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An Interagency Collaboration to Identify Federal Resilience Factors for the U.S. Marine Transportation System

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) presents the results from an interagency collaboration within the U.S. Committee on the Marine Transportation System (CMTS) and its Marine Transportation System Resilience Integrated Action Team (MTS R-IAT) (Figure 1) to identify priority resilience factors affecting operation of the Marine Transportation System (MTS). The MTS R-IAT analyzed resilience factors impacting the MTS to understand, categorize, and prioritize the MTS resilience issues of concern among federal agencies. This CHETN provides guidance on the capabilities for measuring resilience using existing federal datasets and proposes a framework to identify feasible and meaningful factors (metrics) for tracking port or infrastructure system performance before, during, and after disasters. This approach may be useful for understanding vulnerability of other regions or within other types of systems.

Figure 1. Federal membership of the MTS R-IAT.

BACKGROUND

An Interconnected and Intermodal System. The U.S. MTS connects the U.S. economy to the rest of the world. This complex system is comprised of diverse infrastructure components and beneficiaries that include owners, managers, consumers, service providers, and other stakeholders that directly or indirectly depend on systematic coordination across multiple system components to operate optimally and cost efficiently. The MTS, when considered as individual components, or as a whole, is vulnerable to a number of human-induced and natural disturbances that challenge efficient operations during logistical and economic disruptions.

The components that comprise the MTS are diverse, as is the range of possible disruptions and responses. The failure of supporting components can cause cascading failures across the coastline. For example, the loss of weather satellites or tide gauge infrastructure could limit the National Oceanic and Atmospheric Administration's (NOAA) ability to best forecast water levels used in daily MTS operations. The buildup of significant debris or shoaling of a channel may shut down access to a port, even when survey ships and dredges respond as quickly as possible. Terrorist threats lead to a heightened state of national security concerns that might redirect resources away from the United States Coast Guard's aids to navigation and NOAA's Coast Survey missions, delaying access to navigation channels after a shoaling event. Increased number of vessels waiting to re-enter the channel may raise the potential for collisions or accidents, and the surge of activities across port-related intermodal infrastructure once ships return may strain safety systems. MTS-related impacts can also spread to the surrounding region: port-bound/departing automobile traffic may compete with surrounding communities during emergencies such as hurricane evacuations; chemical spills or leaching can lead to widespread environmental impacts; and prioritization of restoration of power and water lines may need to be balanced between port operations and public safety. These examples illustrate how the MTS and neighboring communities and infrastructure systems are reliant upon each other. The interdependent, intermodal nature of the MTS components allows for any one disturbance in the system to cascade across the freight transportation network and its land-side components. Therefore, America's transportation and marine infrastructure system must be resilient to disturbances and stressors across all the MTS's various components. The complexity also requires the identification of resilience factors that can be used to understand, estimate, measure, and track resilience in the MTS through time.

> **MTS Components:** *Sub-units or "parts" of the MTS, such as infrastructure, labor, ships, ports, cargo, etc.*

The potential to invest in and maintain MTS operability requires cooperative foresight and governance to develop solutions beyond those that are solely market based among private entities. The federal government has the capacity to act on behalf of the MTS as a whole to facilitate commerce through the support and improvement of federally maintained MTS infrastructure.

> **Resilience Factor:** *A unit, metric, practice, or characteristic that can be used to measure the resilience of a system.*

METHODS TO ASSESS FEDERAL RESILIENCE FACTORS IN THE MTS

> **Disturbance:** *Singular events that can be addressed through response and recovery procedures.*
>
> **Stressor:** *Long-term disturbances that force the system to adapt to a new equilibrium state.*

Risk, Vulnerability, and Vulnerability Assessment. Risk, vulnerabilities, stressors, and disturbances are related but separate concepts that are often subject to confusion. *Stressors* and *disturbances* are terminology originally derived from ecological disturbance research (e.g., Borics et al. 2013) and are used herein to describe events that affect the successful operation of a system such as the MTS. Disturbances are most commonly described as singular events that can be addressed through response and recovery procedures, for example a severe storm or infrastructure rehabilitation. Stressors are long-term disturbances that force the system to adapt to a new equilibrium state; these can happen in short succession as well as over long time periods and are challenging to address within normal response and recovery procedures. Examples of stressors can include relative sea level change and increased human infrastructure in a port region. Vulnerability is the known exposure within a system that makes it vulnerable to disruption. Risk is the probability that losses or damage will occur based upon those known exposures. These concepts as they relate to the MTS are discussed below.

Vulnerability: *The exposure of a system and the effects that a particular stressor or disturbance could have on a system within a given time.*

Traditional risk assessment is well documented in the literature and has become an integral component to the safe operation of the MTS. For example, risk assessment has been applied to the MTS for a wide variety of issues including ship-on-ship collisions (Montewka et al. 2014; van Dorp and Merrick 2011; route analysis for hazardous material (Iakovou 2001); and national security (Nincic 2005; Trucco et al. 2008). These studies have provided insights to the difficult task of measuring the results of destructive events that occur with high levels of uncertainty. Vulnerability assessments can complement traditional risk assessment by accounting for the interrelated components within a system and identifying how each contributes to the overall health of the system when it is faced with a disturbance. The vulnerability of federal components within the MTS matters most when the impacts from a disturbance cascade through a wide array of components.

When applied to a system, these risk and vulnerability assessments provide insights that can be incorporated into decision-making processes for disaster preparation and recovery. Baker (2005) explores the differences between vulnerability assessment and traditional risk characterization. Baker concludes that vulnerability assessment is a matter of understanding how the system can potentially fail given a specific hazard and risk characterization quantifies both the likelihood of a hazard and the effect that it can have on different aspects of a system. This assessment approach is particularly helpful when estimating the day-to-day operations of a port, port system, or MTS infrastructure, having the potential to answer questions such as the following:

- Will the port be able to continue normal operations in the face of a “100 year storm”?
- Will a channel shoal given a flooding event? What are the implications from this event (i.e., what are the critical operational and cost considerations)?
- Will the growth of the port continue through a downturn in the economy?
- Will workforce operations be stalled by a labor dispute?

To increase resilience within the MTS, it is important to understand the inherent vulnerabilities that exist within the system, the interconnectivity within the system, and the risks that various hazards present. In addition to this awareness, best practices to increase resilience require forethought and planning for how the system will respond and recover over time so that as a result of these challenges, the system will be stronger and more robust than before.

> **Resilience:** *The ability to prepare and plan for, resist, recover from, and more successfully adapt to the impacts of adverse events.*

Resilience in the MTS. Within this MTS R-IAT and other similar federal initiatives, the efforts to comprehend the elements of resilience have historically approached the issue from a theoretical perspective—examining all the possible threats and the mechanisms that might monitor hypothetical interruptions. The term *resilience* itself has multiple definitions across federal sources. The MTS R-IAT has adopted the definition of resilience as "the ability to prepare and plan for, resist, recover from, and more successfully adapt to the impacts of adverse events." This definition is based on Presidential Policy Directive 21, on Critical Infrastructure Security and Resilience (The White House 2013), and the National Academy of Science report *Disaster Resilience: A National Imperative* (NRC 2012). The MTS R-IAT's priorities align with several of the key areas of focus discussed in the recently released Implementation Roadmap for the National Critical Infrastructure and Resilience Research and Development Plan, including understanding interdependencies in infrastructure vulnerabilities, position and navigation support, water infrastructure, applications for transportation infrastructure, and resilient/secure energy delivery (NSTC 2016).

Resilience theory often focuses on low-probability, high-impact events for which it is difficult to justify mitigation actions based on traditional risk management practices alone. Such events might include industrial accidents, natural disasters, or cyber-attacks. The continued function of the MTS depends on owners and operators being able to envision these sometimes billion-dollar rare events (along with typical expected events) ahead of time to make decisions and preparations to decrease their costly consequences. Doing so requires creating future or redundant capacity, allowing for quicker recovery and less loss during the next event. Figure 2 illustrates these concepts schematically.

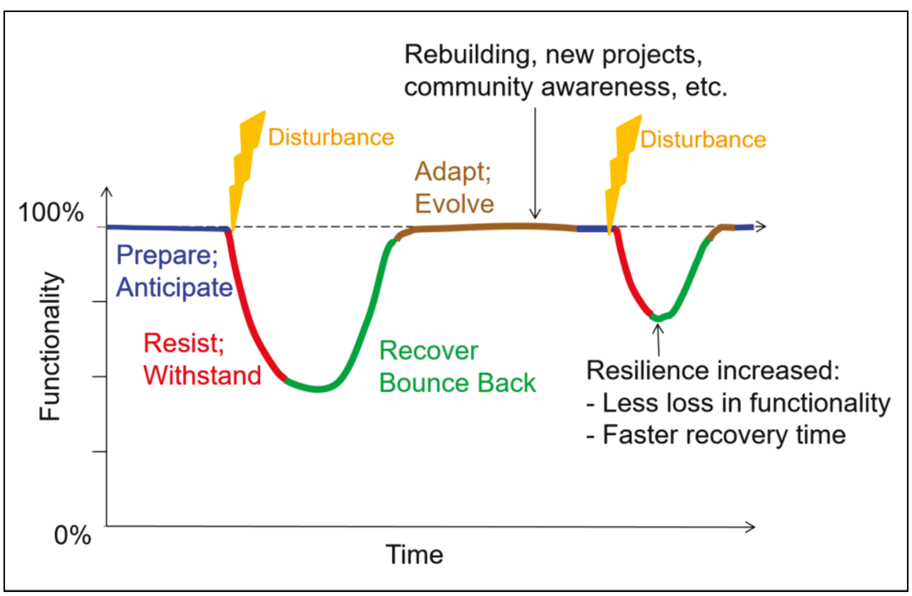

Figure 2. Schematic depicting measuring resilience as an abstract concept through time.

METHODS: MTS R-IAT members characterized the resilience of the MTS through two approaches: first, by developing a method for identifying key factors of federal MTS component vulnerability and second, by assessing resilience through regional applications. Outlined here are the methods and results of the federal MTS component vulnerability approach. The second step, assessing port resilience using metrics across three ports in a region, is available for reference within Touzinsky et al. (2018).

To understand federal MTS component vulnerability, MTS R-IAT members consulted within their organizations to identify the most critical factors that influence resilience of the components of the system. MTS R-IAT member agencies have a broad range of mission areas, and as a result, this survey returned a large number of resilience factors for consideration. The assembled factors were divided into six categories: environmental; logistics/operations; physical infrastructure; security; energy; and general governance, political, or community factors. Categorizing these factors enabled the MTS R-IAT to separate the infrastructure within the MTS that is managed, regulated, or supported by federal agencies from the factors that relate to the hazards or vulnerabilities themselves.

After documenting the broad scope of resilience factors that could be of importance to measure the resilience of the MTS, the MTS R-IAT focused on prioritizing the most actionable resilience factors for collaboration among member agencies. Actionable resilience factors were defined as factors with the greatest amount of agency engagement, and these factors were considered a proxy for areas of the MTS with the greatest need for resilience work. Agency engagement was defined as 11 broad activities including data collection and physical monitoring, ongoing research studies, existing tools and studies, partnerships, programs, policies, numerical modeling, defined metrics, operations, and "other related activities."

Following this data call, relevant datasets were requested to provide a foundation for future analyses. Where federal datasets were sensitive to full dissemination across agencies, MTS R-IAT member(s) identified important data elements to the best extent possible.

These results identified and categorized the variety of resilience factors that federal agencies consider when managing the MTS. While this effort was not exhaustive, the priority categories targeted areas of work and agency engagement where additional information could likely be acquired. These results created the groundwork for selecting future work, including case studies of MTS vulnerability and resilience in a real-world, systems setting.

RESULTS: The following results explain the six categories of environmental and non-environmental factors related to resilience, federal components and datasets, and the degree of involvement across federal agencies.

Resilience Factors for the MTS. The MTS R-IAT utilized the member agency input to develop a comprehensive list of present and potential future hazards and constraints (hereafter, resilience factors) into an MTS Resilience Factors Matrix. Eight member agencies (NOAA, Maritime Administration [MARAD], U.S. Army Corps of Engineers [USACE], Department of Interior's [DOI] Bureau of Safety and Environmental Enforcement [BSEE], Environmental Protection Agency [EPA], U.S. Transportation Command [TRANSCOM], Department of Energy [DOE], and Department of Homeland Security [DHS]) identified 40 factors that pertain to non-environmental issues (e.g., economics, labor, competing use of the MTS) and 31 factors that relate to the environment (e.g., tidal extremes, storm frequency, invasive species). These factors were then divided into categories as listed in Tables 1 and 2.

Table 1. Non-environmental resilience factors.

Non-Environmental Factors					
Logistics/ Operations	*Infrastructure*	*Government/ Political*	*Technology*	*Security*	*Energy*
• Larger vessels • Hazardous materials/oil spills • Emergency response capabilities • Industrial accidents • Maintenance and upkeep • Operational disruptions • Personnel/ labor challenges	• Competing demands for space of multimodal systems • Deteriorating infrastructure • Port congestion • Lock and dam features • Levee breaches • Intermodal connectors	• Community/ environmental justice • Competing uses of land/ ocean/ coastal areas • Regulatory/ political/ budgetary • State and federal funding • Trade relations • Distribution of management for MTS • Ship alliances • Jurisdictional conflicts • Coastal management	• Cyber disruptions • Proprietary data • Electromagnetic spectrum disruption • Navigation system failures • Greening of the fleet	• Terrorism • Criminal activity • Piracy • Law enforcement	• Electric/power disruptions • Marketplace drivers • Energy availability • Limited alternative fuel options • Operational redundancy • Energy infrastructure redundancy • Changing offshore resource use

Table 2. Environmental resilience factors			
Environmental Factors			
Extreme Events	*Climate Change*	*Operations*	*Species*
• Water level extremes • Tidal extremes • Frequency and severity of storms • Extreme precipitation • Extreme heat/thaw • Extreme cold/ice • Seismic disruptions • Tsunamis • Tornadoes • Volcanic activity • Wildfire • Waves • Coastal and riparian erosion	• Water level/ inundation/ surge • Arctic shipping routes opening • Frequency and severity of storms	• Navigation and channel shoaling • Corrosion • Inland waterways/ river conditions • Hazardous debris • Silting • Spill response capabilities • Visibility • General changing sea conditions • Ice • Solar weather	• Invasive species • Threatened and endangered species and protected habitats • Subsistence fishing • Changing migration patterns • Nuisance species

It is useful to think of these resilience factors in terms of their association, relationship, direction, and magnitude with each other and how, when combined, they can decrease or increase the resilience of a system. Different factors are drivers of resilience in different scenarios (either as stressors or disturbances) and relate to different timeframes of resilience. For example, a non-environmental factor such as port congestion (Table 1, Infrastructure category) could be exacerbated by environmental factors, such as nuisance flooding, or non-environmental factor(s) such as the competing use of waterways, a factor that can contribute to port congestion. A real-world example of these interdependencies comes from January 2010 when a 7.0 earthquake struck Port-au-Prince, Haiti, devastating the city, including the seaport and airport infrastructure. Incoming aid shipments were halted for a week after the disaster because of the condition of the MTS infrastructure. The delay at the seaport impacted other infrastructure repair efforts, energy availability, and emergency response capabilities. Although this type of episodic disturbance event cannot be prevented, strengthening key infrastructure components could help speed up overall recovery response. These shortened recovery times can be quantified, and their value monetized, as a means to measure the increase in resilience of that system. Avoided costs given a retrofitted, resilient infrastructure could also be quantified and compared to the cost of retrofitting the system.

Quantifying Actionable Resilience Factors. From the resilience factors listed in Tables 1 and 2, the MTS R-IAT identified priority factors based on two criteria: (1) if the sum of agency engagement activities for that factor fell into the upper quartile of all activities in either the non-environmental and environmental categories, and (2) if that factor had engagement from at least five member agencies. The non-environmental priority factors included infrastructure resilience and emergency response capabilities while environmental priorities included extreme events and water level changes. The results of this agency engagement assessment are listed in Table 3.

Table 3. Priority non-environmental and environmental factors related to resilience that include active engagement for at least five member IAT agencies.

Non-Environmental Factors			**Environmental Factors**		
Resilience Factor	***# Agencies***	***# Activities***	***Resilience Factor***	***# Agencies***	***# Activities***
Infrastructure resilience	8	37	Water level/ inundation/ surge	7	38
Emergency response capabilities	7	34	Water level extremes and long term change	7	36
Regulation/political/ budgetary	6	29	Invasive species	5	39
Hazardous materials/oil spills	5	32	Threatened and endangered species	5	39
Competing uses of land/ocean/coastal areas	5	26	Changing migration patterns	5	28
Larger vessels	5	23			

For the non-environmental factors, 598 agency activities were identified. Infrastructure resilience was the clear priority among the Integrated Action Teams (IAT) agencies, with some degree of involvement from eight agencies (NOAA, MARAD, USACE, DOI, EPA, TRANSCOM, DOE, and DHS) and the greatest number of activities (n=129). Infrastructure resilience is defined as "the capacity of physical and technological elements of the MTS (including built structures, natural features, navigation channels, data and information) to resist damage, recover from, and more successfully adapt to the impacts of adverse events" (CMTS 2017). Infrastructure resilience is a broad topic that encompasses work in many different arenas, so members recommended considering the effects of other environmental and non-environmental resilience factors on infrastructure resilience when developing short and long-term action items.

For the environmental factors, 569 individual agency activities related to environmental resilience factors. The NOAA, EPA, DOI, and USACE had the most focus on environment-related resilience issues. The "Extreme Events" category received the largest number of responses for agency activities (total n=208) with the top four agencies for the subgroup being NOAA, the EPA, DOI, and USACE.

Federal Datasets to Describe the MTS Components When Measuring Resilience. The R-IAT data call initially returned MTS information from eight agencies: NOAA, MARAD, USACE, DOI, EPA, TRANSCOM, DOE, and DHS. These agencies' specific data sources provide a window for identifying measures of MTS performance and functionality across components of the MTS.

Collecting data on different federal components or interests related to resilience can provide insights for the focus of future studies. There is a broad variety of federal interests, activities, and measures across the topic of MTS vulnerability and resilience. The MTS is a complex system that not only includes internal components but also external components that are influenced by its operation (e.g., coastal communities and adjacent ecological habitats). It therefore generates multiple types of datasets that are growing more diverse as the understanding of resilience progresses. These datasets enhance the ability to consider the breadth of data which might allow measurement of system performance, interdependencies, vulnerability, and over time, resilience. Several tools from member agencies, such as NOAA's Digital Coast's Marine Cadastre National Viewer, already exist to translate these datasets to interested users and may have the potential to integrate in new datasets and analyses. Table 4 provides a list of some of these existing data sources and where to find them.

Table 4. Resilience-related data sources by thematic category, resilience factor, agency, location, and dataset description.

MTS Categories	Resilience Factor	Agency	Dataset	Data Source Location
Logistics/ Operations	Multiple: Emergency Response, Port congestion, Throughput	USACE	Automatic Identification System Analysis Package: real- time vessel movements	AIS Analysis Package http://ais-portal.usace.army.mil/
Logistics/ Operations	Throughput	USACE	Commodities at ports; vessel Drafts at Ports; Automatic Identification System (AIS), e.g. average monthly 2012-2015 traffic by port entrance	Channel Portfolio Tool http://cirp.usace.army.mil/products/ cpt.php. Raw data: http://www.navigationdatacenter.us/ wcsc/wcsc.htm.
Infrastructure	Vulnerability to Flooding	Inter-agency	Coastal Lidar	https://www.coast.noaa.gov/ dataviewer/#/lidar/search/
Infrastructure	Vulnerability to Flooding	NOAA	Tides and Currents	https://tidesandcurrents.noaa.gov/
Infrastructure	Federal Navigation Channels	USACE	Survey data of channel boundaries, reaches, and channel quarters	http://navigation.usace.army.mil/ Survey/Framework

MTS Categories	Resilience Factor	Agency	Dataset	Data Source Location
Infrastructure	Federal Navigation Channel Maintenance	USACE, EPA	Ocean Sediment Disposal Sites	https://coast.noaa.gov/dataregistry/search/dataset/info/oceandisposal
Species	Supply and demand of ecosystem services	EPA	EnviroAtlas	http://enviroatlas.epa.gov
Environmental Operations	Water Quality	EPA	Office of Water (OW) data, also EnviroAtlas with water body listings; OW's Climate Ready Water Utilities (multiple tools)	http://www.waterqualitydata.us/portal/ or http://enviroatlas.epa.gov, https://www.epa.gov/crwu
Species	Land Cover	NOAA	Coastal Change Analysis Program, EnviroAtlas	https://coast.noaa.gov/ccapatlas/
Species	Critical Habitats/Endangered Species	NOAA, EPA	Right Whale Habitat, EnviroAtlas has data from NatureServe on T, E, and vulnerable species, as well as data from the U.S.Geological Survey Gap Pgm	Digital Coast or http://www.nmfs.noaa.gov/pr/species/criticalhabitat.htm, http://enviroatlas.epa.gov

Potential Applications of Resilience Factors. The data summarized herein and available for use are applicable across regions and other specific area port and infrastructure systems. A specific application of these datasets could be to assess the operational and cost implications for a port system across a region in response to a major disaster (i.e., hurricane). This framework provides a launching point for which future analyses can qualify, quantify, and measure the ability of a project or process to respond to stressors and disturbances and to test the resilience of the system through an applied case study illustrating real-world elements of the federal government associated resilience.

SUMMARY: This CHETN summarizes the MTS R-IAT's methodology to identify and quantify the importance of a variety of factors related to the resilience of the MTS. In total, at least 31 environmental and 40 non-environmental resilience factors can be leveraged to understand the resilience of a port, infrastructure, or navigation system. This methodology serves as a bridge to future cost-effective federal collaboration on mitigation and analyses to resist natural and manmade disasters. Moving forward, the MTS R-IAT intends to build upon the identified priorities of infrastructure resilience through a systems-approach that includes both environmental and non-environmental factors, meets the needs and individual priorities of member agencies, and can accommodate the variable time scales and processes for each factor (e.g., political and budgetary concerns versus long-term climate change and water level changes). The MTS R-IAT intends to further develop the Resilience Factors Matrix presented in this study by identifying the agencies that are most active in data and physical monitoring, numerical models and studies, defined metrics, and existing tools for each factor and developing a database of these efforts to further inform MTS resilience. These results will further guide collaboration on characterizing and quantifying MTS resilience through metrics and indicators for factors related to Infrastructure Resilience.

POINTS OF CONTACT: This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared as part of the USACE Coastal System Resilience Research (CSR R&D) by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Vicksburg, MS. Additional information pertaining to CSR R&D may be obtained from the Flood and Coastal Technical Director, Dr. Julie D. Rosati (*Julie.D.Rosati@usace.army.mil*). Questions regarding this CHETN can be addressed to Katherine Touzinsky (202-761-7582; *Katherine.F.Touzinsky@usace.army.mil*) at ERDC. This document can be referenced as follows:

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