minutes. Note the travel time estimate for the vessel indicated with blue circles is for a slightly farther distance than that for the other vessel mapped with red circles. This technique, when applied to multiple vessels transiting a waterway segment, can be used to develop travel time statistics for examining waterway performance. Larger sample sizes are expected to produce better estimates over a wider range of operating conditions.

Figure 23. AIS position reports of two vessels on the Mississippi River near Vicksburg, MS. AIS reports at 5-minute intervals are shown for two vessels (red dot, blue dot) that traveled downstream from the origin (yellow rectangle) to the destination (green rectangle) on two different days within the same week. Source: Archived AIS data from USCG (2014d), plotted on GoogleEarth map.



Software can be produced to help automate the process for generating waterway travel time estimates, and researchers at USACE are developing a product for this purpose. The current method uses web services provided to USACE by the USCG, along with the AIS Analysis Package (AISAP). AISAP is custom software developed by USACE to analyze and visualize large amounts of archival AIS data. The AISAP is currently only available to those within USACE.

6.2.1 Methodology limitations

There are limitations to the application of the AIS data for generating travel time statistics. These include the following:

1. Not all vessel position reports are necessarily recorded. This can result from some AIS transmissions being disrupted due to weather and/or terrain or from some vessels not transmitting an AIS signal.
2. There are waterways with few or no vessel trips per day. This limits the availability of statistical methods that can be applied to analyze data from those low-use waterways.
3. Environmental, operational, and other factors and conditions can affect travel times; these are not recorded in AIS data. These instead need to be inferred from other data sources such as hydrographic river gauge data provided by the USGS. For some of these other factors, data are not readily available, such as waterways restrictions or closures, vessel characteristics (e.g., dimensions, horsepower, hull shape), and tow makeup.
4. Lack of access to industry voyage plan data is another limitation. Having voyage plan information (e.g., planned origin, destination, intermediate stops, speed of advance, tow makeup, cargo) would allow for much more detailed analysis of vessel travel time and allow for comparison with industry-planned and actual travel times.

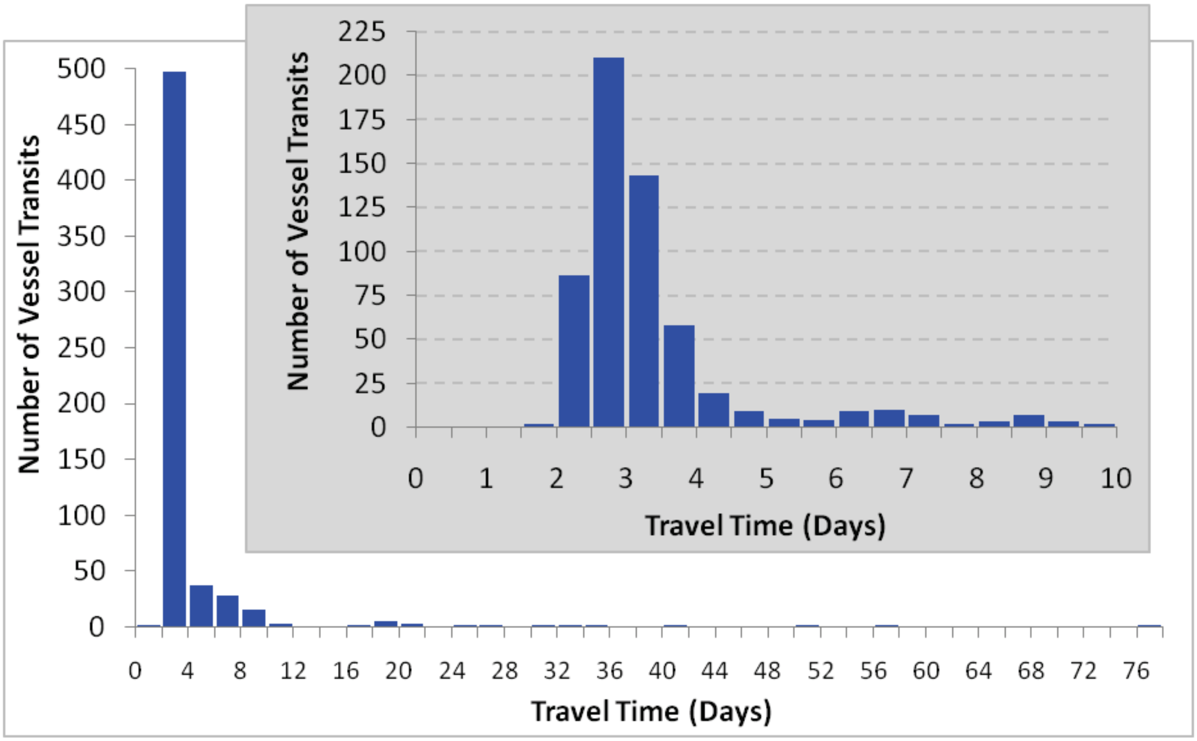
6.2.2 Example case study: Vessel travel times estimated on an inland waterway

Vessel travel times were estimated on the Ohio River from Pittsburgh, PA, to Cairo, IL, and from Cairo, IL, to Baton Rouge, LA, on the Mississippi River. These locations are shown in Figure 24. Cairo, IL, is located at the junction of the Ohio and Mississippi Rivers and is a major waypoint for inland navigation. Archived AIS data from April 2013 through June 2013 are analyzed for this example.

Figure 24. Screenshot of locations of Pittsburgh, PA; Cairo, IL; and Baton Rouge, LA. Source: Google, Inc. (2015).

The individual vessel travel times interpreted from the AIS data are shown in Figure 25. Estimated travel times ranged from 1.61 days to 76.82 days where the distribution is skewed to the right. The Figure 26 inset displays travel times between 1 and 10 days. Note that over 96% of the transits fell within this range, and 80% of the transits were between 2 and 4 days. The travel time outliers are assumed to be due to methodology limitations, such as unrecorded vessel AIS transmissions or vessels with long dwell times at ports.

Figure 25. Vessel travel time estimates from Cairo, IL, to Baton Rouge, LA, for 3 months in 2013. INSET: Graph detail of the number of vessel transits with travel times from 0–10 days.



The 25th percentile travel time, defined as the travel time that 25% of vessels complete the transit within (and that which 75% of vessels exceed), is taken as a representative statistic to indicate waterway segment performance. Note that travel times from Pittsburgh to Cairo are observed to be more than double those travel times from Cairo to Baton Rouge, which likely reflects a combination of factors such as the longer overall distance, queuing time and lockage time at locks along the Ohio River, and dwell time at the numerous ports and mooring areas along the Ohio River. The travel times are listed in Table 2.

Table 2. Travel times between cities estimated by analyzing 2013 AIS data.

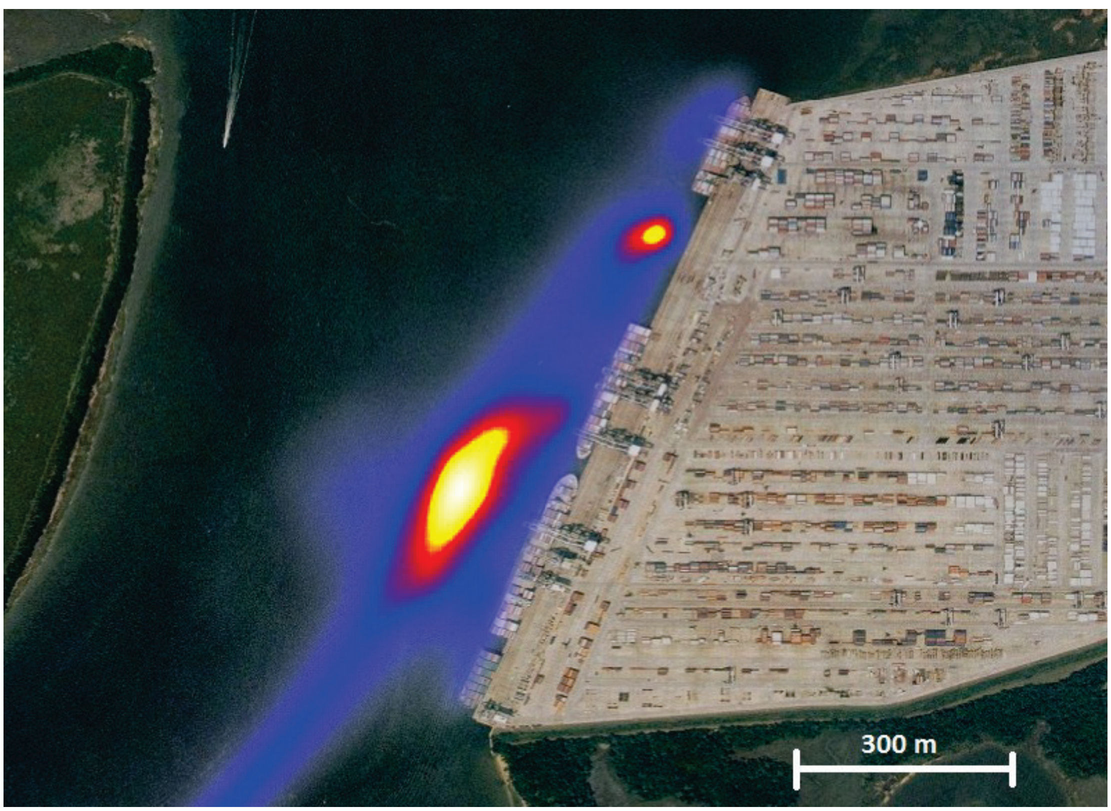
Origin	Destination	Distance (river miles)	25th Percentile Travel Time (days)
Pittsburgh, PA	Cairo, IL	981	6.8
Cairo, IL	Baton Rouge, LA	717	2.7

This case study illustrates the application of AIS data to calculate vessel travel time statistics. Future research in the area includes using AIS data to examine seasonal or yearly differences in travel times, along with differences in travel time by vessel size or type.

6.2.3 Example case study: Vessel dwell times at ports

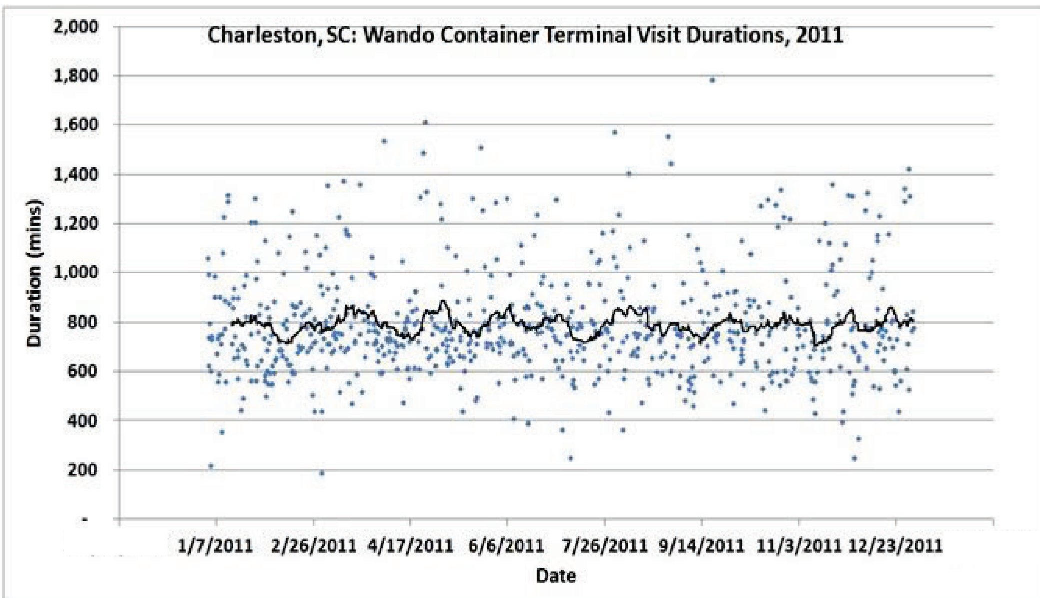
Archival AIS data is applied to analyze vessel dwell times at the Wando Container Terminal at the Port of Charleston, SC, during the entirety of 2012. A relative density plot of AIS position reports depicts the locations of the AIS transponders on the vessels as they docked at the container terminal (Figure 26). Note that heatmap color scales are not absolute; they must be adjusted to illustrate signal density based on the overall sample size. The heatmap in Figure 26 was generated using over 850,000 vessel position reports from 267 different vessels from 1 January to 31 December 2012.

Figure 26. Relative density plot of over 850,000 archived AIS vessel position reports during 2012, overlain on a map of the Wando Terminal in Charleston, SC.



In addition to providing insights into trends of vessel position, archived AIS data can be used to estimate dwell time in a port area. Dwell time is estimated by comparing a vessel's entrance time into the waterway adjacent to a port area and its exit time out of the waterway. Estimates of vessel dwell times at the Wando Terminal during 2011 can be seen in Figure 27. The black line represents the moving average of the dwell time. The moving average for all vessels at the Wando Terminal was close to 800 minutes throughout the year, but individual vessel dwell times ranged from under 200 minutes to almost 1,800 minutes.

Figure 27. Vessel dwell times at the Wando Terminal, Charleston, SC, from January to December 2011.



Examining the amount of time a vessel spends at berth in a port is just one way that archived AIS data can be used to examine waterway utilization. Although many factors affect landside activity related to cargo-handling operations, which can in turn affect vessel dwell time, getting a first-order estimate of vessel dwell times in port areas is possible.

The examples shown above illustrate multiple analytical approaches that can use AIS data to calculate performance measures for parts of the MTS. Questions about vessel movements, vessel travel time, areas of congestion, or environmental conditions that affect operational decisions have the potential to be answered by these kinds of methods. Further refinement is needed to establish standard methods for dealing with data processing decisions, such as the treatment of outliers, but these are expected to develop as use of these data becomes more prevalent.

6.3 Waterway travel time table

Travel time estimates between points of interest, such as port pairs or river locks, can be displayed in a trip table format, similar to those made for other modes of transportation. Work is underway within the USACE Civil Works R&D program to develop these tables for large, high-use portions of the MTS, including the inland navigable waterways, the Great Lakes, and coastal ports, for multiple years. An example of travel time estimates for cities along the Ohio River is shown in Table 3. The table contains the 25th percentile, 50th percentile (median), and 75th percentile travel times for origin-destination pairs along the Ohio River that were estimated from 2013 AIS records.

By having this historical reference available, it will be possible to examine the impacts of events (e.g., drought/flood, unscheduled lock closures) that disrupt commercial traffic movements along major waterway corridors. Vessel movements in the time around an event can be analyzed to determine their variation from the expected average travel time, the potential significance of that variation, and long-term changes in baseline travel times.

Table 3. Travel time estimates for origin - destination pairs along the Ohio River in 2013. Source: Calculated from archived AIS data from USCG (2014d).

Vessel Travel Times
(Hours)

Starting from an origin city move across the chart from left to right to the destination city to determine the 25th, 50th, and 75th percentile vessel travel times.

Travel Time (Hours): 25th percentile / **50th percentile** / 75th percentile

ORIGINS \ DESTINATIONS	Cairo, IL	Evansville, IL	Louisville, KY	Cincinnati, OH
Cairo, IL		30.1 / **36.9** / 50.2	69.3 / **84.1** / 109.9	95.7 / **115.9** / 149.8
Evansville, IL	21.4 / **25.9** / 38.6		33.5 / **40.3** / 50.6	59.9 / **72.1** / 90.6
Louisville, KY	47.1 / **56.0** / 78.5	22.2 / **25.8** / 32.7		21.5 / **28.1** / 32.4
Cincinnati, OH	65.3 / **77.4** / 108.8	40.4 / **47.3** / 62.9	14.8 / **19.0** / 24.5	

Travel time estimates based on 2013 AIS data

7 Interpretation of Performance Measures

This work has documented available data for performance measures in five major categories.

- Economic Benefits to the Nation
- Capacity and Reliability
- Safety and Security
- Environmental Stewardship
- Resilience

Taken together, these measures begin to tell the story of overall MTS performance. An interpretation of the measures in each category is provided in this chapter.

7.1 Economic Benefits to the Nation

The MTS continues to provide significant benefits to the nation as conduit for international trade (Figures 2–4), and as a low-cost, long-haul transportation mode for domestic freight including energy commodities such as coal and petroleum products. The value of exports and imports that are transported via water every year totals hundreds of billions of dollars and forms the cornerstone of U.S. international trade (U.S. Census Bureau, Foreign Trade Division 2015). Since 1988, there has been an approximate eight-fold increase in annual revenues collected by the HTMF, indicating an expansion in trade or an increase in value of goods moving through harbors subject to the ad valorem tax that funds the HMTF (Figure 5) (U.S. Department of the Treasury 2015a). Revenues from the IWTF have not matched disbursements for most of the past decade (Figure 6).

When compared to prices for other modes used for long-distance and bulk freight transportation, the PPI for waterborne transportation has exhibited price stability comparable to truck transport over the past decade (Figure 7) (Bureau of Labor Statistics 2014a). The PPI for water transportation producer prices has increased by approximately 25 points, on par with truck transportation. This is approximately one-quarter of the change in the PPI for pipeline transportation, one-third of the change in the PPI for rail transportation, and less than one-half of the change seen in the PPI for air transportation. Changes in fuel prices are one factor that affects all freight transportation modes, but there has been an overall decline in marine fuel sales since a high point in the late 1990s that is not associated with a concurrent decline in trade volume or value (Figure 17) (U.S. Census Bureau, Foreign Trade Division 2015; U. S Department of Energy 2013). It is possible that the efficiencies of modern vessels and available capacity have contributed to the continued competitiveness of long-distance water transportation services or that ships are buying fuel overseas in response to global price signals. Agricultural commodity exporters are significant users of the MTS, commonly paying for barge services to ship their commodities along inland waterways to deep-draft coastal ports. While there will typically be seasonal swings in barge freight rates due to the increased demand during harvest time, the difference in the index highs and lows has decreased in recent years (Figure 9).

7.2 Capacity and Reliability

Investments in landside port infrastructure are largely driven by private investors or individual states using market-based information about current capacity and forecasts of future demand. Public road infrastructure investments made at the state level may affect supply chains that cross state lines. In light of this reality of interconnectedness, the USDOT is encouraging states to develop freight plans to better incorporate freight-specific needs into the transportation planning process (U.S. Department of Transportation, Federal Highway Administration 2014a). Even with the best of plans, MTS capacity and reliability are the products of many factors such as vessel availability, infrastructure functionality, and uncontrollable weather conditions. In support of navigation under all conditions, 35 of the 59 highest-tonnage USACE Navigation Projects (defined by annual tonnage) have some level of NOAA PORTS instrumentation installed to improve situational awareness for mariners (Figure 12) (National Oceanic and Atmospheric Administration 2013b). Complementary to PORTS is the live Vessel Traffic Service (VTS) run by the USCG at 12 “particularly confined and busy waterways” around the country at providing active monitoring and navigation advice to mariners primarily via radiotelephone (U.S. Coast Guard 2014d). Performance measures related to VTS were not considered for this report.

On inland waterways, the ability of vessels to engage in safe long-distance navigation is heavily dependent upon available navigation locks that have seen an overall increase in the cumulative duration of closures and the number of closure events over the past decade (Figure 11). Unscheduled closures of navigation locks are considered more disruptive to navigation because they preclude planning ahead by the shipping companies. Estimating the immediate cost from a single closure at a specific lock would depend on multiple factors such as time of year, duration of closure, and number of shipments delayed. Since 2001, total inland waterway tonnage has varied between 1.2 billion to 1.4 billion tons per year (U.S. Army Corps of Engineers 2014d). There is uncertainty over the scale of future maintenance needs for inland navigation infrastructure. While the number of closures fluctuate from year to year, any single year from 2000 to 2013 had more total closures than any single year from 1993 to 1999 (Figure 10). A quantitative analysis on the true extent of vessel congestion remains to be developed, but ongoing research in the area of travel time estimates (Figure 13 and Chapter 6) should provide more insight into areas that face repeated vessel congestion and the performance and reliability of specific waterway segments.

7.3 Safety and Security

The MTS is a geographically diverse system, with domestic and international crews and vessels operating under all weather conditions. While an MTS that is free of accidents and injuries is a worthy goal, it simply is not possible for a system as large, disparate, and complex as the national MTS. Despite the variety of hazards associated with maritime activities, the number of casualties associated with commercial operations in U.S. waters has been relatively stable over the past decade (Figures 14–16) (U.S. Coast Guard 2014a). While it may not be possible to prevent every accident, there is a clear need for continued oversight and emergency response capability across the MTS. Greater understanding of the human factors that contribute to accidents is expected to improve safety; research on this topic is being carried out through groups such as the TRB Committee on Marine Safety and Human Factors (Transportation Research Board 2015). However, at present, there are no standardized and widely available public statistics on the effectiveness of specific marine safety interventions. An assessment of MTS security is not possible based on the public data gathered for this report, but research in this area is ongoing.

7.4 Environmental Stewardship

Environmental stewardship is a multifaceted concept for the MTS since it operates across estuarine, freshwater, coastal, and offshore environments that vary greatly in their physical and biological conditions as well as their spatial extent. MTS environmental stewardship considerations are also complex because they span the air, water column, and benthic environments which MTS operations can impact. Identifying and refining key environmental stewardship performance measures will continue. In the interim, preliminary measures that pertain to at least one aspect of air, water column, or benthic environments have been identified. Since air quality is impacted by the burning of fossil fuels, it is possible that air pollutants from the MTS are declining, as reflected in the overall decline in distillate fuel oil sales to maritime consumers since a high point in the late 1990s (Figure 17) (U. S Department of Energy 2013). It is possible that increases in engine efficiency and national or international changes in emissions standards will result in further declines in petroleum-based fuel use. The implementation of Emission Control Areas for U.S. coastal waters and the associated engine emission standards and fuel sulfur limits is expected to reduce air pollution (U.S. Environmental Protection Agency 2014b) and is a topic for future performance measure development.

Changes in fuel emissions regulations are spurring an interest in alternative fuels such as natural gas (World Maritime News 2015) and biodiesel, but it will take the conversion of numerous vessels to make a significant impact on national emissions estimates. In the meantime, local communities in port areas may continue to press for operational changes to improve air quality in response to health concerns. Lacking at present are emissions calculations that include contributions from fuel sold in foreign countries but burned by vessels operating in U.S. waters. As with most transportation modes that rely on liquid fuels, pollution events continue to be a problem although USCG records indicate a slight decline in cases of vessel-based pollution in recent years (Figure 18) (U.S. Coast Guard 2014a). Whether this trend continues remains to be seen; however, reductions in petroleum-based fuel use would be expected to reduce the overall likelihood of petroleum pollution events.

Activities associated with navigation channel maintenance (e.g., jetty reconstruction, dredging, and dredge material placement) present their own types of environmental stewardship considerations. In the short term, environmental considerations are often focused on local benthic and water column environments during construction or dredging-related activities. However, longer-term environmental stewardship might consider the potential relationship between these activities and habitat creation or loss. For sediment dredged out of channels by USACE, there is no distinct trend of increasing beneficial use of this material. Both the percentage and cubic yardage of dredged materials used for wetland nourishment dropped from 2008 to 2013; however, there was a general increase in the cubic yardage and percentage of sediments used for beach nourishment over the same time period (Figure 19) (U.S. Army Corps of Engineers 2014c). Assessments that might reveal regional drivers underlying these national trends (e.g., Hurricane Sandy recovery activities) are not included in this report. One caveat to this interpretation is the limitation on the level of detail available in dredge material placement records as well as regional discrepancies in defining what type of placement qualifies as beneficial use. It is possible that more refined data categories for dredge material placement would reveal different trends. More detailed geographical data would be needed to assess the creation of specific habitat types from beneficially reused sediments. In the water column, interactions between commercial vessels and species of concern such as marine mammals appear to be stable (Figure 20), but within the scientific community, there is believed to be vast underreporting of these events and significant regional variation (Henry et al. 2012; Glass et al. 2008). Useful performance measurement on key topics such as the frequency of new aquatic species introductions, or the rate at which introductions become invasions, remain to be developed.

7.5 Resilience

The term *resilience* is defined by the CMTS Resilience Integrated Action Team as “the ability to prepare and plan for, resist, recover from, and more successfully adapt to the impacts of adverse events” (U.S. Committee on the Marine Transportation System 2015). MTS operations are ultimately inseparable from landside systems, but defining any system requires drawing logical boundaries. For this research, MTS-specific physical infrastructure is the initial boundary condition for examining resilience. Along inland waterways, major public infrastructure in the form of locks, dams, and bridges, continues to age, with uncertain effects on future service capabilities and maintenance costs. The present resilience of these structures within an integrated system might be reflected in historical maintenance needs, but defining such a relationship requires further study. For critical coastal and Great Lakes navigation infrastructure (e.g., rubble-mound jetty and breakwater structures) owned by USACE, a potential measure of the capacity to achieve a desired function could be derived from data on physical rating used as an indicator of resilience. Results from a recent evaluation of this infrastructure portfolio showed the most common physical rating to be a “B”, with grades ranging from “A” (second most common grade) to “F” (Figure 21) (U.S. Army Corps of Engineers 2013b). The relationship between physical rating (an engineering evaluation) and level of service (an operational or functional evaluation) varies, and more detailed information is needed to improve understanding in this area. The level of resilience for privately owned infrastructure such as container terminals or other port facilities was not evaluated as part of this research but is an important consideration for all MTS stakeholders because of the critical nature of these interchange points. If standardized metrics applicable to all ports and locations were available, they would be valuable to this research. Additional resilience measures could potentially be developed from records of shoreline change such as those provided by the National Coastal Mapping Program (U.S. Army Corps of Engineers 2015b).

8 Future Research Directions

Future research efforts towards marine transportation performance measures will need to address a number of existing gaps and also leverage new technologies, data sets, and systems-based methodologies. Technologies such as AIS, designed for real-time monitoring, can be utilized beyond their original purpose to provide historical data; this may be possible for other data sources as well. However, not all information will be provided in real time, and for some measures it will not be necessary to do so. Conversely, it is possible that historical data, such as standardized travel time estimates, will be incorporated into real-time system monitoring to help operators as tools and technologies respond to data availability and user demand.

MTS research projects already underway include development of an MTS freight flow database that includes international shipments and receipts as well as domestic intermodal connections and disaggregation estimates along primary waterway freight corridors. Relevant research programs within Federal agencies and academia exist (e.g., USDOT, Oak Ridge National Lab, University of Kentucky, University of Arkansas); any future research would strive to be complementary to, or in direct collaboration with, those programs in order to leverage the existing variety of transportation research expertise.

8.1 Systems analysis and optimization

A complete MTS performance model, including contributions from the landside modes of transportation, can inform discussions and answer questions concerning how changes in the underlying freight demand (via population shifts, economic growth/downturns, and/or changing societal preferences) and MTS availability will affect waterborne freight flows and overall system performance. However, there will still be a need for rigorous evaluation of a full range of scenarios in order to optimize decision making related to MTS investments, operations, and maintenance. The manner in which limited Federal resources are allocated across the vast MTS (through the various MTS member agencies as well as through subdepartments and business areas within those agencies) determines the resulting availability of individual segments and overall system reliability. Additionally, O&M decisions determine the frequencies, width and depths to which navigation channels are dredged, the reliability of inland locks, and many other aspects of MTS performance. In order to achieve optimal MTS system performance, these decisions need to be rigorously evaluated through structured optimization approaches that account for the myriad interdependencies that exist between ports, waterways, inland rivers, and landside intermodal facilities. Future work is needed to apply operations research (OR) techniques and approaches to MTS decision making. As new technologies provide for ever-increasing amounts of detailed data, and as freight demand and flow modeling capabilities continue to improve, the need for truly optimal MTS decision making will only continue to grow. Responsible stewardship of taxpayer dollars demands that all available information and analysis capabilities be leveraged towards objective, rational, and transparent decision making concerning investments in, operations, and maintenance of the MTS.

8.2 Identification of critical intermodal freight corridors

Freight patterns within the U.S. are highly dynamic and are influenced by a host of factors including industry demands, demographics, and infrastructure provision. Due to the extensive interstate highway system as well as state and locally maintained roads, freight that travels on trucks via highways can almost always take multiple viable routes between an origin-destination (OD). To a lesser extent, the same is true for rail freight, whereas waterborne freight is the most limited, with origins, destination, and routes confined to the relatively limited (when compared to the highway and rail systems) network of navigable ports and waterways. For truck freight, OD information alone does not necessarily provide reliable information about the specific route(s) taken. This is especially true if the OD data is aggregated to a regional level, which is almost always the case due to data-set limitations and concern over release of proprietary supply chain details. There is interest in identifying the criticality of specific sections of transportation networks, such as sections that act as bottlenecks or carry highly valued freight and might benefit from expansion or upgrade of the infrastructure.

The future direction of MTS performance measures research will incorporate intermodal movements to a greater extent. By coupling the land-side freight flow estimates from the USDOT's Freight Analysis Framework (FAF) (U.S. Department of Transportation, Federal Highway Administration 2014a) and other data sets where possible with recorded waterborne freight flows, the continuous multimodal freight corridors can be identified and used to inform analysis. These freight corridors can be developed according to industry sector, supply chain, or other theme of interest. Such a data set for the intermodal freight network would facilitate scenario comparisons as well as operational decision making for the MTS. Understanding the role of the MTS within a single intermodal surface transportation network that allows for supply chains to span multiple modes will require a combination of data sets.

8.2.1 Waterborne freight network modeling with landside connections for operational decision making

Improved capabilities are needed to evaluate system-level impacts from service interruptions in parts of the MTS (port closures, lock outages, etc.), port deepenings and/or landside capacity increases, and shifts in regional and national commodity flows, among other factors. Capabilities such as these could also inform "what if?" scenario planning questions for air emissions, traffic congestion, and cargo flows between and through ports resulting from significant changes elsewhere within the MTS. The following sections describe research areas that can be developed to answer focused questions once posed.

Sample research questions:

- *How has demand for major commodities shifted geographically over the past 20, 30, or 50 years, and what modes have been most affected?*
- *To what degree might the expanded Panama Canal affect overland freight shipment patterns between the U.S. East and West Coasts?*
- *How has road congestion changed in port areas after infrastructure expansions?*

8.2.2 Origin-destination (OD) freight demands

A more nuanced understanding of the underlying economic forces that determine the volumes and types of freight that move globally, nationally, and regionally will assist in intermodal freight flow model development. Freight demands are as dynamic and complex as the populations from which they originate. Data sets such as the Commodity Flow Survey (Bureau of Transportation Statistics 2014), the Carload Waybill Sample (Surface Transportation Board 2015), and the *Waterborne Commerce of the United States* reports (U.S. Army Corps of Engineers 2013a) provide representative samples of historic OD freight flow data; however, to ensure confidentiality of proprietary shipper data, the publicly available versions of these data sets are all aggregated to a fairly high level (i.e., state-to-state or region-to-region). These OD freight flow data sets represent the most readily available sources of freight demand information, particularly for high-level, national studies. However, to more fully inform operational decision making within the MTS, there is a standing need for disaggregated OD freight demand data that can provide insight down to the port level without compromising any proprietary supply chain information.

Sample research questions:

- *How quickly are underlying socioeconomic forces driving changes in freight volumes and types?*
- *The Southeast and Southwest have both seen major population growth in the last 10 years. Has that significantly affected MTS freight movements to those regions, or has demand been met through landside transportation modes?*

8.2.3 Resulting freight flows across modes

For a given level of freight demand between two locations, the transportation costs of the various available modes (road, rail, water, air, pipeline), as well as a host of localized factors and constraints and shipper and carrier-specific considerations, determine the respective volumes of cargo flowing through each. Transportation costs are a function of many factors, including distance traveled, fuel costs, transit time, handling and/or transfer costs, drayage time, and mode reliability and safety. Much work has been done on understanding and modeling the complex economics of freight shipping logistics, mode choice, and the resulting supply chains and freight corridors. There have been many economic studies looking at the *elasticity* of freight flow volumes across the respective modes as supply, demand, transportation costs, and network availability all fluctuate. Future research and development efforts for the MTS need to more fully integrate these freight flow theories to ensure that predicted changes in MTS and intermodal system cargo flows (as a result of port and/or segment outages, expansions; shifts in underlying OD freight demands) are based upon a sound and consistent economics knowledge base.

Sample research question:

- *What are expected changes in the MTS portion of intermodal cargo flows under different economic scenarios?*

8.2.4 MTS performance evaluation within broader intermodal freight network

The physical condition (availability) of an MTS segment combined with the traffic load using that segment both contribute to the overall level of service. Traffic congestion delays, reduced channel depths due to shoaling, and service outages at navigation locks reduce the efficiency by which freight moves through the MTS and drive up overall shipping costs. Additionally, landside freight flow capacity constraints, particularly those in urban areas such as processing delays at container drayage yards, congested roadway connectors, and limited numbers of rail lines, may serve to limit the freight flows through MTS segments well below their theoretical capacities. Much future work is needed to better understand the role of landside freight flow capacity constraints on MTS cargo flows, and vice versa. A recently completed study sponsored by the National Cooperative Freight Research Program (NCFRP) (Kruse et al. 2014) addresses this very question. As described within the final report, even when commodity types and volumes can be tracked across modes to reconstruct intermodal supply chains, there remains a need to be able to evaluate *performance* of the respective modes and more fully understand their contribution to overall system efficiency.

Sample research question:

- *Do landside capacity limits affect waterside freight flows and vice versa? If so, to what extent?*

8.3 Data mining and knowledge extraction

Unprecedented amounts of MTS and landside freight data are increasingly becoming available via an array of new and emerging technologies (e.g., AIS, GPS, shipment tracking, mobile devices); however, extracting new knowledge from these vast stores of information presents significant R&D challenges, particularly in regards to database architecture for computationally efficient data processing and querying. Yet it is exactly this sort of new knowledge that is needed to inform many of the open, longstanding questions concerning many of the MTS and intermodal freight network dynamics and performance baselines mentioned previously. An example of such an effort is the AIS analysis being conducted at the U.S. Army Engineer Research and Development Center (ERDC). The research requires knowledge of both transportation systems and of data architecture; disciplines that historically have little overlap. Therefore, a team was formed of both civil and transportation engineers and of computer scientists to develop methodologies to manage the data efficiently and analyze it for meaningful results as part of an ongoing research effort.

8.3.1 Mining and analysis of reported MTS user data

Though there is a need for more complete and readily available OD freight flow data, there is also a broader need to utilize existing data sources towards more rigorous and comprehensive analysis of MTS performance. Publicly available *Waterborne Commerce* records, Entrance and Clearance records from U.S. Customs, dredging records from the Corps' Dredging Information System (DIS), incident reports from the USCG, and publicly available cruise and ferry passenger data are just some examples of rich, existing public data sets that allow for many aspects of MTS performance to be quantified and evaluated through time. Ongoing research and development (R&D) efforts in support of the CMTS as well as a newly initiated Maritime Data Roundtable will help produce gains along these lines of study. Improvements in raw data collection by any data provider (e.g., transitioning from manual to automatic reporting, improvements in quality assurance, reduced time between collection and publication) will also support more in-depth and timely analysis.

Sample research questions:

- *What is the full extent of available MTS data?*
- *What operational practices promote data publication?*

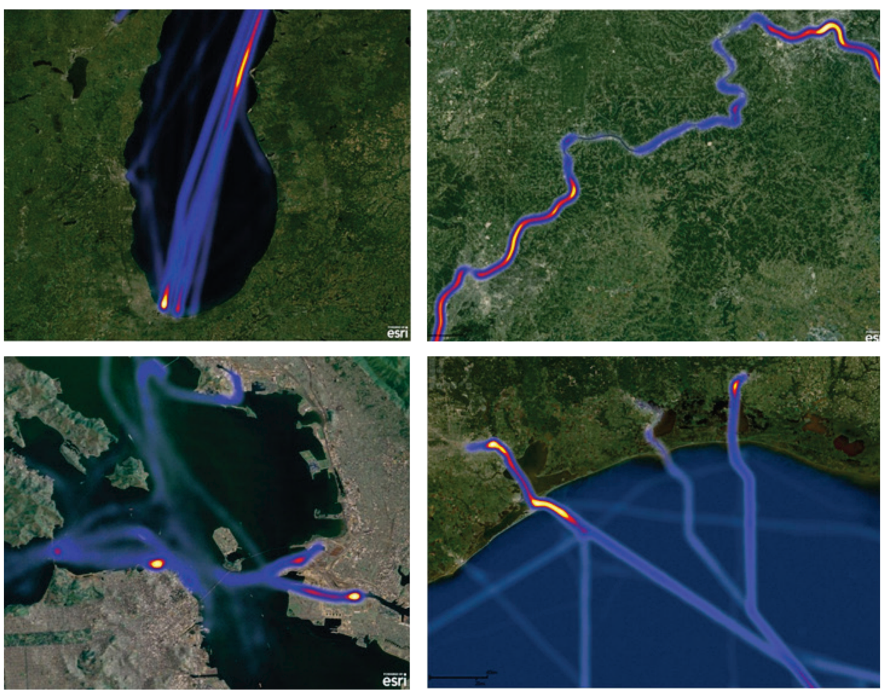
8.3.2 MTS performance monitoring via AIS

Archived AIS vessel position reports represent a wealth of information that can potentially transform the understanding of MTS dynamics and performance trends through time. Though this data source as yet does not contain direct insight into specific commodity types and volumes, there are nonetheless tremendous levels of insight provided into an almost unlimited number of aspects of MTS performance. From straightforward questions such as vessel counts and OD transits to more advanced analytics such as tidal sensitivity parameters (Mitchell and Scully 2014) or average vessel speeds, archived AIS data offers a path forward for quantifying system behavior to an unprecedented degree (Figure 28). This is not to say that challenges are not present. The sheer size of the data sets created by the AIS technology (hundreds of gigabytes of data produced daily for the entire MTS) means that the analysis techniques and data processing algorithms need to be streamlined and optimized for practical application. Furthermore, it is not yet clear to what extent many of the metrics and analytics produced from the AIS data are truly representative of MTS performance per se. These and other questions remain for researchers and MTS stakeholders to undertake.

Sample research questions:

- *How long, and to what extent, did weather conditions associated with Hurricane Sandy affect vessel traffic along the U.S. East Coast in 2012?*
- *Did diverted vessel traffic cause congestion to occur in other ports as a response to these weather conditions?*
- *Can future vessel congestion be predicted from historical AIS records?*

Figure 28. Sample density plots of AIS coverage for (clockwise from upper left) Lake Michigan, middle Ohio River, northeast Texas coast, and San Francisco Bay, CA. Figures for illustrative purposes only; each uses different combinations of vessels, time-span, time of year, and scale.



8.4 Research technical challenges

Each research project brings its own set of technical challenges, some of these challenges have been listed in the body of this report while others are being addressed through existing research programs. Broad technical challenges for MTS performance measures research are summarized below.

- Fulfill the need to conceptually link and technically align disparate data sets, such as environmental and demographic data, and to develop acceptable methods to analyze different data sets due to lack of standardized metrics and data collection from multiple entities.
- Develop methods that couple marine freight data with landside data to provide insight into the interdependencies between waterways, road, and rail.
- Fulfill the need to define *level of service* and then quantify *level of service* across different transportation modes.
- Provide access to data for private industry operations which may be confidential or not uniformly available at a national level.
- Fulfill the need for an authoritative AIS data source to maintain quality metadata, ease of data access, and usage standards for research
- Improve the ability to combine physical environmental data such as river flow with AIS data to understand the interaction between operating conditions and vessel behavior.
- Continue efforts on freight scenario planning, some of which are currently being led by USDOT.
- Improve freight transportation operations across modes to reduce harmful impacts to passengers and communities
- Identify the most useful parameters for research scenario development such as combinations of resource constraints, shifting demographics and drivers of demand, changes in infrastructures stresses, etc. This could expand upon the line of research described in NCFRP Report 32 that examined commodity flows utilizing the deepest drafts of navigation channels at five ports (Kruse et al. 2014).
- Determine how to link performance measurement to specific spending decisions or policy directives and ensure accurate ways to monitor the outcomes of investment decisions over appropriate time spans.
- Continue the development of analysis techniques and data processing algorithms to handle the large amounts of raw data produced by AIS technology.
- Develop analysis methods that can be scaled up or down to answer questions at varying temporal or spatial scales in reasonable amounts of time.
- Measure the value of low-volume or low-tonnage freight movement with regards to regional or sectoral significance.

- Identify and data source measures that serve as proxies for resilience.

The field of intermodal transportation performance measures is still in its infancy; organizations such as TRB recognize this situation. In response, TRB has sponsored workshops to bring attention to these new questions that are being asked about freight flows, supply chains, and transportation planning for a future that might require different solutions than those employed over the past century. Examples of recent conferences include "Development of Freight Fluidity Performance Measures" in May 2014; "Barge and Rail Symposium: Moving Freight between Multimodal Systems" in August 2013; and "Adapting Freight Models and Traditional Freight Data Programs for Performance Measurement Workshop" in April 2013 (Transportation Research Board of the National Academies 2015).

Intermodal performance research deals with a complex system in which the Nation has almost total control over the physical structure but much less insight into the daily interactions among all the pieces. MTS research has an advantage in an extensive history of available waterborne freight data, the recent addition of AIS data, and overall stability of the network. What is needed is a way to combine information from existing sources that have primarily been built to furnish statistical answers about commerce, with other relevant and emerging sources, and then provide answers to new questions in areas such as environmental stewardship, capacity, and resilience.

9 Summary and Recommendations

As illustrated throughout this report, MTS performance measures encompass many types of data from multiple types of sources. Some of these sources have more mature data acquisition and publication practices while others are in their early stages of development. Performance measures research on the marine transportation system within the United States benefits from robust national data collection programs through agencies such as the Bureau of Labor Statistics (Bureau of Labor Statistics 2014b), Census Bureau (U.S. Census Bureau, U.S. Dept of Commerce 2015), USACE (U.S. Army Corps of Engineers 2014c), the National Oceanic and Atmospheric Administration (National Oceanic and Atmospheric Administration 2013c), Department of Transportation (U.S. Department of Transportation 2014), USCG (U.S. Coast Guard 2014b), and the EPA (U.S. Environmental Protection Agency 2014a). Unlocking these rich collections of data has great potential to improve the multifaceted understanding of MTS performance.

Research on MTS performance is far from complete. User priorities will continue to drive the need for increased understanding of how MTS components work together to move cargo and passengers. Some measurements will likely come into greater focus as their utility is realized by multiple user groups while others may prove to be less informative for decision making. Understanding the state of physical assets such as channels, breakwaters, and port property will not in and of itself make the MTS function more efficiently but has relevance to maintenance and resilience planning efforts. It is possible that changes in use patterns and operational practices will be more feasible than infrastructure expansion in areas of congestion. Communication and collaboration among stakeholders will be necessary to make major improvements to the MTS. In the case of port capacity, the 2008 *National Strategy for the Marine Transportation System* pointed out that improving port capacity would require "coordinated action by public and private entities and may entail improving the Federal navigation channels, the intermodal connectors to railways and highways, and communication with industry on port conditions to enable vessel operators and owners to better time their vessel movements" (U.S. Committee on the Marine Transportation System 2008). The result of improved communication and coordination could be a greater harmonization and vertical integration of operations while maintaining independence among users.

Fundamental to improved communication and understanding will be the collection and sharing of data. Multiple research efforts have pointed to the lack of public data that could inform this kind of work, especially in the context of an intermodal transportation network. A 2014 publication from the Texas A&M Transportation Institute noted 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 [transportation] modes and almost no accurate data on origins and destinations (in the case of publicly available data)” (Kruse et al. 2014). Proprietary data will continue to be collected by parties in both the private and government sectors, but new data sharing agreements might be required to make significant progress on modeling efforts. Any research effort will be enhanced by a shared set of national goals for the MTS and a clear understanding of the way in which research contributes to achieving those goals. In the absence of national MTS-specific goals, the current mixture of stakeholder priorities and Federal agency mission area will continue to drive research questions.

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Appendix A: Data Sources

Example of table describing data sources for performance measures.

Category	*Category of Performance*
Measure	*Name of Specific Measure*
Source	*Name of organization or agency in charge of distributing data*
Description	*Explanation of the source of the performance measure data, how it is collected and other relevant details*
Website	*URL for authoritative data source, as of 2014*
Regulatory / Legislative Driver	*Why this data is already being collected*
Unit	*The unit of measure used (e.g., dollars, hours, ton-miles, kilograms)*
Collection Frequency	*Frequency of data collection (e.g., minutes, weekly, quarterly, yearly)*
Reporting Frequency	*How often this data is released/reported by the collecting organization (e.g., continuously, weekly, monthly, yearly)*
Geographic Scope	*Geographic reach of indicator (e.g., national, regional, state, project, port, or a combination of multiple sites)*
Objective	*The larger performance goal that this measure supports*
Application Value	*Does this performance measure directly support Operations (present state), Information (for all stakeholders), or Reference (for longer-term learning and improvement) use?*
Comment	*Informative comments if needed; may be left blank*

Category	**Economic Benefits to the Nation**
Measure	***Amount (Balance) of the Inland Waterways Trust Fund***
Source	U.S. Department of the Treasury, Bureau of the Fiscal Service, Funds Management Branch
Description	The U.S. Treasury Department is responsible for estimating, investing, and administering tax receipts from the Inland Waterways Trust Fund (IWTF), funded by a tax on fuel used by commercial towing companies on the inland and intracoastal waterways. IWTF monies form part of the U.S. Army Corps of Engineers civil works budget and are used to help pay for major construction and rehabilitation of navigation projects on the U.S. inland and intracoastal waterways (U.S. Army Corps of Engineers, Louisville District).
Website	http://www.treasurydirect.gov/govt/reports/tfmp/inwater/inwater.htm
Regulatory / Legislative Driver	There are no limits associated with the IWTF amount; legislation determines allowable uses of funds collected.
Unit	U.S. dollars
Collection Frequency	Monthly
Reporting Frequency	Monthly – The balance of the IWTF is reported online in PDF format.
Geographic Scope	Nationwide, all inland and intracoastal waterways
Objective	Improve infrastructure investment budgeting to meet current demand
Application Value	Reference and Operation. The IWTF balance is one indication of funding levels available for navigation infrastructure projects on inland waterways.
Comment	Can also be used as an indirect measurement of commercial fuel purchases on the inland and intracoastal waterways for greenhouse gas emissions estimates

Category	**Economic Benefits to the Nation**
Measure	***Amount (Balance) of the Harbor Maintenance Trust Fund***
Source	U.S. Department of the Treasury, Bureau of the Fiscal Service, Funds Management Branch
Description	The Harbor Maintenance Trust Fund (HMTF) is capitalized by the Harbor Maintenance Tax (HMT), a Federal import tax collected from shippers based on the value of inbound cargo. The HMT and HMTF were established by the *Water Resources Development Act* of 1986 to pay 40% of the Federal cost of maintaining authorized deep draft navigation channels. The tax was increased in 1990 to cover 100% of maintenance costs (U.S. Senate Committee on Environment and Public Works, 113th Congress 2013).
Website	http://www.treasurydirect.gov/govt/reports/tfmp/hmaint/hmaint.htm
Regulatory / Legislative Driver	HMTF monies must be used for authorized navigation channel maintenance, *Water Resources Development Act* of 1986 (U.S. Senate Committee on Environment and Public Works, 113th Congress 2013).
Unit	U.S. dollars
Collection Frequency	Monthly
Reporting Frequency	Monthly—The balance of the HMTF is reported online in PDF format.
Geographic Scope	Nationwide, all ports that receive imports
Objective	Improve budgeting to meet current demand
Application Value	Reference and Operation—The HMTF balance is one indication of funding levels available for maintenance.
Comment	(no comment)

Category	Economic Benefits to the Nation
Measure	*Number of Jobs in Water Transportation Industries*
Source	U.S. Department of Commerce, Census Bureau
Description	Employment data are collected by the Economic Census every 5 years (U.S. Census Bureau, Economic Planning and Coordination Division 2014). Quarterly Workforce Indicators (QWI) are updated four times per year based on state and local administrative data. Both use the North American Industry Classification System (NAICS) 2-digit codes for categories like “transportation and warehousing” (codes 48-49). Subcategories use 3-digit codes (e.g., water transportation [code 483]). 4-digit codes provide the greatest level of detail for a sub-subcategory (e.g., deep sea, coastal, and the Great Lakes water transportation [code 4831]).
Website	http://www.census.gov/econ/isp/sampler.php?naicscode=483&naicslevel=3
Regulatory / Legislative Driver	The Census Bureau operates under Title 13 and Title 26 of the U.S. Code.
Unit	Number of employees within an NAICS sector
Collection Frequency	Economic Census–every 5 years, data from 2002–ongoing. QWI – ongoing collection/reporting by states
Reporting Frequency	Economic Census–every 5 years, with a 2+ year lag QWI - quarterly, with approximate 9-month time lag
Geographic Scope	Economic Census–national, all states and territories QWI–state, county, metropolitan areas
Objective	Direct employment in the MTS is a conservative measure of how many jobs the overall industry supports.
Application Value	Reference (long-term trends in MTS employment)
Comment	Queries for QWI state-level data: ledextract.ces.census.gov

Category	Economic Benefits to the Nation
Measure	*Total Value of International Trade in Goods (Imports and Exports)*
Source	U.S. Department of Commerce, U.S. Census Bureau
Description	Information about the value of U.S. trade in goods and services is collected as part of the U.S. Census Bureau's economic statistics program. Monthly and quarterly economic indicators for the nation are published online (U.S. Census Bureau 2012). Export statistics cover goods valued at $2,500 or more; import statistics are for goods valued at $2,000 or more per commodity (U.S. Census Bureau 2012). Data on export/import vessel values, vessel shipping weights, containerized vessel value, and containerized vessel shipping weight by port are available in the Port HS6 Databases, available for purchase from the U.S. Census Bureau.
Website	http://www.census.gov/foreign-trade/Press-Release/current_press_release/
Regulatory / Legislative Driver	United States Code, Title 13, requires this program; participation is mandatory. The U.S. Treasury Department assists in the execution of this program (U.S. Census Bureau 2012).
Unit	U.S. dollars
Collection Frequency	Monthly
Reporting Frequency	Monthly–reported 35 days after month end. File formats: PDF, TXT, XLS
Geographic Scope	Nationwide
Objective	The MTS carries a significant percentage of internationally traded goods. Transportation of goods is critical to the U.S. economy; valuing international trade reveals how the MTS supports the economy.
Application Value	Reference
Comment	This measure includes only internationally traded goods, not domestic movements of freight.

Category	**Economic Benefits to the Nation**
Measure	***Producer Price Index: Transportation and Warehousing Services***
Source	U.S. Department of Labor, Bureau of Labor Statistics
Description	The Producer Price Index (PPI) measures the average change over time in the selling prices received by domestic producers for their output. The prices included in the PPI are from the first commercial transaction for many products and some services.(Bureau of Labor Statistics 2014a) The category “transportation and warehousing services for intermediate demand” includes transportation of freight by rail, truck, water, air, and pipeline transportation of petroleum products. Data for subcategories dealing with more specific elements of waterborne transportation are also available.
Website	http://www.bls.gov/ppi/
Regulatory / Legislative Driver	None specified
Unit	Percentage change from index start date (1982)
Collection Frequency	Monthly
Reporting Frequency	Monthly. Available file format: HTML, PDF
Geographic Scope	National
Objective	Over time, comparisons between the PPI for different services can show how fast prices are changing across freight transportation modes.
Application Value	Operations, Reference
Comment	Data can be downloaded in .XLS format via the One-Screen Data Search tool available at http://data.bls.gov/pdq/querytool.jsp?survey=pc .

Category	Safety and Security
Measure	*Number of Nonroutine Vessel Contacts by USCG*
Source	U.S. Department of Homeland Security, USCG
Description	The USCG Port State Information Exchange (PSIX) System is a searchable public database that provides a weekly snapshot of data covered under the *Freedom of Information Act* (FOIA) related to USCG contacts with U.S. flag vessels and foreign vessels operating in U.S. waters (U.S. Coast Guard 2014c). This information is collected and stored as part of the larger Marine Information for Safety and Law Enforcement (MISLE) system. The PSIX allows users to search for an individual vessel's USCG contact history (*Vessel Search*) or all USCG vessel contacts (*Vessel Contact Search*) for a given vessel flag country, classification society, type, tonnage, or date range.
Website	https://cgmix.uscg.mil/PSIX/Default.aspx
Regulatory / Legislative Driver	Data collection on vessel contacts serves the 11 USCG missions that include coastal security, law enforcement, marine safety, and marine environmental protection.
Unit	Number of incidents that required USCG contact with vessel, type of incident
Collection Frequency	Ongoing
Reporting Frequency	Weekly release online
Geographic Scope	National
Objective	This performance measure relates to MTS vessel operations in the broader context of safe operation, suspicious activity, and crew member safety.
Application Value	Operations (recent vessel contacts), Reference (changes in vessel contact trends since 1989)
Comment	As of May 2014, bulk export of USCG data from the PSIX database requires the use of XML webservice.

Category	***Safety and Security***
Measure	***Number of Commercial Mariner Deaths and Injuries (Proxy Metric)***
Source	U.S. Department of Homeland Security, USCG
Description	The USCG collects information on marine accidents resulting in injury or death of commercial mariners as part of its marine safety mission. The Marine Casualty and Pollution Data files provide details about incidents investigated by USCG offices in the United States from the MISLE database (U.S. Coast Guard 2014a).
Website	https://homeport.uscg.mil/mycg/portal/ep/home.do >> Investigations >> Marine Casualty/Pollution Investigations >> Marine Casualty and Pollution Data for Researchers
Regulatory / Legislative Driver	Data collection on commercial mariner deaths and injuries serves USCG missions that include marine safety, search and rescue, and law enforcement.
Unit	Number of injuries, number of deaths
Collection Frequency	Ongoing, as incidents occur and are reported to USCG
Reporting Frequency	Data is reported annually but with a time lag. It is unclear if USCG plans to release data in a different format or timeframe in future.
Geographic Scope	National
Objective	Mariner safety is a critical component to a well-functioning marine transportation system.
Application Value	Information (mariners and regulators have an interest in workplace safety), Reference (identify changes in overall operating conditions)
Comment	As of May 2014: MISLE data files contain records starting in 1982 (marine casualties) or 1973 (polluting incidents) through July 2013.

Category	*Category of Performance*
Measure	***Number of Commercial Vessel Accidents***
Source	U.S. Department of Homeland Security, USCG
Description	The USCG collects information about recreational and commercial vessel accidents, including on-water collisions, allisions, and pollution discharge incidents. Accidents that involve injury to humans are also investigated and reported as marine casualties; enforcement actions or corrective suggestions are noted in accident records.
Website	https://homeport.uscg.mil/mycg/portal/ep/browse.do?channelId=-18374
Regulatory / Legislative Driver	The USCG investigates accidents under its authority (Part D of Title 46, U.S. Code) to enforce U.S. laws and protect public safety.
Unit	Number of accidents
Collection Frequency	Ongoing, as incidents occur
Reporting Frequency	Annually, possibly more frequent
Geographic Scope	National
Objective	Recording the location, type, and severity of vessel accidents can help identify dangerous operating conditions and the need for improved operator guidance.
Application Value	Reference (historical data series)
Comment	(no comment)

Category	*Safety and Security*
Measure	*Number of USCG Incident Investigations*
Source	U.S. Department of Homeland Security, USCG
Description	The USCG investigates and records incidents related to maritime safety, law enforcement, pollution incidents, and other maritime operational issues. Incident investigation records include information about the vessel, organization, and facility involved.
Website	homeport.uscg.mil/mycg/portal/ep/home.do Marine Casualty and Pollution Data for Researchers, *MISLE DATA file*
Regulatory / Legislative Driver	The USCG investigates accidents under its authority (Part D of Title 46, U.S. Code) to enforce U.S. laws and protect public safety.
Unit	Number of investigations
Collection Frequency	Ongoing
Reporting Frequency	Monthly, with an approximate 3-month lag
Geographic Scope	National
Objective	The number of incidents that are investigated can reflect changing operational conditions for USCG enforcement activities.
Application Value	Reference (historical data series)
Comment	Combining this measure with a measure of resource availability (e.g., staff and funding) and the total number of incidents would provide more nuanced information.

Category	*Environmental Stewardship*
Measure	*Petroleum-Based Fuel Use by the U.S. Maritime Industry*
Source	U.S. Department of Energy, Energy Information Administration (EIA)
Description	The EIA reports annual sales volumes for distillate fuel oil (diesel) and residual fuel oil, fuels sold for use by maritime industry consumers under the end use category of vessel bunkering. Vessel bunkering consumers include private recreational boats and vessels. Vessel bunkering sales reported by the EIA do not including military sales.
Website	http://www.eia.gov/dnav/pet/pet_cons_821use_dcu_nus_a.htm
Regulatory / Legislative Driver	The EIA annual survey of sales data for distillates, residual fuel oils, and kerosene
Unit	1000 gallons
Collection Frequency	Annual
Reporting Frequency	Yearly–vessel bunkering end use category sales, with 1+ year lag Monthly–petroleum product prices and volumes, not broken down by end use category
Geographic Scope	National, state, and Petroleum Administration for Defense District (PADD) regions
Objective	Reducing the environmental impacts of MTS operations through reductions in fuel consumption requires accurate information about usage levels.
Application Value	Operational (near-recent usage levels), Reference (historical information about MTS fuel usage)
Comment	Monthly sale prices and volumes for petroleum products at National, regional, and state level, http://www.eia.gov/petroleum/marketing/monthly/

Category	*Environmental Stewardship*
Measure	*Number of Recorded Whale Strikes*
Source	U.S. Department of Commerce, NOAA, Office of Protected Resources
Description	Marine mammals are subject to legal protections under the *Marine Mammal Protection Act;* some species are also protected under the *Endangered Species Act*. Collecting information on vessel strikes or injuries from vessel interactions helps understand the level of impact these interactions have on marine mammal species or stocks (National Oceanic and Atmospheric Administration 2013a).
Website	http://nefsc.noaa.gov/publications/crd/crd1211/crd1211.pdf http://www.nmfs.noaa.gov/pr/sars/region.htm
Regulatory / Legislative Driver	The *Marine Mammal Protection Act* of 1972 (amended in 1994) provides for the preparation of stock assessments for all marine mammal stocks in U.S. waters.
Unit	Number of mortalities and serious injuries for Baleen whales
Collection Frequency	Ongoing, as whale strikes are reported or injured whales are observed
Reporting Frequency	Every 4 years, with an approximate 2-year data lag
Geographic Scope	All waters under U.S. jurisdiction
Objective	Reducing whale strikes is part of minimizing the overall environmental impacts of MTS operations.
Application Value	Reference (historical data series)
Comment	Official numbers are considered serious underestimates due to the difficulty of monitoring whale populations and reliance on self-reporting of vessel strikes.

Category	*Environmental Stewardship*
Measure	***Number of U.S. Ports and Terminals Holding Valid MARPOL COA (Proxy)***
Source	U.S. Department of Homeland Security, USCG
Description	The International Convention for the Prevention of Pollution from Ships (MARPOL) sets standards limiting the release of the following pollutants from ships: garbage, sulfur dioxide and nitrogen oxide air emissions, sewage, noxious liquids, and oil (International Maritime Organization [IMO] 2014). The USCG MARPOL Service Facilities database contains a searchable list of U.S. ports and terminals holding valid MARPOL Certificates of Adequacy (COAs). COAs demonstrate that facilities meet the requirements of specific sections of MARPO, known as Annexes I, II, and V (dealing with different pollutants).
Website	http://cgmix.uscg.mil/MARPOL/MARPOLSearch.aspx
Regulatory / Legislative Driver	Data collection on port and terminal facilities serves USCG missions including law enforcement and marine environmental protection.
Unit	Number of certificates of adequacy (COA)
Collection Frequency	Ongoing, as facilities acquire COAs
Reporting Frequency	Weekly updates to the MARPOL Service Facilities database
Geographic Scope	National
Objective	Maintaining and using pollution prevention facilities is part of minimizing the overall environmental impacts of MTS operations.
Application Value	Operations (location and current MARPOL services available)
Comment	As of May 2014: Bulk download from this database requires the use of XML webservices via http://cgmix.uscg.mil/XML/Default.aspx .

Category	*Environmental Stewardship*
Measure	*Marine Pollution Incidents and Discharge Volumes*
Source	U.S. Department of Homeland Security, USCG
Description	The USCG responds to and investigates marine pollution incidents. Data collection for pollution incidents began in 1973. The USCG publishes multiple data files available for public download including *Notable Oil Spills in U.S. Waters 1989 to 2011*, *Oil Spill Compendium 1969 to 2011*, and *Marine Casualty and Pollution Data for Researchers* (updated annually).
Website	https://homeport.uscg.mil/mycg/portal/ep/programView.do?channelId=-18374&programId=91343&programPage=%2Fep%2Fprogram%2Feditorial.jsp&pageTypeId=13489
Regulatory / Legislative Driver	The USCG investigates accidents and pollution incidents under its authority to enforce U.S. laws and protect public safety.
Unit	Oil spill incidents (gallons)
Collection Frequency	Ongoing, as incidents occur
Reporting Frequency	Periodic, at least annually for the *Marine Casualty and Pollution Data for Researchers* public file.
Geographic Scope	National
Objective	Recording and tracking marine pollution incidents can help identify repeat offenders, hazardous conditions, and changes in pollutant discharges.
Application Value	Reference (historical data series)
Comment	(no comment)

Category	*Environmental Stewardship*
Measure	*Amount of Dredged Material Reclaimed for Beneficial Use*
Source	U.S. DoD, USACE
Description	Federal navigation channels require varying amounts of dredging to maintain safe operating conditions. Uncontaminated dredged sediment can be disposed of in multiple ways, some of which provide quantifiable environmental benefits such as shallow-water habitat creation or wetland nourishment. Individual project dredging contracts have a placement method listed as part of the contract specifications.
Website	http://www.navigationdatacenter.us/dredge/drgdisp.htm
Regulatory / Legislative Driver	None
Unit	Cubic yards of dredged material
Collection Frequency	Ongoing, project by project
Reporting Frequency	Annual
Geographic Scope	National (reported), but data exists for specific projects
Objective	Reusing dredged material retains sediment in the system and can be less energy intensive than historical placement practices such as offshore disposal.
Application Value	Reference (historical information about dredge material disposal practices)
Comment	Information on the dredge material disposal method for individual dredging contracts is available at http://www.navigationdatacenter.us/dredge/dredge.htm

Category	*Capacity and Reliability*
Measure	***NOAA PORTS Instrumentation Availability at 59 High-Tonnage USACE Navigation Projects***
Source	U.S. Department of Commerce, NOAA
Description	NOAA's National Ocean Service provides real-time oceanographic and meteorological data to promote safe and efficient navigation within U.S. waters. The Physical Oceanographic Real-Time System (PORTS) is a decision-support tool that integrates real-time environmental observations, forecasts, and geospatial information to provide a clearer picture of the navigation environment tailored to the local community. The level of instrumentation at each PORTS installation varies according to the needs of local users (National Oceanic and Atmospheric Administration 2013b).
Website	http://tidesandcurrents.noaa.gov/ports.html
Regulatory / Legislative Driver	Oceanographic and meteorological observations are recorded as part of NOAA's mission to support safe navigation in U.S. waters.
Unit	Number of harbors with PORTS systems in place
Collection Frequency	Ongoing, as agreements are established
Reporting Frequency	As updates occur, no established reporting frequency
Geographic Scope	National
Objective	The provision of information for safe navigation contributes to the reliability of the MTS overall.
Application Value	Operations (number and location of instrumented harbors), Reference (increase in number of installations reflects utility and perceived necessity)
Comment	PORTS information is publicly accessible in a variety of formats.

Category	*Capacity and Reliability*
Measure	*Unscheduled and Scheduled Navigation Lock Downtime*
Source	U.S. DoD, USACE, Navigation Data Center
Description	Temporary lock closures are classified as *scheduled* (usually for routine maintenance) or *unscheduled* (due to weather, accidents, or emergency repairs). A record of historical lock closures, both scheduled and unscheduled, is available through the USACE.
Website	http://www.navigationdatacenter.us/lpms/lpms.htm
Regulatory / Legislative Driver	This data is collected as part of routine USACE operations and maintenance activities.
Unit	Number of lock closures (by river or by USACE Division/District)
Collection Frequency	Ongoing, as lock outages occur
Reporting Frequency	Yearly
Geographic Scope	National, all inland and coastal navigation locks
Objective	Reliable travel on inland waterways requires functioning navigation locks; historical trends in lock closures can identify maintenance needs.
Application Value	Reference (for longer-term learning and improvement)
Comment	Select data on the *current* status of navigation locks is available at corpslocks.usace.army.mil .

Category	*Capacity and Reliability*
Measure	*Navigation Lock Closures in Real-Time*
Source	U.S. DoD, USACE
Description	The Corps Locks website contains lock specific information derived from the USACE Lock Performance Monitoring System (LPMS). The information on the LPMS represents a half-hourly updated snapshot of *Freedom of Information Act* (FOIA) data on U.S. flag vessels and foreign vessels operating in U.S. waterways that transited a Corps-owned or operated lock structure (U.S. Army Corps of Engineers 2014a). Users can search for information on specific vessels, locks, or river systems.
Website	http://corpslocks.usace.army.mil/lpwb/f?p=121:1:8235674291931104:::::
Regulatory / Legislative Driver	USACE operates and maintains locks for safe navigation of commercial and recreational vessels on waterways throughout the United States; sharing information about lock status helps lock users plan their transits.
Unit	Number of lock closures
Collection Frequency	Continuous
Reporting Frequency	Every 30 minutes, through Corps Locks website
Geographic Scope	National, all USACE navigation locks
Objective	Reliable travel on inland waterways requires functioning navigation locks; system-wide information on lock closures can identify possible delay points.
Application Value	Operations (real-time information on lock availability and delays). Data web services are available from the Corps Lock website for external application development.
Comment	Summary tonnage reports by month and lock are available, updated at 10:00 a.m. daily.

Category	*Capacity and Reliability*
Measure	*Federal Ship Channels at Authorized Dimensions According to USACE eHydro Observations*
Source	U.S. DoD, USACE
Description	There are 59 high-use USACE projects that service 10 million tons of cargo or more per year. The commercial tonnage that transits these 59 projects represents the majority of cargo (~95%) traveling through USACE navigation channels. The ability to aggregate survey data information for multiple channels to inform a National perspective has been limited by operational differences among USACE Districts. Measuring and reporting the channel conditions is essential for planning maintenance dredging. eHydro will automate reporting of channel survey data.
Website	http://www.usace.army.mil/Missions/CivilWorks/Navigation.aspx
Regulatory / Legislative Driver	Maintaining navigation channels within authorized dimensions is part of the USACE Civil Works mission.
Unit	Number of channels in the 59 high-use projects at authorized dimension
Collection Frequency	Yearly, can be more frequent depending on channel conditions
Reporting Frequency	USACE is updating procedures; expected frequency is quarterly.
Geographic Scope	National
Objective	This supports the need to for the performance measure of *full depth, half width* of navigation channels maintained by USACE.
Application Value	Information (channel conditions) to plan maintenance
Comment	The eHydro program is currently being implemented across USACE. Expected to be fully operational by 2015, eHydro will allow for improved analysis at multiple spatial scales.

Category	*Capacity and Reliability*
Measure	*Travel Time Reliability for Select Waterway Segments*
Source	USCG, USACE
Description	Vessel movement data for these research efforts are supplied by an agreement with USCG, the authority for collection and archival of AIS-based vessel tracking data. Although calculated travel time statistics are not yet regularly available, they are under development as part of ongoing research by USACE.
Website	http://www.uscg.mil/acquisition/nais/
Regulatory / Legislative Driver	USCG requires commercial vessels in coastal waters to use AIS under the *Maritime Transportation Security Act* of 2002.
Unit	Multiple measures related to vessel movement
Collection Frequency	Ongoing, continuous
Reporting Frequency	Archival data is available to the general public with a lag time of 3 days
Geographic Scope	National
Objective	Examining vessel travel time can reveal congestion points that could be improved by operational or investment changes.
Application Value	Operations (understanding near-current vessel travel times), Reference (historical travel time comparisons are essential to evaluate investment or operational changes)
Comment	(no comment)

Category	***Resilience***
Measure	***Physical Condition Ratings for USACE-Owned Coastal Navigation Infrastructure***
Source	U.S. DoD, USACE
Description	USACE is responsible for maintaining multiple types of infrastructure as part of a national portfolio of infrastructure that supports safe coastal and inland waterway navigation. Coastal navigation infrastructure components operated by USACE have been graded according to their physical condition. While the linearity of the relationship between physical condition and functional performance varies by type of infrastructure, physical condition is readily observable and predictive of structural resilience in the face of challenging event conditions.
Website	http://operations.usace.army.mil/asset.cfm
Regulatory / Legislative Driver	Internal USACE asset management initiatives for infrastructure management
Unit	Physical rating (A, B, C, D, F, complete failure) of individual component
Collection Frequency	Ongoing, inspection frequency varies by infrastructure type
Reporting Frequency	(Currently under revision within USACE)
Geographic Scope	USACE individual project, District, and Division
Objective	Monitoring asset condition and functional reliability as it relates to risks and consequences of infrastructure failure informs maintenance and budgeting decisions.
Application Value	Operations (present state of navigation infrastructure assets)
Comment	Information on the USACE Asset Management program is available at http://operations.usace.army.mil/asset.cfm .

Appendix B: Extended List of Suggested MTS Performance Measures

Economic Benefits to the Nation

- Amount of Harbor and Inland Trust Funds ($)
- Producer Price Index (PPI)
- Number of jobs generated (direct, indirect, and induced)
- Percentage of Gross Domestic Product (GDP) contributed to by marine transportation (advantage, exports, domestic)
- Amount of Federal, state and local taxes generated ($)
- Amount of private investments based on transportation assets ($)
- Percentage of production cost of goods attributable to marine transportation ($)
- Total value of trade (in and out, internationally)
- Amount of value added to goods ($, pre- vs. post-transportation and processing)
- Cost of living advantages due to imports ($)

Capacity and Reliability

- Percentage of infrastructure utilization
- Percentage of ship slots used (berth occupancy and number of ships)
- Degree of channel width/depth utilization
- Number of lock and channel closures not due to nature
- Fluidity of the system (average time/unobstructed time)
- Percentage of ship channels at project depth/width
- Number and severity of congested nodes
- Anchorage utilization and availability

Safety and Security

- Number of ship accidents (collisions, allisions, groundings)
- Safety/security comparison to other modes of transportation
- Number of ports that meet required security standards
- Number of injuries (personal injuries, deaths) per 1000 trips
- Number of serious security incidents
- Percentage of at risk vessel cargos inspected before entry into U.S. ports

Environmental Stewardship

- Percentage of industry using clean technologies (biofuels, new engines, ballast water treatment technology)
- Amount of dredged material used for beneficial use
- Air quality/greenhouse gas emissions from MTS operations
- Acreage and type of habitat restoration and/or creation
- Percentage of projects incorporating climate change considerations into planning
- Percentage of ports/waterways with impaired water quality
- Percentage or number of invasive species expansion into new waterways
- Percentage capacity of disposal sites/percentage of ports without adequate disposal areas
- Number of interactions with threatened and endangered species

Resilience

- Available alternate capacity during disruption
- Travel time index for origin-destination areas
- Percentage of time not available due to unscheduled closures
- Percentage of time at reduced capacity and/or efficiency (planned or not)
- Number or percentage of critical infrastructure in immediate danger of failure as a result of underfunding
- Number or percentage of critical infrastructure not functional as a result of underfunding
- Value to National defense due to redundancy (unused capacity)

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14. ABSTRACT

Performance measures for the marine transportation system (MTS) span many operational categories including economic benefits, capacity and reliability, safety and security, environmental stewardship, and resilience. The measures of greatest interest to any one group of stakeholders depend upon their underlying values and goals; however, some measures have been identified by expert groups as fundamental to understanding MTS operations. Within the United States, multiple Federal agencies have a role in maintaining and regulating the MTS. This has resulted in compartmentalized authorities and data collection efforts, unintentionally limiting the access to and utility of multiple data sets. The research presented in this technical report provides historical context for the development of performance measures for Federally managed MTS infrastructure, identifies authoritative data sources (or relevant proxies) for performance measures of interest, and provides extracted data that allows for assessment of performance over time. This work lays the foundation for examining MTS performance as an interconnected system and within a larger intermodal supply chain network. The final section suggests using observed data to develop models that explore a wide range of future scenarios and provide insight into potential effects on MTS performance.

15. SUBJECT TERMS
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