Marine Transportation System Resilience Assessment Guide

EXECUTIVE SUMMARY

DECEMBER 2023

Cybersecurity and Infrastructure Security Agency

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NAVIGATION

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SUMMARY

The Executive Summary highlights the most relevant content of the Marine Transportation System Resilience Assessment Guide (MTS Guide) and functions independently as a condensed version of the larger document. Its' purpose is to summarize the key points, highlight advanced analysis from case studies and recommendations, save time by quickly navigating users through the larger body of the document, provide users with a variety of resources to support resilience assessments, and identify practices or investments that can enhance resilience and inform mitigation decision-making.

The U.S. Department of Transportation reports that maritime transportation is a vital catalyst for local, regional, and national economies. In 2020, maritime vessels accounted for 40% of U.S. international trade value, nearly 70% of trade weight, and 18% of total GDP. The challenges of hurricanes, coastal storms, riverine flooding, and drought can disrupt marine operations. These and other disruptions like the COVID-19 pandemic, trade policies, and labor negotiations shed light on the need to better understand functions of important infrastructure systems that support the MTS (e.g., communications and cyber infrastructure, electric power, roads, rail, water/wastewater, and warehousing) and the governance systems and communities that the MTS operates within. These challenges and the complicated nature of the interdependent systems that comprise the MTS are paired with an almost overwhelming number of datasets and approaches for analyzing disruptions and enhancing resilience.

The Cybersecurity and Infrastructure Security Agency (CISA) released the MTS Guide to better help federal, state, local officials and private infrastructure owners and operators understand and plan to increase the resilience of maritime infrastructure systems and functions. The MTS Guide provides a consistent, repeatable process for conducting uniform assessments of the resilience of the complicated systems that comprise the MTS. The MTS Guide provides advice for assembling the diverse group of public and private stakeholders and agencies that manage these systems; provides a framework for conducting resilience assessments; and provides a variety of resources to support resilience assessments.

MARITIME VESSELS

18%
GDP

40%
TRADE VALUE

KG
70%
TRADE WEIGHT

America's Marine Transportation System, or MTS, is expansive. It includes waterways, ports and land-side connections, moving people and goods to and from the water. Coordination, leadership, and cooperation are essential to addressing MTS challenges in manner that benefits all MTS users and stakeholders. Information must be shared among federal, regional and local agencies, as well as private sector owners and operators. CISA released the MTS Guide to better help federal, state, local officials and private infrastructure owners and operators understand and plan to increase the resilience of maritime infrastructure systems and functions. The MTS Guide integrates the expertise and experience of partner agencies, available information sources, methodologies, and resources into a repeatable, step-by-step framework by:

- Providing a primer on the importance of resilience in the maritime domain and an overview on the purpose, intended users, and use cases.
- Defining four key objectives for conducting resilience assessments within the MTS.
- Proposing a framework for conducting an assessment beginning with issue identification and continuing through implementation activities.
- In addition to guidance for conducting assessments of port resilience, the MTS Guide includes four case studies which assessed different components of the maritime transportation system that are critical in helping users access and understand content demonstrating application of advanced analysis tools to assess resilience.

OVERVIEW

The MTS Guide was co-developed under a Memorandum of Agreement with the United States Army Engineer Research and Development Center (ERDC) using a special Congressional appropriation for the agencies (members of the U.S. Committee on the Marine Transportation System Resilience Integrated Action Team) and other resources. The MTS Guide organizes multiple methodologies and port resilience assessment tools to support resilience planning. The contents of the MTS Guide are based on CISA's extensive experience conducting resilience assessments through the Regional Resiliency Assessment Program (RRAP) and ERDC's significant domain subject matter expertise.

The MTS Guide is a result of integrating the expertise and experiences of partner agencies, available information sources, methodologies, and resources into a repeatable, step-by-step framework. It first provides an overview of intended users, uses, and discusses the importance of resilience in the maritime domain. It then provides an outline of four key objectives for conducting resilience assessments within the MTS. Finally, it proposes a framework for conducting an assessment beginning with issue identification and continuing through implementation activities. The MTS Guide can be implemented as a standalone assessment or it can be a supplement to the RRAP methodology or the Infrastructure Resilience Planning Framework (IRPF).

PURPOSE

The purpose of the MTS Guide is three-fold:

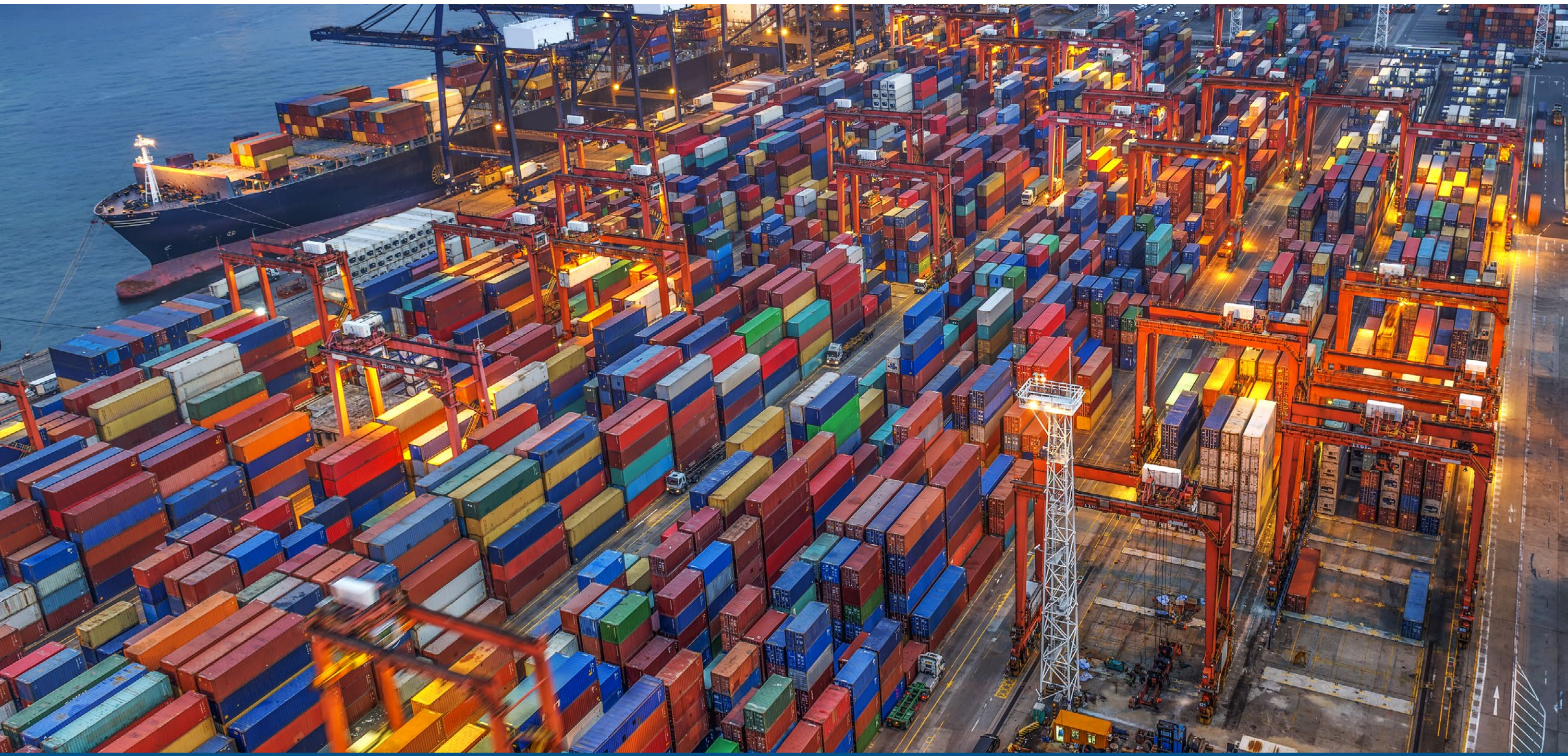
1. To provide guide users with a shared understanding of how to design and conduct a resilience assessment of MTS components;
2. To close the gap between available resources and needs by organizing and identifying planning tools, academic studies, datasets, and methodologies used to assess MTS resilience; and,
3. To illustrate the assessment process through examples and case studies across three scopes that have been developed to represent a wide variety of existing systems and potential applications.

The MTS Guide provides a process for organizing and understanding the complicated systems that comprise the MTS. The MTS Guide also provides advice for assembling a diverse group of public and private stakeholders and agencies that manage these systems; a critical step in ensuring that an assessment is more than a report on a shelf. Finally, it introduces a framework for structuring a resilience assessment and assembles a variety of resources that make an assessment possible based on the goals of the guide user by outlining a process for assessing resilience and lead users to relevant data sets, methods, tools according the their objectives, available time and resources.

The MTS Guide is intended to supplement and improve existing processes — not to replace them — by helping guide users to conduct resilience assessments and incorporate resilience enhancements into planning and investment activities.

GOALS OF THE MTS GUIDE

- **Provide a shared understanding of what comprises an MTS resilience assessment**
- **Provide the right resources to those who need them**
- **Demonstrate resilience assessments through case studies and examples**



HOW IS THE MTS GUIDE ORGANIZED?

The MTS Guide introduces Four Key Resilience Assessment Objectives that link assessment results to critical functions (e.g. maintaining channel dimensions, drayage, intermodal exchanges, warehousing) and the infrastructure that supports them and pro vide information tailored for future decision-making needs.

FOUR KEY RESILIENCE OBJECTIVES

1. **Define functions and characterize the system in steady state**
2. **Analyze critical infrastructure and dependencies**
3. **Understand the impacts of disruptive events**
4. **Identify and evaluate resilience enhancement alternatives**

HOW TO USE THE MTS GUIDE

The resilience assessment process is similar to other planning and project management frameworks where the user moves through a series of phases intended to help them identify the issues and stakeholders, focus the assessment and activities, execute the assessment, and implement findings.

The MTS Guide begins with a resilience primer defining resilience and related concepts for the MTS. It then walks users through each step in the framework and includes detailed appendices on each of the four key resilience assessment objectives. The MTS Guide also contains a Resilience Resource Appendix that identifies and outlines 100+ resources, tools, methodologies, and datasets that could be applicable for Guide users. The MTS Guide is built upon four resilience objectives that lay the foundation for how an assessment should be conducted.

WHO USES THE MTS GUIDE AND HOW DOES IT HELP?

MTS Guide users can come from a wide variety of backgrounds and are not required to have specific expertise besides a basic understanding of the MTS. To address any differences in background, the MTS Guide provides references to existing resources, studies, and findings to help a guide user design their own assessment.

The MTS Guide provides an approach to conducting a resilience assessment that is customizable and scalable according to user objectives, desired level of information for decision-making, scope of interest, and available resources.

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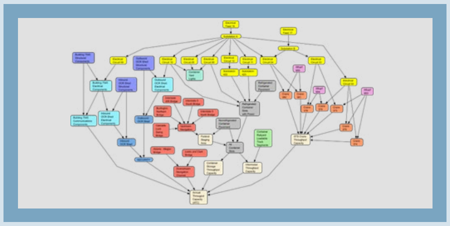
CASE STUDIES

The MTS guide includes a set of case studies that demonstrate the application of advanced analytical techniques to inform a resilience assessment in the MTS. New case studies may be added based on the experience of Guide users.

The MTS Guide identified three scopes, illustrated on the next page, to represent the movement of people and cargo – two functions that are considered top priority for ports and the MTS.

These scopes include, 1) a single port, including the navigation systems, intermodal connections, and communities that support its ability to move goods; 2) an inland waterway and the physical infrastructure located along the waterway to support navigation and intermodal transportation; and 3) an MTS port network which embodies the connectivity of a group of ports and their ability to meet supply chain demands.



SINGLE PORT

Resilience Assessment at a Navigation Terminal using Probabilistic Networks at Port of Portland.

Resilience Objectives:

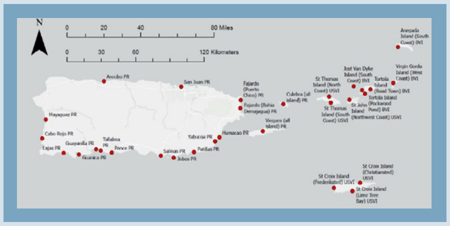
- Define Functions and Characterize System
- Analyze Critical Inf. and Dependences
- Understand the Impacts of Disruptive Events
- ID & Evaluate Resilience Alternatives

INLAND WATERWAY

Cumberland/Tennessee River Inland Water-way Resilience Analysis.

Resilience Objectives:

- Define Functions and Characterize System
- Analyze Critical Inf. and Dependences
- Understand the Impacts of Disruptive Events
- ID & Evaluate Resilience Alternatives



MTS NETWORK

U.S. Port Connectivity and Ramifications for Port Resilience.

Resilience Objectives:

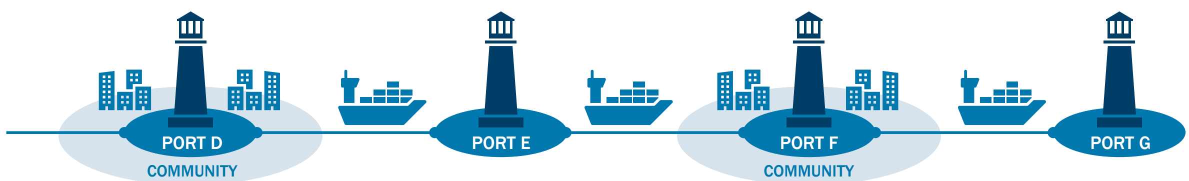
- Define Functions and Characterize System
- Analyze Critical Infrastructure and Dependences

SCOPES

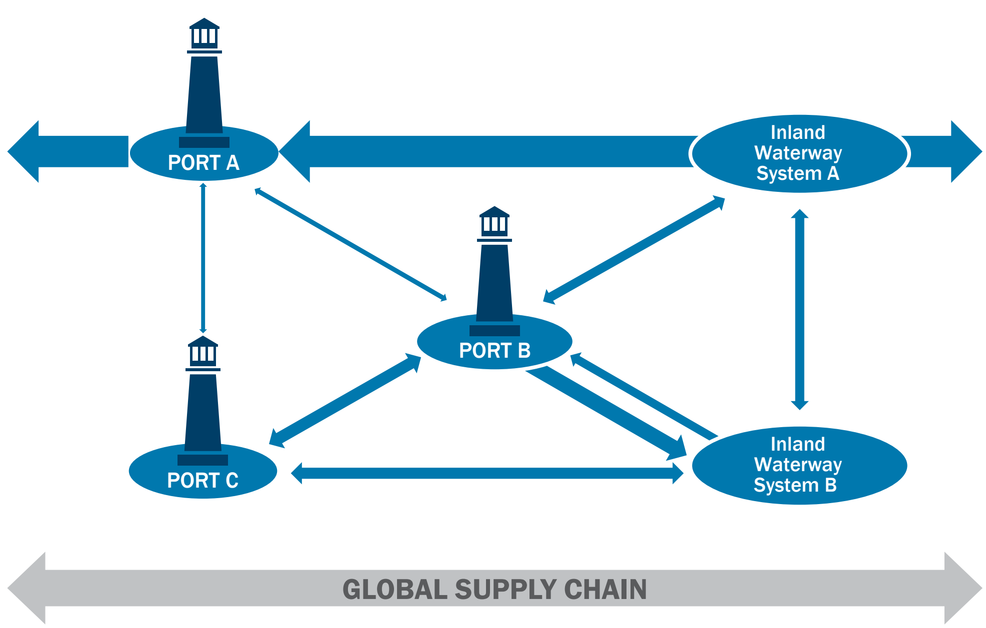
Three scopes have been selected to represent a wide extent of possible resilience assessments.

Single Port

Inland Waterway



MTS Network



INTRODUCTION

WHAT IS RESILIENCE?

Resilience is a measure of how well a system performs its intended function over the course of either an extreme event or a gradual accumulation of stress.

The cycle represents:

1. How a system operates during normal times,
2. Loss of function, which depends on the ability of the system to absorb stress and withstand disruptions and damages,
3. How it then regains function over time, through response in the short-term, and recovery over a longer time horizon,
4. Potentially even improving function above pre-event or sub-optimal operations through adaptation.

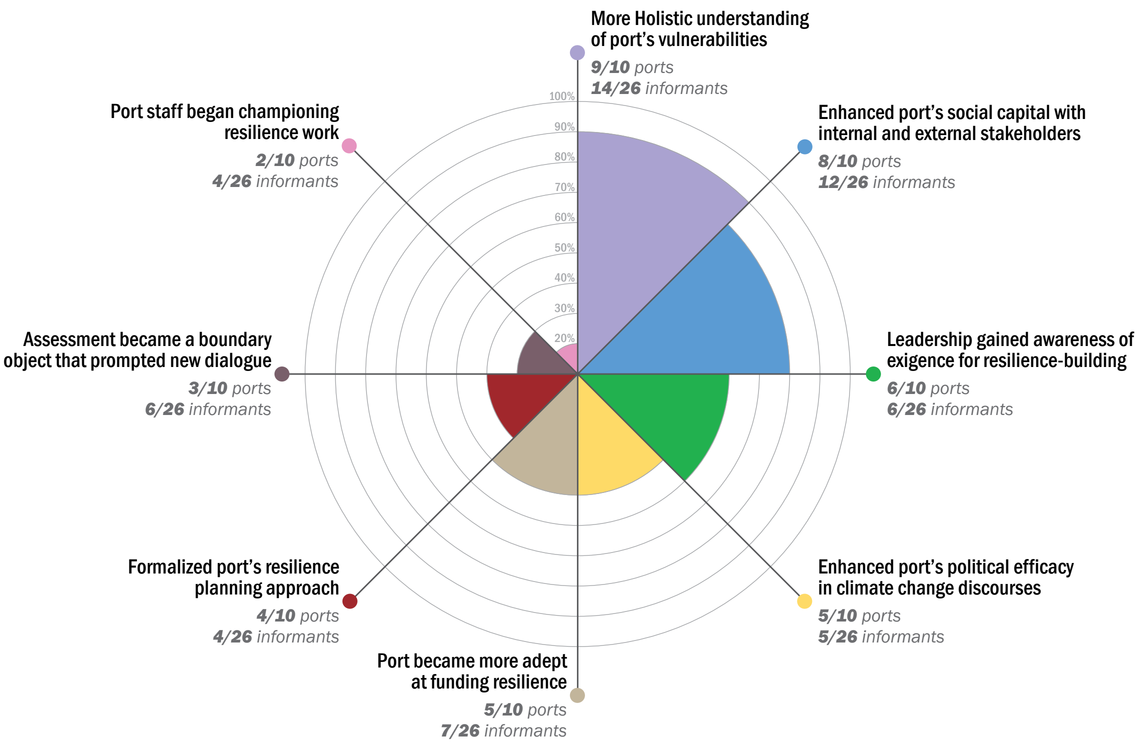
A resilience assessment will help determine whether the necessary capabilities exist and are sufficient to maintain critical functions under stresses and shocks. This is especially done through Objective 3: (How it then regains function over time, through response in the short-term, and recovery over a longer time horizon) by anticipating what will happen during a disruptive event, immediately after, and further out in the future.

This MTS Guide emphasizes taking a broad view of the system to understand dependencies and find potential vulnerabilities and opportunities for resilience enhancement. A holistic view that looks at physical infrastructure, people, organizations, and their interactions will help to formulate a portfolio of strategies to reduce overall losses when disruptive events occur. These could include creative and “easy-win” solutions, ones that improve supporting capacities, build characteristics that activate during and after disruptive events (e.g., adaptable, agile, and flexible), and deliver diverse benefits.

BENEFITS

WHY PERFORM A PORT RESILIENCE ASSESSMENT?

The benefits of completing a resilience assessment include a closer relationship with stakeholders and partners who may not traditionally be involved in planning exercises, a holistic understanding of the system's most important vulnerabilities and functions, buy-in from agency or port leadership, an awareness of the dependencies and interdependencies within a system, and the identification of practices or investments that can reduce the risk of disruption and save time, effort, and funding in the future. The figure below, based on RRAP feedback, outlines the key benefits of resilience assessments, as reported by personnel involved in these assessments at 10 ports across the country. The MTS Port Resilience Guide was developed to make the methodology broadly available for other ports to use.



RESILIENCE ASSESSMENT OBJECTIVES

The overarching goal of a resilience assessment is to understand how well a system will perform its intended function(s) over time, including under scenarios that can disrupt normal functioning. This guide describes an assessment process that is fulfilled through four key objectives that support analysis of the MTS and its diversity of system types and contexts.

These four objectives form the foundation of any resilience assessment and can provide a framework to assess project goals, determine the emphasis of an assessment, and design an assessment plan and analytic strategy that is tailored accordingly.

FOUR KEY RESILIENCE ASSESSMENT OBJECTIVES

THE FOUNDATION OF ANY RESILIENCE ASSESSMENT

Define functions & characterize system in steady state

Concerned with identifying the functions performed by the MTS and understanding normal operations, including key stakeholders and operators, governance structures, planning activities, and characteristics of MTS activities.

Analyze critical infrastructure & dependencies

Concerned with understanding the infrastructure systems that support operations as well their dependencies, including dependence on infrastructure outside of the port or region being studied.

Understand the impacts of disruptive events

Concerned with assessing risks from disruptive events on baseline operations, including likelihood and potential consequences from incidents as well as the capacity of a port or MTS network to prepare for, resist, recover, and adapt to adverse circumstances.

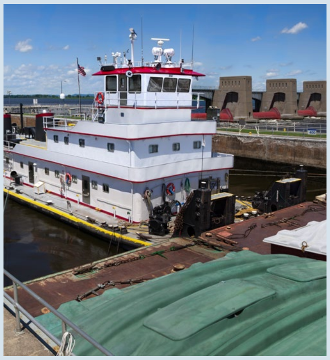
Identify and evaluate resilience enhancement alternatives

Concerned with identifying, evaluating, and prioritizing actions that can improve resilience to disruptive events, including potential investments and planning activities that can reduce system risk.

FUNCTIONS & SYSTEMS

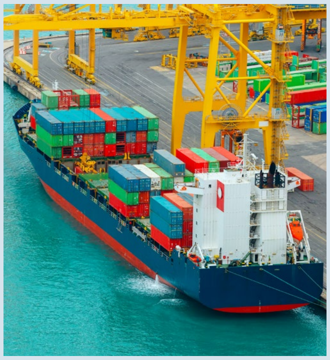
DEFINE FUNCTIONS & CHARACTERIZE SYSTEM IN STEADY STATE

Characterization provides a baseline for an assessment. The MTS Guide provides a framework for identifying functions, sub-functions, and infrastructure systems that support them.



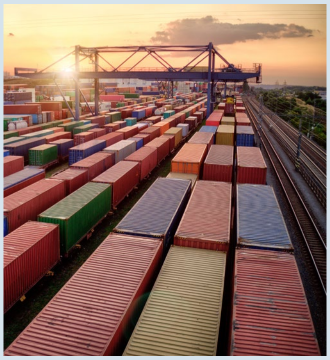
NAVIGABLE WATERWAYS

Open-ocean, channels, and river and canal systems upon which maritime vessels operate.



PORTS

Nodes at the interface between maritime and land-based transportation systems where cargo is loaded and unloaded.



INTERMODAL CONNECTIONS

Linkages that enable the transfer of cargo between transportation modes at the land/water boundary, located on or near terminals within the port area including truck, rail, pipeline, and air services which facilitate both inbound and outbound movement of goods.

COMMUNITIES

Areas and interests surrounding ports and intermodal connections that support and rely upon MTS operations and the coastal and riverine resources, including infrastructure operators providing lifeline services to the MTS, the MTS workforce; employers that rely on the MTS for operations; residents living near the MTS; and state and local government and community groups with interests in land use and transportation planning, the local economy, and environmental impacts.

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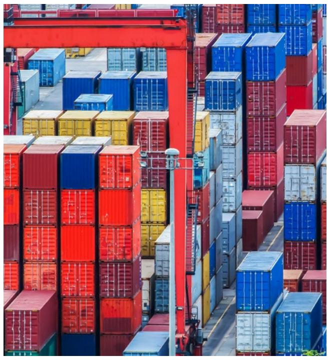
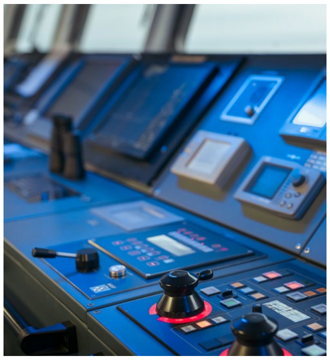
ANALYZE CRITICAL INFRASTRUCTURE AND DEPENDENCIES

Understanding infrastructure system operations and dependency relationships supports identification of resilience issues. The MTS Guide provides a framework for identifying and analyzing these relationships.



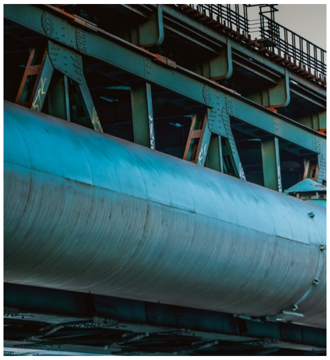
PHYSICAL

Dependency on material output(s) of other infrastructure through a functional and structural linkage between the inputs and outputs of two assets. In other words, a commodity produced by one infrastructure is needed as an input by another infrastructure for its operation. This includes reliance on personnel needed to support infrastructure operations.



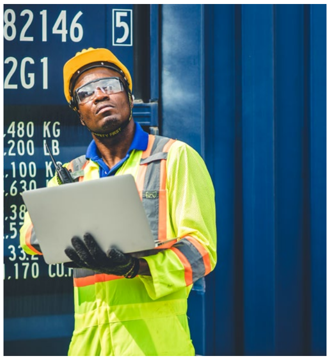
CYBER

Dependency on information and data transmitted through the information infrastructure via electronic or informational links. Outputs from the information infrastructure serve as inputs to other infrastructure, with the relevant commodity being information.



GEOGRAPHICAL

Dependency on the local environment, where an event can trigger changes in the state of operations in multiple infrastructure assets or systems. A geographic dependency occurs when elements of infrastructure assets are in close spatial proximity (e.g., a joint utility right-of-way).



LOGICAL

Dependency on the state of other infrastructure via connections other than physical, cyber, or geographical. Logical dependency is attributable to human decisions and actions and is not the result of physical or cyber processes and can include policy, regulatory, and financial constraints.

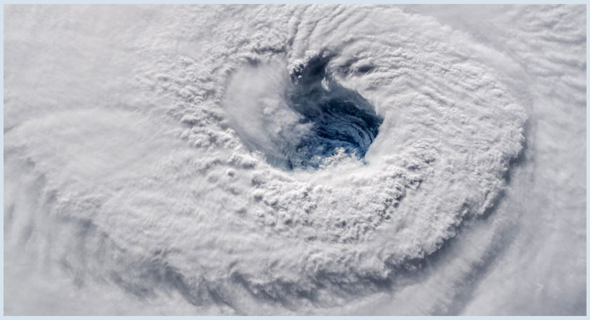
DISRUPTIVE EVENTS

UNDERSTAND THE IMPACTS OF DISRUPTIVE EVENTS

To measure or assess the impacts of a disruptive event, one must first identify pertinent threats and hazards to consider. Those hazards or threats should be modeled or discussed with experts to identify potential impacts. These two steps are often the first actions undertaken in a risk assessment. Risk management is a well-developed field with a large variety of resources and methodologies that will be quickly summarized in this section. Risk assessments are closely related to resilience assessments. The nature of this relationship is debated in the literature but centers around how both concepts can be integrated as part of a management strategy to understand what losses could be suffered, the system's ability to recover degraded or lost functions, and the options that exist in the future to minimize those losses. Preparation begins with risk awareness, leading toward proactive risk management steps that will ideally promote the flexibility of the system for a wide range of scenarios and avoid unintended consequences of future investments.

MTS stakeholders must regularly make choices and take actions to promote or increase safety, continuity, and preparedness. To do this, they must be aware of what threats could damage or disrupt the system and be able to identify and weigh options for averting losses. Risk assessment methods help guide users to characterize the potential for loss or harm due to specific threats that exploit vulnerabilities in their system. The Federal Emergency Management Agency's (FEMA) Threat and Hazard Identification and Risk Assessment (THIRA) Framework suggests asking the following questions:

- Which realistic threats and hazards will be the most challenging to manage?
- If they occurred, what impacts would those threats and hazards have?
- Based on those impacts, what capabilities will the system need to manage the incident?



Hurricane Florence

The MTS Guide provides a collection of methods and resources that can be used to assess risks that could disrupt port operations

Risk assessment methods help guide users to characterize the potential for loss or harm due to specific threats that exploit vulnerabilities in their system

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RESILIENCE ENHANCEMENT ALTERNATIVES

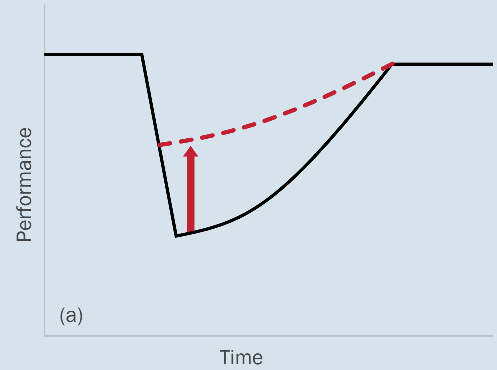
IDENTIFY AND EVALUATE RESILIENCE ENHANCEMENT ALTERNATIVES

The various activities and analyses of the resilience assessment process to achieve the objectives prescribed in the MTS Guide (Define functions & characterize system in steady state; Analyze critical infrastructure & dependencies; and Understand the impact of disruptive events) establish a baseline picture of system resilience. Areas of relative weakness across the resilience cycle are more apparent and can be approached as opportunities for improvement. As depicted by the trajectory of the recovery curves in the figures on the right, resilience enhancement can generally have an impact via:

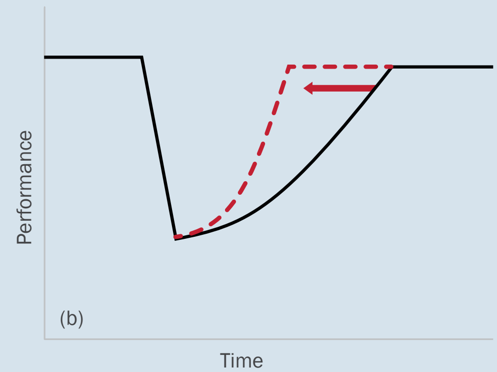
a) Planning and mitigation measures to reduce the impact of a disruption
b) Measures to expedite recovery times
c) Measures to improve system function during recovery
d) Measures to improve system performance to better than before the disruption

Evaluating and selecting alternatives provides a basis or improving resilience under constrained budgets and multiple objectives

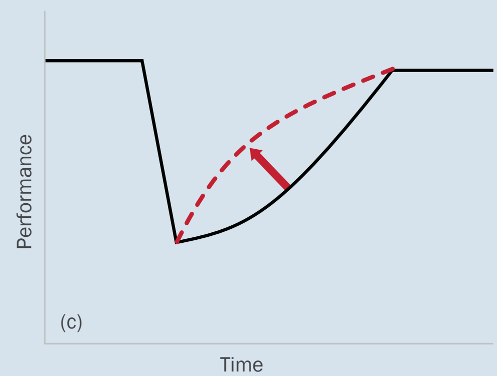
The MTS guide provides approaches for identifying and evaluating resilience enhancement alternatives



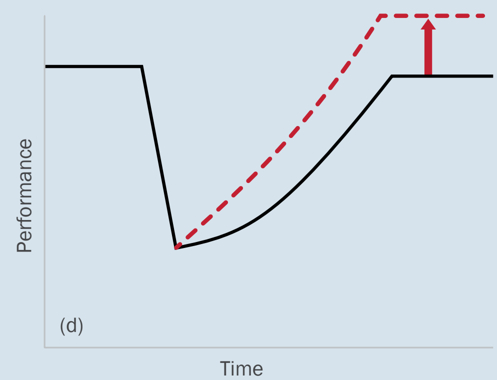
IMPROVED MITIGATION



IMPROVED RECOVERY



IMPROVED RESPONSE

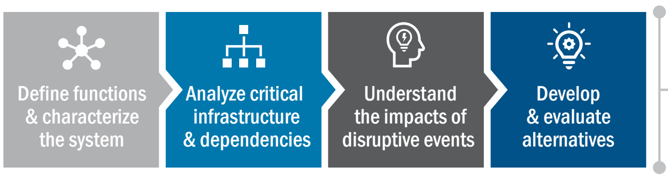


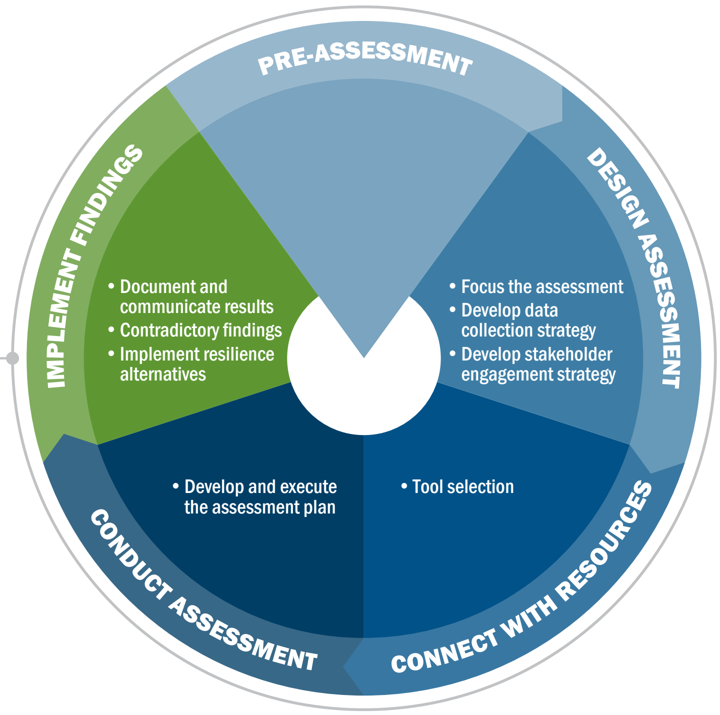
IMPROVED ADAPTATION

RESILIENCE ASSESSMENT PROCESS

THE FIVE STEPS

Key Resilience Assessment Objectives





What is the resilience issue? Have issues been highlighted during past incidence or exercises? Are there previous assessments, planning groups, or intelligence reports that have called out an issue? Are there trends and forecasts that point to a looming potential issue?

Who is relevant to the issue in question? Whose perspec tive will be important? What entities will be needed to take action on the study recommendations? Whose buy-in is important? What is the governance structure that the assessment and subsequent action will take place in?

The five steps of the Resilience Assessment Process is built upon the four resilience assessment objectives that inform the design of the assessment. This process shown is similar to other planning and project management frameworks where the user moves through a series of phases intended to help them identify the issues and stakeholders, focus the assessment and activities, execute the assessment, and implement findings.

While the Executive Summary previously discussed the four key resilience objectives that comprise a resilience assessment, this outlines a generalized process for planning, designing, executing an assessment and implementing its results providing an approach for conducting resilience assessments, practical tips and considerations that can lay the foundation for a sound assessment and ensure it stays on track throughout execution.

The MTS Guide provides background (and appendices) on these objectives as reference points. As a guide user moves beyond pre-assessment into design, each of these objectives should be addressed in some manner depending on the specific scope of each assessment.

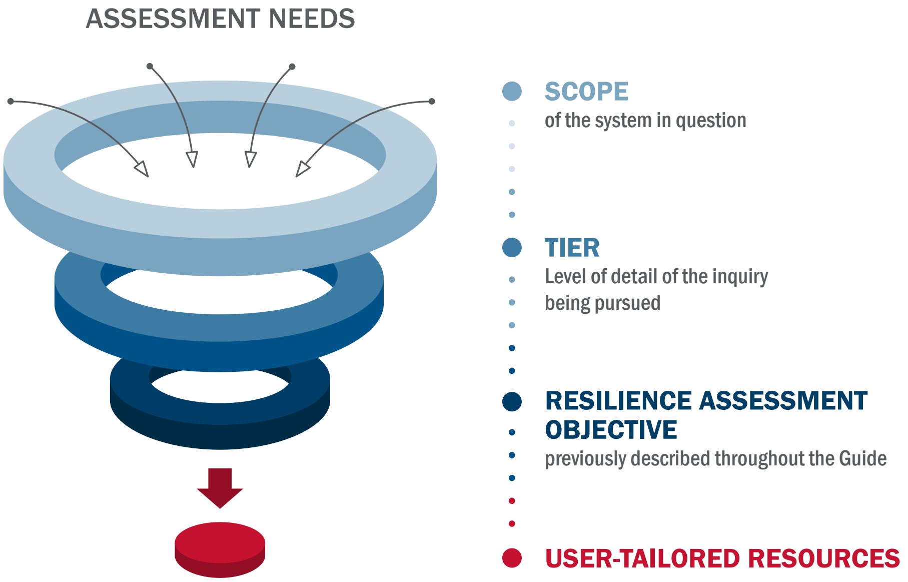
CONNECT WITH RESOURCES

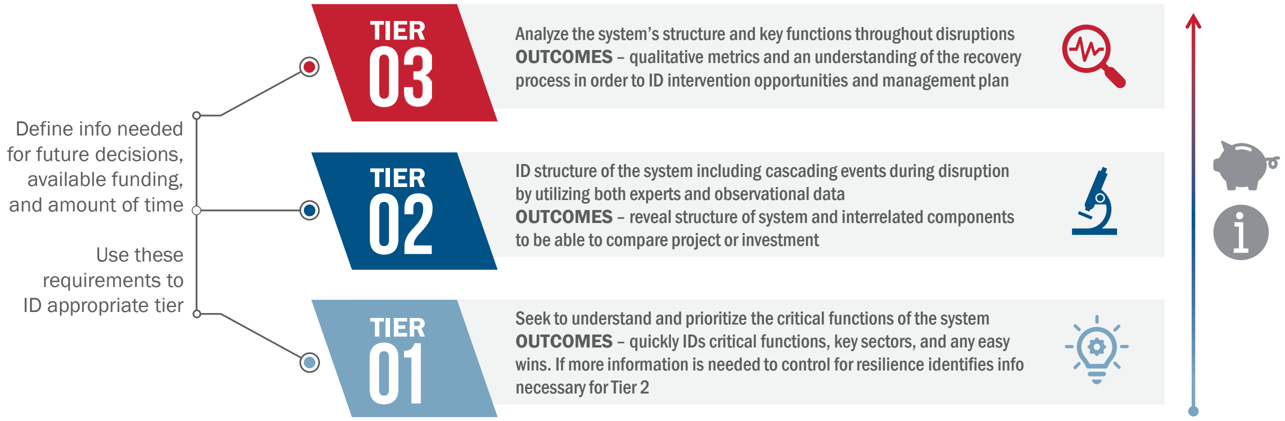
A resilience assessment is a mixed-methods endeavor by nature; to fulfill assessment objectives and goals, projects will leverage information generated from past efforts, available data, and analytic methods drawn from a variety of disciplines.

This section provides information on selecting resources that can be used to answer research questions. The Resilience Assessment Resource Matrix provides a list of 100+ off-the-shelf tools, methods, data sources, guides, and useful examples from government agencies and research labs, industry, and academic institutions. The list of resources is not comprehensive, however, so guide users are encouraged to check for updates or new developments.

The Resilience Assessment Resource Matrix and resources filters proposed match assessment needs and existing resources based on their needs. The filters proposed to match assessment needs and existing resources are shown in the figure at right.

We envision that users piece together their assessment by utilizing a variety of resources. For example, users might identify the relevant critical functions of their MTS by consulting past assessments, government reports, and certain stakeholders.

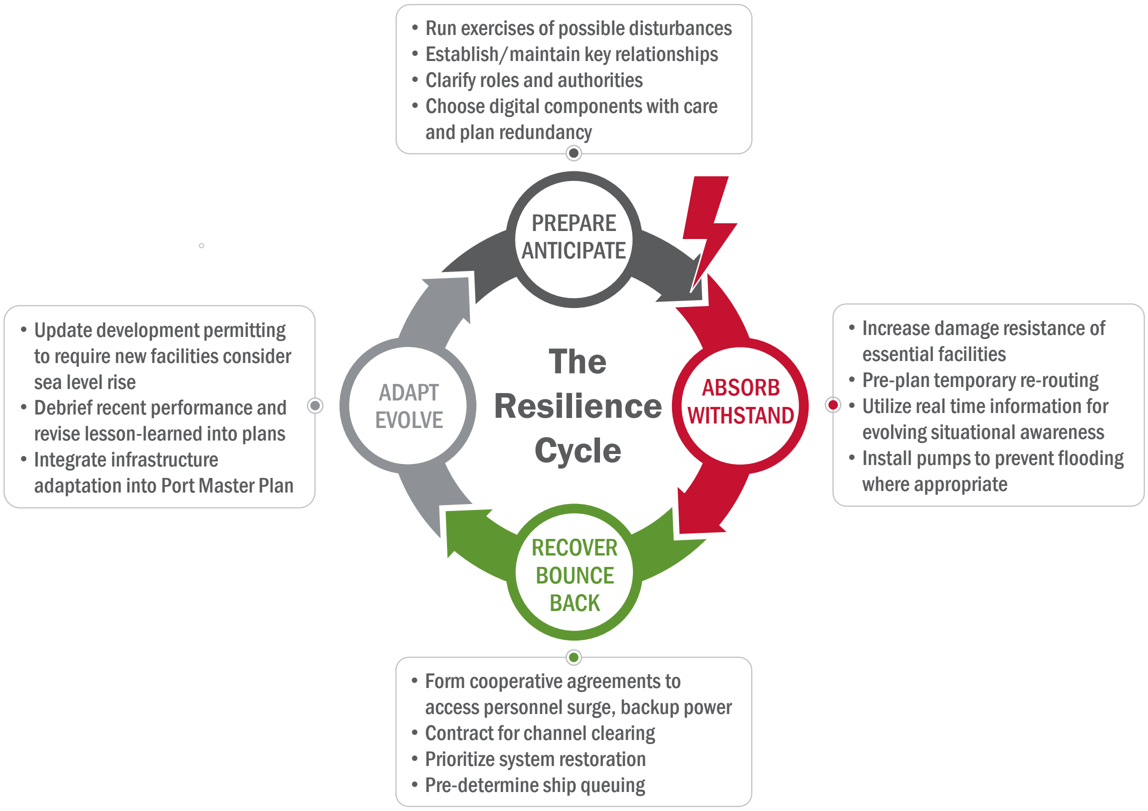




Assessment findings can help decision makers manage risk across the spectrum of resilience

An assessment can inform multiple types of decisions from preparedness and response planning to recovery objectives and long-term planning for system resilience and adaptation to changing conditions. The assessment design executed by the guide user should help avoid the well-worn problem of "studies on a shelf" through strategic inclusion of a champion, decision makers, and stakeholders throughout the entire assessment process.

Resilience assessments can provide information for planning, management and investment decisions, including identifying priority areas for long-term resilience enhancements, addressing gaps and vulnerabilities, and mitigating impacts to critical infrastructure. The implementation of an assessment recommendation requires alignment of several decision makers' interests within and outside the port area depending on the resilience-related objectives. It also identifies desired outcomes of these stakeholders, around which a guide user will build the assessment, so that the findings inform actions leading to desired resilience outcomes. Good examples of this are performing a resilience assessment specifically with the goal of informing a long-term risk mitigation strategy, or the updating a regional emergency response plan. The findings then fit into the existing activity or process of the stakeholders.



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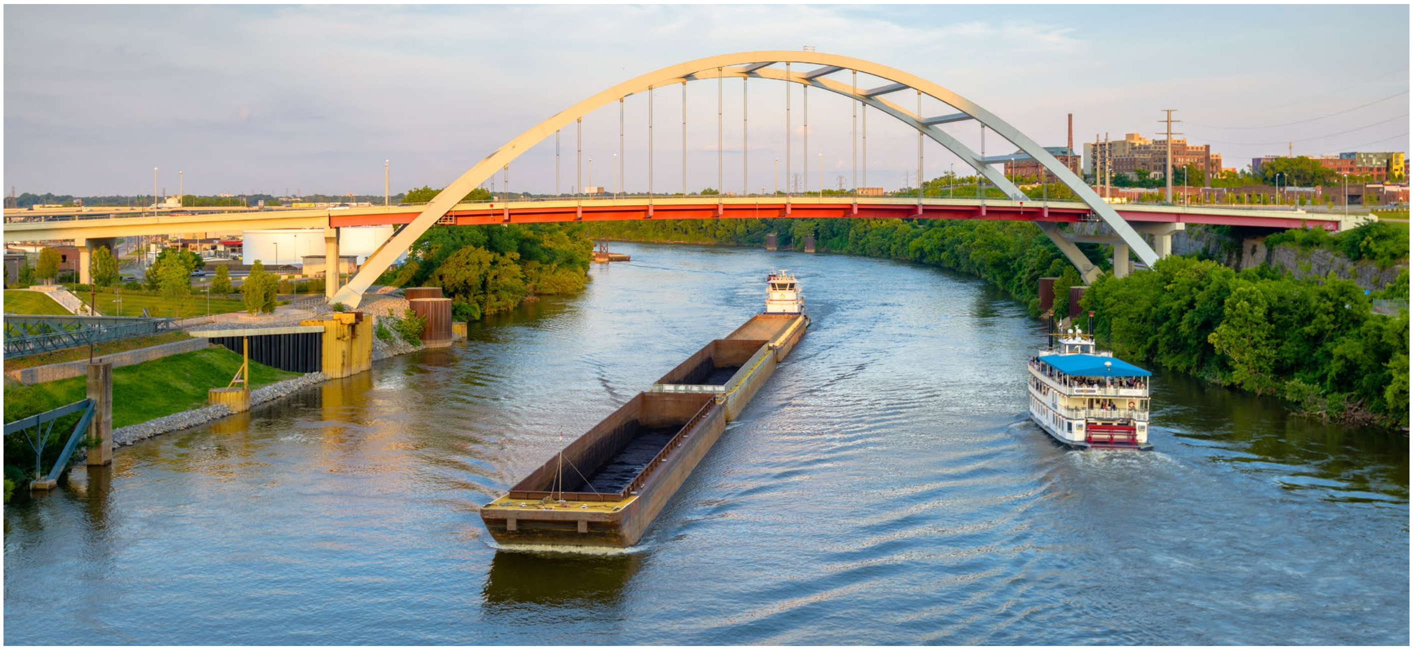
CONCLUSION

The MTS is composed of an array of interdependent physical parts, including coastal and inland waterways, ports and terminals, vessels, intermodal connectors like highways, railways, and pipelines, as well as the communities, companies, organizations, and workers that use, operate, maintain, and coexist with the system.

The MTS Resilience Assessment Guide offers a generalized process and tools for conceiving, designing, and implementing a resilience assessment. The process leverages four key resilience objectives to ensure that every assessment results in a broader understanding of the MTS, its development drivers, interactions with stakeholders, and the critical functions and infrastructure interdependencies. The process also provides an organized set of tools and resources to complete an assessment according to guide user objectives, scope, and available resources. The objective of the MTS Guide is to draw on existing resources to provide a consistent replicable framework for conducting a resilience assessment that result in actionable resilience recommendations for federal agencies, state and local governments, academia and private industry.

CASE STUDY

CUMBERLAND/TENNESSEE RIVER INLAND WATERWAY RESILIENCE ANALYSIS



BACKGROUND AND OBJECTIVES

This case study provides a demonstration of the process outlined in the Port Resilience Guide toward performing a resilience assessment of inland waterway systems. For this study, the two primary navigable tributaries to the Ohio River, the Tennessee and Cumberland Rivers, and the surrounding region are used as the area of focus (Figure 1). As part of the case study, multiple disruption scenarios are considered (Box 1) including a waterway outage (such as that which may be created by flood, drought, or planned or unplanned closure due to maintenance or an incident), a major earthquake, and a disruption of the Colonial Pipeline. Given that the 2021 ransomware attack of the Colonial Pipeline occurred during the study, it provided a unique case study example for consideration of how the inland waterway system provides redundancy and energy security in the middle Tennessee region as well as several lessons learned from the experience. This study involved a multi-faceted approach including stakeholder engagement, utilization of publicly available data sets for replicability of the approach to other waterway systems, and integration of mobilized large, crowd-sourced data sets to extract previously unavailable insights regarding the extent of waterway and pipeline disruptions.

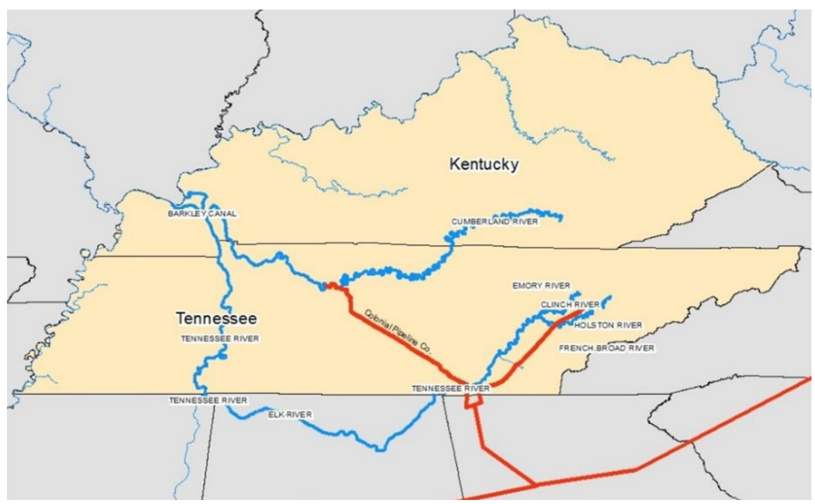


Figure 1: The case study area including the Cumberland and Tennessee Rivers in blue and the Colonial Pipeline in red.

BOX 1: DISRUPTION SCENARIOS CONSIDERED

1. Alternative Mode Impacted: Colonial Pipeline Spur to Tennessee Service Interruption
2. Lock Outage: Cheatham Lock and Dam Maintenance
3. Navigability of Waterway Junction Impacted by Earthquake: New Madrid Fault Event

APPROACH

Both stakeholder engagement and data analysis techniques were utilized in the project. Stakeholders were identified and convened in two roundtable sessions during the study with the first focused on identification of key assets and limitations of the system and the second focused on consideration of three disruption scenarios (Box 1) and resilience enhancement options (REOs). The project team identified and acquired publicly available data to characterize the broader system and individual ports and terminals. This effort involved developing maps of assets within the region, gathering data on the 31 public ports, and performing spatial analysis using ESRI's ArcGIS Pro to identify connectivity to rail and highway networks. The team also utilized the USACE's Lock Performance Monitoring System (LPMS) data to characterize commodity flows in the region (Figure 2). Historical accounts of disruptive events in Tennessee and related to the Colonial pipeline were reviewed to provide context and considerations for the disruption scenarios under consideration. The second stakeholder meeting involved expert presentations about the impacts anticipated for the disruption scenarios and a review of historic events in the region. Resilience options were discussed and presented based upon general categories of REOs identified from multiple sources such as Regional Resiliency Assessment Programs (RRAPs).

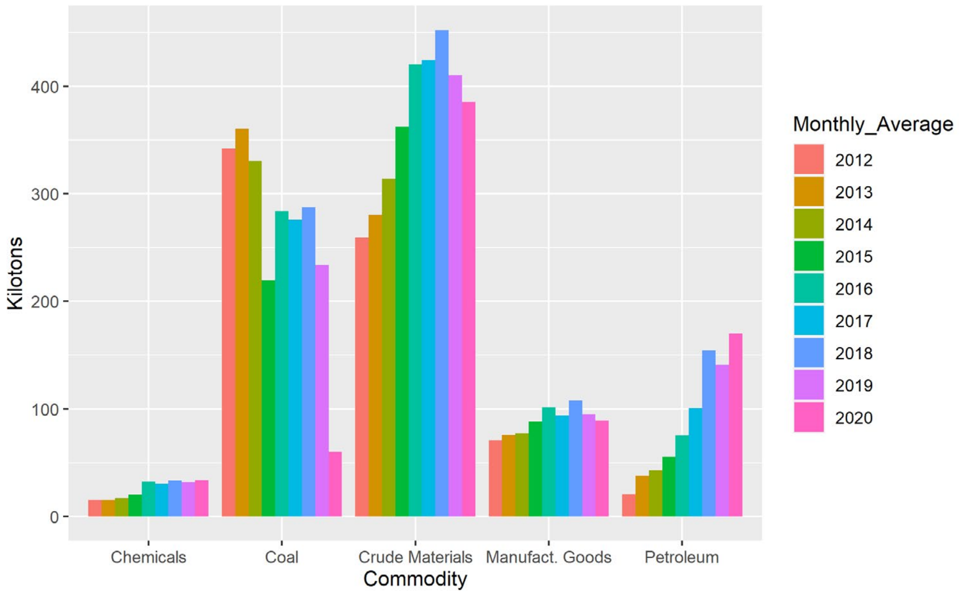


Figure 2: Historical Monthly Average Commodity Flows, 2012 – 2020, through the Cheatham Lock on the Cumberland River.

KEY TAKEAWAYS (PRESENTED WITH RESPECT TO SCENARIOS CONSIDERED):

1. There is a statistically significant relationship between access to waterborne petroleum and decreased gas station outages during a prolonged disruption of the Colonial Pipeline. As a disruption of the Pipeline occurs, the relationship becomes increasingly significant. In the 2021, Colonial Pipeline Disruption, Nashville experienced less gas station outages than with limited or no access to water way transport of the petroleum products. This suggests that the Cumberland waterway's access to petroleum provides some level of resilience.

2. Thirty-one key ports were characterized and geolocated within the broader Tennessee waterway system. Nearly all public ports feature at least one multimodal connection to a primary competing transportation mode, ensuring local distribution of commodity once it arrives. A potential resilience enhancing measure for the state of Tennessee could be to invest in additional connections between waterway terminals and rail lines to facilitate improved transferabili ty and redundance of transport networks.

3. While a New Madrid Earthquake event may not directly damage middle and east Tennessee waterway infrastructure, a seismic event in this area may significantly disrupt connected supply chains. According to stakeholders, alternative routes such as the Tennes see Tombigbee Waterway could create a redundant shipping lane to access the Gulf of Mexico in the event of a Mississippi closure. In addition, flood, droughts, and other earthquakes may threaten the inland waterway's system ability to remain open to the point of reducing the system's overall reliability. Shippers should consider opportunities to develop more redundant river detours, such as the Barkley Canal, or more multimodal capable ports, to navigate past outages in the event of disruptions. Port and terminal operators should consider following USACE's example and hardening their equipment and power supplies from extreme river stage heights, while state DOT's should harden bridges and other single-point-of-failure infrastructure that may jeopardize the supply chain. Future work could identify which ports should be prioritized for resiliency upgrades by leveraging flood and seismic mapping tools such as US EPA's EnviroAtlas [18].

IDENTIFIED REOS FOR REGION:

REO 1: Expand Chattanooga and Knoxville terminals to accept fuel barges and add terminal at Clarksville

REO 2: Explore the Feasibility of Increasing Traffic on Tombigbee River as an Alternate Route

REO 3: Update building codes for waterway (ports, terminals, locks and dams) and other infrastructure

REO 4: Industry-specific messaging during fuel-related events

CASE STUDY

RESILIENCE ASSESSMENT AT A NAVIGATION TERMINAL USING PROBABILISTIC NETWORKS

BOX 1: TACTICAL OBJECTIVES OF THE RESILIENCE ASSESSMENT

1. Quantify the resilience of the container handling function;
2. Evaluate alternatives for strengthening resilience;
3. Assess the readiness and ability to support an FSA; and
4. Assess the impact of an FSA on the container terminal.

INFRASTRUCTURE NETWORK

The network of critical infrastructure considered in this resilience assessment includes structural, electrical, and mechanical components used to transfer containers from ship to shore, store containers in the yard, and transfer containers to road and rail networks (Figure 1). The infrastructure network includes the Columbia River Navigation Channel (CRNC) from the river mouth to Bonneville Dam and seven bridges that provide air clearance for vessels in the channel.

BACKGROUND AND OBJECTIVES

A resilience assessment was demonstrated using probabilistic networks to quantify the ability of a container terminal to maintain and recover its commercial cargo handling function following a disturbance. The site of the demonstration was Port of Portland's Terminal 6, located on the Columbia River in Portland, Oregon. The region is exposed to seismic hazards from a number of sources, so this analysis addresses the resilience to ground shaking and ground deformation caused by tectonic movements at geologic faults in the region. While the primary function of the terminal is to transfer cargo between waterways and road or rail networks, the Port of Portland has also prioritized supporting emergency operations and response and regional long-term recovery efforts following a disaster. Therefore this study also considers the readiness and ability to support a federal staging area (FSA) at the terminal and assesses the impact of an FSA on container terminal operations (Box 1). The approach to resilience used in this study can be readily adapted for other navigation terminals, and other hazards and systems that are supported by networked infrastructure.

APPROACH

The initial step is to conduct a hazards analysis to estimate the probability and severity of disturbance events. The annual throughput capacity (ATC) of the system is then modeled as a function of the availability of critical infrastructure components (CIC), which are any infrastructure components that, if damaged by a disturbance and rendered non-functional, would reduce the capacity or performance of the system. Dependence among CIC is modeled using a probabilistic network in which CIC damage states are uncertain and are directly dependent upon seismic loads. Uncertainties are propagated through the network to characterize uncertainty in CIC function, restoration times, and residual ATC at points in time during a one-year restoration period. This simulation produces many realizations of the resilience curve, which describes recovery of the system in terms of residual ATC during the restoration period. These recovery trajectories are used to compute metrics of resilience under the status quo, and estimate the benefits of alternatives for enhancing resilience.

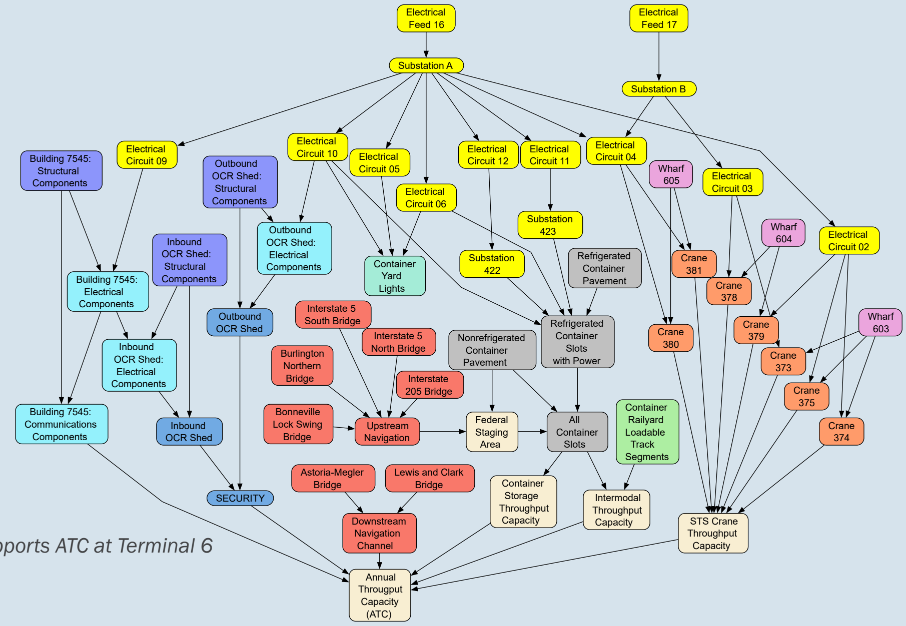


Figure 1. Network of CIC that supports ATC at Terminal 6

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STATUS QUO RESILIENCE

The metric of resilience used in this study describes the residual ATC, or the fraction of maximum ATC that could be handled over a one year restoration period with the existing infrastructure network. Overall resilience of the container terminal to seismic loads is 0.817. Interpreted, this means that given the occurrence of a seismic event with the potential to disrupt container handling, the terminal could process an expected 81.7% of maximum ATC (474,656 TEUs/year) during the one-year restoration period following the event. Conditional resilience metrics describe resilience to seismic loads of a given return period. For example, given a seismic load with a 975-year return period, it is expected the terminal could process 57.1% of maximum ATC during the subsequent one-year restoration period (Table 1).

RETURN PERIOD	CONDITIONAL RESILIENCE
72	1.000
225	0.918
475	0.803
975	0.571
2475	0.529
4750	0.505

BENEFITS OF RESILIENCE ENHANCING ALTERNATIVES

Five alternatives for strengthening resilience are considered in this study (Box 2). The potential benefit of each alternative is the expected increase in residual ATC that would be realized by implementing that alternative. Conditional benefits describe the expected increase given the occurrence of a seismic event with a specific return period. An overall benefit describes the expected benefit over all potential events and over a 30-year planning horizon. The latter is necessary because the expected benefits will be proportional to the number of seismic events that occur during that planning horizon, which is uncertain. The benefits of resilience strengthening measures can be expressed in twenty-equivalent units (TEUs/year), which is more consistent with how capacity and performance are usually described at container terminals.

Security and communications are essential functions at any container terminal. At Terminal 6, these appear to be fragile systems that are vulnerable to seismic loads with lower return periods. These two functions must be secured before the benefits of other alternatives will be realized. The conditional expected benefit and the overall expected benefit of each alternative over a 30-year planning horizon are summarized in Table 2. For SEC and COMM, these are calculated for each alternative both individually and jointly. Together, the benefits are super-additive because these subsystems often fail together and both systems must be functional to support the movement of containers. It is assumed that the remaining alternatives would be implemented in addition to SEC and COMM. NAV shows the greatest expected benefit while ELEC is lowest. This may seem contrary to expectations because the entire terminal depends on a connection to the electrical grid. However, electrical subsystems are usually restored relatively quickly, while damage to other systems is still limiting residual ATC. While the conditional benefits of SEC & COMM, NAV, and B603 are high, suggesting that these alternatives are very effective at increasing residual ATC, expected overall benefit of each alternative over a 30-year planning horizon is much lower. The expected values are low because the planning horizon, 30-years, is much shorter than the length of the return periods.

BOX 2: ALTERNATIVES FOR STRENGTHENING RESILIENCE AT TERMINAL 6

1. **SEC: Secure ability to conduct optical character reader (OCR) and radiation scans.**
2. **COMM: Secure ability to track containers and communicate with equipment.**
3. **ELEC: Seismically retrofit electrical substations and circuits.**
4. **B603: Seismically retrofit the wharf at Berth 603 and refurbish the Panamax cranes.**
5. **NAV: Advance contracting for removal of debris from the navigation channel.**

BENEFITS	RETURN PERIOD	ALTERNATIVE			ALTERNATIVES IN ADDITION TO SEC & COMM			
		SEC	COMM	SEC & COMM	NAV	ELEC	B603	ALL
Conditional benefit	72	0	0	0	0	0	0	0
	225	19,549	3	38,696	465	3	319	787
	475	39,230	8	84,979	4,790	24	3,257	8,098
	975	48,529	45	148,834	33,644	38	7,982	43,144
	2475	35,487	17	97,752	65,803	69	12,010	86,036
	4750	24,474	18	71,542	87,459	35	11,007	109,530
Overall benefit		373.8	0.080	788.5	46.4	0.112	17	65.9

KEY TAKEAWAYS

Probabilistic network models are valuable tools for quantifying resilience and for evaluating and comparing alternatives to strengthen resilience. Networks offer an intuitive way to model the dependencies among infrastructure components in systems. Probabilistic methods offer a rigorous way to deal with the many uncertainties that exist when considering the consequences of events with which there may be limited past experience. Together, these methods are critical to understanding the system's behavior and the benefits of proposed alternatives aimed at enhancing resilience. These behaviors and benefits could not be anticipated without quantitative analysis. The benefits of resilience strengthening alternatives should be calculated over a planning horizon. Similarly, intuition is not a substitute for quantitative analysis when the benefits of alternatives are calculated over an investment planning horizon. This study also shows that non-structural measures (e.g., NAV) can yield benefits that are equally effective and, possibly much less costly, than structural measures.

CASE STUDY

INSIGHTS FROM SEAPORT RESILIENCE ASSESSMENT INTERVENTIONS

BACKGROUND AND OBJECTIVES

Resilience assessments can aid the management of complex critical infrastructure systems in the face of the evolving risks and uncertainties associated with climate change and other threats and hazards. Yet, resilience assessment methodologies are relatively new, and hence there are currently no best management practices for undertaking resilience assessments that are available to practitioners. This is particularly true for seaports and other constituents of the maritime transportation system. Hence, the objectives of this study were threefold: (1) to elucidate the key benefits and challenges associated with undertaking resilience assessment interventions; (2) to identify the resilience enhancement options that seaports pursue after completing resilience assessments; and (3) to determine the extent to which resilience assessments enhance seaports' capacities to manage and adapt to climate hazards.

APPROACH

In consultation with a steering committee composed of personnel from the U.S. Army Engineering Research and Design Center and the Cybersecurity and Infrastructure Security Agency, the research team searched for seaports that had completed resilience assessment interventions based on several criteria, such as the geographic scope of their planning and the hazards they addressed. All 115 U.S. ports within 10 miles of the coastline were invited to participate. Ten ports had completed a resilience assessment approach and were selected for this study. The completed studies were reviewed to determine the methodology used, the key findings, and the resilience enhancement strategies recommended to the seaport. We synthesized the experiences of 10 U.S. seaports that have undertaken resilience assessments using a qualitative research approach.

KEY TAKEAWAYS

Through survey and interview responses from 26 seaport decision-makers at the 10 seaports, we identified four key themes.

Resilience assessments offer more than just a nuanced understanding of vulnerabilities

Resilience assessments provide a suite of co-benefits beyond identifying vulnerabilities in infrastructure and management systems. Key among these is enhanced social capital between the port organization and its internal and external stakeholders as a result of the collaborative processes that resilience assessments require.

"The workshop and the internal stakeholder engagement in the development of the [resilience assessment], really brought us together as a port team."

The most widespread challenge of resilience assessments was engaging stakeholders in the process

Unlike the benefits, challenges associated with resilience assessments were often case specific, though several overarching challenges should be expected by organizers of future resilience assessments. For example, engaging stakeholders in various phases of the assessment stymied processes such as selecting sea level rise projections to plan for or getting consensus on what resilience means for their seaport. Communicating vulnerabilities that were discovered through the resilience assessment was also a challenge for decision-makers who were concerned about how such information would impact the seaport's marketability to potential tenants and investors.

"The major challenge was just getting everybody on the same page and getting them to participate, because everybody has different priorities for their jobs."

Seaports prioritized infrastructure-related investments as a result of their resilience assessment findings

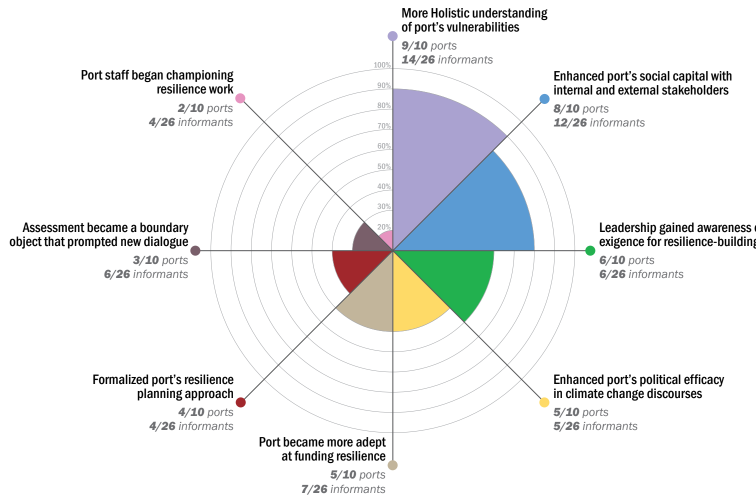
We identified 155 resilience enhancement strategies that were prescribed to seaports, which we categorized into six different strategy typologies. Of these, "infrastructure enhancements", such as stormwater management infrastructure, were most frequently implemented following resilience assessments. By contrast, strategies falling under building codes and land use regulations (e.g., basing design flood elevations on sea level rise projections) were both prescribed to and implemented by seaports the least.

Resilience assessments improved their organizations' capacities to manage their seaports' resilience and adapt to climate change

Decision-makers indicated that their organizations' capacities to manage resilience improved as a result of undertaking a resilience assessment.

OTHER RELEVANT INFORMATION

Additional takeaways captured in this research provide valuable insights that can inform users of this guidebook on how to undertake their resilience endeavors in a calculated manner and how to plan for obstacles along the way. This research constitutes a valuable contribution to practitioner audiences on resilience planning and adaptive management of climate change risks by exploring how seaports and stakeholders operationalize resilience planning and assessment practice. Seaports, with their importance to regional and national transportation services, their complex ownership and governance context, and climate change challenges, present an important setting for evaluating largely normative resilience planning and adaptive management theories for managing complex social and ecological systems.



Although most of the selected cases were undertaken by the port authorities and not the larger set of stakeholders, and were initially focused on protecting business operations, the perceived benefits supported adaptive management and resilience assessment premises—that planning builds social capital that is essential to adapting to climate change and other threats across a complex system. Resilience assessment practices enhanced social capital developed between the seaport and its stakeholders and seemed to result in shared information and political will needed for implementation of resilience enhancement alternatives. Seaport leaders reported improved awareness of the exigence of resilience-building, which has important implications for seaport adaptive capacity, as supported by existing research. Survey results capturing decision makers' perceptions of their resilience assessments' institutional impacts, further complemented our findings regarding the adaptive capacity impacts of resilience assessments. Findings suggest that organizers of future assessments should strategize how to transcend anticipated stakeholder-related obstacles early in the process.

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CASE STUDY

ANALYSIS OF THE U.S. PORT NETWORK USING AIS DATA: METRICS FOR THE CARIBBEAN

BACKGROUND AND OBJECTIVES

The maritime transportation system (MTS) is a critical part of the U.S. economy, and a vital supply chain link for Puerto Rico and the Virgin Islands due to their reliance on shipping to sustain daily life. This study was intended to identify metrics that will aid in incorporating the redundancy and connectivity of a network of ports (and the supply chains they support) into decisions about maintenance funding beyond present metrics like total annual tonnage (IWR 2020). To accomplish this, the study utilized Automatic Identification System (AIS) data to quantify five years of vessel traffic patterns across 325 ports with a focus on Puerto Rico and U.S. Virgin Island ports (Figure 1). The study included several objectives: 1) define the baseline conditions of the MTS network through observation of vessel transits; 2) identify the connectivity of these ports to understand each ports contribution to traffic flow in the region; and 3) define network resilience via metrics to measure the importance of each port relative to others in the network and the impacts if that port were to be closed by a disruptive event. The final objective of this case study is to provide a national dataset that can be quickly queried to evaluate the connectivity of any port region and the impacts of any historical disruption in the past 5 years.

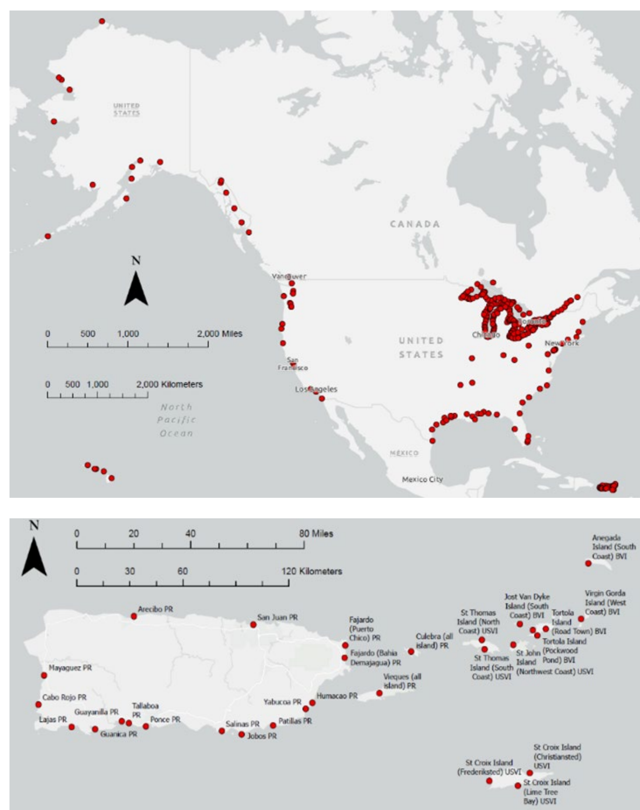

Figure 1. (Top) Map of North America depicting the locations of 325 ports in the network and (Bottom): map of the Caribbean showing 30 ports of focus in Puerto Rico and the USVI. Reprinted with permission from Young et al. 2022

APPROACH

This study used a publicly available aggregation of AIS data from the Nationwide AIS (NAIS) system from 2015 – 2020 (USCG 2020), sub-sampled at one-minute intervals, provided via the Marine Cadastre program (BOEM and NOAA 2018). The 325 port areas in this study are not exhaustive but they account for over 84% of the total tonnage of all ports in U.S. waters in 2019 (IWR 2020). The port areas were defined by identifying each port's local terminals and adjoining waterways as polygons within ArcPRO (ESRI) software (ESRI 2021). After preliminary analysis to understand traffic flow across key ports based on time and vessel type, the authors ran a PageRank analysis on the AIS dataset. PageRank (Page et al. 1999) is a technique for estimating the centrality of a node within a network and was originally developed to quantitatively estimate the importance of web pages. To analyze a network of ports with PageRank, the port areas are conceptualized as individual web pages, and the vessel traffic as links between web pages (Scully and Chambers 2019). Because it is based on high-frequency AIS data, PageRank can be calculated for vessel traffic at a higher temporal resolution than possible with traditional traffic statistics.

KEY TAKEAWAYS

Finding 1 - AIS data allow us to describe the connections between all port areas in the network.

For example, Figure 2 describes the movement of all Cargo vessels into the port of San Juan, and Cargo vessel departures from San Juan to other ports in the PR-VI region. Figure 3 also demonstrates that San Juan operates as a local hub for other ports in the area, receiving large cargo shipments from feeder ports on the East and Gulf Coasts (i.e. Jacksonville, Houston, New York/New Jersey) and sending and receiving cargo vessel from other Caribbean ports. The Port of Jacksonville, despite its small size relative to Houston and New York/New Jersey, serves as the most critical stateside cargo vessel hub for the port of San Juan and by extension, the PR-VI region. PageRank scores validated this claim – Jacksonville's centrality for the PR-VI region resulted in high PageRank scores relative to its tonnage. Conversely, while tonnage was high for PR and VI ports, PageRank scores reflect their relatively low contributions to traffic flows amongst the network of 325 ports evaluated.

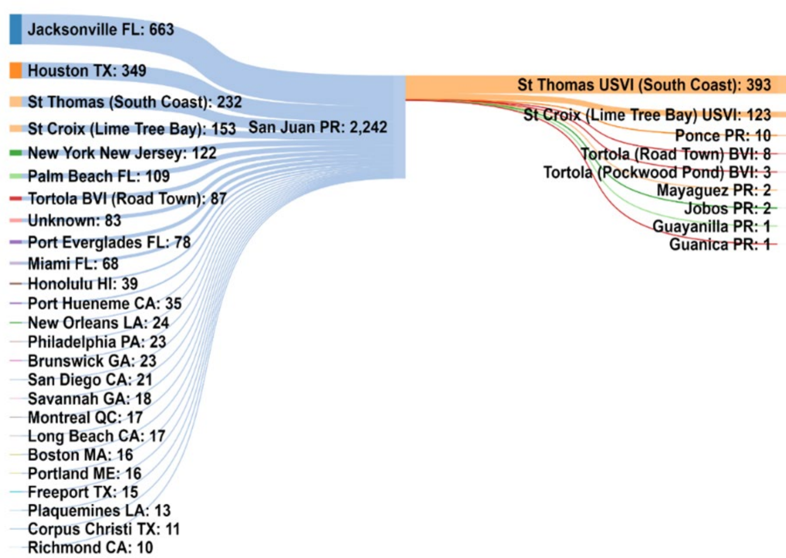

Figure 2: Movement of all Cargo vessels into the port of San Juan, and Cargo vessel departures from San Juan to other ports in the PR-VI region.

Finding 2 - AIS-derived metrics are beneficial for describing the movement of vessels that would not be highly ranked in commercial tonnage metrics but may contribute substantially to the local economy.

Figure 3 displays total vessel exchanges at selected PR-VI ports broken out by vessel type. It makes clear that, although San Juan, PR may be the largest port in terms of combined tanker/cargo vessels, the port of St. Thomas (South Coast), USVI exchanges the most vessels overall, due to the large passenger, sailing, and leisure vessel numbers.

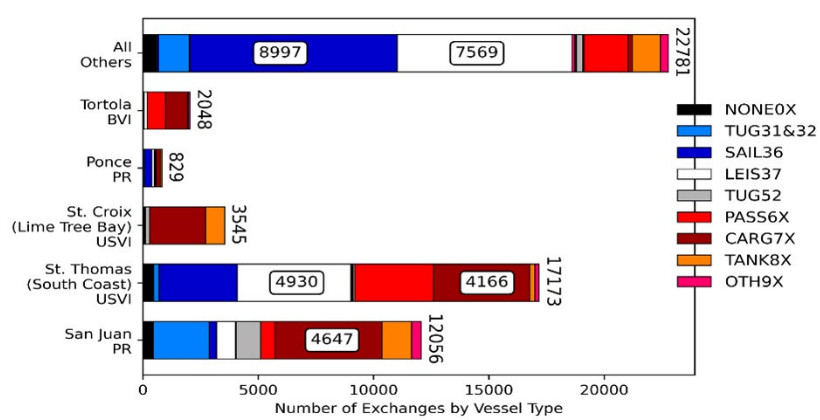

Figure 3: Total vessel exchanges at selected PR-VI ports broken out by vessel type.

Finding 3 - AIS data can describe vessel migration on the weekly timescale to investigate the effects of disruptive events.

Figure 4 (a) shows the weekly number of arrivals and (b) PageRank score for the 11 most-visited PR-VI ports (and Jacksonville, FL) for mid-July to mid November 2017, a 5-month period covering normal conditions before Hurricane Maria, the immediate aftermath (shown in gray), and the return to pre-storm 'centrality' levels for ports.

This capability met the established objectives of the resilience assessment and will ideally serve as an available tool for future analyses. Future iterations of the dataset will include 15 years of data and an even more extensive list of ports. Any region of interest can be identified and evaluated to understand baseline vessel movements and type, the redundancy of ports (i.e. exchange of vessel traffic between similar ports) within a network, and the impacts of disruptive events.

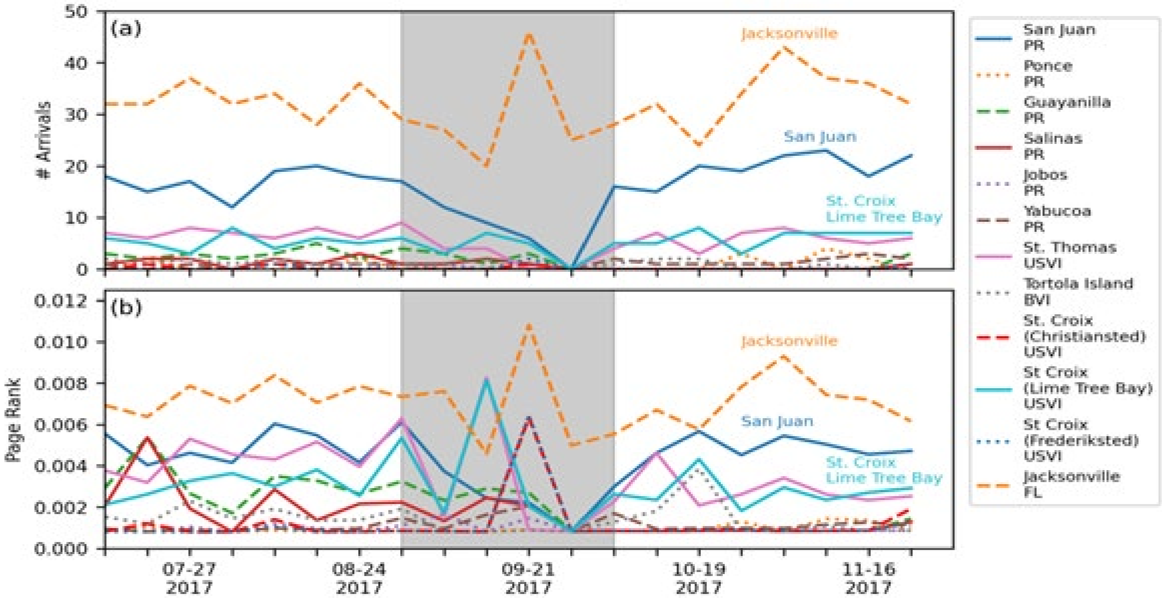

Figure 4: Weekly (a) number of arrivals and (b) PageRank score for the 11 most-trafficked Caribbean ports (and Jacksonville, FL) for mid-July to mid November 2017. Grey area shows Hurricane Maria landfall and several weeks of aftermath.

REFERENCES

Bureau of Ocean Energy Management (BOEM) and National Oceanic and Atmospheric Administration (NOAA). [2018]. "Automatic identification system (AIS) data." Accessed January 23, 2019. https://marinecadastre.gov/ais.

ESRI. [2021]. ArcPro. [software program]. Redlands, CA. https://support.esri.com/.

Page, L., Brin, S., Motwani, R., and Winograd, T. [1999]. "The PageRank citation ranking: Bringing order to the web". Stanford InfoLab.

Scully, B.M. and Chambers, K.F. [2019]. Measuring Port Disruptions with Automatic Identification System Data. In Ports 2019: Port Planning and Development (pp. 311-321). Reston, VA: American Society of Civil Engineers.

United States Army Corps of Engineers Institute of Water Resources (IWR) [2020]. "Principal Ports of the United States, Tonnage for selected U.S. ports". Accessed January 15th 2020. https://www.iwr.usace.army.mil/about/technical-centers/wcsc-waterborne-commerce-statistics-center/.

United States Coast Guard (USCG). [2020]. "Nationwide automatic identification system". Accessed October 7, 2020. https://www.dcms.uscg.mil/Our-Organization/Assistant-Commandant-for-Acquisitions-CG-9/Programs/C4ISR-Programs/nais/.

Failure to embrace resilience as a planning paradigm can result in investments and operations that are isolated, require frequent and expensive repair, and do not consider the capability of the MTS to adapt and preserve its functions in the future.

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