NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

VULNERABILITIES TO U.S. WATERWAY INFRASTRUCTURE IMPACTING THE ABILITY TO PROJECT NAVAL POWER

by

Alex J. Monson

March 2022

Thesis Advisor: Rodrigo Nieto-Gomez
Second Reader: Daniel Eisenberg

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC, 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** March 2022	**3. REPORT TYPE AND DATES COVERED** Master's thesis	
4. TITLE AND SUBTITLE VULNERABILITIES TO U.S. WATERWAY INFRASTRUCTURE IMPACTING THE ABILITY TO PROJECT NAVAL POWER			**5. FUNDING NUMBERS**
6. AUTHOR(S) Alex J. Monson			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

This thesis answers the question: What are the core domestic maritime transportation system waterway vulnerabilities for the Carrier Strike Group power projection capabilities of the United States? There is a multitude of threats that the United States Navy faces in today's world, such as terrorism, great power competition, and contention for freedom of the seas. Some of these originate in the homeland, such as threats to U.S. waterways that are home to surface naval vessels. Vulnerabilities to these waterways in the form of natural disasters, accidents, adversarial attacks, and management issues can potentially disrupt normal maritime operations and the power projection capabilities of the U.S. Navy. Within the continental United States, surface fleet naval bases are located within open civilian waterways, complete with interdependent infrastructure including international trade terminals, bridges, tunnels, and transportation nodes. When operating within the United States maritime transportation system infrastructure, the U.S. Navy operations are vulnerable. This thesis describes and analyzes three regions where carriers are homeported in the United States and assesses the maritime transportation system through risk assessment, reliability engineering, worst-case planning, and surprise adaptation. The assessments are then compared and contrasted to provide recommendations for improving domestic vulnerabilities to aircraft carrier power projection.

14. SUBJECT TERMS maritime, transportation system, critical infrastructure, naval power projection, carrier strike group, vulnerabilities, domestic waterways			**15. NUMBER OF PAGES** 133
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

VULNERABILITIES TO U.S. WATERWAY INFRASTRUCTURE IMPACTING THE ABILITY TO PROJECT NAVAL POWER

Alex J. Monson
Lieutenant, United States Navy
BA, Virginia Military Institute, 2015

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF ARTS IN SECURITY STUDIES
(HOMELAND SECURITY AND DEFENSE)

from the

NAVAL POSTGRADUATE SCHOOL
March 2022

Approved by: Rodrigo Nieto-Gomez
Advisor

Daniel Eisenberg
Second Reader

Afshon P. Ostovar
Associate Chair for Research
Department of National Security Affairs

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This thesis answers the question: What are the core domestic maritime transportation system waterway vulnerabilities for the Carrier Strike Group power projection capabilities of the United States? There is a multitude of threats that the United States Navy faces in today's world, such as terrorism, great power competition, and contention for freedom of the seas. Some of these originate in the homeland, such as threats to U.S. waterways that are home to surface naval vessels. Vulnerabilities to these waterways in the form of natural disasters, accidents, adversarial attacks, and management issues can potentially disrupt normal maritime operations and the power projection capabilities of the U.S. Navy. Within the continental United States, surface fleet naval bases are located within open civilian waterways, complete with interdependent infrastructure including international trade terminals, bridges, tunnels, and transportation nodes. When operating within the United States maritime transportation system infrastructure, the U.S. Navy operations are vulnerable. This thesis describes and analyzes three regions where carriers are homeported in the United States and assesses the maritime transportation system through risk assessment, reliability engineering, worst-case planning, and surprise adaptation. The assessments are then compared and contrasted to provide recommendations for improving domestic vulnerabilities to aircraft carrier power projection.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I. INTRODUCTION....1
A. BACKGROUND....1
B. REGIONAL MARITIME TRANSPORTATION SYSTEMS AND CARRIER STRIKE GROUPS....3
C. LITERATURE REVIEW....4
1. Maritime Transportation System Literature....5
2. Vulnerabilities....7
3. Power Projection....12
D. HYPOTHESES AND POTENTIAL EXPLANATIONS....13
E. RESEARCH DESIGN AND METHODS....14

II. MARITIME TRANSPORTATION SYSTEM....19
A. MARITIME TRANSPORTATION SYSTEM DEFINED....19
1. System....20
2. Subsystem....21
3. Unit....25
4. Part....26
B. DISCUSSION....27

III. NORFOLK REGIONAL ASSESSMENTS....29
A. NORFOLK REGIONAL PORT OPERATIONS SUBSYSTEM....29
1. Naval Station Norfolk....30
2. Yorktown Naval Weapons Station....31
3. Norfolk Naval Shipyard....31
4. Huntington-Ingalls Industries Newport News Shipbuilding....31
B. INTERMODAL CIVILIAN MARINE INFRASTRUCTURE IN HAMPTON ROADS....32
1. Intermodal Infrastructure....33
2. Navigable Waterways....33
C. HAMPTON ROADS MARITIME TRANSPORTATION SOCIAL UNITS....34
1. Virginia Department of Transportation....35
2. United States Coast Guard Sector Virginia....35
3. Virginia Pilot Association....35
4. Tugboat Companies....35
D. HAMPTON ROADS VULNERABILITY ASSESSMENT....36

1. Risk Assessment 36
2. Reliability Engineering 42
3. Worst-Case Scenario..45
4. Resilience Engineering through Surprise 47
E. HAMPTON ROADS MTS SUMMARY 48

IV. SAN DIEGO REGIONAL ASSESSMENT 51
A. SAN DIEGO REGIONAL PORT OPERATIONS SUBSYSTEM......52
1. Naval Base Coronado 52
2. Naval Base San Diego 52
3. San Diego Shipyards...53
B. INTERMODAL CIVILIAN MARINE INFRASTRUCTURE IN SAN DIEGO 53
1. San Diego Bay Waterway...53
2. San Diego-Coronado Bay Bridge...55
3. Coronado Ferry 55
4. Tourist Terminals 55
5. Recreational Marinas 56
C. SAN DIEGO MARITIME TRANSPORTATION SOCIAL UNITS...56
1. Caltrans District 11- San Diego..56
2. Port of San Diego 57
3. U.S. Coast Guard Sector San Diego...57
4. San Diego Bay Pilots Association, Inc..58
5. San Diego Tugboats 58
D. SAN DIEGO VULNERABILITY ASSESSMENT.................................59
1. Risk..59
2. Reliability 61
3. Worst-Case...63
4. Resilience Engineering through Surprise 65
E. SAN DIEGO MTS SUMMARY 69

V. PUGET SOUND REGIONAL ASSESSMENT..71
A. PUGET SOUND REGIONAL PORT OPERATIONS SUBSYSTEM 71
1. Naval Base Kitsap 72
2. Naval Station Everett..73
3. Puget Sound Naval Shipyard 73
B. INTERMODAL CIVILIAN MARINE INFRASTRUCTURE IN PUGET SOUND 74

1. Puget Sound Waterways....74
2. Ferry Transportation....76
3. Shipping Terminals....76

C. PUGET SOUND MARITIME TRANSPORTATION SOCIAL UNITS....77
1. Washington State Department of Transportation....77
2. Port of Seattle....77
3. Port of Tacoma....78
4. U.S. Coast Guard Sector Puget Sound....78
5. Puget Sound Pilots....79
6. Puget Sound Tugboats....79

D. PUGET SOUND VULNERABILITY ASSESSMENT....80
1. Risk....80
2. Reliability....83
3. Puget Sound MTS Worst-Case Scenario....85
4. Resilience Engineering through Surprise in Puget Sound....87

E. PUGET SOUND MTS SUMMARY....88

VI. CONCLUSION....91
A. REGIONAL COMPARISONS....93
B. REGIONAL DIFFERENCES....95
C. POWER PROJECTION VULNERABILITIES....96

LIST OF REFERENCES....101

INITIAL DISTRIBUTION LIST....113

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

Figure 1. United States Surface Naval Carrier Bases..4
Figure 2. Holarchical view of Maritime Transportation System of Systems. 22
Figure 3. Maritime Transportation System Flow Diagram 24
Figure 4. Maritime Transportation System Component Chart.................................27
Figure 5. Hampton Roads Internal Waterways 30
Figure 6. Carrier Maintenance Homeport Locations..32
Figure 7. NOAA Chart 12222, Chesapeake Bay Entrance Chart 34
Figure 8. 36-Month Aircraft Carrier Maintenance Cycle over the 50-Year Expected Service Life 43
Figure 9. Hampton Roads Maritime Network Interdiction Map..............................46
Figure 10. San Diego Maritime Transportation Infrastructure...................................51
Figure 11. NOAA Chart 18773- San Diego Bay...54
Figure 12. San Diego Maritime Network Interdiction Map 64
Figure 13. Tsunami Inundation Map of San Diego Bay 67
Figure 14. Puget Sound (Bremerton and Everett) Maritime Infrastructure 72
Figure 15. NOAA Chart 18440 Puget Sound...75
Figure 16. Puget Sound Maritime Network Interdiction Map 86

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

Table 1. Hampton Roads MTS Risk Assessment 41

Table 2. San Diego Maritime Transportation System Risk Assessment 61

Table 3. Puget Sound MTS Risk Assessment...82

Table 4. Summary of Key Subsystems for Each Carrier Homeport 92

Table 5. Summary of Key Vulnerabilities for Each Carrier Homeport 93

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ARG	Amphibious readiness group
BB	Battleship
COLREGS	Collision Regulations
CVN	Aircraft Carrier, nuclear-powered
DDG	Destroyer, guided missile
DHS	Department of Homeland Security
DOT	Department of Transportation
GAO	Government accountability office
LHD	Landing, Helicopter Dock
MARAD	Maritime Administration
MTS	Maritime Transportation system
NAVFAC	Naval Facilities Engineering Systems Command
NBC	Naval Base Coronado
NBK	Naval Base Kitsap
NCF	National critical functions
NSE	Naval Station Everett
NOAA	National Oceanic and Atmospheric Administration
PSNS & IMF	Puget Sound Naval Shipyard & Intermediate Maintenance Facilities
SAAL	Sensing, Anticipating, Adapting, Learning
USCG	United States Coast Guard
USS	United States Ship
USNS	United States Naval Ship
VDOT	Virginia Department of Transportation
VTS	Vessel Traffic Service
WSDOT	Washington State Department of Transportation

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

The experience of writing this thesis certainly has been one of a life-time. Thank you to my wife, Katelyn, for supporting me at home. She helped me in every way possible throughout this whole adventure and this document would not exist without her. I also want to thank my thesis committee, Dr. Rodrigo Nieto-Gomez and Dr. Daniel Eisenberg, whose classes, instruction, and guidance significantly helped construct this research. I would not have completed this thesis without them.

I want to thank my cohort buddies, Josh and Samantha, for the support and venting opportunities we shared throughout our NPS journey. See you out in the Fleet.

Finally, I want to thank COVID-19 for making this way harder than it needed to be and highly do not recommend graduate school during a global pandemic (although the business-leisure attire at home was good while it lasted).

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. BACKGROUND

This thesis answers the question: What are the core domestic maritime transportation system waterway vulnerabilities for the Carrier Strike Group power projection capabilities of the United States?

There is a multitude of threats that the U.S. Navy faces in today's world, such as terrorism, great power competition, and contention for freedom of the seas. Some of these originate in the homeland, such as threats to U.S. waterways that are home to surface naval vessels. Within the continental United States, surface fleet naval bases are located within open civilian waterways, complete with interdependent infrastructure including international trade terminals, bridges, tunnels, and transportation nodes. Vulnerabilities to waterways in the form of natural disasters, accidents, adversarial attacks, and management issues can potentially disrupt normal maritime operations and the power projection capabilities of the U.S. Navy. Thus, when operating within the United States maritime transportation system (MTS) infrastructure, the U.S. Navy operations are vulnerable. For the purposes of this work, we refer to vulnerabilities as susceptibilities that can disrupt regional maritime transportation systems in a manner to limit aircraft carriers from going to sea and U.S. power projection.

More specifically, the Carrier Strike Group concept is the Navy's primary asset in projecting power abroad and there are many vulnerabilities to the 11 nuclear carriers that the United States operates and maintains. These Carrier Strike Group vulnerabilities include susceptibility to kinetic weapons from rival countries, but also domestic vulnerabilities such as the budget constraints that limit the cost of building, operating, and maintaining these ships and the facilities they require. The United States Government Accountability Office (GAO) reported the four main locations of aircraft carriers within the United States as Norfolk, Virginia; San Diego, California; Everett, Washington; and

Bremerton, Washington.[1] A fifth homeport for nuclear aircraft carriers exists within Yokosuka, Japan, but this thesis focuses primarily on homeports located within the continental United States, as they relate mostly to homeland security.[2] Even though operational security precludes Navy personnel from discussing ship movements, it is undeniable for the surrounding environment to recognize a carrier's presence in-port, even more so when there are three to four in the same port.

The United States Navy's surface fleet, and most other seafaring vessels, distinguish between two modes of operation: underway and not underway. The *Navigation Rules for International and Inland Waters* by the U.S. Coast Guard defines the term underway as "a vessel that is not at anchor, or made fast to the shore, or aground."[3] While underway operations may differ between local training operations and forward deployments, they are similar in that the ship is not moored to a pier, at anchor, or aground in either case.

The distinction between underway and not underway is demonstrated by the local infrastructure and manpower requirements on U.S. ports and waterways. A carrier's depth is deep, power requirements are great (when the reactor is shut down), and personnel are vast. Maurer reports that an aircraft carrier can bring up to 5,000 Naval personnel, excluding spouses and families, to an area.[4] A carrier not underway generates significant shifts in population, traffic, and maintenance requirements in the local land-based city in which the carrier makes its berth. In contrast, a carrier underway requires a different network of infrastructure among pier facilities and accessible waterways to ensure safe passage towards or away from berth. When a carrier is in port there is a significant difference in population, traffic, and maintenance requirements to the local land- based city

[1] Diana Maurer, *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,* GAO-21-345 (Washington, DC: Government Accountability Office, 2021), 5, https://www.gao.gov/assets/gao-21-345.pdf.

[2] Maurer, 6.

[3] Department of Homeland Security, *Navigation Rules, International-Inland,* Commandant Instruction M16672.2D (Washington, DC: Department of Homeland Security, 2014), 9.

[4] Maurer*, Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,*1.

in which the carrier makes its berth. Thus, a single carrier creates the need for a vast network of infrastructure, both within pier facilities and accessible waterways. As personnel and operating logistics for underway versus in-port ships differ significantly, this thesis focuses on the logistics and reliant maritime infrastructure required to get carriers underway, not shore-based operations.

B. REGIONAL MARITIME TRANSPORTATION SYSTEMS AND CARRIER STRIKE GROUPS

Maintaining waterways to ensure safe passage of a carrier requires a large network of infrastructure, referred to broadly as the MTS. The MTS is used to describe all maintained waterways in the U.S., including inland rivers and lake networks. However, the United States has the largest aircraft carriers in the world; because of their size, they require specific water depths, channel widths, and overhead clearance requirements that limit their transit to certain waterways. The requirements to operate a carrier in them limits the geographic locations a carrier can be berthed or docked. This thesis examines the limitations and vulnerabilities that the Navy faces when operating aircraft carriers in specific regions' local waterways. Having only three or four locations within the U.S. for carriers to be supported, can create a substantial problem to the ability for the U.S. Navy to use its main power projection asset. The interconnected infrastructure within these waterways can create significant bottlenecks and other operating hazards for large-scale ships. If unplanned accidents, adversarial attacks, and environmental factors blocked one or all these locations it would hinder the Navy's surface fleet power projection capabilities.

Maritime harbor infrastructure is a complex system of natural waterways, human-engineered architecture, and social components. The three waterways and harbor systems this thesis addresses are located within Puget Sound, the Chesapeake Bay, and the San Diego Bay. All three of these waterways and harbor systems have only one access point out to sea for maritime vessels which are controlled by various actors within the harbor system at large. Figure 1 shows the domestic surface naval bases relevant to this study, their waterways, and their single point of access to international waters.

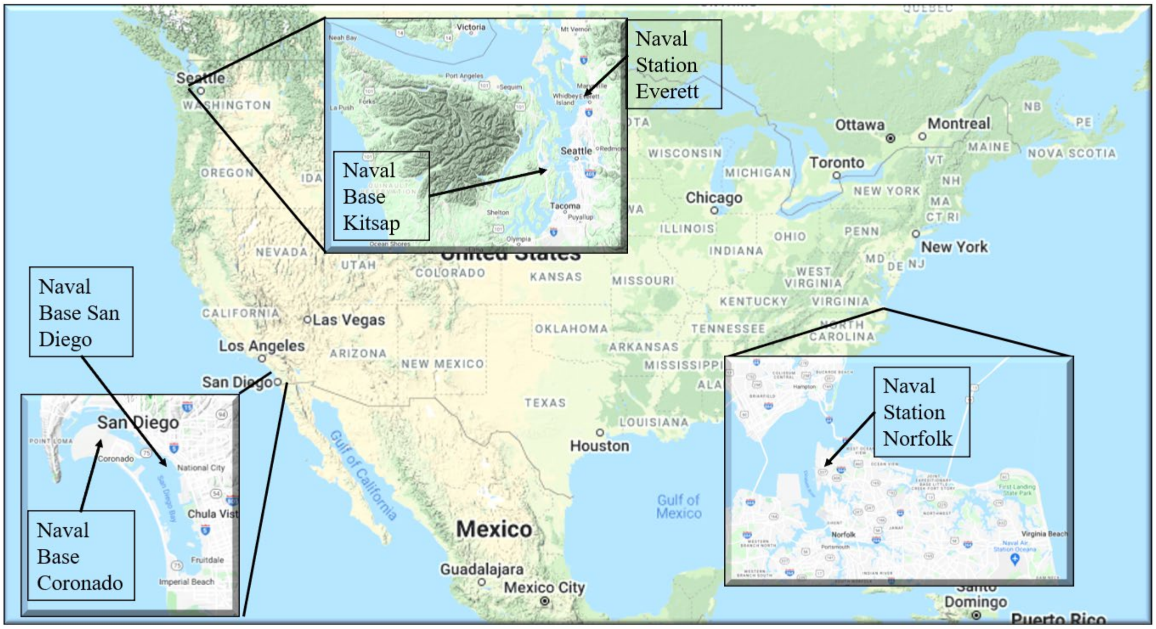

Figure 1. United States Surface Naval Carrier Bases[5]

Laws, local operating procedures, and maintenance regulations are the primary sources for learning about port and waterway infrastructure as well as mariner navigational charts. Literature for the capacity and condition of each harbor exists which covers economic impacts, supply chains, and the Navy's use of the waterways.

C. LITERATURE REVIEW

Extensive literature exists on the importance of United States waterway infrastructure and U.S. Naval power projection. However, many of these works focus on economic impacts, operator safety, and naval operations abroad throughout the world. The objective of this thesis is to synthesize the importance of naval homeport waterway infrastructure and the impacts of maritime transportation system on the ability of the United States Carrier Strike Group concept to project power globally.

[5] Adapted from https://www.google.com/maps/@37.4637116,-92.6444553,4.63z; Hampton Roads map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/place/Norfolk,+VA/@37.0462908,-76.2973368,10.72z/data=!4m5!3m4!1s0x89ba973a5322ca45:0xab99107fce7a1e0a! 8m2!3d36.850505!4d-76.2856293.; Puget Sound map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/@47.8599866,-122.5124113,8.48z.; and San Diego Bay map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/@32.6672632,-117.1762958,12z.

This thesis combines the ideas of port infrastructure importance, domestic vulnerabilities, and naval power projection into a single causal outcome. The relevant research and information available typically discuss one of these three aspects alone, but does not combine them into a coherent interdependent system.

Literature on critical maritime infrastructure focuses largely on its protection, resilience, and governance. These aspects are usually accompanied by security or vulnerability assessments of specific pieces of the maritime infrastructure systems. Most critical infrastructure protection and maritime infrastructure research focus on economic security, supply chains, and follow-on effects of a disruption in the system. There is also literature about environmental factors affecting maritime infrastructure, such as natural disasters, climate change, and sea level rise. The Navy's power projection literature largely lies within governmental strategy and operational doctrine. The following three sections introduce the relevant resources that pertain to the importance and make up of critical infrastructure systems, their vulnerabilities, and the Navy's power projection strategies. Maritime Transportation System Literature

1. Maritime Transportation System Literature

Two federal agencies that are governing authorities on U.S. MTS are the Department of Homeland Security (DHS) and the Department of Transportation (DOT). The Department of Homeland Security was "tasked to oversee the development of a National Strategy for Maritime Security and eight supporting implementation plans."[6] These eight plans provide significant insight into U.S. national strategy on "maritime domain awareness, intelligence integration, threat response, outreach and coordination, infrastructure recovery, system security, commerce security, and domestic outreach."[7] The Department of Transportation also assessed the national MTS; described its economic, national security, environmental, and recreational values; described its principal

[6] U.S. Department of Homeland Security, *Maritime Transportation System Security Recommendations for the National Strategy for Maritime Security* (Washington, DC: U.S. Department of Homeland Security), April 2006, i, https://www.dhs.gov/sites/default/files/publications/HSPD_MTSSPlan_0.pdf.

[7] U.S. Department of Homeland Security, i.

components and functions; and growing levels of demand.[8] These national policy documents serve to provide system descriptions, strategic importance, and recovery plans for the national MTS.

Mansouri et al. offer a System of Systems Engineering outlook on the Maritime Transportation System.[9] Their writing provides good insight into the system structure, functions and organization, while focusing on the different methods of managing the system. Their models and findings suggest the need for an effective management framework within the Maritime Transportation System. These authors provide detailed explanations of the maritime system, its interconnectedness, and system structures. Users and managers are constant throughout the MTS and providing better management practices or strategies could reduce vulnerability to the system.

Conceptually, it is important to view maritime infrastructure as a system. Charles Perrow explains the concepts of a system, subsystems, parts, and units, as well as accidents or disruptions to systems.[10] He provides many conceptual arguments and definitions about systems, including nuclear power systems, aircraft and airways, marine systems, and what he calls "exotic" systems, such as space, weapons and DNA. The definitions of how systems can be viewed, what constitutes an accident, and the problems he portrays within the marine system will help guide understanding of the research question.

---

[8] U.S. Department of Transportation, *An Assessment of the U.S. Marine Transportation System* (Washington, DC: U.S. Department of Transportation, September 1999), https://www.maritime.dot.gov/sites/marad.dot.gov/files/docs/resources/2386/assessmntoftheusmts-rpttocongrsep1999combined.pdf

[9] Mo Mansouri, Alex Gorod, Thomas H. Wakeman, and BrianSauser, "Maritime Transportation System of Systems Management Framework: A System of Systems Engineering Approach," *International Journal of Ocean Systems ManagementI* 1, no, 2 (2009): 200–226, https://www.researchgate.net/profile/Brian-Sauser/publication/228675041_Maritime_Transportation_System_of_Systems_management_framework_a_System_of_Systems_Engineering_approach/links/0c96051598e3b79d5c000000/Maritime-Transportation-System-of-Systems-management-framework-a-System-of-Systems-Engineering-approach.pdf.

[10] Charles Perrow, *Normal Accidents: Living with High-Risk Technologies* (New Jersey: Princeton University Press, 1999).

Watts, Thekdi and Santos, González and Trujillo study supply chain security and economic efficiencies within the maritime transportation system.[11] These studies demonstrate the importance of the maritime transportation system and its economic role in today's world.

Several relevant governmental reports also study the maritime transportation system as it relates to aircraft carriers. Lepore, Caldwell, O'Rourke, and Maurer all provide various aspects of reporting to Congress about the maritime transportation system, critical infrastructure protection, and Navy policy.[12]

A geographic approach to studying the maritime transportation system add to the conversation by discussing water depths, infrastructure support, and future development. Hayut and Hoyle provide different models of developing ports based on geography as part of the maritime transportation system.[13]

2. Vulnerabilities

The vulnerabilities of each port are well documented, and some are kept secret due to security and safety concerns. However, there is significant open-source material that can be analyzed for potential threats or weaknesses to the port systems. These vulnerabilities

[11] Robert Watts, "Maritime Critical Infrastructure Protection: Multi-Agency Command and Control in an Asymmetric Environment." Homeland Security Affairs 1, Article 3 (August 2005), https://apps.dtic.mil/sti/pdfs/ADA484165.pdf.; and Shital A. Thekdi and Joost R. Santos, "Supply Chain Vulnerability Analysis Using Scenario-Based Input-Output Modeling: Application to Port Operations," Risk Analysis, 36, no.5, 2016, 1026, https://doi.org/10.1111/risa.12473.; and Gonzalez, M. M. and Trujillo, L. "Efficiency Measurement in the Port Industry: A Survey of the Empirical Evidence." Journal of Transport Economics and Policy, 43, no. 2 (2009): 157–192, https://www.researchgate.net/publication/46557334_Efficiency_Measurement_in_the_Port_Industry_A_Survey_of_the_Empirical_Evidence.

[12]Brian Lepore, *Defense Infrastructure: The Navy's Use of Risk Management at Naval Stations Mayport and Norfolk,* GAO-12-710R (Washington, DC: Government Accountability Office, 2012), 6–7, https://www.gao.gov/assets/gao-12-710r.pdf; and Stephen Caldwell, *An Implementation Strategy Could Advance DHS's Coordination of Resilience Efforts across Ports and Other Infrastructure*,GAO-13-11(Washington, DC: Government Accountability Office, 2012), https://www.gao.gov/assets/gao-13-11.pdf.; and Ronald O'Rourke, *Navy Nuclear Aircraft Carrier (CVN) Homeporting at Mayport: Background and Issues for Congress,* CRS Report No. R40248 (Washington, DC: Congressional Research Service, 2010), https://apps.dtic.mil/sti/pdfs/ADA522947.pdf; and Maurer, *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements.*

[13] Yehuda Hayuth, 1981. "Containerization and the Load Center Concept," *Economic Geography* 57, no. 2 (April 1981): 160–176 https://www.jstor.org/stable/144140?seq=9#metadata_info_tab_contents; and Brian S. Hoyle (1989) "The Port-City Interface: Trends, Problems and Examples," *Geoforum*, 20 no. 4 (1989): 429–435, http://dx.doi.org/10.1016/0016-7185(89)90026-2.

include, but are not limited to, physical threats to infrastructure, environmental threats to geographic locations of the ports, and the vulnerabilities and risk the Navy accepts of its current force dispersal and grouping. Not only are there vulnerabilities to the port systems, but these vulnerabilities extend to being vulnerabilities for naval power projection. Much of the relevant literature uses the 2000 terrorist bombing of the USS Cole (DDG 67) and the 2006 Workers' Strike Shut Down in the Port of Los Angeles as examples of vulnerabilities to maritime security; however, these resources focus on force protection and economic functions. Not much literature currently exists on the concept of being able to weaken the Navy's power projection without necessarily attacking its ships-- such as the inability for the Navy to operate carriers if a vulnerability resulted in a port being inoperable.

Vulnerabilities have the potential to lead to disruptions, whether they are minor or major. Stephen Graham defines different types of disruptions and failures for infrastructure systems. Using his cascading failure definition and concepts, offers insight into the severity a vulnerability can become. He demonstrates how one small component failure, such a loss of electricity, can lead to the loss of a whole electrical system as well as interconnected systems like water, sewage, transportation, and food processing.[14] The interconnectedness of infrastructure systems is highly important to understanding vulnerabilities to a broader maritime transportation system.

Physical threats to port infrastructure can be accidental or deliberate attacks. Several examples of accidental failures demonstrate the possibility of physical threats impacting carrier waterways. The March 2021 blockage of the Suez Canal by a large container ship is an example of an accidental physical threat to a waterway.[15] The Navy is not exempt from such accidents while operating warships, as is evident by the four incidents in the 7th Fleet in 2017.[16] Another example of modern vulnerabilities to maritime

[14] Stephen Graham, *Disrupted Cities: When Infrastructure Fails* (New York: Rutledge, 2010).

[15]Theo Leggett, "Egypt's Suez Canal Blocked By Huge Container Ship," *BBC,* March 24, 2021, https://www.bbc.com/news/world-middle-east-56505413.

[16] The Associated Press, "USS McCain Crash Is 4th Navy Accident in Pacific This Year," *The Associated Press,* August 22, 2017, https://apnews.com/article/4959fea69cd94a66b6d9a8cd9b594e2f.

transportation infrastructure that does not involve ships operating at sea is the 2020 Beirut port explosion.[17]Many of the security measures in place for these ports are kept secret or given out on an official need- to-know basis, which is good for strengthening security.

Berle, Rice, and Asbjørnslett describe failure modes within the maritime transportation system.[18] Their work thoroughly describes vulnerabilities in the system and offers "a structure for assessing and reducing the disruption vulnerability for a maritime supply chain."[19] Similarly, Cheng-Hsein, Hui-Huang and Yang-Ning offer vulnerability assessments based on critical infrastructure interdependency.[20] They conducted empirical research on four international commercial ports "to analyze the port vulnerability and verify the feasibility of systematic interdependency assessments."[21]

Security is yet another field of study both relevant to maritime transportation system for supply chains and for naval force protection. Richardt and Ames et al. study these aspects and how the U.S. Coast Guard and Navy protect the waterways and the ships within the system.[22] In testimony before the House Armed Services Subcommittee on Seapower and Power Projection Forces, Michael Horowitz acknowledged threats abroad from China and Russia on "carrier-killer" missiles and offered ideas for innovation to

---

17 BBC, "Beirut Explosion: What We Know So Far," *BBC,* August 11, 2020, https://www.bbc.com/news/world-middle-east-53668493.

18 Øyvind Berle, James B. Rice Jr. & Bjørn Egil Asbjørnslett, "Failure Modes in the Maritime Transportation System: A Functional Approach to Throughput Vulnerability," *Maritime Policy & Management*, 38, no. 6 (2011): 605–632, https://www.tandfonline.com/doi/full/10.1080/03088839.2011.615870.

19Berle, Rice and Asbjørnslett.

20 Cheng-Hsien Hsieh, Hui-Huang Tai & Yang-Ning Lee, "Port Vulnerability Assessment from the Perspective of Critical Infrastructure Interdependency," *Maritime Policy & Management*, 41:6 (2014): 589–606, https://www.tandfonline.com/doi/full/10.1080/03088839.2013.856523.

21Hsieh, Tai, and Lee.

22 Timothy Richardt, "Security and Defense of America's Ports: An Assessment of Coast Guard and Navy Roles, Capabilities and Synchronization." In *Homeland Security Digital Library*. Army War College (U.S.), 2006, https://www.hsdl.org/?abstract&did=; and Ames, Morgan, Chun Man Chan, Kim Chuan Chng, Andrew Cole, Dale Johnson, Kiah Wen Kwai, Kim Leng Koh et al. "Port Security Strategy 2012." Master's Thesis, Monterey, California. Naval Postgraduate School, 2007, https://calhoun.nps.edu/handle/10945/6921.

continue aircraft carriers as the primary means for naval power projection.[23] The testimony shows threats and vulnerabilities abroad to the Carrier Strike Group concept and also discusses the need for future re-evaluation of the concept as a whole in regards to procurement and evolution of the aircraft carrier.

Environmental vulnerabilities are the subject of much research due to a variety of factors that impact port operation. The environmental field covers topics such as climate change, sea level rise, marine biology, and natural disasters.

The Department of Defense has written several policy documents about climate change and their assessment of it. The Department of Defense explains "climate change is a direct threat to the national security of the United States and is impacting stability in areas of the world both where the United States Armed Forces are operating today, and where strategic implications for future conflict exist."[24] Another planning document by the Department of Defense recommends "adaptation lines of effort as climate-informed decision making; train and equip a climate-ready force; resilient built and natural installation infrastructure; supply chain resilience and innovation; and enhance adaptation and resilience through collaboration."[25] These documents provide the Department of Defense's outlook and strategy towards climate change and recognize the strategic and operational impacts the environment can have now or in the future.

For instance, the City of San Diego has conducted both a "Climate Change Vulnerability Assessment" and "State Lands Sea Level Rise Vulnerability Assessment," both in which they find various vulnerabilities to shore-based infrastructure. Climate change has potential impacts within California leading to "changes in the frequency and

[23] Ensuring the Future of Naval Power Projection: The Role of Carrier Aviation: Testimony for the House Armed Services Subcommittee on Seapower and Power Projection, 114th Cong. 2 (2016) (statement of Michael C. Horowitz, University of Pennsylvania Associate Professor), https://docs.house.gov/meetings/AS/AS28/20160211/104318/HHRG-114-AS28-Wstate-HorowitzM-20160211.pdf.

[24]Department of Defense, *Department of Defense Climate Risk Analysis* (Washington, DC: Department of Defense, October, 2021), 7, https://media.defense.gov/2021/Oct/21/2002877353/-1/-1/0/DOD-CLIMATE-RISK-ANALYSIS-FINAL.PDF.

[25]Department of Defense, *Department of Defense Climate Adaptation Plan* (Washington, DC: Department of Defense, September 2021), 5–21, https://media.defense.gov/2021/Oct/07/2002869699/-1/-1/0/DEPARTMENT-OF-DEFENSE-CLIMATE-ADAPTATION-PLAN-2.PDF.

severity of wildfire, sea level rise and related coastal hazards, changes in precipitation, and extreme heat events."[26] The San Diego sea level assessment discusses coastal flooding and erosion which could lead to flooded or damaged shore infrastructure such as docks, marinas, repositioning of buoys, and many other costly repairs.[27] The California Department of Transportation has also had seismic testing done on the Coronado Bridge due to the earthquake vulnerability within California.[28] These are all environmental vulnerabilities that have been previously assessed on the infrastructure surrounding the San Diego Bay.

Within Puget Sound, a similar set of environmental assessments have been conducted as well. The Institute for Hazard Mitigation Planning and Research submitted a "Hazard Mitigation Plan 2018" for the City of Everett, Washington ranking environmental risks from earthquakes, flooding, and severe storms to climate change and fire.[29] These also cause potential risks to infrastructure and the Navy from destruction of physical maritime structures to flooding and navigational hazards.

Finally, the Chesapeake Bay has its own set of environmental vulnerabilities as assessed by the City of Norfolk and the U.S. Coast Guard. The Hampton Roads Planning District Commission Staff wrote "The Potential Economic Impact of Hurricanes on Hampton Roads, which discusses the impact hurricanes can have in the area from high winds, flooding, and debris.[30] The Chesapeake Bay area has similar vulnerabilities to the

---

[26] ICF International, *Climate Change Vulnerability Assessment*, San Diego, CA: City of San Diego, February 2020, 2, https://www.sandiego.gov/sites/default/files/climate-change-vulnerability-assessment.pdf.

[27] Brad Hurley, "State Lands Sea Level Rise Vulnerability Assessment," *ICF*, July 2019, 13, https://www.sandiego.gov/sites/default/files/state-lands-sea-level-rise-vulnerability-assessment.pdf.

[28] R. Dameron et al. "Seismic Analysis of the San Diego-Coronado Bay Bridge: Comparison of Dynamic Analysis Methods," California Department of Transportation, 1997, https://trid.trb.org/view/498467.

[29]Michael Godried et al., "Hazard Mitigation Plan 2018," Seattle, WA: University of Washington Department of Urban Design and Planning, 2018, 6, https://www.everettwa.gov/DocumentCenter/View/13998/EverettHMP_2018.

[30] Hampton Roads Planning District Commission, "The Potential Economic Impact of Hurricanes on Hampton Roads," Hampton Roads Planning District Commission, July 2006, https://www.hrpdcva.gov/uploads/docs/Hurricanes.pdf.

West Coast locations, such as sea level rise and climate change, but lacks the big threat of earthquakes while gaining hurricanes.

While much of the reviewed literature assesses the vulnerabilities and their impact on the economy, the vulnerabilities can be translated over to the effect the disruptions have on the Navy.

3. Power Projection

In the history of navies, naval power projection has always been a topic of discussion and studied. The United States' Carrier Strike Group model, as a superior and preferred method for maritime power projection, provides many more aspects to discuss in terms of economics, logistical support, and tactical support. Most written work, in regard to naval power projection, is comparative to other world powers and based on military assets available. The United States Navy also has other platforms with varying uses available for power projection besides the Carrier Strike Group.

Most existing literature of naval power projection exists in historic assessments of national strategy and naval policy. Sea power projection and its importance is famously tied to Alfred Mahan, who stressed that a nation's strength came from its sea power.[31] More recently, Stavridis agrees with sea power shaping the modern world and its necessity for strong nations to maintain a fleet.[32] Following a historic recounting of naval power, Bruns assesses the United States use of naval forces between 1980–2016 and labels sea power as the "foundation for American hegemony."[33] These are all broad generalizations over the importance of sea power being available, but are not directly linked to mandating the use of aircraft carriers.

The aircraft carrier option has been selected and maintained by the U.S. government over time but is not written in stone for the future. The United States Navy surface fleet

---

[31] Alfred Mahan, *The Influence of Sea Power Upon History, 1660–1783* (New York: Dover Publications, INC, 1987).

[32] James Stavridis, Sea Power: The History and Geopolitics of the World's Oceans, New York: Penguin Books, 2017).

[33] Sebastian Bruns, U.S. Naval Strategy and National Security: The Evolution of American Maritime Power, New York, NY: Routledge, 2018, 29.

consists of approximately 240 vessels, so some believe large aircraft carriers are not as important anymore.[34] Another concept that exists for naval force projection is the Amphibious Readiness Group (ARG). James Geiger argues for greater importance in the role of power projection from the Amphibious Fleet.[35] This concept is fully capable of projecting power but will not be used in the discussion of America's power projection capability.

D. HYPOTHESES AND POTENTIAL EXPLANATIONS

United States power projection depends on the ability for carrier strike groups to conduct underway operations within the continental United States. Regional MTS vulnerabilities and their impacts have been studied in general with regards to local waterways, military installations, and regions where carrier strike groups homeport. However, there is limited work connecting these two lines of inquiry. Research on power projection tends to focus on peer adversaries or terrorist attacks and their impacts on carrier strike groups outside the continental United States. Research on regional MTS vulnerabilities do not identify how potential threats and consequences may impact military operations and power projection.

This work aims to connect these two perspectives to provide greater understanding on how regional MTS vulnerabilities may reduce naval power projection capabilities. As stated above, the key research question motivating this work is: What are the core domestic maritime transportation system waterway vulnerabilities for the Carrier Strike Group power projection capabilities of the United States? Underlying this research questions are the following hypotheses:

---

[34] Robert C. Rubel, "The Future Of Aircraft Carriers," *Naval War College Review* 64, no. 4 (2011): 12–27, http://www.jstor.org/stable/26397241.

[35] James Geiger, "Strategic Shaping Capability of the Amphibious Force: The Case for Capital Ship Statues for the Amphibious Fleet," (master's thesis, U.S. Army Command and General Staff College, 2019), https://apps.dtic.mil/sti/pdfs/AD1085020.pdf.

- Hypothesis 1: Disruptions to regional MTS nearby carrier strike group homeports can negatively impact power projection and underway operations.
- Hypothesis 2: Case study assessment of multiple carrier strike groups homeports will reveal common vulnerabilities across different regional MTS. Managing these vulnerabilities will improve the resilience of carrier strike group operations during future disasters.

E. RESEARCH DESIGN AND METHODS

Utilizing a systematic qualitative regional study of three main waterways, this thesis assesses how United States naval power projection may be impacted by disruptions of domestic waterways and ports. The research in this thesis involves defining regional MTS used by carrier strike groups in the continental United States and determining local vulnerabilities that may disrupt underway operations. The Puget Sound, Hampton Roads Harbor, and San Diego Bay are chosen as case study locations for this work as they are the only locations with aircraft carriers homeported in the United States.

Defining regional MTS and vulnerabilities involves identifying the relevant maritime transportation system components must first be identified and defined for each of these homeports and determining underway operations for aircraft carriers while near home ports. Regional MTS will be defined using a framework developed by Perrow that considers local systems, incidents, and accidents.[36] National Oceanic and Atmospheric Administration (NOAA) charts, satellite imagery of geography, and social management components will be used as primary data to define these systems. I also review underway operations by aircraft carriers while near continental United States homeports. Underway operations are determined by analyzing existing maritime infrastructure policy and vulnerability assessments and expand on the vulnerabilities they create for maritime sea power and the impacts abroad. I also evaluate port and waterway disruptions and their effects on power projection through means of immediate deployment, short-term

[36] Perrow, *Normal Accidents,* 70.

consequences, and follow-on long-term repercussions within deployment and maintenance schedules. I study how dependent Carrier Strike Groups are to a properly functioning homeport versus a cascading failure within a disrupted homeport harbor system.

After defining regional MTS and underway operations for carrier strike groups, I develop case studies evaluating homeport vulnerabilities based on four different vulnerability perspectives: risk assessment, system and reliability engineering, worst case scenarios and unexpected surprises.

Risk assessment involves measuring the probability of an event happening with the severity of outcome if the event were to occur. The Navy uses "Operational Risk Management" from Office of the Chief of Naval Operations Instruction 3500.39, which assigns a code number to the final severity versus probability outcome. Hubbard also defines risk as "the probability and magnitude of a loss, disaster, or other undesirable event." The Coast Guard also conducts working group studies involving subject matter experts from different maritime fields and produces "Ports and Waterways Safety Assessments" utilizing six categories of risks and consequences which are "vessel conditions, traffic conditions, navigational conditions, waterway conditions, immediate consequences, and subsequent consequences."[37] A similar method will be used for the risk assessments made for each homeport. The information that will feed this evaluation are well studied and predictable environmental factors, local operating procedures, and threat assessments.

Reliability engineering assessment will review the waterway systems' reliability and expected failures. Defining what components of the system should work all the time, some of the time, or expected to rarely work gives further insight into how vulnerable the maritime transportation system can be. Tortortella explains that reliability can be evaluated based on system "requirements, figures of merit and corresponding metrics derived from

---

[37] United States Coast Guard. *Ports and Waterways Safety Assessment Workshop Report Hampton Roads, Virginia.* Washington, DC: United States Coast Guard, July 2016, 3, https://www.navcen.uscg.gov/pdf/pawsa/WorkshopReports/Hampton_Roads_PAWSA_workshop_report_July_2016.pdf.

these requirements, failure mechanisms, and monitoring the achievement of goals."[38] Kapur and Pecht use further metric of environmental conditions and time to assess system requirements and failure.[39] Reliability engineering takes into consideration the life cycle of components and their probable expiration. Data that will feed this analysis is engineered construction, existing maintenance practices, and funding of the given maritime transportation system.

Worst-case scenarios involve war gaming style events that could disrupt the waterways of these homeports and their waterways. This analysis will include the defined system flow from a Carrier Strike Group sitting at its homeport to transiting out to sea to be able to conduct its power projection mission. This means that one or two critical nodes or components of the system could create a large or total disruption of the system to prevent the Navy's power projection. Geographical bottlenecks, critical system links, and war gaming "what ifs" will be used to conduct this evaluation.

Resilience Engineering involve surprises which analyze unknown consequences that are possible within the maritime transportation system waterways. The smartest people in the world can conduct risk assessment, worst case scenarios, and reliability engineering, but there is always the possibility of a surprise disruption happening. Wears and Webb distinguish between two different forms of surprise, "Fundamental surprise refutes basic beliefs about 'how things work', while situational surprise is compatible with previous beliefs."[40] This method seeks to answer what major crisis occurred? What actions do people take? And what ways can people extend operations?[41]These vulnerabilities consist

[38]Michael Tortorella, "Service Reliability Theory and Engineering," (Piscataway, NJ: Rutgers University, January 2005), 4, http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=A268D4041A4CA1E1823E76BCF5C27263?doi=10.1.1.182.6433&rep=rep1&type=pdf.

[39] Kailash Kapur and Pecht, Michael, *Reliability Engineering,* Hoboken, New Jersey: John Wiley and Sons, Inc, 2014.

[40] R. L. Wears and L. K. Webb, "Fundamental on Situational Surprise: a Case Study with Implications for Resilience," in *Resilience Engineering in* Practice *Volume 2: Becoming Resilient,* London: CRC Press, December 2016, 61–74.

[41] Daniel Eisenberg, "The Four Horsemen of Critical Infrastructure Vulnerability" (lecture, Naval Postgraduate School, Monterey, CA, October 3, 2020).

of analyzing natural disasters, accidents, and unexpected component failure that occurred in the past to better understand what might happen in the future.

After each of these assessments has been conducted on all three homeports, the data and assessments will be organized to show similarities and differences between homeports. I will determine how dependent the Carrier Strike Group projection capabilities are to disrupted waterways, by assessing potential cascading failures within Navy homeport waterways. The Navy's Optimized Fleet Response Plan will be the critical piece while assessing these failures. Everything from projected recovery times of initial disruptions to extended follow-on consequences of waterway disruptions are key components to how successful Naval operations can continue in times of distress. This naval instruction lays out the desired maintenance, training, and operational life cycles for surface combatants. A significant delay or disruption to multiple or even just one Carrier Strike Group can be seen as impacting the Navy's power projection capabilities. The conclusion will be drawn from these similarities and differences to assess and recommend potential policy changes for the Department of Homeland Security, Department of Defense and Department of the Navy. Deep water harbors to support Carrier Strike Groups are rare and assessing them through risk management, reliability engineering, worst-case scenario, and surprises will provide a holistic view on the vulnerabilities Carrier Strike Group power projection faces at home.

THIS PAGE INTENTIONALLY LEFT BLANK

II. MARITIME TRANSPORTATION SYSTEM

The maritime transportation system that the Navy uses when its carriers are underway is a complex system that combines both technological and social components. In this chapter, I will define a generic model of a regional MTS as it relates to aircraft carriers underway.

A. MARITIME TRANSPORTATION SYSTEM DEFINED

To be able to define a system or disruption of a system, there must be a purpose for the given system. Charles Perrow describes this as "task analysis" in accident modeling; this is also referred to as defining system function or operation in infrastructure modeling research.[42] Defining a system's task is important as Perrow defines an accident as an event that "involves some damage to people, objects, or to both," with respect to its primary task. Perrow uses an analogy of a paint scratch on a car to demonstrate.[43] Normally, a small scratch would not impede the purpose and operations of a vehicle. However, Perrow writes, "If I had planned to take the car to a rally the next day and show it off to other automobile buffs, I might very well call the scratch in the parking lot an accident. The system, from my point of view, involves me going to a rally to meet people, impress people, and show off my car, and it is interrupted."[44]

The purpose of the MTS, as an infrastructure system, is broadly defined based on the functions it provides society and missions. For example, the Department of Homeland Security defines 55 national critical functions (NCF) organized in four categories that an MTS can support – connect, distribute, manage, and supply.[45] In general, the "tasks" or "operations" of an MTS fall under all categories, including but not limited to:

---

[42] David L. Alderson, Gerald G. Brown, and W. Matthew Carlyle, "Operational Models of Infrastructure Resilience," *Risk Analysis* 35, no. 4 (2015): 562–586.

[43] Perrow, *Normal Accidents*, 64.

[44] Perrow, 64.

[45] Cybersecurity and Infrastructure Security Agency, *National Critical Functions: Status Update to the Critical Infrastructure Community*, Washington, DC: U.S. Department of Homeland Security, December 2021, 3, https://www.cisa.gov/sites/default/files/publications/2021_ncf-status_update_508.pdf.

- providing positioning, timing, and navigation services (connect);
- maintain supply chains (distribute);
- transport cargo and passengers by vessel (distribute);
- provide and maintain infrastructure (manage);
- provide material and operational support to defense (supply); and,
- supply water (supply).[46]

For the purposes of this work, we define a regional MTS task as enabling a carrier from being in-port to steaming underway at sea. This task combines systems that support multiple NCFs. Therefore, more specificity on the assets and systems that support underway carriers is required to relate regional MTS to carrier strike groups. Without more detail, it becomes difficult to define accidents and failures without a clear system definition.

Perrow's work provides a useful framework for defining regional MTS structure and function. Perrow defines complex systems like an MTS as being "divided into four levels of increasing aggregation: units, parts, subsystems, and systems."[47] We use this hierarchy as a basis for defining a general model of a regional MTS.

1. System

To support an underway carrier strike group, the MTS must include everything between the dock or pier the ship is berthed at and the Line of Demarcation where ships switch from inland to international rules and regulations. For the purpose of defining the system in which this thesis is focused, the system will be limited to subsystems, units, and parts within or around inland waters. Thus, the geographical boundary of a regional MTS is defined by the Collision Regulations (COLREGS) as, "the navigable waters of the United States shoreward

[46] Cybersecurity and Infrastructure Security Agency, *National Critical Functions: Status Update to the Critical Infrastructure Community,* 4,

[47] Perrow, *Normal Accidents,*70 .

of the navigational demarcation lines dividing the high seas from harbors, rivers, and other inland waters of the United States."[48]

A few components are present throughout all tiers of the system. These are federal agencies, ships, and users. U.S. Departments of Defense, Homeland Security, and Transportation are all national government management agencies that are stakeholders in the national MTS. The U.S. Department of Transportation provides a more delegated collection of federal agencies called the Maritime Administration (MARAD). A division that oversees the regulation and "support the technical aspects of America's maritime transportation infrastructure -- things like ships and shipping, port and vessel operations, national security, environment, and safety."[49]They also collaborate with the National Port Readiness Network, involving the "Coast Guard, Military Sealift Command, U.S. Army Forces Command, U.S Transportation Command, U.S. Army Corps of Engineers, U.S. Northern Command, Transportation Security Administration, and Surface Deployment and Distribution Command."[50] Together these governmental organizations regulate and support the maritime transportation system through strategic, economic, legal, and security aspects. Commercial and military ships are present throughout the entire system along with their operators and users.

2. Subsystem

With a geographical boundary of the system set to only inland waters, the system further dives into what lies within the inland waters where carriers are homeported. Using Perrow's next step down in level, the system consists of subsystems that operate within a regional MTS. Mansouri et al. describe an MTS in five subsystems: ships, ports, users,

---

[48] U.S. Coast Guard, *Navigation Rules and Regulations Handbook,"* (Washington, DC: Department of Homeland Security, June 2019), 9, https://www.navcen.uscg.gov/pdf/navRules/Handbook/CG_NAV_Rules_29Apr2020.pdf.

[49] Maritime Administration, "About Us," U.S. Department of Transportation, last modified December 1, 2021, https://www.maritime.dot.gov/about-us.

[50] Maritime Administration, "National Port Readiness Network (NPRN)," U.S. Department of Transportation, last modified December 7, 2021, https://www.maritime.dot.gov/ports/strong-ports/national-port-readiness-network-nprn .

waterways, and intermodal connects.[51] Their work focuses on the civilian management of the Maritime Transportation System whereas I am concerned with the military ramifications. Figure 2 shows Mansouri et al. system diagram in a web of interconnected subsystems with units attached to each subsystem. I recognize that commercial shipping and military shipping also have intermodal connects beyond ports but will not study them here.

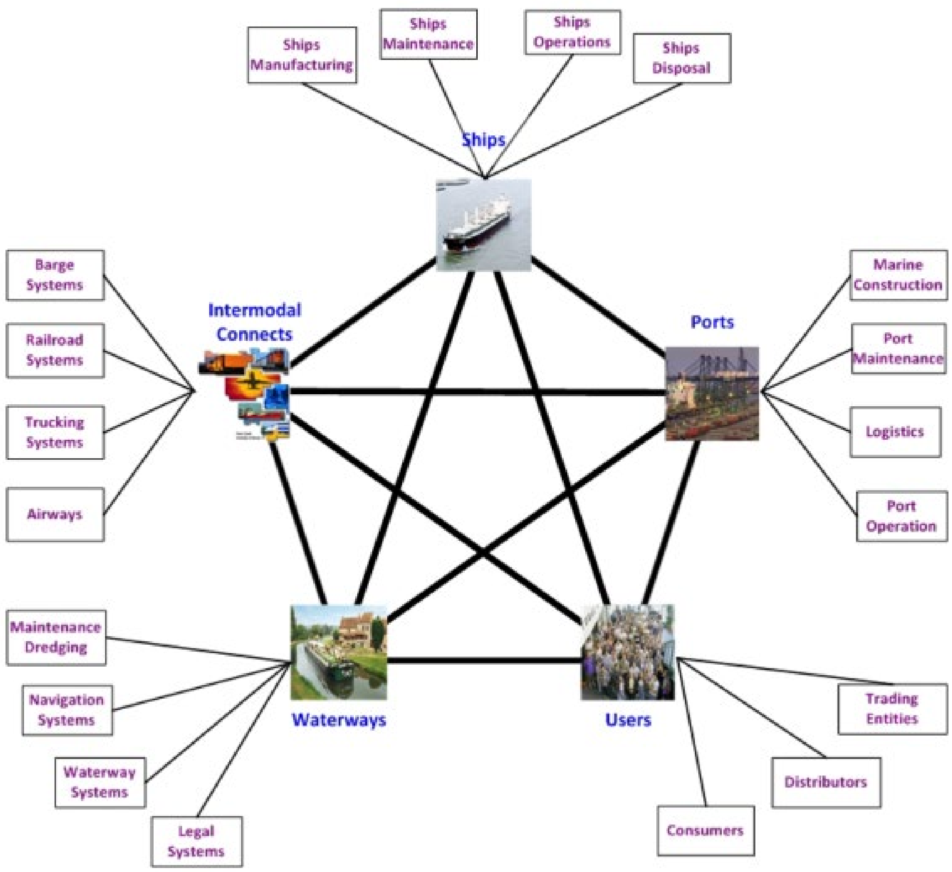

Figure 2. Holarchical view of Maritime Transportation System of Systems.[52]

[51] Mansouri et al., "Maritime Transportation System of Systems Management Framework," 210.

[52] Mansouri et al., "Maritime Transportation System of Systems Management Framework," 210.

For the purposes of this work, a regional MTS consists of three functional subsystems: ports, inbound and outbound transit, and at sea voyage. Figure 3 shows the generic flow of the Marine Transportation System for commercial operations to distribute products from Point A to Point B.[53] In this case, Point A is a carrier in port or out at sea, transiting through inland waterways to arrive at Point B, which is either out to sea or returned to port depending on what Point A was. While a simplification of true waterways, these general subsystems provide the necessary functions to support underway carrier strike groups.

[53] Sea Traffic Management, *Defining Sea Traffic Management,* Sea Traffic Management, Brussels, BE: European Union Sea Traffic Management, accessed August 6, 2021, 7, http://s3-eu-west-1.amazonaws.com/stm-stmvalidation/uploads/20160420153415/Act_2_MONALISA20_lowres.pdf

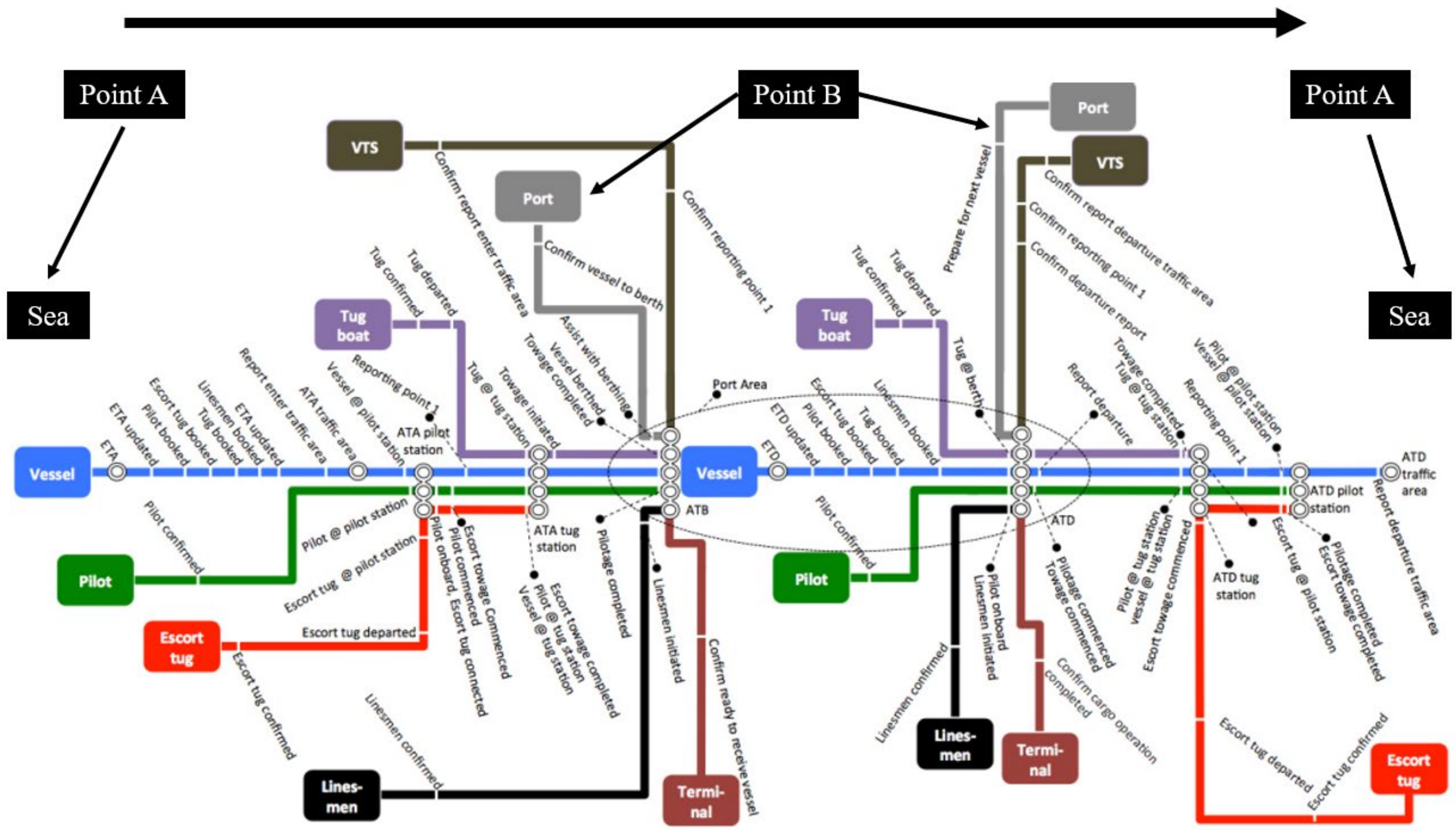

Figure 3. Maritime Transportation System Flow Diagram[54]

54 Adapted from Sea Traffic Management, *Defining Sea Traffic Management,* Sea Traffic Management, Brussels European Union Sea Traffic Management, accessed August 6, 2021, 7, http://s3-eu-west-1.amazonaws.com/stm-stmvalidation/uploads/20160420153415/Act_2_MONALISA20_lowres.pdf

Each of these subsystems serves a different purpose within a regional MTS. The purpose of port operations is to supply, repair, store, and prepare for the next transit or voyage a ship will make. The purpose of the transit subsystem is to provide a safe pathway from port to sea through various means of navigation, communication, scheduling, and security. Finally, the last subsystem is the sea voyage which includes much of the same units of the transit subsystem but is more independent of shore-based infrastructure. The different purposes of each subsystem lead to the different units required to make each subsystem function together.

3. Unit

The next step down are the units that comprise each subsystem. While some units, such as ships or aircraft carriers are a part of all subsystems, each subsystem has unique units that provide the subsystems to accomplish its tasks. The units within port operations are naval bases, port authority, shipyard companies, marine terminals, shore-based communication companies, tugboat and piloting companies, and security companies. These units all work together to provide ships with supplies, repairs, housing, and preparation.

The transit waterway subsystem is composed of units to help with the safe travel of ships to and from sea. To conduct this function, the waterways consist of navigational aids, safe water channels, regulatory and security agencies such as the U.S. Coast Guard, dredging companies, and tugs and pilots. Each of these provide safe and smooth flow of ships from inland and out to sea. The transit subsystem also allows the introduction of other units that operate within the waterways but are not necessarily part of the global Marine Transportation System. These units are other transportation systems, such as bridges, tunnels, and ferry systems that operate locally but interact with the Marine Transportation System. Other units within the same waterways are tourism, recreation, domestic fishing, and environmental and maritime research.

The sea voyage subsystem also exists to provide the safe flow of marine transportation which includes individual ships and their obedience to international laws and regulations. The focus of this subsystem will stay on the entrance and exit from inland waters and the navigational areas in which the connecting of this subsystem with the transit system are joined. Many safe water channels are littered with anchorages that are located just outside the waterways to provide temporary locations for ships to stay. This subsystem is not as important to this thesis as the other two because it mostly remains within international waters and is less constricted by geography and infrastructure.

4. Part

Finally, defining what a part is within the Marine Transportation System is tricky because a nuclear-powered aircraft carrier is a “whole beast” of a system to start with. A “part” on a ship could be considered any individual item on the ship, such as a crewmember, a valve, or a whole subsystem for propulsion. Anything that is smaller than the cohesive unit of a ship will be considered a part, within this system. A navigational channel contains parts to include individual buoys, range markers, safe water markers, anchorages, and water depths. Tugboat companies consist of multiple tugs, but an individual tug, its crew, its towing capacity are all parts of the tugboat company unit. A piloting association as a unit contains individual pilots with different experiences and availability. Dredging companies, as a unit, contain the individual dredging barges available to keep the navigation channels deep enough and wide enough to allow deep water maritime movement. Figure 4 shows the expansion of different levels within the Maritime Transportation System and how it combines to form one system.

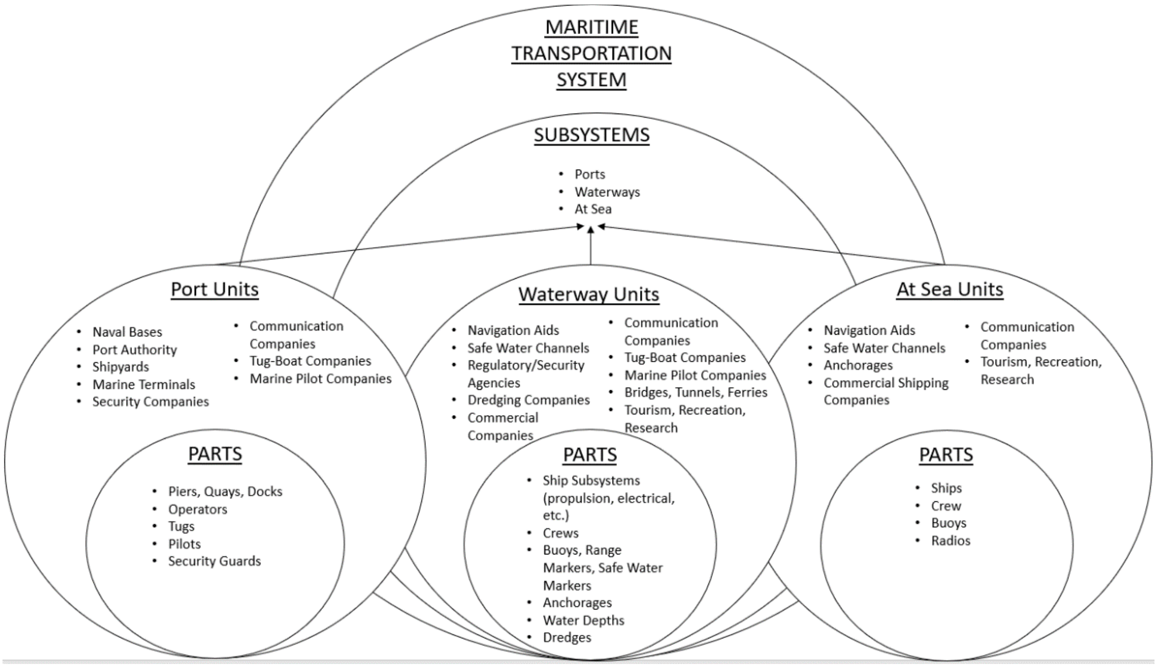

Figure 4. Maritime Transportation System Component Chart[55]

There are several more units that make up each of these subsystems. The ships operating in the MTS are an example, as well as multiple piers and docks. Navigational aids working in conjunction with one another is another example of a unit level description. Communications units could be considered as radio towers.

B. DISCUSSION

As with most infrastructure, the MTS is a complex integrated system with many subsystems, parts and units that can lead to accidents or disruptions. It is important to consider both physical technological aspects of the system and social aspects because these systems are not fully automated yet. Human operators and regulators have a huge role to play within the MTS and in some cases can be the cause of system failure.

But what is an MTS system failure? Looking back at what the system was as and what the task at hand is, a system failure in the MTS would be the inability for one or

[55] Adapted from, Department of Transportation, *An Assessment of the U.S. Marine Transportation System,* Washington, DC: U.S. Department of Transportation, September 1999, 24–32, https://www.maritime.dot.gov/sites/marad.dot.gov/files/docs/resources/2386/assessmntoftheusmts-rpttocongrsep1999combined.pdf.

multiple U.S. Navy carriers to depart their berths and head to sea. Perrow taking his car to the rally with a scratch in the paint did not disrupt the rally as a whole and only his system. Likewise, the focus on the carrier getting to sea needs to stay at the forefront of the task analysis. I have placed the carrier as a unit within this system, but it is operating within a much larger system. The domestic MTS may not be disrupted if a carrier cannot go to sea, but many disruptions in the MTS will also disrupt the carrier's task.

III. NORFOLK REGIONAL ASSESSMENTS

This chapter studies vulnerabilities for the Marine Transportation System within the Hampton Roads and Norfolk region by assessing port operation and transit subsystems such as naval installations, broad force disposition, and critical infrastructure. First, it will focus on the technological and social aspects that make up this regional MTS. The existence of naval bases, shipyards and other applicable naval shore-based infrastructure provides the reason for the Navy homeporting aircraft carriers in this location. However, these naval installations are not the only subsystems that operate within these waterways as other civilian and commercial enterprises use the same transit subsystem that the Navy uses to travel to and from the sea. Then, this chapter analyzes the critical infrastructure within the regional MTS requires for the normal operation of this waterway. Regional MTS vulnerabilities are derived from identifying accidents that can disrupt these critical infrastructure units and parts. The final section of this chapter will argue the impacts of these vulnerabilities on the U.S. Navy's aircraft carrier aspect of power projection.

A. NORFOLK REGIONAL PORT OPERATIONS SUBSYSTEM

The naval installations that make up subsystems within the Marine Transportation System in Hampton Roads provide the context and purpose for the study of this region. The installations within this region include two surface naval bases, a weapons station, a nuclear naval shipyard, and many commercial shipyards. Each of these shore-based installations provide different services and requirements for the U.S. Navy, but are all located on the inland side of the Line of Demarcation for the area. These installations provide most, but not all, of the Hampton Roads port operations subsystem. The units within the port operation subsystem are Naval Station Norfolk, Yorktown Naval Weapons Station, Portsmouth Naval Shipyard, and multiple commercial shipyards located throughout the region. Figure 5 portrays the geographic layout of the Hampton Roads system.

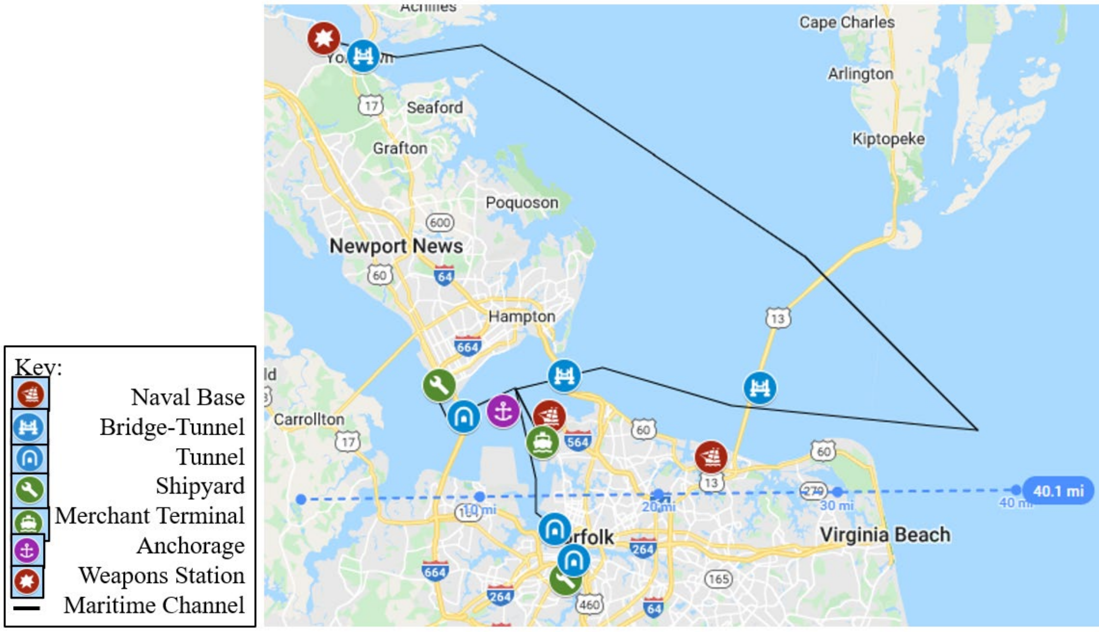

Figure 5. Hampton Roads Internal Waterways[56]

1. Naval Station Norfolk

Naval Station Norfolk is a huge subsystem within this region because of all the services and capabilities it provides to the Navy. Naval Station Norfolk is the largest naval complex in the world.[57] Within its 14 piers located in the Elizabeth River, it is the sole location for the East Coast, Atlantic Fleet and is the homeport of exactly half of the United States' domestic-based aircraft carriers.[58] The importance of this base and support activities is that they provide extensive shore services, force protection, logistical support, and pure capacity. While these are all important factors for supporting an aircraft carrier, they are not the focus of this section. What is important to note is that the location provides enough water depth, transit depth, support activities, and shear space to house this many

---

[56] Adapted from Hampton Roads map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/place/Norfolk,+VA/@37.0462908,-76.2973368,10.72z/data=!4m5!3m4!1s0x89ba973a5322ca45:0xab99107fce7a1e0a!8m2!3d36.850505!4d-76.2856293.

[57] Commander, Naval Installations Command, "Naval Station Norfolk," United States Navy, accessed January 27, 2022, https://www.cnic.navy.mil/regions/cnrma/installations/ns_norfolk.html.

[58] Lepore, Defense Infrastructure: The Navy's Use of Risk Management at Naval Stations Mayport and Norfolk, 5.

warships all at once. The mere fact that this many carriers can be supported in a single location creates the topic for debate. It is not common for all five of the homeported carriers to be in port at this base at once, due to operational or maintenance requirements, but the potential for this to happen does provide an interesting case to be made on the redundancy or dispersal of this means of naval power projection.

2. Yorktown Naval Weapons Station

Yorktown Naval Weapons Station is an important subsystem within Hampton Roads and a large part in the power projection aspect of the Navy for reasons that are rather obvious. This installation provides munitions to carriers, escort ships, and supply ships. The pier for loading ships lays on the inside of the Coleman Memorial Bridge up the York River.

3. Norfolk Naval Shipyard

Another naval installation that makes Hampton Roads an area of great concern to aircraft carrier power projection is the Portsmouth Naval Shipyard. This shipyard provides nuclear program maintenance for carriers and lies deep within the Elizabeth River past four bridges and tunnels. The ships in this shipyard are planned to be out of deployable service for a significant amount of time, but are still a vulnerable asset.

4. Huntington-Ingalls Industries Newport News Shipbuilding

Newport News Shipbuilding is another subsystem that is vital to the Navy's aircraft carrier maintenance and sustainment. Along with Norfolk Naval Shipyard, Newport News Shipbuilding lies on the inland waters and supports carriers in many ways from the ship building of the new *Ford* class carrier to being the only maintenance facility able to conduct required midlife refueling of a carrier as shown in Figure 6.[59] Schank et al. concur with the importance of this facility and its capabilities stating, "Newport News Shipbuilding is the largest shipbuilder in the United States in terms of both facilities and employment and

[59] Maurer, *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,* 21.

is the only U.S. shipyard with the capability to build and refuel nuclear aircraft carriers."[60] This subsystem serves as both the creator and care-taker of carriers throughout their life cycles and is relatively close to Naval Station Norfolk in terms of geography.

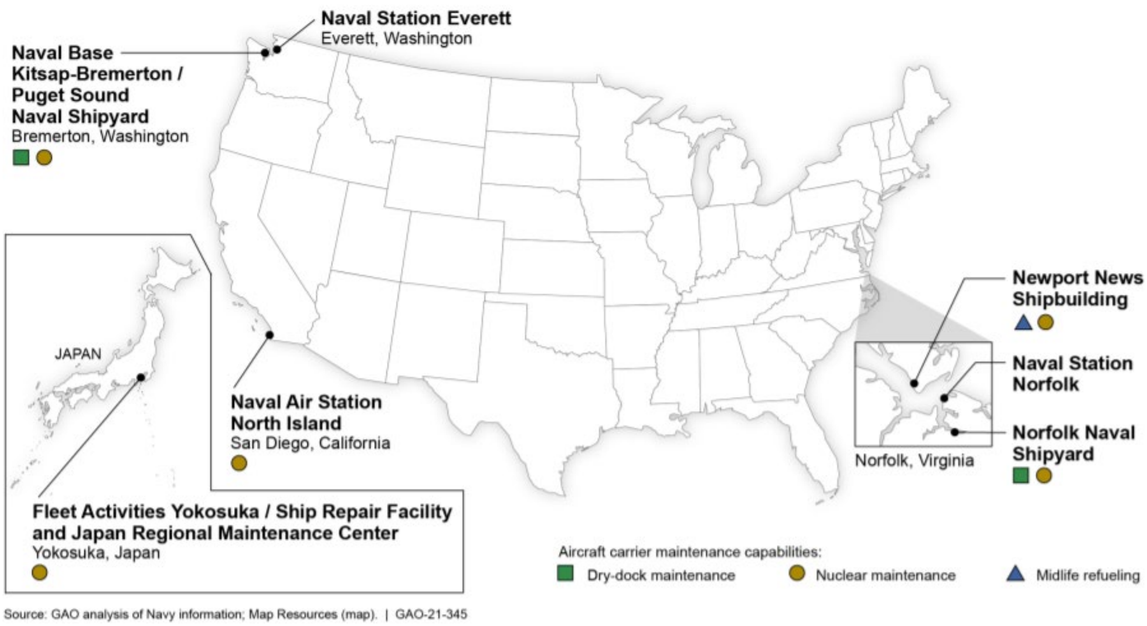

Figure 6. Carrier Maintenance Homeport Locations[61]

B. INTERMODAL CIVILIAN MARINE INFRASTRUCTURE IN HAMPTON ROADS

Civilian subsystems, units, and parts support the Hampton Roads MTS and can impact carrier underway operations. Key subsystems include the navigation channels, Norfolk International Terminal, highway road systems that cross over or are buried under the waterways, and many smaller marine businesses. Each of these subsystems that are not directly affiliated with the Navy still interact with or commune on the same inland waterway system that the Navy used to get its carriers to and from sea.

60 John F. Schank et al. *Refueling and Complex Overhaul of the USS Nimitz (CVN 68),* MR-1632 (Santa Monica, CA: RAND, 2002), 8, https://www.rand.org/content/dam/rand/pubs/monograph_reports/MR1632/RAND_MR1632.pdf

61 Maurer, *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,* 21.

1. Intermodal Infrastructure

a. Port of Virginia

The Navy is not the only significant marine shipping subsystem that operates in the Hampton Roads area. The Port of Virginia operates six trade commercial shipping terminals in the Hampton Roads area.[62] A report from William and Mary's Raymond A. Mason School of Business during fiscal year 2021 calculated the ports generated "more than $100.1 billion in ancillary economic impact."[63] The largest of these terminals, Norfolk International Terminal, sits directly south with adjacent piers to Naval Station Norfolk. The Port of Virginia serves as a communication and authorization hub for coordinating arrivals and departures from this waterway.

b. Highway Transportation System

Several highways in Hampton Roads cross the rivers that create the maritime system used by the Navy. These highways are engineered to either go over or under the navigable channels to ensure ships are able to continue use of the maritime system. The most significant highways that interact with the Hampton Roads maritime system are State Route 13 and the Chesapeake Bay Bridge; I-64 and the Hampton Roads Bridge-Tunnel; I-664 and the Monitor Merrimac Memorial Bridge Tunnel; U.S. 58 Midtown Tunnel; I-264 and the Downtown Tunnel; and finally, U.S. 17 and the George P. Coleman Memorial Bridge. Each of these intermodal highway transportation roads cross the relevant waterways within Hampton Roads and provide potential vulnerabilities to the system.

2. Navigable Waterways

To the untrained eye looking at Figure 5, the waterways appear to be free to get from point A to point B. However, this is not the case, and the maritime transportation system involves navigable channels, similar to "roads" for ships. Several different "roads" exist within the Hampton Roads system, including Thimble Shoals Channel, Norfolk

[62] "Facilities," Port of Virginia, accessed January 31, 2022, https://www.portofvirginia.com/facilities/.

[63] Kate Andrews, "Port of Va. Had $100B+ Economic Impact in FY21," Virginia Business, January 27, 2022, https://www.virginiabusiness.com/article/port-of-va-had-100b-economic-impact-in-fy21/.

Harbor Reach, Newport News Channel, Chesapeake Channel and the York River Channel. Figure 7 shows the navigable channels for ships to take based on their hull depth. Each of these waterways needs to be able to support carrier depths and widths for transit.

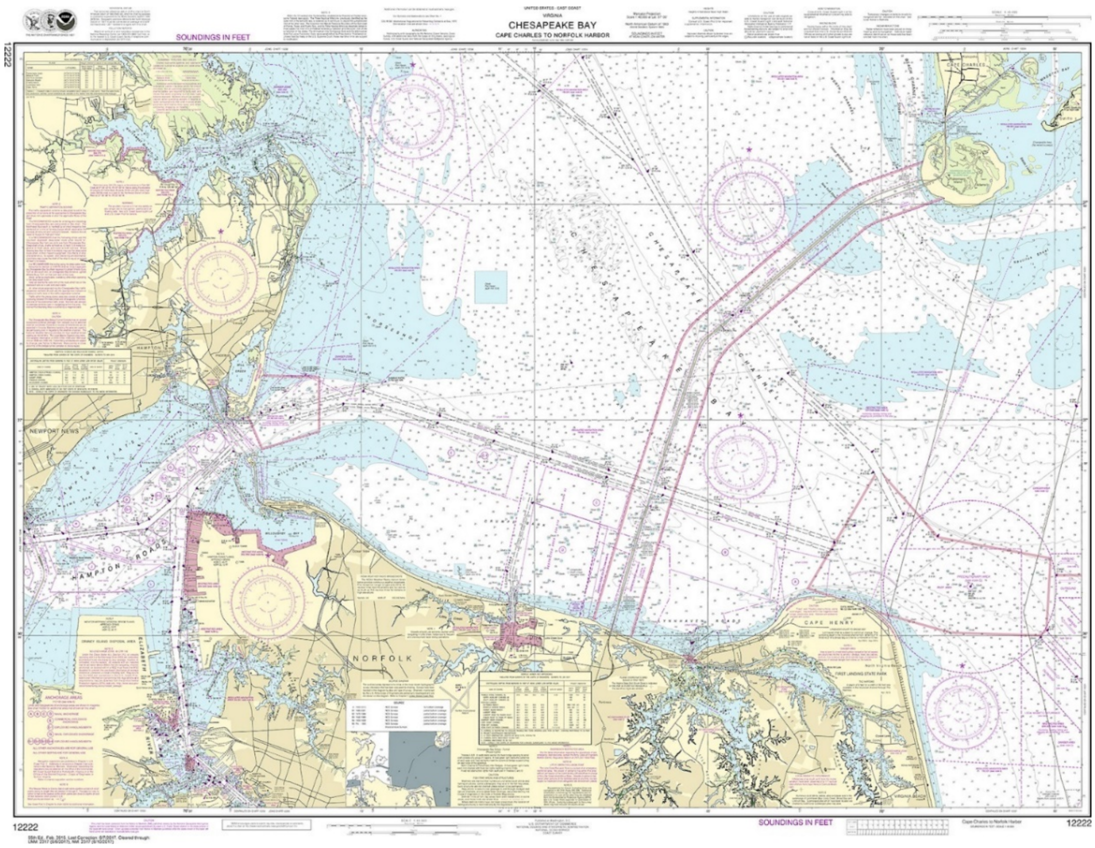

Figure 7. NOAA Chart 12222, Chesapeake Bay Entrance Chart[64]

C. HAMPTON ROADS MARITIME TRANSPORTATION SOCIAL UNITS

The social aspects of the Hampton Roads include the management, standard operating procedures, legal requirements for operating in the system, maintenance of the waterways, and the human operators of components within the system.

64 *Chesapeake Bay: Cape Charles to Norfolk Harbor,* National Oceanic and Atmospheric Administration, accessed January 31, 2022, https://www.charts.noaa.gov/OnLineViewer/12222.shtml

1. Virginia Department of Transportation

Virginia Department of Transportation (VDOT) is the commonwealth's social unit in the port and waterway subsystems that conducts managerial and funding role. "VDOT is responsible for building, maintaining, and operating the state's roads, bridges and tunnels. And, through the Commonwealth Transportation Board, it provides funding for airports, seaports, rail and public transportation."[65] The supervision of the intermodal bridges and tunnels in the Hampton Roads' subsystems, such as the Hampton Roads Bridge Tunnel, is under the authority of the Virginia Department of Transportation.

2. United States Coast Guard Sector Virginia

The U.S. Coast Guard serves as both a security force for hard technological infrastructure, but also as a regulatory and servicing agency as well. U.S. Coast Guard Sector Virginia serves to conduct "maritime law enforcement, foreign and domestic vessel inspections, port safety and security inspections, waterways management, waterfront facility inspections, marine environmental protection and aids to navigation."[66]

3. Virginia Pilot Association

This organization provides expert navigational recommendations while transiting Hampton Roads waterways. Professional Mariner explains, "the association, which dates back more than a century, has 42 pilots and 20 boat captains and deck hands. Its fleet consists of six pilot launches, including *Hampton Roads*."[67] These pilots are obligatory to vessels over a certain size and serve both naval ships and merchant mariners.

4. Tugboat Companies

Tugs are an important part of this system because of the large container ships and aircraft carriers that operate within it. Ships this size require close coordination with the ship's

---

65 "The Commonwealth's Transportation Agency," Virginia Department of Transportation, August 12, 2019, https://www.virginiadot.org/about_vdot/default.asp

66 "Sector Virginia," United States Coast Guard Atlantic Area, accessed January 31, 2022, https://www.atlanticarea.uscg.mil/Atlantic-Area/Units/District-5/Sector-Virginia/.

67 Professional Mariner Staff, "Hampton Roads," Professional Mariner, Journal of the Maritime Industry, November 2018, https://professionalmariner.com/hampton-roads/.

crew, harbor pilot, tugboat captains, and line handlers. The Hampton Roads system primarily uses the Moran Tug Company and McAllister Towing of Virginia for the maneuvering of large ships. Standard practice is for the harbor pilot to use four tugboats to help maneuver a carrier in close proximity to the piers. Other tugboat companies exist with smaller capacity tugs.

a. Moran Tugs

The Moran Tug company is a well-established tugboat company that operates all throughout the East Coast. It operates 14 tugs out of this specific region, and some are permanently docked at Naval Station Norfolk and used frequently to maneuver ships next to and away from the piers.[68] This tug company also uses its tugs for large commercial shipping entering and exiting the shipping terminals.

b. McAllister Towing of Virginia

McAllister Towing also offers large tugs capable of being used for maneuvering ships within the system. As advertised on their Virginia website, "McAllister has been in the port of Hampton Roads for roughly fifty years, serving Yorktown, Piney Point, Hampton Roads, Norfolk, and the Chesapeake area with unsurpassed towing and general harbor assist work" and they host six tugboats in their Norfolk fleet[69] These are primarily utilized for commercial movements.

D. HAMPTON ROADS VULNERABILITY ASSESSMENT

1. Risk Assessment

The risk assessment for Hampton Roads Maritime Infrastructure involves looking at the threats, likelihoods, and consequences of system disruption. This analysis involves threat or hazard identification, estimating their probability of occurring, and measuring their consequences on the Hampton Roads maritime transportation system.

[68] "Tug Fleet," Moran Towing, accessed January 6, 2022, https://www.morantug.com/fleet/

[69] "Virginia," McAllister Towing and Transportation, accessed January 6, 2022, https://www.mcallistertowing.com/ports-and-rates/virginia/.; and "Fleet Location," McAllister Towing and Transportation, accessed January 6, 2022, https://www.mcallistertowing.com/fleet-information/tug-fleet/

As the primary social manager and regulator of the waterway subsystem, the U.S. Coast Guard Sector Hampton Roads held a "Port and Waterways Safety Assessment" workshop consisting of maritime experts from various fields of work. These workshops produce reports assessing port and waterway safety in the Hampton Roads MTS. This report delivered a "list and assessment of 24 variables across six categories of vessel conditions, traffic conditions, navigational conditions, waterway conditions, immediate consequences, and subsequent consequences."[70] In their conclusion, the Coast Guard workshop identified that "mitigations for volume of small craft traffic, small craft quality, dimensions of the waterway and mobility in the waterway were not balanced enough to reduce the risk of these hazards."[71] The 2016 "Port and Waterways Safety Assessment" is very insightful for the standard operation, flow, condition, and consequences of disruptions within the Hampton Roads regional MTS.

The "Hampton Roads Hazard Mitigation Plan" conducted by the Hampton Roads Planning District offers a comprehensive overview of risk management throughout the area. This document identifies hazards to the area as "flooding, sea level rise and land subsidence, tropical/coastal storm, shoreline erosion, tornado, winter storm, earthquake, wildfire, drought, extreme heat, and hazardous materials incident."[72] While these are an assessment for city planning and management, the same threats apply to the regional MTS.

Weather is a constant threat that impacts infrastructure, and the Hampton Roads MTS is no exception. Hampton Roads is threatened yearly by hurricanes and nor-easter storms that bring with them a myriad of effects such as navigation system displacement, flooding, and coastal erosion. The risks are well documented and expected, or probable and known.[73] Hurricanes, heavy storms, and high winds threaten ships within the system through a variety

---

[70] United States Coast Guard. *Ports and Waterways Safety Assessment Workshop Report Hampton Roads, Virginia,* 12.

[71] United States Coast Guard. *Ports and Waterways Safety Assessment Workshop Report Hampton Roads, Virginia,* 11.

[72]Hampton Roads Planning District Commission, *Hampton Roads Hazard Mitigation Plan* (Hampton Roads, VA: Hampton Roads Planning District Commission, 2017), 47, https://www.hrpdcva.gov/uploads/docs/2017%20Hampton%20Roads%20Hazard%20Mitigation%20Plan%20Update%20FINAL.pdf.

[73] Hampton Roads Planning District Commission, *Hampton Roads Hazard Mitigation Plan*, 49.

of means. From my experience in Norfolk, ships respond to storms in one of two ways: they either place extra precautions on securing the ship to the pier, or they get underway preemptively to avoid the storm at sea. High winds that accompany heavy storms and hurricanes also threaten ships navigating the water by pushing ships off course and creating stronger currents.

Flooding threatens both port infrastructure and waterway subsystems through misplaced buoys, flooded roads, debris, and other hazards. It is not uncommon for buoys to disappear, break free of their anchors, and ultimately be misplaced.[74] This is significant because the operators of ships rely on an accurate channel system to help navigate in and out of port. A misplaced buoy can lead to false confidence about the location of a ship and lead to potentially unsafe water. Flooding of roads and tunnels in Norfolk can be severe, but is temporary and is would not prevent a carrier getting underway.

Several hazards also exist from the social side of the system, mainly the operators. Navigational errors, improperly operating equipment, miscalculation of decision-making are all hazards that create risk. As shown in the Navy's *Comprehensive Review of Recent Surface Force Incidents* all of these hazards led to multiple different ships colliding or running aground.[75] Operating a warship within the Hampton Roads waterway requires all human operators on all vessels to be doing the correct actions for the system to continue functioning. Another Navy human decision-making and navigational error local to this region is the grounding of the USS Missouri (BB-63) in 1950. Newell describes the event and the involved decision-making and operation of the ship's sea and anchor detail with multiple miscommunications between operators that ultimately led to the battleship running aground in the Chesapeake Bay.[76] This specific incident led to three new buoys being added to the navigational waterway to serve as caution indicators and mitigate future groundings.

---

[74] Commander, Fifth Coast Guard District, "Local Notice to Mariners: District 5," (Portsmouth, VA: United States Coast Guard District 5, January 04, 2022), 5–9, https://www.navcen.uscg.gov/pdf/lnms/lnm05012022.pdf.

[75]U.S. Fleet Forces Command, "Comprehensive Review of Recent Surface Force Incidents," (official memorandum, Norfolk, VA: Department of the Navy, 2017), https://s3.amazonaws.com/CHINFO/Comprehensive+Review_Final.pdf.

[76]Gordon Newell, Smith, Allan, *Mighty Mo: The USS Missouri: A Biography of the Last Battleship,* Seattle, Washington: Superior Publishing Company, 1969, 71–72.

A component or part failure is another hazard that can lead to system disruption. Communications, ship engineering, or navigational equipment malfunctions all add risk to the operation of the maritime transportation system. The Navy has procedures and checklists to ensure all required equipment meets operational thresholds, but accidents may still happen. A loss of radio communication may not be as probable or severe in lower-traffic areas or wider navigational sections of the channel. In the Chesapeake Bay, certain VHF radio channels are pre-selected to communicate with both port controllers and other maritime traffic.

Heavier traffic may increase the severity and probability of loss of radio communications because of increased radio traffic and saturation of the physical waterways, creating a greater risk of collision. This hazard is mitigated through several redundancies and maritime communication such as alternate radio channels, sound signals, and visual flag communications (although not as often used). Engineering equipment risks involve propulsion, electrical, auxiliary systems, and damage control.

With the potential of having multiple nuclear reactors in very close proximity to one another in Hampton Roads, an engineering equipment malfunction within a nuclear reactor or supporting systems could severely disrupt the system. Notwithstanding a nuclear reactor melting down in the Chesapeake Bay, electricity or propulsion to a carrier could very well block the usable deep-water channel for any other ships. The *Ever Given* in the Suez Canal is an example of the severity of this hazard.[77] The navigational equipment malfunction could cause the same disruption at narrow areas of the channel causing an increasingly severe hazard. Experienced harbor pilots, tugs, and ship operators are used to mitigate this hazard.

Another hazard to carriers is receiving a significant maintenance overhaul at one of the shipyards. As seen in Figure 6, Hampton Roads contains the most extensive nuclear maintenance facilities and shipyards for the Navy. Shipyards create a multitude of risks to ships because of the work that is being conducted. RAND's report on *USS Nimitz* (CVN 68) offers a few of the hazards brought about by the shipyard environment as "safety aspects of work, including the closing of valves and circuit breakers, ship security, and immediate

[77] Leggett, "Egypt's Suez Canal Blocked by Huge Container Ship."

response to fire or flooding"[78] A regular shipyard creates higher risk from fire, flooding, or toxic gas leaks because there is an increase in spark producing work, ship systems are isolated or out of commission, and a lot of extra personnel, materials, and trash is brought onboard ships. Because of the type of nuclear work conducted in the Hampton Roads shipyards, the probability and severity of this threat are increased. A study on the conducted by the Naval Nuclear Propulsion Program explains that "Results of numerous tests conducted by shipyards under the same conditions that most radiation exposure was received showed that film measurements averaged 15 percent higher than actual radiation exposures."[79] The handling of nuclear material and movement outside of normal protective shields during these maintenance phases provides increased opportunity for nuclear release, which can cause harm to personnel and the environment.

Finally, the hazard of terrorism exists, and a successful terrorist attack could be highly severe, although not probable. Ames et al. provide a study based on four different threat groups labeled "terrestrial, regional seaborne, source seaborne, and internal personnel"[80] This is to say that planned attacks on carriers can come from the shore, local sea area, international seas, or from within the Navy. Another possible hazard creating risk to carriers in Hampton Roads is the Norfolk International Airport, as conceivably a terrorist could hijack a plane and crash it into a carrier. These are high severity but low probability risks to carriers in Norfolk due to certain force protection mitigations and intelligence.

These are known risks within the Hampton Roads maritime system. The 2017 Hampton Roads Planning District report assessed their listed risks on a scale of high risk, moderate, low, and negligible.[81] I agree with their assessments on natural disasters. Using the Navy's Operational Risk Management Risk Assessment Matrix, I assessed the remaining risks based on their probability and severity. Table 1 depicts these assessments.

---

[78] Schank et al. Refueling and Complex Overhaul of the USS Nimitz (CVN 68), 9.

[79] T. J. Mueller, Weishar, T. M., Hallworth, J.M, and Lillywhite, T. F., "Occupational Radiation Exposure from U.S. Naval Nuclear Plants and their Support Facilities" Report NT-19-2, May 2019, 6, https://www.energy.gov/sites/prod/files/2019/09/f66/NT-19-2.pdf

[80] Ames et al. "Port Security Strategy 2012." xxviii-xxix.

[81] Hampton Roads Planning District Commission, *Hampton Roads Hazard Mitigation Plan,* 206

Table 1. Hampton Roads MTS Risk Assessment[82]

Critical Hazard: High Risk	Nuclear Materials Release
	Flooding
	Tropical/Coastal Storm
Critical Hazard: Moderate Risk	Navigational Error
	Terrorist Attack by Internal Water
	Terrorist Attack by International Water
	Sea Level Rise and Land Subsidence
	Tornado
	Winter Storm
	Hazardous Materials Incident
	Decision Making Error
Noncritical Hazard: Low Risk	Terrorist Attack by Land
	Terrorist Attack by Internal Person
	Terrorist Attack by Air
	Terrorist Attack by Subsurface
	Shoreline Erosion
	Earthquake
	Wildfire
	Engineering Equipment Operator Error
	Engineering System Failure
	Navigational System Failure
Negligible	Communications Failure
	Drought
	Extreme Heat

Due to the severity of a nuclear meltdown on a carrier, it is a high-risk factor. The hazards listed as moderate risk are assessed as such because they may occur over time, but could also have a high severity. Hazards are assessed as low risk because significant

[82] Adapted from Hampton Roads Planning District Commission, *Hampton Roads Hazard Mitigation Plan,* 206; Ames et al., "Port Security Strategy 2012." xxviii-xxix.; United States Coast Guard. *Ports and Waterways Safety Assessment Workshop Report Hampton Roads, Virginia.*; T. J. Mueller, Weishar, T. M., Hallworth, J.M, and Lillywhite, T. F., "Occupational Radiation Exposure from U.S. Naval Nuclear Plants and their Support Facilities."; and Schank et al. *Refueling and Complex Overhaul of the USS Nimitz* (CVN 68), 9.

mitigations are in place to make the probability of them occurring unlikely, yet the hazards still have the potential for high severity or death. Finally, communications failure is negligible because a total loss of communications with other vessels in the system is unlikely to occur through several mitigations, redundancies, and ships being able to communicate with broad maneuvers.

2. Reliability Engineering

Infrastructure age, condition, sector practices, and part failure rate all make up how reliable the Hampton Roads waterway system is. The Virginia Department of Transportation is responsible for maintaining the relevant bridges and tunnels with the oldest tunnel in the system being the Hampton Roads Bridge Tunnel built first in 1957 and another lane in 1976.[83] Age and yearly use are important factors in Hampton Roads area because that drives the need for regularly scheduled maintenance of the transportation system. Gokey et al. conducted a study on the bridges of the Hampton Roads area and created tools to assess transportation infrastructure based on maintenance, and political factors.[84] Reilly conducted a load test study on the Hampton Roads Bridge Tunnel stating "Throughout its 60 years in service, the harsh environment along the Virginia coast has taken its toll on the main load carrying girders. Concrete spalling has exposed prestressing strands within the girders allowing corrosion to spread. Some of the more damaged girders have prestressing strands that have completely severed due to the extensive corrosion."[85] As Reilly mentions, the Hampton Roads Bridge Tunnel has experienced normal wear and tear from the weather and the system has degraded. This failure of the bridge tunnel might more directly affect daily drivers and commuters using the tunnel, but a significant failure of the bridge tunnel could bring increased maritime

[83] "Hampton Roads Tunnels and Bridges," Virginia Department of Transportation, December 3, 2021, https://www.virginiadot.org/travel/hro-tunnel-default.asp#the_tunnels.

[84] Jonathan Gokey et al., "Development of a Prioritization Methodology for Maintaining Virginia's Bridge Infrastructure Systems," *Systems and Information Engineering Design Symposium* (2009), 252–257, https://ieeexplore.ieee.org/abstract/document/5166190.

[85] James Reilly, **"**Load Testing Deteriorated Spans of The Hampton Roads Bridge-Tunnel for Load Rating Recommendations,**"** (master**'**s thesis, Virginia Polytechnic Institute and State University, November 29, 2016), 2, https://vtechworks.lib.vt.edu/bitstream/handle/10919/74302/Reilly_JJ_T_2017.pdf?sequence=1&isAllowed=y.

traffic at a choke point throughout the Hampton Roads waterway. As discussed in Section A of this chapter, the bridges and tunnels all throughout this system have the potential to isolate one or more carriers inside the waterways.

Navy ships maintain an extensive maintenance schedule from daily preventative maintenance to extensive long-term life cycle upgrades. There are also pre-operational equipment maintenance checks to operate certain parts or units within the carriers. Figure 8 explains a three-year maintenance schedule of a carrier that repeats for its planned 50-year life span. Carriers also require a mid-life nuclear refueling overhaul that is only able to be done in Hampton Roads.[86] The funding for aircraft carriers is extensive and consistent because of the nature of carriers being a strategic national asset. Schank et al. describe funding fluctuation for the Nimitz mid-life refueling from growth work, budget adjustments, and foreign affairs affecting the maintenance budget and total cost of the project. He states, "Cost growth and overruns during execution increased the total amount to approximately $2.18 billion in the FY01 budget."[87]

Figure 8. 36-Month Aircraft Carrier Maintenance Cycle over the 50-Year Expected Service Life[88]

---

[86]Maurer, *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,* 7.

[87] Schank et al., *Refueling and Complex Overhaul of the USS Nimitz (CVN 68),* 19.

[88] Maurer, *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,* 7.

Ship maintenance culture can also increase or decrease the reliability of systems. Having experienced both positive and negative ship maintenance culture, proactive corrosion control and respect for equipment can produce dividends of equipment longevity. For example, a fire-pump, responsible for pumping highly corrosive saltwater, that is well maintained to avoid leaks and clogs will operate better than a fire-pump that is neglected. A well-maintained fire-pump could then be relied upon to put out a fire on the ship, extending the reliability of the unit.

The Coast Guard conducts safety inspections and maintenance on the aids to navigation in this system. Coast Guard Sector Virginia maintains a "Waterways Management Division monitors a variety of marine activities and events, such as dredging and marine construction projects, the status of aids to navigation, the removal of hazards and obstructions, and a wide variety of sponsored marine events."[89] All of these actions are system practices that attempt to maintain the working system through digging required water depths, keeping the navigational channel preserved, and ensuring undisrupted flows through the system.

Taken together, the key subsystems that have reliability vulnerabilities in the Hampton Roads MTS are civilian highway transportation, Navy repair facilities, and Coast Guard maintenance practices for waterway management. Each bring different potential vulnerabilities that can impact carrier underway operations. Within the transportation subsystem, units such as tunnels and bridges in the North Hampton region are nearing their design life and are likely to fail in the future, especially if experiencing extreme weather or other disasters identified as risks. In contrast, several Navy repair facilities are well-funded, but require long lead times for maintenance and overhaul. These lead times may extend beyond the 36-month cycle for a carrier repair, possibly forcing carriers to remain underway when in need of repairs or creating situations where they become inoperable and unable to be fixed. Finally, units and parts of the Coast Guard

[89] "Prevention," U.S. Coast Guard Atlantic Area, accessed January 15, 2022, https://www.atlanticarea.uscg.mil/Our-Organization/District-5/District-Units/Sector-Virginia/Prevention/

subsystem that provide navigation, dredging, and waterway maintenance are essential for accessing Navy ports and repair facilities.

3. Worst-Case Scenario

Whereas risk and reliability vulnerabilities depend on the likelihood of failure, worst-case vulnerabilities for Hampton Roads waterways focuses on identifying the critical parts of the regional MTS that, if disrupted for any reason no matter how likely, can greatly reduce the ability for a carrier strike group to leave or enter the port. Identifying these bottlenecks is possible by creating a network model of the Hampton Roads MTS and interdicting nodes and arcs to assess their impact carrier operations. Using the imagery from Google Maps satellite view, we develop a representative network model for carriers in-port in Hampton Roads.[90] This open-source imagery (while not accurate intelligence reporting) shows there are two carriers at piers on Naval Station Norfolk, one carrier in-port at Newport News Shipyard, and one carrier in-port in Norfolk Naval Shipyard. Figure 9 illustrates the vital arcs of the Hampton Roads system with the example of four carriers in-port. Transit routes between both Norfolk Naval Shipyard and Newport News Shipyard only support the capacity of one carrier.

[90] Hampton Roads map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/place/Norfolk,+VA/@37.0462908,-76.2973368,10.72z/data=!4m5!3m4!1s0x89ba973a5322ca45:0xab99107fce7a1e0a!8m2!3d36.850505!4d-76.2856293.

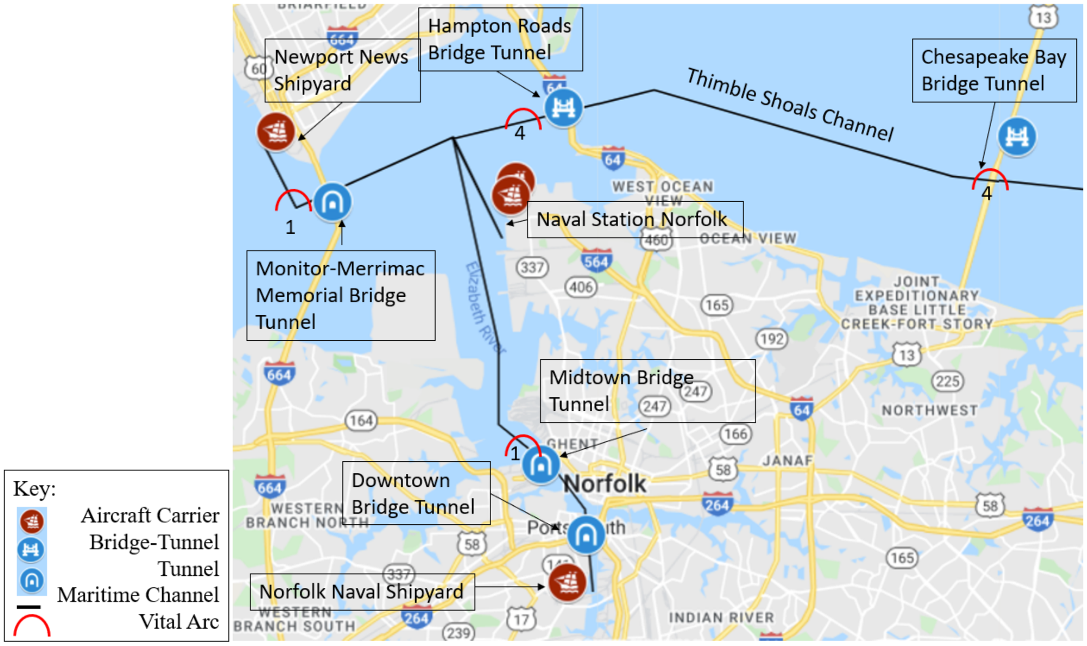

Figure 9. Hampton Roads Maritime Network Interdiction Map[91]

As shown in Figure 9, significant nodes exist at Naval Station Norfolk, Newport News Naval Shipyard, Norfolk Naval Shipyard, and each of the bridge-tunnels. Vital arcs exist in the waterways between each of these nodes. These are vital arcs for carrier movement and power projection but not necessarily the worst-case for the maritime transportation system flows. If arcs between the shipyards and Hampton Roads Bridge Tunnel are blocked then 1 carrier would be unable to exit the channel. If arcs between Naval Station Norfolk and the Hampton Roads Bridge Tunnel is blocked, 2 carriers would be unable to transit. The arc between Hampton Roads Bridge Tunnel and Chesapeake Bay Bridge Tunnel supports a flow of 4 carriers. The most critical nodes for this regional system are the Hampton Roads Bridge Tunnel and the Chesapeake Bay Bridge Tunnel and the most vital arcs are between port subsystem nodes (bases and shipyards) to the Hampton Roads Bridge Tunnel and the Thimble Shoals channel between Hampton Roads Bridge Tunnel and Chesapeake Bay Bridge Tunnel.

[91] Adapted from Hampton Roads map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/place/Norfolk,+VA/@37.0462908,-76.2973368,10.72z/data=!4m5!3m4!1s0x89ba973a5322ca45:0xab99107fce7a1e0a!8m2!3d36.850505!4d-76.2856293.

Several worst-case scenarios can create the disruption of nodes and arcs shown in our network model. . As discussed in the Hampton Roads risk analysis, terrorism could cause any number of the units to be unavailable. To stay true to the idea behind this thesis of "reducing carriers' ability to project power without a direct attack on a carrier," the worst-case could be a disruption of the Hampton Roads Bridge Tunnel node or Chesapeake Bay Bridge Tunnel node. The vital arcs are the waterways leading up to the Hampton Roads Bridge Tunnel from port nodes or the Thimble Shoals Channel. The geography of the system does not allow for immediate alternate flows to be available, although dredges working around the clock could theoretically be used to create a new route. A physical blockage of the water over Hampton Roads Bridge Tunnel would cause a 100 percent blockage to the system, while eradication of capable tugs would equally reduce carriers' ability to get underway and enter the transit subsystem, leaving them stuck in port. Neither of these would involve a direct attack on a U.S. Naval vessel but would significantly reduce their ability to project power abroad.

4. Resilience Engineering through Surprise ~~T~~

Surprise in the Hampton Roads system is best understood via analysis of previous disasters and how well local subsystems were able to sense, anticipate, adapt, and learn from the events.[92] Assessing the potential for surprise identifies ways to enhance safety and resilience in the system and achieve resilience outcomes for systems (e.g., fast recovery)[93] Utilizing sensing, anticipating, adapting and learning, the Hampton Roads system has strengthened its robustness. Actions taken after the January 1950 grounding of the *USS Missouri* shows how the Hampton Roads MTS may respond to future surprises as the system sensed the potential for shoal water, anticipated another grounding, installed new navigational buoys, and now teach this lesson to mariners that transit these waters. In this case, system resilience was enhanced after the grounding.

[92] Thomas, John E., Daniel A. Eisenberg, Thomas P. Seager, and Erik Fisher, "A Resilience Engineering Approach to Integrating Human and Socio-Technical System Capacities and Processes for National Infrastructure Resilience," Journal of Homeland Security and Emergency Management 16, no. 2 (2019), https://calhoun.nps.edu/handle/10945/63114.

[93]Daniel A Eisenberg, "How to Think About Resilient Infrastructure Systems." (PhD diss., Arizona State University, 2018), https://core.ac.uk/download/pdf/158457105.pdf.

While the Navy responds to and trains for situational surprises that occurred in the past such as navigation failures, engineering, security, and casualty control surprises, currently there is little evidence that there is training for fundamental surprises, i.e., events that have not happened before. A possible surprise event in the Hampton Roads MTS is an unresponsive and out of control container ship on a collision course within the tight channel. This event has never occurred in this channel, but has occurred in other MTS. If it were to happen, the oncoming ship could be sensed via radar, communications, and sight and the impacts adapted to by giving the ship a large passing distance. But depending on where the closest point of approach is in the channel, adaptation may not be feasible, especially for an aircraft carrier that is large and difficult to move.

E. HAMPTON ROADS MTS SUMMARY

Overall, the ability for a carrier to traverse the Hampton Roads MTS to and from its homeport involves many military and civilian units in the port and waterway subsystems. While Navy infrastructure units include Naval Station Norfolk and Norfolk Naval Shipyard, other units in the port subsystem are Newport News Shipbuilding and the Port of Norfolk are also critical units to an underway carrier strike group. Critical units in this regional MTS subsystem are the navigable channel, tugboats, and the interconnected highway system. Several key social subsystems include: VDOT, U.S. Coast Guard Sector Hampton Roads, Port of Virginia management, and the Virginia Pilots Association.

We find the following subsystems to be the most important from a vulnerability perspective:

- Civilian transportation (bridges, tunnels)
- Navy repair facilities
- Coast guard waterway maintenance subsystems

Integrating assessments, we find the most important vulnerabilities are:

- Risks related to nuclear failure and operational errors that can cause ships to block maritime channels.

- Reliability issues that can cause transportation infrastructure to fail and block channels or prevent ingress / egress to the Navy shipyards

- Worst-case disruptions that involve attack or failure of key bridges can block maritime channels.

- An inability to manage fundamental surprises (e.g., adapt to unforeseen events as they occur) and a need to attenuate damages of rogue or unmanned ships and quickly move a carrier to a safer location.

The combination of these key regional MTS subsystems and vulnerabilities are used to measure the vulnerability of carrier power projection. The Hampton Roads regional MTS is just one of three regional systems that create the power projection system this thesis studies.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. SAN DIEGO REGIONAL ASSESSMENT

Like Chapter III, this chapter maps out the maritime transportation system within San Diego Bay by identifying relevant naval, civilian, and social maritime infrastructure. Then, San Diego MTS vulnerabilities are assessed using four different models: risk assessment, reliability engineering, worst-case, and resilience engineering. Compared to Hampton Roads and Puget Sound, San Diego provides the least amount of maritime infrastructure supporting carriers, but hosts the second-largest surface fleet base in the United States. The entire waterway and supporting infrastructure fits in a 10-mile by 10-mile region, making this the smallest scale of the three ports studied. Figure 10 depicts this region and its associated infrastructure. The San Diego MTS consists of naval bases, maintenance facilities, intermodal infrastructure, and social units.

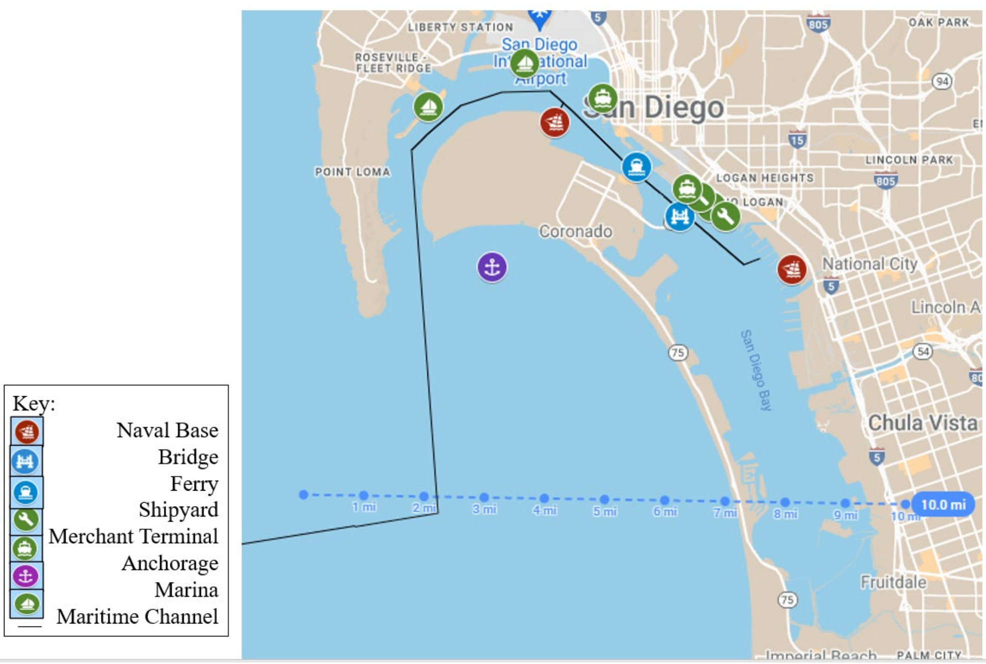

Figure 10. San Diego Maritime Transportation Infrastructure[94]

[94] Adapted from San Diego Bay map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/@32.6672632,-117.1762958,12z.

A. SAN DIEGO REGIONAL PORT OPERATIONS SUBSYSTEM

At first glance, San Diego Bay appears to be a simple maritime system with only one waterway. This one waterway is crowded by multiple different naval installations, shipyards, a cruise terminal, multiple civilian recreational marinas and the entrance/exit to the bay lies close to an international border with Mexico. This location includes one naval base for aircraft carriers, one base for surface combatants and supporting ships, a separate submarine base, and a multitude of naval shipyards. The relevant naval installations here are Naval Base Coronado, Naval Base San Diego, and the San Diego Shipyards.[95] These locations are important to the Carrier Strike Group concept because they homeport carriers and supporting assets of a strike group or conduct routine depot level maintenance.

1. Naval Base Coronado

Naval Base Coronado (NBC) is the location for carriers berthed in San Diego and one of two locations on the West Coast, the other location being Puget Sound. As it describes itself, Naval Base Coronado is "unequalled in operational scope and complexity, NBC provides a shore-based platform for helicopters, aircraft carriers, SEAL Teams and other ashore and afloat commands for access to a comprehensive quantity of ground, sea, air, and undersea operational and training space."[96]Naval Air Station North Island is the specific naval installation within Naval Base Coronado in which carriers are homeported. Berthing carriers at the naval air station creates a separation from the other surface ships that carriers deploy with for protection in a Carrier Strike Group. Most other surface combatants are homeported at the 32nd Street Naval Base San Diego.

2. Naval Base San Diego

Most of the surface fleet forces stationed within this region are homeported and supported by Naval Base San Diego. This base offers thirteen piers and a dry dock within

95 *San Diego Bay 18773,* National Oceanic and Atmospheric Administration, accessed January 19, 2022, https://www.charts.noaa.gov/OnLineViewer/18773.shtml.

96 Commander, Navy Installations Command Notification, "Welcome to Naval Base Coronado," Department of the Navy, accessed February 11, 2022, https://www.cnic.navy.mil/regions/cnrsw/installations/navbase_coronado.html.

waterfront real estate. A brief description of the base by the Navy follows, "Naval Base San Diego is homeport to the Pacific Fleet Surface Navy with 56 U.S. Navy ships and two auxiliary vessels including USNS Mercy (TAH - 19)."[97] This base is geographically located in an interior position relative to the Coronado Bridge, meaning all ships leaving the base must pass under the bridge in between set pylons of the bridge.

3. San Diego Shipyards

San Diego supports a robust naval shipyard enterprise along the waterfront with the main shipyard companies being Continental Maritime of San Diego, BAE Systems, and General Dynamics NASSCO.[98] These shipyards have both wet and drydocks for the maintenance of ships, but unlike both Puget Sound and Hampton Roads, San Diego does not provide drydocking maintenance facilities for carriers.[99] These companies are still able to provide nuclear maintenance but the maintenance not as extensive as the other two locations due to the lack of existing facilities.[100] These shipyards are also located in an interior position to the Coronado Bridge, except Continental Maritime which is directly under the bridge. These shipyards along with Naval Base Coronado and Naval Base San Diego create the relevant naval maritime port infrastructure subsystem within San Diego. There are other naval installations along this waterway, but they do not provide significant contribution to carrier power projection.

B. INTERMODAL CIVILIAN MARINE INFRASTRUCTURE IN SAN DIEGO

1. San Diego Bay Waterway

The San Diego Bay waterway is a small-scale transit through a narrow channel that approaches from the south and loops around Coronado Island to the east and then south.

---

[97] Commander, Navy Installations Command, "Welcome to Naval Base San Diego."

[98] "Shipyards," Port of San Diego, accessed January 19, 2022, https://www.portofsandiego.org/maritime/shipyards.

[99] Maurer, *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,* 21.

[100] Maurer, 21.

This channel ranges in width at times, but on average is about 750 yards wide.[101] Multiple anchorages exist at the eastern entrance to the waterway, and five anchorages exist within the waterway south of Harbor Island.[102] Figure 11 shows the navigational chart of San Diego Bay with its charted water depths, hazards and navigation aids. The transit between port to sea is only a short distance for carriers parked on the northeast corner of Coronado Island, but is a little longer for supporting ships to make it to Naval Base San Diego farther inland.

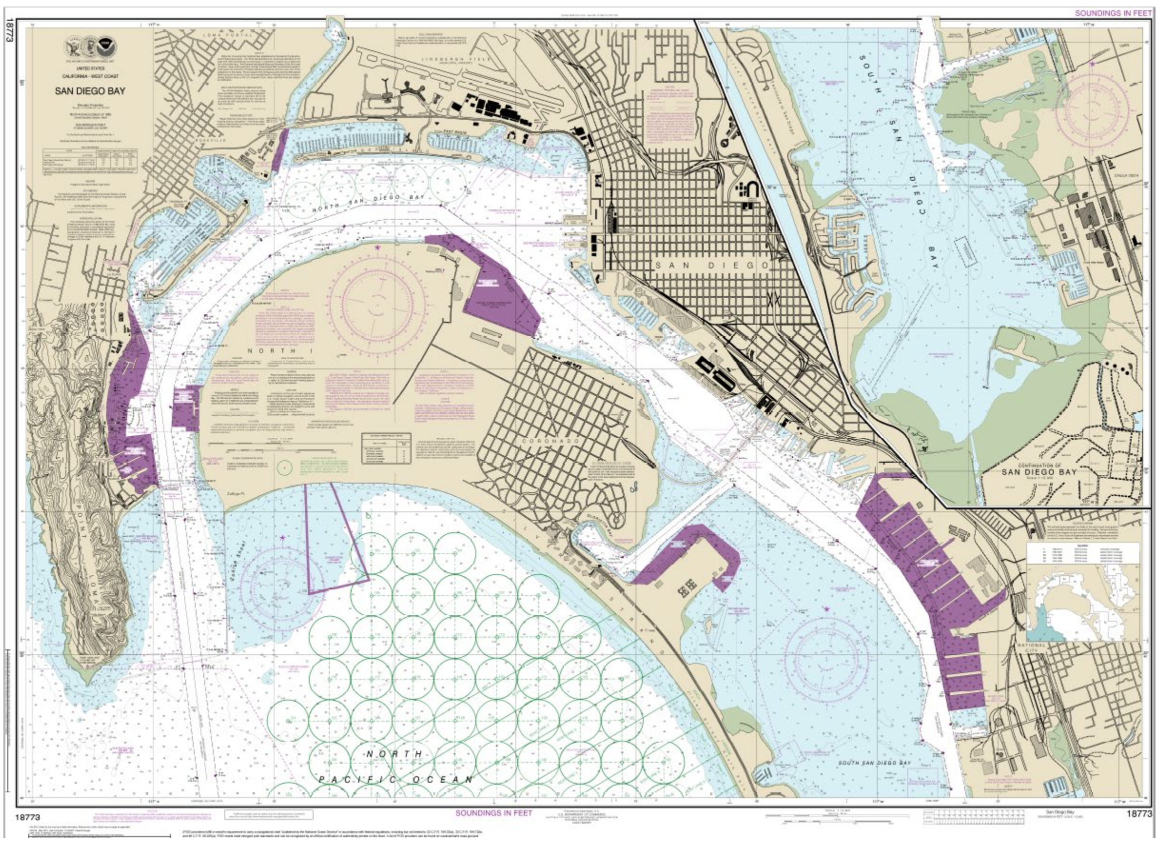

Figure 11. NOAA Chart 18773- San Diego Bay[103]

---

[101] NOAA, *San Diego Bay Chart 18773.*

[102] NOAA, *San Diego Bay Chart 18773.*

[103] NOAA, *San Diego Bay Chart 18773.*

2. San Diego-Coronado Bay Bridge

The San Diego-Coronado Bay Bridge or California Route 75 connects the mainland of San Diego with Coronado Island. It is one of the few routes to take between the two landmasses and crosses over the San Diego Bay waterway. The Coronado Bridge provides two pathways through the water for inbound and outbound maritime traffic required to operate within the channel (naval warships). In keeping with the rules of the road, traffic stays to the right of the "road," so outbound ships pass under the bridge to the northern side of the channel and inbound ships pass under on the south side of the channel. This bridge throttles the maritime traffic in the channel by narrowing the navigable water space at that specific point to 220 yards.[104]

3. Coronado Ferry

A small ferry transits between Coronado Island and the City of San Diego through marked routes cutting directly across the channel. This ferry runs every half an hour, providing another mode of transportation to and from Coronado Island and across the San Diego Bay channel.[105] These provide routine shipping movements that do not interfere with naval operations.

4. Tourist Terminals

Across the channel from where carriers park on Naval Air Station North Island, a cruise ship terminal and the USS Midway Museum are stationed. While the *USS Midway* no longer gets underway, it does jut out into water near the carriers. The cruise ship terminal provides for increased big shipping traffic near the same vicinity. These ships operate on the same waterways as the U.S. Navy, but are also well-documented and predictable movements that do not impede with U.S. Navy shipping.[106]

---

[104] NOAA, *San Diego Bay Chart 18773.*

[105] "Best Fall Activities in San Diego," Flagship Cruises and Events, accessed February 21, 2022, https://flagshipsd.com/blog/fall-things-to-do.

[106] "Cruise and Cargo Ship Calls," Port of San Diego, accessed February 21, 2022, https://www.portofsandiego.org/events/cruise-and-cargo-ship-calls

5. Recreational Marinas

Another use of the San Diego waterway system is for recreation within San Diego Bay. There are two major civilian marinas that provide housing and fueling for recreational boaters in the bay. Figure 11 indicates Shelter Island lies on the northwest side of the channel and Harbor Island on the north side above Coronado Island. On a sunny day in San Diego (read almost always), hundreds of sailboats, motorboats, jet skis, paddleboarders, and kayaks are launched from these and other marinas in the bay. This significantly increases maritime traffic and uncertainty of intentions to operators of the warships. The COLREGs dictate "right of way" in certain situations, but it Coast Guard studies show sail boaters in San Diego Bay is not always mindful of these regulations.[107] Shelter Island also is the location of the Harbor Control Headquarters for radio communications and coordination throughout the area.[108]

C. SAN DIEGO MARITIME TRANSPORTATION SOCIAL UNITS

The human operators, managers, maintainers, and regulations of San Diego Bay create another important element of the maritime transportation infrastructure. Rules and regulations create standard operating procedures and normalize how the system is run within this area. The Port of San Diego, City of San Diego, U.S. Coast Guard, shipyard companies, civil engineers, and other users make up the social components.

1. Caltrans District 11- San Diego

Caltrans is California's Department of Transportation and is a stakeholder in the maritime system through economic project funding, regulations, maintenance, and management. Caltrans sets the standards for environmental management but leaves the infrastructure management to the Port of San Diego.[109] Caltrans District 11 runs a "San Diego-Coronado Bay Bridge Suicide Deterrent" project because "After the Golden Gate

[107] U.S. Coast Guard, "Ports and Waterways Safety Assessment: San Diego," U.S. Coast Guard, March 2003, 14, https://www.navcen.uscg.gov/pdf/pawsa/workshopReports/San%20Diego.pdf.

[108] "Vessel Entry and Clearance Procedures," Port of San Diego, accessed January 19, 2022, https://www.portofsandiego.org/maritime/mariner-resources/vessel-entry-and-clearance-procedures

[109] Port of San Diego, "Climate Action Plan," San Diego, CA: Unified Port of San Diego, 2013, https://pantheonstorage.blob.core.windows.net/environment/Port-of-San-Diego-Climate-Action-Plan.pdf, 8.

Bridge, it is recognized as the second most frequently used bridge for suicide in the state."[110] I have unfortunately witnessed such an incident while aboard a ship docked at one of the shipyards underneath the bridge and it affects operators in the system both physically and mentally. Caltrans also manages the California highway system that intersects San Diego Bay with the Coronado Bridge.

2. Port of San Diego

The Port of San Diego is the primary authority for managing maritime cargo and trade, waterfront development, public safety, tourist experiences, and environmental protection.[111] The Port of San Diego offers connections and resources for all these components within the bay, such as tug companies, terminal availability, shipping schedules, pilotage services, and customs clearance.[112] They coordinate waterfront development projects, public works along the bay, and harbor police for security. Overall, the Port of San Diego is the lead coordinating manager of the San Diego Bay waterway.

3. U.S. Coast Guard Sector San Diego

U.S. Coast Guard Sector San Diego is a federal entity that conducts many of the regulatory, safety, and security inspections in this system. It conducts the same functions listed in Chapter III Section C.1 relative to the infrastructure laid out in this chapter. The Coast Guard does not have a Maritime Transportation System Recovery Plan published for San Diego, but does have one for the sector just north of San Diego, Sector Los Angeles- Long Beach. This is an important planning process for the recovery of the maritime transportation system should it be disrupted due to any number of reasons. Ideally, the Coast Guard regulations and inspections mitigate and safeguard against any major disruptions. The Sector San Diego maintains an Aids to Navigation Team and four patrol boats within its area of

[110] "San Diego – Coronado Bay Bridge Suicide Deterrent Project," Caltrans, accessed January 20, 2022, https://dot.ca.gov/caltrans-near-me/district-11/current-projects/coronadobridge

[111] "What We Do," Port of San Diego, accessed January 20, 2022, https://www.portofsandiego.org/

[112] Port of San Diego, "Vessel Entry and Clearance Procedures."

responsibility.[113] U.S Coast Guard Sector San Diego is another important federal social component of San Diego Bay system operations.

4. San Diego Bay Pilots Association, Inc

The San Diego Bay Pilots Association is a group of harbor and navigational experts that help navigate ships safely in this region's waterway. Directed under Coast Guard regulations, "All foreign vessels and vessels from a foreign port or bound thereto, and all vessels over 300 gross tons sailing under register between the port of San Diego and any other U.S. port, are subject to pilotage charges and unless permission is granted from the U.S. Coast Guard Captain of the port shall be under the direction of a federally licensed pilot for the port of San Diego."[114] These pilots are the coordinating operators between a ship's crew and harbor tugs and also provide navigational recommendations based on local conditions. Navy vessels utilize these pilots, but are still accountable for the ship's movements and maneuvers. A well-trained crew could get underway or dock without the use of a pilot, but they are still frequently used. Admiral Stavridis details a sea-story in which he "foolishly declined to use an offered tug, and didn't heed the advice of the experienced harbor pilot," and learned his lesson to "use the tugs and listen to the pilot" after an allision he had with a pier while docking a ship as a junior officer.[115] These pilots are important and well-trusted within San Diego mariner community.

5. San Diego Tugboats

There are a variety of tugboats available to ships in San Diego, but many are small push/pull tugs used for moving barges. The Navy preferred tractor tugs in San Diego are from Edison Chouest Offshore, Foss Maritime Company, and Crowley Maritime.[116] These companies provide the high horse-power tugs preferred by the Navy with Edison Chouest

[113] "District Eleven Units," U.S. Coast Guard, accessed January 5, 2022, https://www.pacificarea.uscg.mil/Our-Organization/District-11/Units/

[114] Port of San Diego, "Vessel Entry and Clearance Procedures."

[115] Stavridis, *Sea Power*, 29–30.

[116] Stephen Dobyns, "Tugboats of San Diego Bay," *San Diego Reader,* January 24, 2002, https://www.sandiegoreader.com/news/2002/jan/24/all-good-scenery-nice-sunsets-sunrises/#:~:text=Foss%20and%20Crowley%20have%20tugs,Navy%20uses%20six%20Chouest%20tugs.

being "under long-term charter to the U.S. Navy" in San Diego.[117] Working closely with pilots and ship's crew, harbor tugs maneuver ships on and off piers and are able to help turn ships towards the direction they need to be moving. Tugboats in San Diego are an integral component in moving carriers between port and waterway subsystems.

D. SAN DIEGO VULNERABILITY ASSESSMENT

1. Risk

Reports conducted by the U.S. Coast Guard, City of San Diego, non-governmental organizations, Caltrans, and personal experience with the system are used to identify hazards, assess their probability and severity, and measure overall MTS disruption.

The Coast Guard studied many hazards prevalent in the San Diego regional MTS specific to vessel conditions, traffic conditions, navigational conditions, and waterway conditions. From this study, they identified hazards with above average risks as "personal injuries, mobility, volume of recreational traffic, recreational boater proficiency, regional system configuration, petroleum discharge, economic, bottom soil type, and congestion."[118] The Coast Guard study assessed other hazards in the regional MTS as well but considered these to be the riskiest. Through already existing mitigations or newly recommended control factors, this study concluded recreational boater proficiency, visibility impediments, mobility, and shallow draft mariner proficiency risk mitigations are not currently balanced within the regional MTS.

Some of the risk assessments conducted for the San Diego area encompass the entire San Diego County and are not limited to the immediate San Diego Bay waterway. A "Multi-Jurisdictional Hazard Mitigation Plan" developed by San Diego County, identifies several hazards and mitigation plans across multiple cities in San Diego County. This report identified potential hazards to the county as "coastal storms, erosion, tsunamis, dam failure, drought, earthquakes, floods, hazardous materials release, landslide, liquefaction, nuclear materials

117 "Highly Specialized Vessels Designed for Job-Specific Tasks," Edison Chouest Offshore, accessed February 4, 2022, https://www.chouest.com/vessels.html.

118 U.S. Coast Guard, "Ports and Waterways Safety Assessment: San Diego," 5.

release, terrorism, wildfire/structure fires."[119] Due to the national security sensitivity of information about terrorism, nuclear materials release, and hazardous materials release San Diego County does not report those metrics in open-source documenting. Many of these hazards have implications and potential for disrupting San Diego's maritime system by affecting technical components or operators.

Another similar report for hazard identification was conducted by the City of San Diego. This report identifies the hazards of "changes in frequency and severity of wildfire, sea level rise and related coastal issues, changes in precipitation, and extreme heat events."[120] However, wildfires, sea-level rise, and changes in precipitation are included in my assessment of the San Diego system. Fires, both ashore and onboard ships, are hazards to both ship units and port subsystems because of their destructive nature. The report identifies that coastal flooding and coastal erosion are associated hazards to sea-level rise.[121] These directly affect the waterway and port infrastructure located on or near the water by changing the characteristics of the channel and reducing the land available for supporting infrastructure. Increased periods of precipitation could also cause flooding or landslides, blocking interconnected road systems. This report only contained environmental hazards that have potential to disrupt San Diego's maritime system.

Utilizing these reports and Ames et al. terrorist categories, I have made a comprehensive list of hazards with capabilities to disrupt San Diego's maritime system. Table 2 compiles a list of identified hazards and ranks them using the Navy's Operational Risk Management Matrix. These hazards were selected on the basis of disrupting a San Diego based carrier, the San Diego Bay waterway, or another component in the system with ability to disrupt either of the first two.

---

[119] Office of Emergency Services, and Unified Disaster Council, "Multi-Jurisdictional Hazard Mitigation Plan," San Diego, CA: County of San Diego, October 2017, 2018 Hazard Mitigation Plan.pdf (sandiegocounty.gov)

[120] ICF International, *Climate Change Vulnerability Assessment*, 2.

[121] ICF International, 2.

Table 2. San Diego Maritime Transportation System Risk Assessment[122]

Critical Hazard: High Risk	Nuclear Materials Release
Critical Hazard: Moderate Risk	Navigational Error
	Terrorist Attack by Internal Water
	Decision Making Error
	Earthquake
	Terrorist Attack by International Water
	Tsunami
Noncritical Hazard: Low Risk	Terrorist Attack by Land
	Terrorist Attack by Internal Person
	Terrorist Attack by Air
	Terrorist Attack by Subsurface
	Engineering Equipment Operator Error
	Engineering System Failure
	Navigational System Failure
	Wildfire/ Structure Fire
	Hazmat Release
	Floods
	Sea-Level Rise
	Erosion
Negligible	Communications Failure
	Coastal Storms

San Diego's maritime system is vulnerable to environmental concerns with climate change bringing more intense weather events like increasingly intense seasons of precipitation or drought which, in turn, causes more severe flooding and wildfires. These hazards increase the risk to the port infrastructure subsystem in San Diego. The regional MTS design also creates vulnerabilities from port locations in relation to cross-connecting civilian transportation infrastructure.

2. Reliability

San Diego's maritime transportation system is currently reliable based on factors of infrastructure age, current conditions, sector practices, and expected failure rates of

122 ICF International. *Climate Change Vulnerability Assessment*, 2.; Ames et al. "Port Security Strategy 2012."; U.S. Coast Guard, "Ports and Waterways Safety Assessment: San Diego,"; and Office of Emergency Services, and Unified Disaster Council, "Multi-Jurisdictional Hazard Mitigation Plan."

components. Social components responsible for the maintenance and funding of infrastructure are Naval Facilities Engineering Systems Command (NAVFAC), Caltrans, and the City of San Diego. The most important reliability vulnerabilities to this regional MTS are naval port units and civilian highway transportation.

NAVFAC is responsible for maintaining the piers and naval base structures on Naval Air Station North Island. The Public Works Department conducts "recurring service, including preventative and corrective maintenance" to ensure the piers can be continually operational. Naval Air Station North Island homeported its first carrier in 1924 and has 4 piers able to support carriers.[123] A base instruction provides standard procedures and practices for ships and operators to utilize the piers and keep it well maintained through proper use of hotel services (potable water, electricity, etc.), weight limits, and operator uses.[124] These standard procedures deliver approved and safe practices to ensure continued use of the pier infrastructure by not allowing excess weight on the piers, hazardous materials corrosion or fire hazards.

The age, maintenance, and construction of the Coronado Bridge is another piece of infrastructure that merits a reliability assessment. Caltrans maintains the San Diego- Coronado Bay Bridge, which was constructed in 1969. The 53-year-old bridge is well funded and receives a portion of Caltrans' "$450 million annual budget on bridge maintenance, preservation, and inspection."[125] The bridge also receives studies for seismic impacts on the bridge's structural integrity due to being in an earthquake prone region.[126] Caltrans claims that through their funding, preservation, retrofitting, and inspection that the amount of structurally deficient bridges in California have reduced, allowing for more reliable

[123] Commander, Navy Region Southwest, "Naval Air Station North Island," Department of the Navy, accessed February 4, 2022, https://www.cnic.navy.mil/regions/cnrsw/installations/navbase_coronado/about/installations/nas_north_island.html

[124] Commanding Officer, Naval Base San Diego, *Policy Governing Port Operations and Laydowns,* Naval Base San Diego Instruction 3170.1 (San Diego, CA: Department of the Navy, January 2021), https://www.cnic.navy.mil/regions/cnrsw/installations/navbase_san_diego/about/policies.html

[125] "Structural Check-up: Bridge Health Increased," Caltrans, 2013, https://dot.ca.gov/-/media/dot-media/programs/risk-strategic-management/documents/mm-2014-q1-bridge-health-a11y.pdf.

[126]James E. Roberts, "Highway Bridges," in *Practical Lessons from the Loma Prieta Earthquake* (*1994)* (Washington, DC: National Academy Press, 1994), https://www.nap.edu/read/2269/chapter/8

bridges.[127] This is a positive note for the reliability of the Coronado Bridge, as it can be expected to be well maintained. Overall, Caltrans' maintenance practices track and provide for expected fault tolerances in their area of responsibility.

Recreational boating practices in the San Diego Bay also cause reliability vulnerabilities because of their proficiency and traffic mix. The U.S. Coast Guard states, "recreational boaters often lack situational awareness and understanding of commercial vessel maneuvering capabilities" and "some recreational boats operate too close to commercial vessels (i.e., along side or do not yield right of way)- a result of curiosity or lack of knowledge. Particularly problematic with sailboats."[128] According to the Coast Guard, recreational boaters in San Diego tend to not follow standard operating procedures and MTS safety practices. This leads to unreliable operators in the regional system and cause for panic in the wheelhouse of larger ships.

The reliability of Naval Air Station North Island and the Coronado bridge reduce vulnerabilities to the San Diego regional MTS, while recreational boaters produce increased vulnerability to collision or bad decision making. In review, the port subsystem of San Diego is reliable, yet the waterway subsystem is vulnerable from the proficiency and increased traffic of recreational boaters.

3. Worst-Case

San Diego's worst-case scenario is assessed by identifying the critical parts of the regional MTS that the system cannot function without, regardless of the probability of actual disruption. A satellite overview of the area shows two carriers in-port at Naval Air Station North Island at Kilo Pier and Lima Pier.[129] Figure 12 depicts vital arcs in the maritime system in relation to carriers. Important nodes in this regional MTS are Naval Air Station North Island, Naval Base San Diego, and the Coronado Bridge. Vital arc are the pathways carriers

---

[127] "Value and Cost of California's Bridges," Caltrans, accessed February 12, 2022, https://dot.ca.gov/-/media/dot-media/programs/risk-strategic-management/documents/mm-2015-q1-bridge-health-a11y.pdf

[128] U.S. Coast Guard, "Port and Waterways Safety Assessment: San Diego," 12–14.

[129] San Diego Bay map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/@32.6672632,-117.1762958,12z.

and strike group assets take between nodes. There are no vital arcs to carrier movement from Naval Base San Diego because there are no carriers homeported there and they cannot fit through the Coronado Bridge. This is a vital arc for strike group assets, however. A vital arc exists anywhere beyond the northwest and southwestern part of the channel but because of the deeper water depths outside the navigational channel allowing for extra leeway in maneuverability it is unlikely to happen.[130]

Figure 12. San Diego Maritime Network Interdiction Map[131]

The system could potentially be completely disrupted by a collision between two very large ships that block the 1000-yard safe channel. Therefore, the San Diego system might offer better insight into a power projection disruption from the Carrier Strike Group point of view. Naval Base San Diego and its 55 homeported ships lie interior to the Coronado Bridge. A blockage of this bridge would serve to block about 20 percent of the Navy's surface vessels from leaving port, assuming they were all in-port. Linder accounts for this same idea and

[130] U.S. Coast Guard, "Port and Waterways Safety Assessment: San Diego."

[131] Adapted from San Diego Bay map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/@32.6672632,-117.1762958,12z.

details how the Navy was involved in the design of the bridge's construction.[132] Aircraft carriers are safe from a network interdiction standpoint within San Diego, short of a nuclear reactor blowing up and disabling both carriers.

The worst-case scenario for the San Diego regional MTS would be a disruption blocking the waterway subsystem between the entrance of the channel up to Harbor Island. This would completely cut off ingress or egress of both carriers and strike group assets from reaching the ocean.

4. Resilience Engineering through Surprise

A surprise with the potential to disrupt San Diego's maritime system would be an earthquake that led to a tsunami. Many tsunamis have been observed in the San Diego area since the 1800s with "the most significant remote tsunami to hit southern California in 1960, when an 9.5 magnitude earthquake off the coast of Chile generated a tsunami resulting in 4-foot waves."[133] The same model of sensing, anticipating, adapting, and learning (SAAL) is used in San Diego to increase resilience from tsunamis. Several organizations, such as Ready San Diego and the San Diego Fire Foundation, provide information to the general population about tsunamis, evacuation routes, and safety checklists. San Diego Fire Foundation states that improving tsunami detection, or sensing, is being improved through the use of "Scripps Institution of Oceanography, NASA Jet Propulsion Laboratory, and NOAA, who have developed a way to measure earthquake size, intensity, and potential damage through GPS, pressure, temperature, and seismic data in real-time."[134] These functions cover the entire spectrum of resilience engineering because they are improving sensing through increased technology, anticipating tsunamis from better sensed earthquakes, adapting their response and warning systems for more time-conscious responses, and have learned from past historical

[132] Bruce Linder, *San Diego's Navy,* Annapolis, Maryland: Naval Institute Press, 2001, 156–157.

[133] "Tsunami," Ready San Diego, accessed February 18, 2022, https://www.readysandiego.org/tsunami/.; and "It's Not a Matter of If a Tsunami is Coming, It's When and How Large?" San Diego Fire Foundation, accessed February 16, 2022, http://www.sdfirefoundation.org/commandpost/spotlight/its-not-a-matter-of-if-a-tsunami-is-coming-its-when-and-how-large/#:~:text=Obey%20firefighters%2C%20lifeguards%20%26%20police.,has%20trained%20for%20tsunami%20evacuation.&text=Have%20a%20contact%20out%20of,responders%20give%20the%20all%20clear.

[134] San Diego Fire Foundation, "It's Not a Matter of If a Tsunami is Coming, It's When and How Large?."

examples. The learning aspect continues with the further education of the community and users within the maritime system.

The California Department of Conservation provides Tsunami Inundation Maps to show the areas potentially affected by tsunamis. Figure 13 shows the tsunami inundation areas within San Diego Bay, showing the entire island of Coronado in an inundation line and much of the coastline, including Naval Base San Diego piers, within an inundation area.

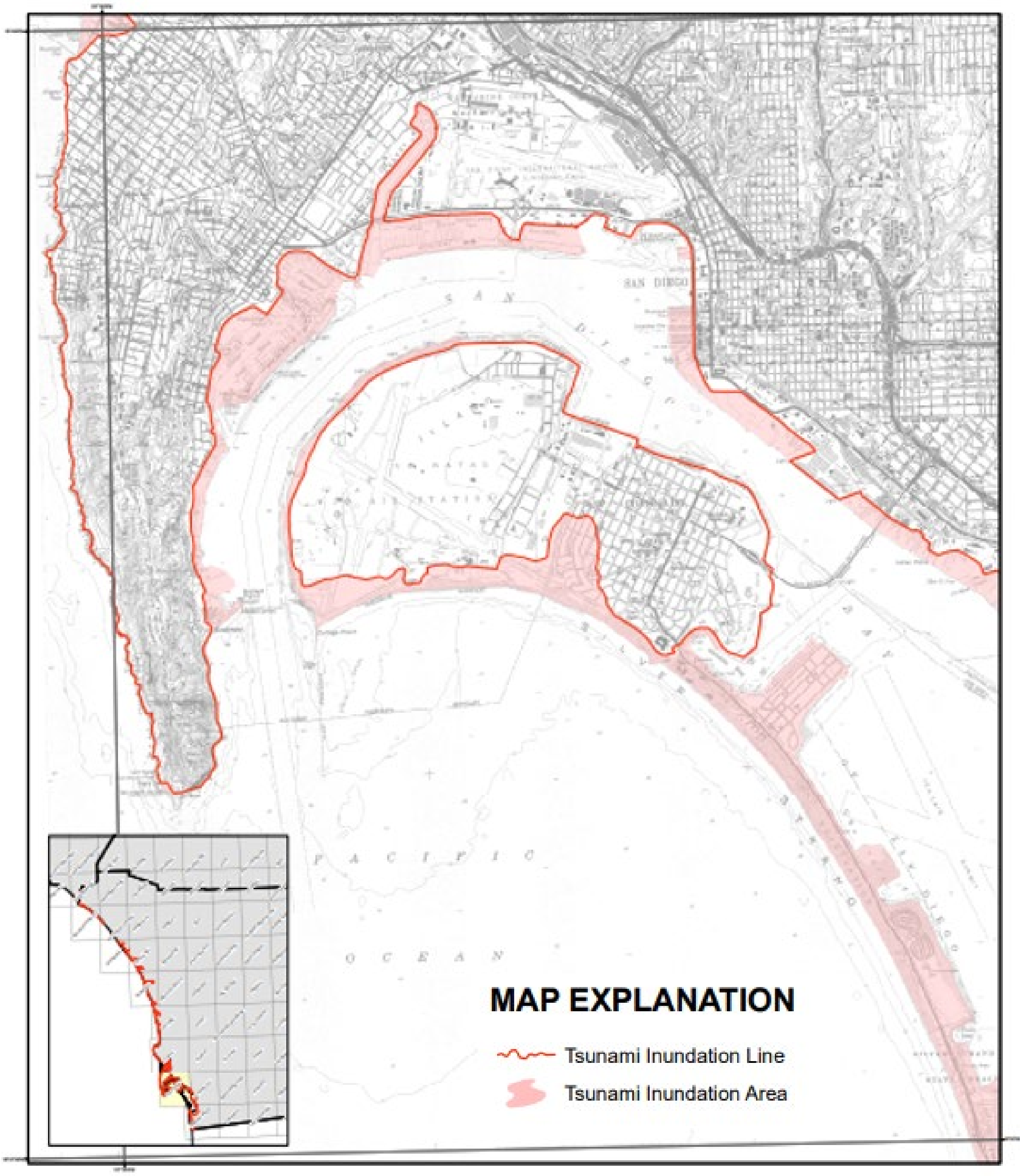

Figure 13. Tsunami Inundation Map of San Diego Bay[135]

[135] *Tsunami Inundation Map for Emergency Planning: Point Loma Quadrangle*, California Emergency Management Agency, California Geological Survey, and University of Southern California, accessed January 15, 2022. https://www.conservation.ca.gov/cgs/Documents/Publications/Tsunami-Maps/Tsunami_Inundation_PointLoma_Quad_SanDiego.pdf.

As seen in the risk assessment section of San Diego, tsunamis may be an increasing hazard to maritime infrastructure in the future and the resilience engineering of tsunami sensing, anticipating, adapting, and learning should continue with the option for increased tsunami protection at the forefront of decision makers' minds. Currently, it seems much of the resilience engineering provided is on improving detection and anticipating damages, but not so much on preventing damages.

However, a single part disruption, such as an internal personal threat, can create a surprise disruption to the system. As seen in the fire that burned down *USS Bonhomme Richard* (LHD 6) in-port San Diego in July 2020.[136] The incident, that ended with the Navy's decision to decommission the amphibious aircraft carrier, happened from a sailor onboard the ship who committed arson in a flammable area of the ship during an extensive maintenance period. The ship was moored Naval Base San Diego, not in a controlled shipyard, and the investigation that followed detailed "a degradation of material condition, insufficient training and readiness, inadequate integration between the ship and shore-based firefighting organizations, and an absence of effective oversight."[137] As seen in Figure 10, San Diego has a robust naval shipyard capability, but the *USS Bonhomme Richard* was not at a naval shipyard facility. This parallels the fact that carrier shipyard maintenance performed in San Diego is not performed at a designated carrier shipyard, but rather it is conducted on base with coordination from Puget Sound Naval Shipyard and Intermediate Maintenance Facility.[138]

Being part of the command-and-control structure that was implemented as the fire burns through several days, I witnessed the responders adapt and learn from fighting the fire over time. The crew of *USS Bonhomme Richard* did not have many of the normal

[136]Vice Chief of Naval Operations, "Command Investigation into the Circumstances Surrounding the Fire Onboard USS Bonhomme Richard (LHD 6) on or about 12 July 2020," (Washington, DC: Department of the Navy, 2021), https://www.documentcloud.org/documents/21089014-for-release-bhr-command-investigation-20-oct-21?responsive=1&title=1.

[137] Vice Chief of Naval Operations, "Command Investigation into the Circumstances Surrounding the Fire Onboard USS Bonhomme Richard (LHD 6) on or about 12 July 2020," 417.

[138]Naval Sea Systems Command, "Puget Sound Naval Shipyard and Intermediate Maintenance Facility," Naval Sea Systems Command, accessed February 13, 2022, https://www.navsea.navy.mil/Home/Shipyards/PSNS-IMF/.

firefighting tools and capabilities they normally would, and they adapted by borrowing gear and personnel from ships across the waterfront. However, as viewed from the pier and listed in the initial investigation, the firefighting effort was “concerned about the impact of firefighting water on the stability of BONHOMME RICHARD, but they did not anticipate the significant list shift that occurred on 15 July 2020.”[139] Luckily, this list was eventually noticed and corrected, but could have been prevented in the first place through anticipation. The SAAL process was more beneficial after this event, but could have possibly prevented the event completely.

The Navy already conducts yearly Insider Threat training, but also immediately implemented a reactionary form of SAAL to the rest of the Navy. The required actions by ships included “intensive material inspections across all ships, regardless of maintenance status (sensing), a review of user qualifications (sensing), verify appropriate mitigations are in place for unavailable damage control systems (anticipating and adapting), and multiple tiers of crew firefighting training to include live training scenarios and educational lectures (learning)”[140]

San Diego’s maritime system may be clear of geographic or infrastructure chokepoints for carriers but are still vulnerable to other hazards that are able to disrupt carrier strike group components. The San Diego MTS can engineer resilience through increased hazard sensing of the environment and the MTS users.

E. SAN DIEGO MTS SUMMARY

Throughout this chapter, the San Diego maritime transportation system was described through its port subsystem and waterway subsystem. Vital port units are Naval Base Coronado (including Naval Air Station North Island), Naval Base San Diego, several naval shipyards, and civilian shipping terminals. Important units in the waterway are the ships, the navigation channel, the tugboats, recreational boaters, and the Coronado Bridge.

[139] Vice Chief of Naval Operations, “Command Investigation into the Circumstances Surrounding the Fire Onboard USS Bonhomme Richard (LHD 6) on or about 12 July 2020,” 419.

[140] Vice Chief of Naval Operations, “Command Investigation into the Circumstances Surrounding the Fire Onboard USS Bonhomme Richard (LHD 6) on or about 12 July 2020,” 418–419.

Social units throughout both these subsystems are Caltrans, Navy sailors, San Diego Bay Pilot Association, U.S. Coast Guard Sector San Diego, and the Port of San Diego authority. Finally, vulnerabilities of the system were described to be climate change, sea level rise, earthquakes, tsunamis, and terrorists.

This study observes the following subsystems to be the most significant from a vulnerability standpoint:

- Civilian transportation (bridges)
- Navy homeport bases
- Waterway subsystem traffic

- Combining assessments, we find the most important vulnerabilities are:
    - Risks related to nuclear failure, climate change and associated environmental changes, and maritime traffic.
    - Reliability issues that can cause transportation infrastructure to fail and block channels or prevent ingress / egress to the Navy shipyards and bases.
    - Worst-case disruptions that involve failure or attack of a key bridge that can block maritime channels for supporting CSG elements.
    - An inability to manage fundamental surprises (e.g., adapt to unforeseen events as they occur) and a need to diminish damages of rogue actors.

The merging of these key regional MTS subsystems and vulnerabilities are used to measure the vulnerability of carrier power projection. San Diego's regional MTS is only a third of the regional systems that make up the U.S. carrier power projection MTS system. Another regional portion of the national power projection MTS is the Puget Sound regional maritime transportation system.

V. PUGET SOUND REGIONAL ASSESSMENT

A. PUGET SOUND REGIONAL PORT OPERATIONS SUBSYSTEM

The Pacific-Northwest hosts a smaller naval presence than that of San Diego or Hampton Roads, but nonetheless, is vital for aircraft carrier power projection. The naval facilities located here consist of two separate surface bases and a naval shipyard.[141] The regional scale of this waterway is approximately 125 miles by 95 miles from the southern end near Tacoma out to sea through the Strait of Juan de Fuca. Figure 14 depicts various naval bases, ferry routes and shipping terminals throughout Puget Sound. This is the largest scale area the Navy operates in and shares a maritime border with Canada in the Strait of Juan de Fuca.

[141] *Puget Sound,* National Oceanic and Atmospheric Administration, accessed January 31, 2022, https://charts.noaa.gov/PDFs/18440.pdf

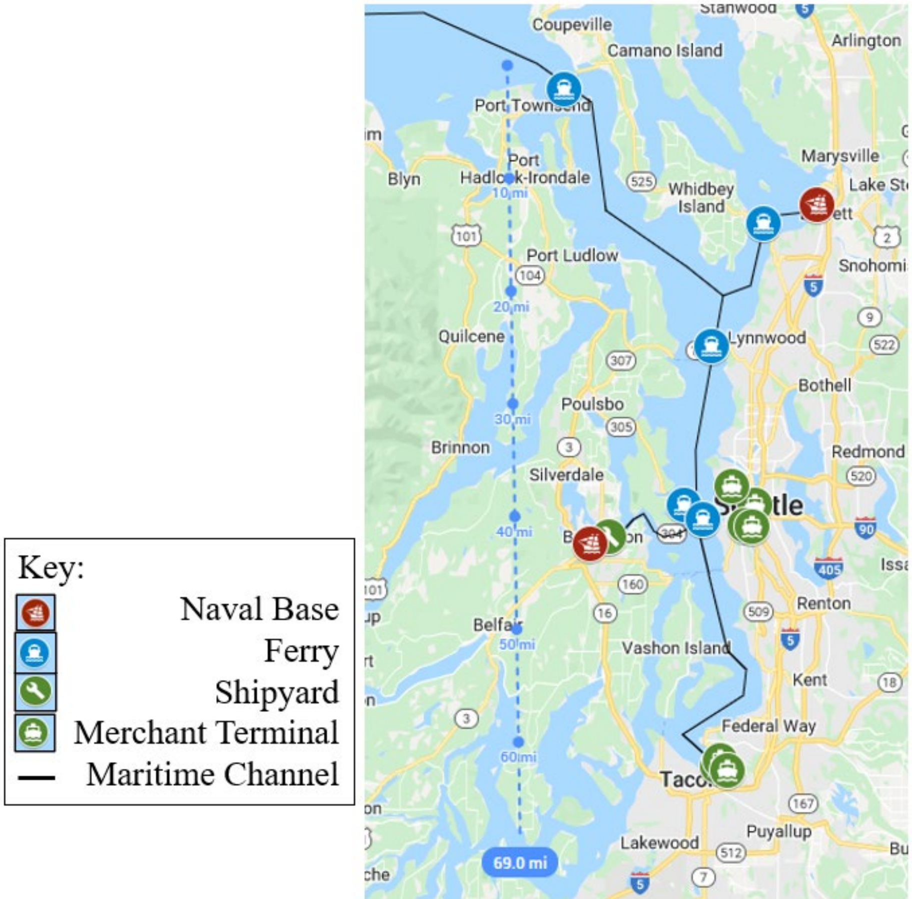

Figure 14. Puget Sound (Bremerton and Everett) Maritime Infrastructure[142]

1. Naval Base Kitsap

Importantly, Naval Base Kitsap (NBK) homeports two more of the Navy's aircraft carriers on the West Coast. "NBK is the third largest U.S. Navy installation in the United States, and arguably the most complex. NBK is home to a diverse range of high-value strategic missions, including all types of submarines, two Nimitz-class aircraft carriers, Puget Sound Naval Shipyard, and the largest fuel depot in the Continental U.S."[143] These assets make it

[142] Adapted from Puget Sound map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/@47.706495,-122.4594233,9z.

[143] Commander, Navy Region Northwest, "Naval Base Kitsap," accessed February 21, 2022, https://www.cnic.navy.mil/regions/cnrnw/installations/navbase_kitsap.html.

the most significant of the Puget Sound bases. The location of the base is also the farthest transit through the waterway that naval ships have to make within this region.

2. Naval Station Everett

Naval Station Everett is relevant to the discussion because it houses several surface combatants used in the carrier strike group construct, but does not currently homeport any carriers:

> Naval Station Everett (NSE) is the most modern shore installation in the U.S., and one of only two Navy-owned deep-water ports on the continental west coast. Located along Possession Sound in Everett, Washington, it's home to Navy surface ships and the command staffs of Commander, Carrier Strike Group 11 and Commander, Destroyer Squadron 9. It also supports Coast Guard vessels and Military Sealift Command supply vessels.[144]

Like Naval Base San Diego, surface combatants and aircraft carriers are berthed on separate bases. However, Naval Station Everett does have the capability to house aircraft carriers and was originally designed for that purpose.[145] Maurer explains a difficulty with Naval Station Everett writing, "In 2015 and 2019, the Navy decided to homeport aircraft carriers at Bremerton and San Diego because Everett lacked nuclear maintenance facilities."[146] Although it is not currently housing carriers, this base remains vital because of its capability to homeport carriers that are not in need of nuclear maintenance or dry-docking.

3. Puget Sound Naval Shipyard

The Puget Sound Naval Shipyard is the primary naval shipyard in the Pacific Northwest region. The Naval Sea Systems Command states that the "Puget Sound Naval Shipyard and Intermediate Maintenance Facility (PSNS & IMF) provides our Navy with high quality, on-time maintenance, modernization, recycling and support that helps assure America's dominance at sea. The shipyard in Bremerton is the Pacific Northwest's largest

---

[144]Commander, Navy Region Northwest, "Naval Station Everett: About," accessed February 21, 2022, https://www.cnic.navy.mil/regions/cnrnw/installations/ns_everett/about.html.

[145]Commander, Navy Region Northwest, "History," accessed February 21, 2022, https://www.cnic.navy.mil/regions/cnrnw/installations/ns_everett/about/history.html.

[146] Maurer, *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,* 21.

Naval shore facility and one of Washington state's largest industrial installations."[147] Also as Figure 8 shows, this shipyard is the only naval dry dock facility able to house carriers, as well as provide nuclear maintenance.[148]

B. INTERMODAL CIVILIAN MARINE INFRASTRUCTURE IN PUGET SOUND

1. Puget Sound Waterways

The Puget Sound waterways are connected to the sea via the Strait of Juan de Fuca, which is about a ten-mile stretch of water separating the Canadian Vancouver Island from the U.S. state of Washington. Entering through an area known as the Eastern Bank, Puget Sound contains several islands, interconnected waterways, and the relevant naval bases.[149] The entire transit out to the Pacific Ocean through the Strait of Juan de Fuca is large, but Puget Sound covers about 70 miles north to south and 30 miles east to west.[150] Because of the size of this entire waterway, several charts need to be studied at different scales depending on where the user intended to operate. The water depths throughout these waterways are deep and the narrowest part of a transit for a naval vessel is less than 600 yards between Point White and Point Glover in Rich Passage on the way to Bremerton.[151] Puget Sound also divides eastern Seattle and Tacoma metropolitan areas from the western inhabited islands. Figure 15 depicts the navigational chart for the entirety of Puget Sound, showing depths, distances, and navigational aids. The geographic features of this waterway do not provide much constriction of flow to the maritime transportation system because of these wide and deep waterways.

---

[147] Naval Sea Systems Command, "Puget Sound Naval Shipyard and Intermediate Maintenance Facility."

[148]Maurer, *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,* 21.

[149] *Strait of Juan de Fuca: Eastern Part,* National Oceanic and Atmospheric Administration, accessed January 31, 2022, https://www.charts.noaa.gov/OnLineViewer/18465.shtml

[150] Puget Sound map.

[151] *Puget Sound: Seattle to* Bremerton, National Oceanic and Atmospheric Administration, accessed January 31, 2022, https://www.charts.noaa.gov/OnLineViewer/18449.shtml.

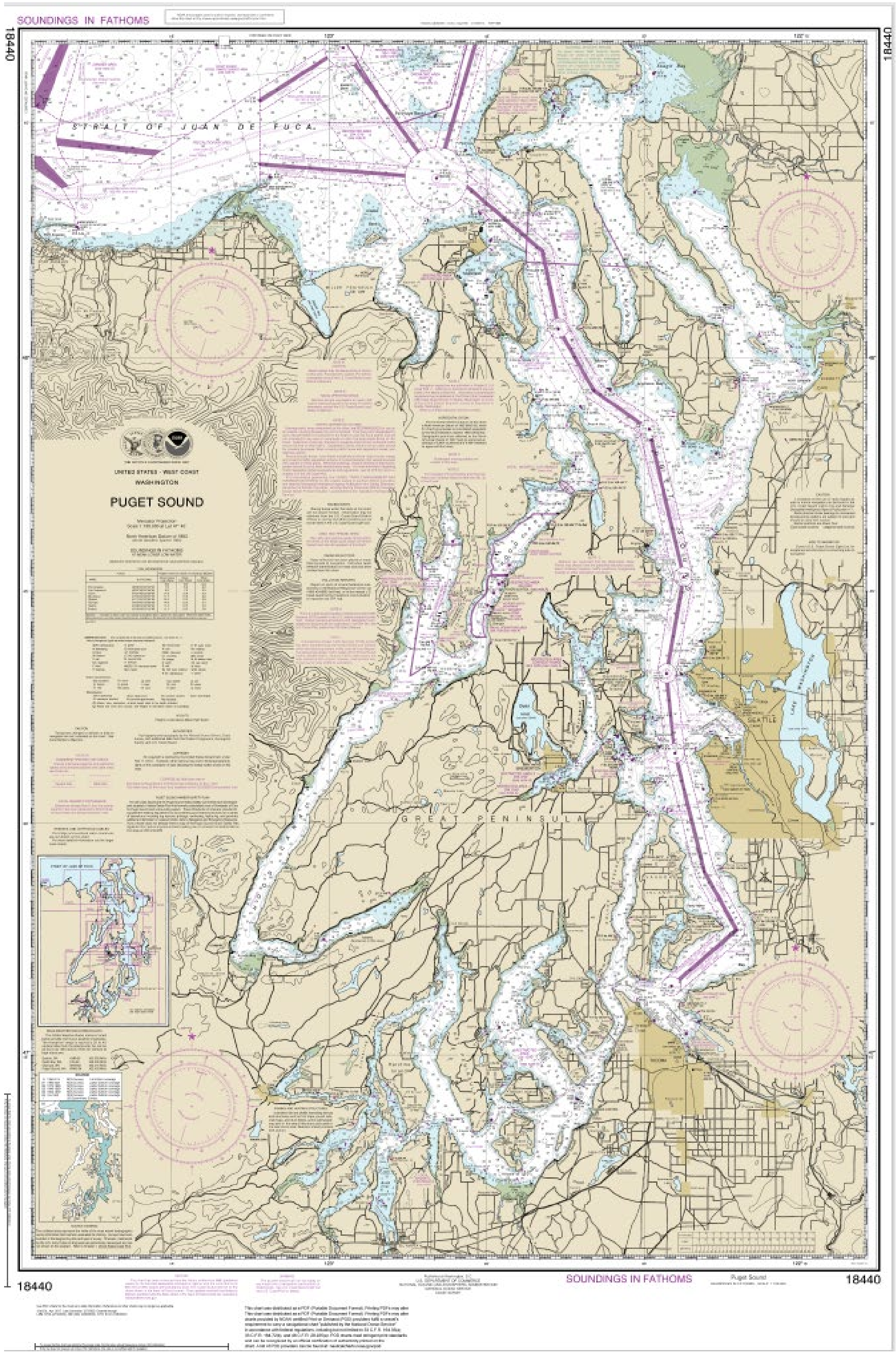

Figure 15. NOAA Chart 18440 Puget Sound[152]

2. Ferry Transportation

Because of the geographic divide that Puget Sound provides between the landmasses of the area, ferries are a popular mode of transportation across the waterway. There are neither bridges nor tunnels that cross the main Puget Sound channel, nor approaches to Bremerton and Everett. Instead, the Washington Department of Transportation supports ten different ferry routes making connections across the waterway in various directions.[153] There are six other commercial ferry companies that utilize Puget Sound as well but are not specifically owned and operated by the Washington State Department of Transportation. These ferries take both cars and personnel across the waterways utilizing the same maritime transportation system as the Navy. These are known and tracked shipping movements that are predictable but still crowd the waterways.

3. Shipping Terminals

There are many commercial shipping terminals throughout Puget Sound that bring increased traffic of larger merchant mariners through the waterways. According to an economic impact study conducted by Jellicoe, "The Northwest Seaport Alliance is a marine cargo operating partnership between the Ports of Seattle and Tacoma. The Alliance, as a combined entity, represents the fourth-largest container gateway in North America."[154] The Port of Seattle and the Port of Tacoma are both international shipping terminals that bring in large amounts of commercial imports and exports. As seen in Figure 14, the Port of Seattle lays across the channel from Bremerton and Tacoma is farther south into the channel. This means that all merchant shipping to these ports takes the same route as Navy ships to and from Bremerton and increases maritime traffic flows. North of the Port of Seattle also hosts a cruise ship terminal, bringing yet more traffic to the area.

---

[152] National Oceanic and Atmospheric Administration, *Puget Sound.*

[153] Washington State Department of Transportation, "Real-Time Map," accessed February 17, 2022, https://wsdot.com/ferries/vesselwatch/default.aspx

[154] Michaela Jellicoe, "Marine Cargo Economic Impact Analysis," Community Attributes, INC, January 2019, https://www.portseattle.org/sites/default/files/2019-01/CAI_NWSA_Marine_Cargo_Economic_Impacts_190122.pdf.

C. PUGET SOUND MARITIME TRANSPORTATION SOCIAL UNITS

1. Washington State Department of Transportation

The Washington State Department of Transportation (WSDOT) plays a very active role in the maritime system of Puget Sound by supporting ferries and terminals, engineering standards, environmental standards, and providing funding to infrastructure projects.[155] They also provide emergency management training and have a public emergency management plan.[156] The Washington State Department of Transportation is a large stakeholder in this maritime system.

2. Port of Seattle

The Port of Seattle is another managerial unit in the system that is responsible for policies, finance, port police, and the port fire department around the area of Seattle.[157] The Port of Seattle also serves a coordinating function between commercial shipping, tourist cruises, and civilian marinas.[158] In partnership with the Port of Tacoma, the Port of Seattle is in a marine cargo partnership titled the Northwest Seaport Alliance. The importance of this partnership is cited as, "Key domestic responsibilities include handling 80% of all trade between Alaska and the continental United States, and the main facilitator of trade from Hawaii. With over $73 billion in international trade flowing through the Northwest Seaport Alliance, there is a strong impact on the local economy as well- over

---

155"How Do You Want to Travel?" Washington State Department of Transportation, accessed February 20, 2022, https://wsdot.wa.gov/.; "Washington State Ferries," Washington State Department of Transportation, accessed February 20, 2022, https://wsdot.wa.gov/travel/washington-state-ferries.; "Engineering and Standards," Washington State Department of Transportation, accessed February 20, 2022, https://wsdot.wa.gov/engineering-standards.; "Construction and Planning," Washington State Department of Transportation, accessed February 20, 2022, https://wsdot.wa.gov/construction-planning.; "Business with WSDOT," Washington State Department of Transportation, accessed February 20, 2022, https://wsdot.wa.gov/business-wsdot.

156 Washington State Department of Transportation, "Emergency Support Function: ESF #1," Washington State Department of Transportation, January 2017, https://mil.wa.gov/asset/5ba421155ca72

157"Our Mission," Port of Seattle, accessed February 20, 2022, https://www.portseattle.org/about/our-mission.

158"Cruise Seattle," Port of Seattle, accessed February 20, 2022https://www.portseattle.org/maritime/cruise#.

48,000 jobs are supported and $4.3 billion in revenue."[159] This port authority is a very important manager in the operations that exist within Puget Sound.

3. Port of Tacoma

The Port of Tacoma is another commercial shipping port, like Port of Seattle that lies at the southern end of Puget Sound. This port is not near the naval bases listed, but the traffic from this port passes by through bases through the same waterways, creating increased traffic. The Port of Tacoma is responsible for "nearly $3 billion in economic activity in Pierce County depend on the Port of Tacoma."[160] This economic activity does not provide a significant positive addition to the waterway from the naval perspective, but also provides a big enough presence in the system that cannot be ignored.

4. U.S. Coast Guard Sector Puget Sound

U.S. Coast Guard Sector Puget Sound from Coast Guard District 13 is the primary Coast Guard component in this region and based out of Seattle.[161] With the Puget Sound region containing large international shipping terminals, naval presence, and international border, the U.S. Coast Guard plays a large role in the regulation, safety, and management of the Puget Sound waterway. All of these aspects provide to increased traffic and usage of Puget Sound's system and because of this, the U.S. Coast Guard institutes a "Vessel Traffic Service (VTS)."

The Puget Sound Vessel Traffic Service 2021 User's Manual lays out rules and regulations for operating in these waterways. Such regulations are the "use of radiotelephone, Automatic Identification System usage, specific regulated navigation areas, traffic separation schemes, ferry crossing routes, commercial fishing areas, and

[159] "Northwest Seaport Alliance," Port of Seattle, accessed February 20, 2022, https://www.portseattle.org/page/northwest-seaport-alliance.

[160] "About," Port of Tacoma, accessed February 20, 2022, https://www.portoftacoma.com/about

[161] "Sector Puget Sound: Seattle, WA," U.S. Coast Guard, accessed February 20 2022, https://www.pacificarea.uscg.mil/Our-Organization/District-13/Units/Sector-Puget-Sound/

vessel operator guides."[162] As with the other two regions, the Coast Guard fulfills its mission of providing safety inspections on navigational aids and ships. It provides harbor security on the inland waters not governed by individual ports, and it provides the means of coordination between users through the Puget Sound Vessel Traffic Service.

5. Puget Sound Pilots

This organization provides the experience and knowledge of the Puget Sound waterways and helps ships navigate them safely. Labeling themselves as a "public resource," the Puget Sound Pilots take on a larger role than just navigating large ships. They state that "Puget Sound Pilots work proactively to identify and implement measures that will enhance public safety and environmental safeguards."[163] They also explain their involvement in shaping the maritime system through "sitting on safety councils and committees to analyze and improve marine safety, providing expertise when ports and shipping companies develop or expand Puget Sound's marine facilities, and helped develop the state's landmark tug escort rules for oil tankers calling in Puget Sound."[164] The forward-thinking and involvement of the Puget Sound Pilots offer more to the Puget Sound region than embarking large ships and offering navigational guidance.

6. Puget Sound Tugboats

Tugboats are an integral part of the Puget Sound system by providing escorts and maneuver assistance. Similar to the tugboat companies in San Diego, both Foss Maritime and Crowley are large tug companies that provide their services and tugboats to Puget Sound. Island Tug and Barge Company is another company with carrier-capable tugs, though not used by the Navy. Revised Code of Washington Title 88.16.190 is a piece of state legislation affecting the use of tugs in that it requires all oil tankers and liquified natural gas carriers in the Puget Sound waters to be escorted by tugs of a certain horsepower

[162] Commander, U.S. Coast Guard Sector Puget Sound, *Puget Sound Vessel Traffic Service, 2021 User's Manual* (Seattle, WA: U.S. Coast Guard, 2021), I-2-I-5 (https://www.pacificarea.uscg.mil/Portals/8/District_13/sectpugetsound/VTSpugetsound/2021_UsersManual.pdf

[163] "A Public Resource," Puget Sound Pilots, accessed February 20, 2022, https://www.pspilots.org/what-we-do/a-public-resource/.

[164] Puget Sound Pilots, "A Public Resource."

capacity.[165] This creates an increased demand for tugboat companies in the region. This legal requirement and the overall need for tug services make the tugs in Puget Sound critical components to the maritime system.

D. PUGET SOUND VULNERABILITY ASSESSMENT

1. Risk

The Puget Sound risk assessment identifies hazards, probabilities, and consequences of disruption of the Puget Sound maritime system. Several studies over the years have been conducted on known environmental factors and man-made hazards.

Studies on climate change and follow-on effects are relevant to Puget Sound. The Coast Guard has not conducted a "Ports and Waterways Safety Assessment" for Puget Sound. The Washington State Department of Transportation conducted a study and identified "sea level rise, precipitation change, temperature change, and fires" as hazards.[166] In their assessment, they conclude that:

> Many of the improvements we have made for other reasons, such as seismic retrofits, fish passage improvements, culvert replacement, and drilled shaft bridges, have made our system more resistant to extreme weather events. In general, we found that climate change will exacerbate existing conditions such as unstable slopes, flooding, and coastal erosion. Many of the high-impact ratings are in the mountains, along rivers, and in low-lying areas subject to flooding or inundation due to sea level rise.[167]

This report was conducted as a requirement for the Federal Highway Administration and encompasses statewide hazards, but relevant hazards to the maritime system have been noted.

---

[165] Oil Tankers—Restricted Waters—Requirements, RCW 88.16.190 (2019), https://app.leg.wa.gov/RCW/default.aspx?cite=88.16.190

[166] Washington State Department of Transportation, "Climate Impacts Vulnerability Assessment," Olympia, WA: Washington State Department of Transportation, November 2011, 7–9, https://wsdot.wa.gov/sites/default/files/2021-10/Climate-Impact-AssessmentforFHWA-12-2011.pdf.

[167] Washington State Department of Transportation, "Climate Impacts Vulnerability Assessment," 22.

The City of Everett published a "Hazard Mitigation Plan" in 2018 that also listed several hazards to the City and Port of Everett.[168] These hazards are identified as "earthquake-related ground-shaking, soil liquefaction, hazardous material spills, tsunamis, and seiches."[169] These hazards create or expose vulnerabilities to the port and waterways by potentially disrupting infrastructure though structural degradation or sea level rise on fixed piers and docks.

The Coast Guard and DHS have both identified terrorist attacks as another threat to the Puget Sound MTS. The Coast Guard recognizes "earthquake, tsunami, lahar, cyber-attack with infrastructure damage, and terrorist attack" as hazards with infrastructure impact.[170] While not specific to Puget Sound the persistent threat to the MTS and the United States in general, is the threat of terrorism. A DHS National Terrorism Advisory System Bulletin states "continued calls for violence directed at U.S. critical infrastructure" has increased the volatility, unpredictability, and complexity of the threat environment."[171] Using Ames et al.'s categories of attacks, the terrorism hazard is assessed in Puget Sound.[172] Statistics and threat intelligence on this specific region are not available for open-source reporting, but this risk assessment will judge the "heightened threat level" with the probability of "possible to occur." Table 3 summarizes and assesses risks to the Puget Sound regional MTS.

[168] University of Washington Institute for Hazard Mitigation Planning and Research. *City of Everett Hazard Mitigation Plan.* Everett, WA: City of Everett, 2018, 11, https://everettwa.gov/DocumentCenter/View/13998/EverettHMP_2018.

[169] University of Washington Institute for Hazard Mitigation Planning and Research. *City of Everett Hazard Mitigation Plan.* Everett, 11.

[170] U.S. Coast Guard Sector Puget Sound, "Marine Transportation System Recovery Plan (MTSRP) for Puget Sound," Seattle, WA: U.S. Coast Guard Sector Puget Sound, 2018, 1, https://homeport.uscg.mil/Lists/Content/Attachments/66938/SecPS%20Approved%20Marine%20Transportation%20Recovery%20Plan%20NVIC%2004-18.pdf

[171] National Terrorism Advisory System, "Bulletin," U.S. Department of Homeland Security, February 7, 2022, https://www.dhs.gov/sites/default/files/ntas/alerts/22_0207_ntas-bulletin.pdf.

[172] Ames et al. "Port Security Strategy 2012."

Table 3. Puget Sound MTS Risk Assessment[173]

Critical Hazard: High Risk	Nuclear Materials Release
Critical Hazard: Moderate Risk	Terrorist Attack by Internal Person
	Terrorist Attack by Internal Water
	Decision Making Error
	Earthquake
	Terrorist Attack by Air
Noncritical Hazard: Low Risk	Terrorist Attack by Land
	Terrorist Attack by International Water
	Terrorist Attack by Subsurface
	Navigational Error
	Engineering Equipment Operator Error
	Engineering System Failure
	Navigational System Failure
	Wildfire/ Structure Fire
	Tsunami
	Hazmat Release
	Floods
	Sea-Level Rise/ Climate Change
	Seiches
	Erosion
Negligible	Communications Failure
	Lahar/Debris Flows

173 Adapted from *Tsunami Hazard Map of Everett, Washington: Model Results for Magnitude 7.3 and 6.7 Seattle Fault Earthquakes,* Washington State Department of Natural Resources and NOAA Center for Tsunami Research, December 2014, https://www.dnr.wa.gov/Publications/ger_ofr2014-03_tsunami_hazard_everett.pdf.; University of Washington Institute for Hazard Mitigation Planning and Research. *City of Everett Hazard Mitigation Plan, 11.;* Oil Tankers—Restricted Waters—Requirements, RCW 88.16.190 (2019).; Washington State Department of Transportation, "Climate Impacts Vulnerability Assessment," 7–9, 22.; U.S. Coast Guard Sector Puget Sound, "Marine Transportation System Recovery Plan (MTSRP) for Puget Sound," 1.; National Terrorism Advisory System, "Bulletin."; and Ames et al. "Port Security Strategy 2012."

Many more environment hazards exist in Puget Sound than in Hampton Roads or San Diego, but due to the geographic size of the Puget Sound MTS and waterway, they do not provide a significant increase in risk to the system. Nuclear material release from a carrier or by other means could be high risk to the MTS due to radiation poisoning or a significantly destructive explosion. Moderate risks are assessed as such because of the high impact to system but lower probability they have. Of note, there are significant fault lines throughout the region and earthquakes could also trigger tsunamis. The geographic space of Puget Sound significantly decreases the probability of some hazards assessed as low risk because increased operating space creates more time and distance to correct errors. Tsunamis are assessed as low risk because research suggests they do not affect Bremerton and only moderately affect Everett. Communications failures are negligible because of the abundancy of redundancies in communications equipment and the robust communications network included in the Puget Sound Vessel Traffic Service. Lahars are also negligible because the regional volcanoes are not located close to the MTS.

2. Reliability

Based on the reliability engineering model, Puget Sound maritime transportation system is assessed on the age, maintenance practices, and current conditions of the maritime infrastructure. Units that create vulnerability to the system are the Puget Sound Naval Shipyard and the multiple ferries operated by Washington State Department of Transportation.

The reliability of the naval installations is related to their age, current condition, maintenance, and operating procedures. Puget Sound Naval Shipyard was originally constructed as Naval Station Puget Sound in 1892 with dry docks for battleships.[174] In 1990, the base modernized and started a program to recycle nuclear powered ships and was consolidated under command of Naval Base Kitsap. Common practices for safeguarding ships are to berth them on the western sides of north-south piers for more favorable

[174]"Puget Sound Naval Shipyard and Intermediate Maintenance Facility History," Naval Sea Systems Command, accessed February 23, 2022, https://www.navsea.navy.mil/Home/Shipyards/PSNS-IMF/History/.

mooring conditions from strong southwestern winds.[175] Despite being able to produce reliable ships on schedule, Puget Sound Naval Shipyard still seems to be due for an upgrade in facilities with a new contract from the Navy providing "a combined cumulative value of $8 billion" in support of the Navy's Shipyard Infrastructure Optimization Program.[176] Puget Sound Naval Shipyard has received increased funding and conducts required maintenance on ships in a timely manner making it a reliable shipyard that does not produce vulnerabilities to the regional MTS.

The ferries that move people, cars, and cargo multiple times a day across the Puget Sound waterway subsystem create a vulnerability for the regional MTS because some are old, their standard practices are opposite of normal operations in the waterway, and they are consistently used. WSDOT operates 21 ferries between 20 different ports in the "largest ferry fleet in the United States."[177] Within this ferry fleet, there are some very old ferries with the oldest being built in 1959 and rebuilt in 1991.[178] The average age of the built and rebuilt ferries is 19 years-old and the oldest non-rebuilt ferry was built in 1982 and the most recent ferry built in 2018. However, using the years of original construction of the ferries the average age of the fleet is 30 years-old.[179] The Bureau of Transportation Statistics reports that the average age of ferries reported in 2016 was 27 years-old.[180] Therefore, the average Puget Sound ferry is older than the average ferry with only 8 of the

[175] "Naval Station Bremerton," Global Security, accessed February 23, 2022, https://www.globalsecurity.org/military/facility/bremerton.htm.

[176] PSNS and IMF Public Affairs, "Nimitz Completes Availability One Day Early," Naval Sea Systems Command, December 22, 2021, https://www.navsea.navy.mil/Media/News/Article/2880890/nimitz-completes-availability-one-day-early/.; and NAVFAC Headquarters Public Affairs and Communications Office, "Navy Contracts with Five Companies to Compete for Future Possible Shipyard Modernization Projects in Hawaii and Washington," Naval Sea Systems Command, November 15, 2021, https://www.navsea.navy.mil/Media/News/SavedNewsModule/Article/2842768/navy-contracts-with-five-companies-to-compete-for-future-possible-shipyard-mode/.

[177] "WSDOT Ferries Division Fleet Guide," Washington State Department of Transportation, May 2020, https://wsdot.wa.gov/sites/default/files/2021-10/WSF-FleetGuide-May2020.pdf.

[178] Washington State Department of Transportation.

[179] Washington State Department of Transportation.

[180] Janine McFadden, Andrew Barrows, and Clara Reschovsky, "2016 Highlights of Ferry Operations in the United States," Bureau of Transportation Statistics November 2, 2017, https://www.bts.gov/2016-highlights-ferry-operations-united-states-0.

21 being built after the year 2000.[181] The age of the ferries could impact their reliability when operating out on the water, causing a potential equipment malfunction or collision.

Their task of transporting people and goods across the waterway is also a vulnerability to the regional MTS because they do not conform to normal traffic patterns. Crossing perpendicular to the standard traffic flows creates uncertainty to operators in the system because operators with the right of way, may perceive the ferries as a hazard and make irrational decisions. While their movements may be well-documented and predictable, actions on the water are not always so predictable and could also lead to collision due to uncertainty or failure to maneuver in accordance with the laws.

In summary, the Puget Sound MTS is vulnerable because the maintenance facilities for carriers are in need of upgrades and the ferry units operate on old platforms that are used constantly and operate against the standard practices of the regional MTS.

3. Puget Sound MTS Worst-Case Scenario

The worst-case scenario for the Puget Sound MTS would be for Puget Sound Naval Shipyard to be disrupted. Non-real time satellite imagery provided from Google shows two aircraft carriers in-port at Puget Sound Naval Shipyard.[182] Disrupting this shipyard in a way that both carriers could not leave would ultimately be the worst-case scenario for carrier power projection from this MTS. Figure 16 demonstrates the example scenario and how any node or arc along the path from Bremerton to the Strait of Juan de Fuca would prevent 100 percent of carrier underway operations. Important nodes here are the naval bases and ferry crossing routes. Vital arcs exist between each of these nodes, from bases to the main Puget Sound channel running north and south, and out to sea through the Strait of Juan de Fuca.

---

[181] Washington State Department of Transportation, "WSDOT Ferries Division Fleet Guide."

[182] Puget Sound map.

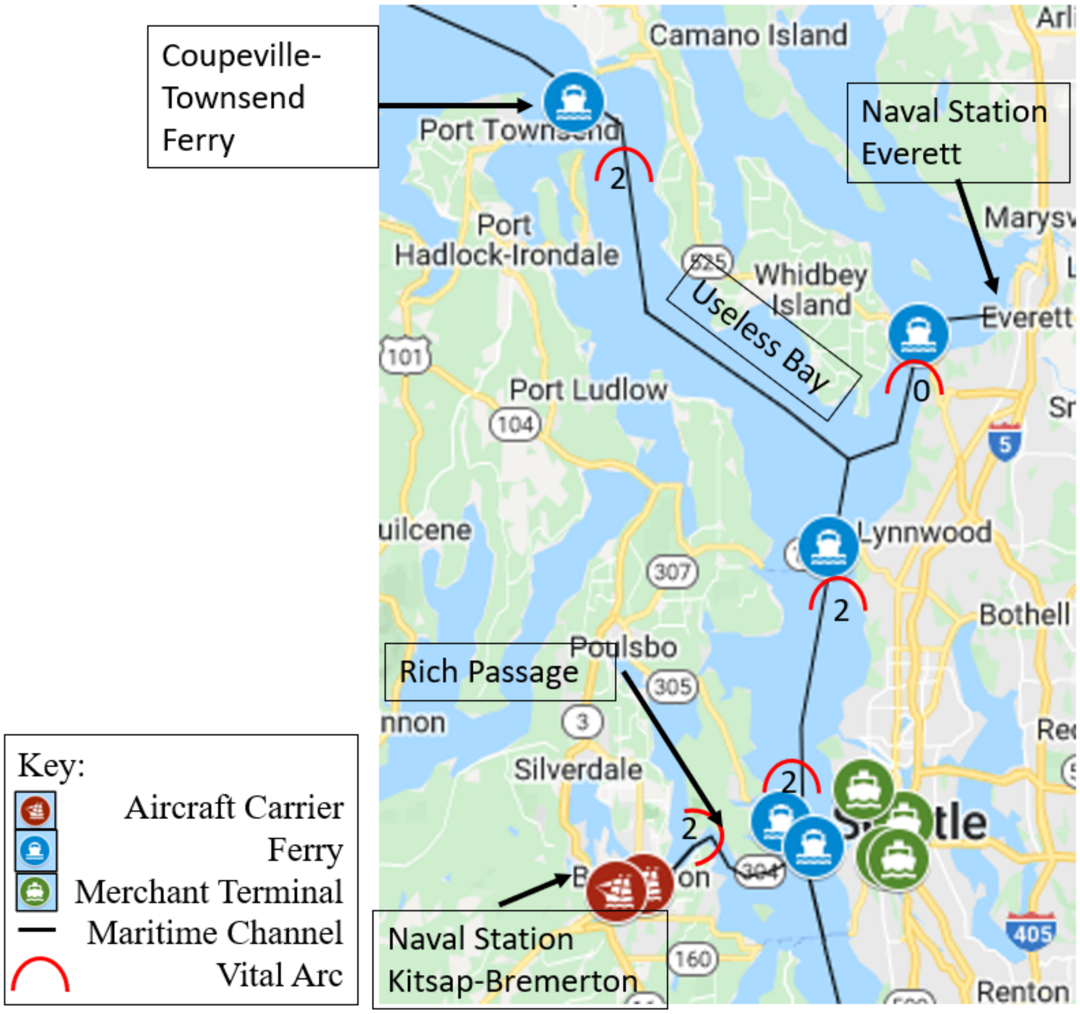

Figure 16. Puget Sound Maritime Network Interdiction Map[183]

This worst-case scenario could come from a severe environmental event such as a landslide or earthquake or a ship accident in Rich Passage, which is less than 500 yards wide. Rich Passage supports high ground on either side of the waterway and is a narrow channel. If a collision, engineering malfunction, or navigational malfunction of a large vessel took place in this section of the waterway, the Bremerton node would be cut off from sea as well. Several other opportunities exist for collisions leading to hazardous materials spilling as well due to the ferry and commercial shipping traffic that takes place

183 Adapted from Puget Sound map, Google Maps, accessed January 19, 2022, https://www.google.com/maps/@47.706495,-122.4594233,9z.

in the main waterway. In the current example, Rich Passage might serve to cut off the only carriers stationed at Bremerton, but would still leave the Everett node open for operation. Therefore, disrupting the arc between the Coupeville-Port Townsend Ferry node and Useless Bay would be the worst-case scenario for the Puget Sound MTS in terms of power projection because it would block carriers from moving between either naval base node to sea.

4. Resilience Engineering through Surprise in Puget Sound

Engineering resilience in the Puget Sound MTS is accomplished by evaluating historical disruptive events and how well the regional MTS could sense, anticipate, adapt, and learn from the events. Puget Sound has experienced many earthquakes with some documented as early as 1880.[184] These earthquakes generate vulnerabilities to the Puget Sound MTS by damaging port subsystem infrastructure or creating follow on effects, like a tsunami that damage both the waterway and the port subsystems. These earthquakes and others like the "2004 Indonesia earthquake and tsunami and the 2011 Japan earthquake and tsunami are recent examples of subduction zone earthquakes."[185] Off the coast of Washington lies the Cascadia Subduction Zone, which is where the largest earthquakes occur.[186] While a recent earthquake has not taken place in history from this fault line, regional stakeholders have taken other earthquake/tsunami combinations and created their own simulation of the same scenario in Puget Sound.

In 2016 Washington, along with Oregon and Idaho, took part in a scenario called "Cascadia Rising," in which they simulated a 9.0 magnitude earthquake and enacted plans for the coordination and restoration of transportation systems.[187] This scenario sensed the disruption in transportation systems through technological sensors and lessons learned

[184] "Significant Earthquakes Experienced in Washington Since 1872," Washington Military Department, accessed February 24, 2022. https://mil.wa.gov/asset/5ba41f67ab6be

[185] Washington Military Department, *Washington State 2016 Cascadia Rising Exercise After-Action Report* (Camp Murray, WA: Washington Military Department, 2018), 4, https://mil.wa.gov/asset/604b7fa186e5f.

[186] Washington Military Department, 4.

[187] Washington Military Department, 2.

from foreign countries. The entire scenario is based on anticipation of the most disruptive earthquake they can imagine, and then they have a plan set in place to adapt and overcome this disruptive event. After the scenario 2016, they created a list of lessons learned and are conducting another national exercise in June 2022. Though, this exercise is not based on an event this region suffered historically, they have anticipated the potential disruption in their own system and subsystems and have acted to practice adapting and learning from this event. Conclusions they learned from the 2016 scenario were "Washington residents need to prepare, transportation systems would be destroyed and isolate people, management agencies need to complete comprehensive, coordinated plans, and catastrophic response requirements are fundamentally different than anything else."[188] Anticipating this type of disruptive event leads to resilience in the Puget Sound MTS because users and stakeholders are involved in the process and can learn to adapt through surprise situations.

E. PUGET SOUND MTS SUMMARY

In summary, the Puget Sound regional MTS provides two naval bases capable of supporting carriers, several commercial maritime shipping terminals, an extensive ferry transportation system, and multiple social components for managing and operating the regional MTS. Significant port subsystem units in the Puget Sound MTS are Naval Base Kitsap, Naval Base Everett, and the Ports of Seattle and Tacoma. In the waterway subsystem, carriers, tugs, ferries, and the navigational channel are important units. Key social units operating across both port and waterway subsystems are the WSDOT, Puget Sound Pilots, Northwest Seaport Alliance (including port authorities in Seattle and Tacoma, and the U.S. Coast Guard Sector Puget Sound.

In Puget Sound we learn the following subsystems to be the most important from a vulnerability perspective:

- Civilian transportation (ferries)

[188] Washington Military Department, 8.

- Navy repair facilities
- Navy carrier homeport redundancy
- Coast guard waterway maintenance subsystems
- Coast Guard waterway operation
- Merchant shipping traffic

Synthesizing vulnerability assessments, this study determines the most important vulnerabilities in the Puget Sound regional MTS are:

- Risks related to nuclear failure, operational errors that can cause ships collide, and uncontrollable environmental hazards that could disrupt port subsystems.
- Reliability issues that can cause Navy bases to not be well maintained creating inoperable port subsystems, and civilian maritime transportation modes to break down and block waterways.
- Worst-case disruptions that involve attack or intense environmental events causing disruption
- A tested reactionary plan to handle a fundamental environmental surprise that requires more social and technical integration to be able to adapt to disrupting events.

The Puget Sound regional MTS is the final regional assessment of three case studies. Puget Sound offers carrier port redundancy and geographically open waterways with prevailing environmental and regional system vulnerabilities.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. CONCLUSION

The ultimate goal of this thesis is to answer the question: What are the core domestic maritime transportation system waterway vulnerabilities for the Carrier Strike Group power projection capabilities of the United States? This thesis brings together the maritime system that aircraft carriers are dependent upon to operate. To synthesize separate fields of study between city planning and disaster prevention; business models and best practices; and naval force protection, a broader maritime transportation system had to be taken under consideration. Portraying and assessing each domestic port that homeports carriers helps in understanding the different levels of hazards and threats that the maritime transportation system can experience. Assessing the vulnerabilities of Hampton Roads, San Diego, and Puget Sound through a variety of methods also provides a spectrum of vulnerabilities.

Many of the regional systems' components are similar in nature and function and some are even under the authority of the same federal agency with different districts. Yet, each port and waterway provide different tier of maintenance and operational importance to nuclear naval aircraft carriers, and each regional MTS is constructed differently.

As defined in Chapter I, vulnerabilities are ones that have the potential to disrupt each specific regional maritime transportation system and limit aircraft carriers from going to sea. High impact but low probability events such as a direct terrorist attack on a port, as illustrated in Tom Clancy's *The Sum of all Fears,* are rather obvious threats that tend to gather much attention.[189] However, this study also assessed vulnerabilities of smaller aspects, such as bridge maintenance or busy ferry traffic, that might be a little less appealing for a fiction novel but just as important.

Comparing and contrasting regional subsystem units, conclusions can be drawn about core vulnerabilities of the domestic maritime systems in which aircraft carriers operate. Table 4 summarizes the key subsystems in each regional MTS through the technological and social units.

---

[189] Tom Clancy, *The Sum of All Fears,* New York: Berkley, 1991.

Table 4. Summary of Key Subsystems for Each Carrier Homeport

	Tech: Military	**Tech: Non-Military / Civilian**	**Social: Military**	**Social: Non-Military / Civilian**
Hampton Roads	1 Naval Base (carrier capable)	1 Nuclear Naval Shipyard	USCG Sector Hampton Roads	VDOT
	1 Nuclear Naval Shipyard	1 Commercial Seaport	Ship Operators	Port of Virginia
	5 Homeported Aircraft Carriers	5 Crossing Bridges/ Tunnels		Virginia Pilot Association
				Tugboat Companies
San Diego	1 Naval Air Base (carrier capable)	3 Non-Nuclear Naval Shipyards	USCG Sector San Diego	Caltrans
	1 Surface Naval Base (not carrier capable)	1 Commercial Seaport (2 cargo terminals, 1 tourist terminal)	Ship Operators	Port of San Diego
	2 Homeported Aircraft Carriers	2 Large Recreational Marinas		San Diego Bay Pilots Association
		1 Crossing Bridge		Tugboat Companies
Puget Sound	2 Naval Bases (carrier capable)	20 Civilian Ferry Crossings	USCG Sector Puget Sound	WSDOT
	1 Nuclear Naval Shipyard	2 Commercial Seaports with multiple terminals	Ship Crew	Northwest Seaport Alliance
	2 Homeported Aircraft Carriers	Vessel Traffic Service		Puget Sound Pilots
				Tugboat Companies

Next, Table 5 summarizes key vulnerabilities found at each regional MTS and categorizes them by risk, reliability, worst-case, and surprise. This summary excludes terrorist threats in all regions due to the lack of open-source region specific terrorist threat data. These allow for the easy visual comparison of regional MTS.

Table 5. Summary of Key Vulnerabilities for Each Carrier Homeport

	Risk	**Reliability**	**Worst-Case**	**Surprise**
Hampton Roads	Nuclear Materials Release	Bridge Tunnel Age	Multiple Bottlenecks from Infrastructure	Narrow Navigable Waterway shortens decision making time
	Flooding	Bridge Tunnel Current Condition		
	Navigational Error	Nuclear Mid-life Refueling Practices		
	Waterway Navigation Subsystem Current Condition			
	Sea Level Rise and Land Subsidence			
	Winter Storm			
	Hazardous Materials Incident			
San Diego	Nuclear Materials Release	Recreational Boaters	Coronado Bridge Disruption	Tsunami
	Earthquake			Uncontrollable Ship Fire
	Tsunami			
Puget Sound	Nuclear Materials Release	Naval Repair Facilities	Waterway Bottleneck at Useless Bay	Fault Line Earthquake and Tsunami
	Decision Making Error	Ferry Age and Current Condition		
	Earthquake			

A. REGIONAL COMPARISONS

Hazards identified through risk assessment, weak links in reliability of units, worst-case chokepoints, and ability to overcome surprises all identify vulnerabilities in the MTS. Similarities in the regional systems exist, such as interior geographic positions, capacity to homeport multiple carriers, reliance on harbor pilots and tugs, and the influence of extreme weather events.

All three ports and waterways studied lay within waters semi-surrounded by land. This is because land provides a natural barrier to the open ocean that can aid to the protection of both natural and man-made threats. However, because they are located on inland waters, the interior locations create vulnerabilities from other threats. Such vulnerabilities have the potential to close a channel off from either infrastructure unreliability failure, terrorist attack, or operator error. Depending on location, a disruption in the waterway or port could lead to total disruption of the system. Since all the waterways only have one way in and one way out, they are also vulnerable to chokepoint disruptions.

Ports being able to homeport more than one carrier are a valuable extensibility to the MTS, as it allows for carriers to shift homeports if one was to somehow be disrupted. While the ability to relocate carriers to redundant locations is important, it also aggregates carriers in fewer locations reducing further redundancy. The ability to relocate is more important in the long run if a disrupted port was slow to return to operating conditions because aircraft carriers are mobile and could stay at sea and replenish by other means. Still, carrier dry-docks are even less extensible as they are only located in two of the three regions and two of the four bases/shipyards.

Harbor pilots and tugboats offer extensive service in all three regions and could be provided by multiple companies. The Navy has contracts with the specific companies they use, but that is not to say they could not use others within the region. Navy ship handlers often train without the use of harbor pilots in simulators and could safely navigate a ship in or out to sea without them. Yet, harbor pilots, for the most part, provide expert advice on local operating conditions for the day and are obligatory in all naval ports. The Navy's reliance on these services generates vulnerability in getting their ships to sea. Specifically, getting underway or mooring in tight docking maneuvers, ships would become vulnerable to allisions with piers. This could lead to damage to either the ship, port infrastructure or both.

All three regions are threatened by some type of extreme weather that is prevalent in their area. Although some of these weather events are different, climate change is assessed to influence all regions through sea-level rise and increased precipitation. This makes system infrastructure vulnerable to increased failure through corrosion, erosion, component failure, and flooding. Increased saltwater on surface areas of bridges, piers, and other infrastructure could increase corrosion and component failure over time. Flooding and erosion can take away foundations supporting port infrastructure making them more vulnerable to failure.

The similarities between regions make hazard mitigation factors all that more significant in the upkeep of the system. Sensing and anticipating these vulnerabilities can lead to better planning and faster recovery if the vulnerabilities were to disrupt the system.

B. REGIONAL DIFFERENCES

Differences in the region stem from the naval infrastructure in each port, environmental threats, waterway and port management, and intermodal waterway infrastructure.

The naval infrastructure, specifically carrier maintenance infrastructure, is different in all three ports. Hampton Roads boasts the most extensive aircraft carrier shipyards and maintenance facilities with Newport News Shipbuilding and Norfolk Naval Shipyard. As Figure 8 illustrates, the Hampton Roads system is the only mid-life refueling shipyard and is one of two dry dock locations for carriers, Bremerton in Puget Sound being the second.[190] San Diego is able to do nuclear maintenance, but that capability also comes from a detachment from Puget Sound Naval Shipyard. Hampton Roads is also the only location on the East Coast that provides for carriers, though the West Coast has two.[191] The lack of redundancy in nuclear maintenance facilities makes the Navy vulnerable from a sustainability point of view.

---

[190] Maurer, Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements,21.

[191] Maurer, 21.

While the comparison of regions states all locations have extreme weather events, these events differ by location and therefore create different vulnerabilities to each system independent of the others. For example, the West Coast locations are more susceptible to earthquakes, wildfires, and tsunamis and the East Coast is more likely to experience hurricanes, tropical storms, and extreme winter storms. These create different vulnerabilities based on region and are closely tied to the management of systems.

Local city municipalities, state transportation departments, and port authorities all manage the system differently because of funding, maritime cultural support, and environmental factors. From personal experience, each coast is focused on the environment differently because they have different environmental factors to manage. Operating a ship out of Norfolk, one must be concerned with the Northern Right Whale migrations. The City of San Diego also induces harsher punishments on hazardous material spills in the San Diego Bay. Each of these environmental factors provides nuance to the locality of the regional systems and creates different vulnerabilities.

Finally, the difference in intermodal maritime infrastructure in each case requires different management and operating practices. Hampton Roads is characterized by narrow bridge-tunnels throughout the navigable waterways. San Diego has crowded recreational traffic and the Coronado Bridge effecting supporting ships of a Carrier Strike Group. Lastly, Puget Sound has crowded commercial shipping and multiple ferry crossings. These make carriers vulnerable to system disruption from chokepoints or collisions.

C. POWER PROJECTION VULNERABILITIES

The vulnerabilities of aircraft power projection seem simple at first but need to be thought about in terms of cascading failures. Graham wrote "disruption or destruction at one point in a water, transport, communication, or energy grid tends to move through the whole system. And because these systems are densely interlinked and mutually dependent—or tightly coupled in engineering parlance—disruption in one tends to cascade to others very quickly."[192] The idea of one regional system being disrupted leads to extra demand or stress on the other regional systems.

To answer the research question of this study, the following hypotheses were proposed:

- Hypothesis 1: Disruptions to regional MTS nearby carrier strike group homeports can negatively impact power projection and underway operations.

- Hypothesis 2: Case study assessment of multiple carrier strike groups homeports will reveal common vulnerabilities across different regional MTS. Managing these vulnerabilities will improve the resilience of carrier strike group operations during future disasters.

Through detailed analysis of risk, reliability, worst-case, and surprise, Hypothesis 1 has been proven by showing the decrease in total carrier output from disrupted regional systems. Hypothesis 2 revealed common vulnerabilities such as severe environmental events like earthquakes and tsunamis on the West Coast and severe weather storms on the East Coast with potential to disrupt operations. Being able to learn, adapt, and mitigate these vulnerabilities in all regional MTS will decrease vulnerabilities to carrier power projection.

Woods offers four ideas for creating more resilient systems that can be applied here: robustness, extensibility, rebound, and adaptability.[193] These concepts are defined as, "Robustness is the ability for the system to continue to function as intended. Extensibility is the ability for the system functions to stretch to support new needs. Rebound allows

[192] Graham*, When Infrastructure Fails*, 18.

[193] David D Woods, "Four Concepts For Resilience And The Implications For The Future Of Resilience Engineering." *Reliability Engineering & System Safety* 141 (2015): 5–9.;

systems to return to previous functions. Adaptability allows system changes to function in new ways.[194] These concepts offer frameworks through which to apply recommendations.

In terms of nuclear aircraft power projection, these four concepts need to be applied to all aspects of the three regional systems to create a resilient power projection system.

Robustness of the maritime system can be improved by strengthening parts and components of units in each subsystem to improve reliability, improved technologies to counteract environmental vulnerabilities, and building smarter, stronger intermodal infrastructure. For example, if tsunamis are a growing concern for the West Coast, building tidal walls along the coast could improve robustness. Caltrans has instituted a Seismic Retrofit Program for bridges to create a "No Collapse" performance standard for all bridges throughout the state.[195] The retrofit of bridges improves the robustness of the Coronado Bridge from being vulnerable to collapse from earthquakes.

The extensibility of the aircraft carrier system includes having multiple locations in which an aircraft carrier can dock. As mentioned before, an operational carrier might not even need to dock immediately during a disrupting event, which is another extensibility. The vulnerability of Hampton Roads is ripe for discussion while talking about extensibility because of it being the only location for mid-life nuclear refueling. This vulnerability could have very long-term cascading effects for future ship maintenance. Slight extensibility of dry-docking also exists within two separate locations already in operation. Another option to increase extensibility throughout the entire maritime system could be to use commercial cargo ship dry docks. These already exist and could ostensibly be more easily activated for the Navy's use.

Rebound options include building back the original system, which might take longer than other options. Sea level rising and coastal erosion is an example where rebound

194 Woods, "Four concepts for resilience and the implications for the future of resilience engineering," 5–9.; Eisenberg, Daniel. "The Four Horsemen of Critical Infrastructure Vulnerability." Lecture, Naval Postgraduate School, Monterey, CA, October 3, 2020.

195 Mark Mahan, "Seismic Retrofit Guidelines for Bridges in California: Memo to Designers 20–4," California: Caltrans, June 2016), 1, https://dot.ca.gov/-/media/dot-media/programs/engineering/documents/memotodesigner/f0002889_20-4_a11y.pdf.

might be seen through land reclamation projects and continual dredging. Intermodal infrastructure disruptions such as the Hampton Roads Bridge Tunnel rupture or Coronado Bridge collapse would not be quick fixes and take time, potentially blocking navigable channels for long periods of time. However, by moving the ships out of the way and keeping the channel open for others the system could rebound quickly from a collision between ships. This may affect one aircraft carrier but does not make the whole power projection system vulnerable.

Adaptation to a disrupting event involves ingenuity and innovation in the system to overcome disruption. If the Hampton Roads Bridge Tunnel were to block the waterways, adaption might provide for dredging a new channel to create a second entrance to the harbor. It could also involve creating a new facility for nuclear maintenance or another homeport for carriers to be berthed.

Overall vulnerabilities from the worst-case nuclear power projection system disruption are depicted in Figures 8, 12, and 16. assuming a total maritime disruption of the regional systems. Placing a numbered weight of 1 per 1 aircraft carrier, power projection can be graded on usable carriers accessible to sea. Using the example satellite pictures from Google, Hampton Roads has a power projection weight of 4 if the Hampton Roads system was disrupted on that day. Similarly, Puget Sound and San Diego both hold a weight of 2 each, with 1 domestically homeported carrier being underway that day. Although, the maintenance facilities at each location might add more weight to power projection ability as well because those affect future capabilities and not the immediate to get underway. If a carrier remains weighted 1, a nuclear maintenance facility is also weighted 1, a dry dock is weighted 2 per dock, and a shipbuilding or mid-life refueling shipyard is weighted 3, then results of ports change. Under this scale, Hampton Roads weighs 10 for its capacity, San Diego weighs 3, and Puget Sound weighs 5. These numbers are arbitrary but show that different ports provide greater importance to the power projection system. Alas, this weight is irrelevant because both shipyards with the sole capacity to build future aircraft carriers or refuel current carriers reside inside the Hampton Roads MTS.

In conclusion, thinking about the maritime transportation system as a whole leads to a comprehensive understanding of the vulnerabilities aircraft carrier power projection faces from infrastructure at home. Carrier Strike Group based power projection is vulnerable to environmental factors, intermodal infrastructure, and the lack of redundancy throughout the East Coast homeports and maintenance capability of carriers. These vulnerabilities could lead to future disruptions having major impacts on the ability to house, maintain, and distribute carrier forces domestically or globally. This thesis hopes to highlight these vulnerabilities and recommend new redundancies be built into carrier maintenance facilities and locations as well as a more spread-out force distribution.

LIST OF REFERENCES

Alderson, David L., Gerald G. Brown, and W. Matthew Carlyle. "Operational Models of Infrastructure Resilience." Risk Analysis 35, no. 4 (2015). https://doi.org/10.1111/risa.12333.

Ames, Morgan, Chun Man Chan, Kim Chuan Chang, Andrew Cole, Dale Johnson, Kiah Wen Kwai, Kim Leng Koh et al. "Port Security Strategy 2012." Master's Thesis, Monterey, California. Naval Postgraduate School, 2007. https://calhoun.nps.edu/handle/10945/6921.

Andrews, Kate. "Port of Va. Had $100B+ Economic Impact in FY21." Virginia Business. January 27, 2022. https://www.virginiabusiness.com/article/port-of-va-had-100b-economic-impact-in-fy21/.

The Associated Press. "USS McCain Crash Is 4th Navy Accident in Pacific This Year." *The Associated Press.* August 22, 2017. https://apnews.com/article/4959fea69cd94a66b6d9a8cd9b594e2f.

BBC. "Beirut Explosion: What We Know So Far." August 11, 2020. https://www.bbc.com/news/world-middle-east-53668493.

Berle, Øyvind, James B. Rice Jr. & Bjørn Egil Asbjørnslett. "Failure Modes in the Maritime Transportation System: A Functional Approach to Throughput Vulnerability." *Maritime Policy & Management* 38, no. 6, (2011): 605–632. https://www.tandfonline.com/doi/full/10.1080/03088839.2011.615870.

Bruns, Sebastian. U.S. Naval Strategy and National Security: The Evolution of American Maritime Power. Routledge: New York, NY, 2018.

Caldwell, Stephen. *An Implementation Strategy Could Advance DHS's Coordination of Resilience Efforts across Ports and Other Infrastructure*. GAO-13-11. Washington, DC: Government Accountability Office, 2012. https://www.gao.gov/assets/gao-13-11.pdf.

California Emergency Management Agency, California Geological Survey, and University of Southern California. *Tsunami Inundation Map for Emergency Planning: Point Loma Quadrangle.* Accessed January 15, 2022. https://www.conservation.ca.gov/cgs/Documents/Publications/Tsunami-Maps/Tsunami_Inundation_PointLoma_Quad_SanDiego.pdf.

Caltrans. "Structural Check-up: Bridge Health Increased." 2013. https://dot.ca.gov/-/media/dot-media/programs/risk-strategic-management/documents/mm-2014-q1-bridge-health-a11y.pdf.

Caltrans. “San Diego – Coronado Bay Bridge Suicide Deterrent Project.” Accessed January 20, 2022. https://dot.ca.gov/caltrans-near-me/district-11/current-projects/coronadobridge.

Caltrans. “Value and Cost of California’s Bridges.” Accessed February 12, 2022. https://dot.ca.gov/-/media/dot-media/programs/risk-strategic-management/documents/mm-2015-q1-bridge-health-a11y.pdf.

Chesapeake Bay: Cape Charles to Norfolk Harbor. National Oceanic and Atmospheric Administration. Accessed January 31, 2022. https://www.charts.noaa.gov/OnLineViewer/12222.shtml.

Clancy, Tom. *The Sum of All Fears.* New York, NY: Berkley, 1991.

Commander, Fifth Coast Guard District. “Local Notice to Mariners: District 5” Portsmouth, VA: United States Coast Guard District 5. January 04, 2022. https://www.navcen.uscg.gov/pdf/lnms/lnm05012022.pdf.

Commander, Naval Installations Command. “Naval Station Norfolk.” United States Navy. Accessed January 27, 2022. https://www.cnic.navy.mil/regions/cnrma/installations/ns_norfolk.html.

Commander, Navy Installations Command Notification. “Welcome to Naval Base Coronado.” Department of the Navy. Accessed February 11, 2022. https://www.cnic.navy.mil/regions/cnrsw/installations/navbase_coronado.html.

Commander, Navy Region Southwest. “Naval Air Station North Island.” Department of the Navy. Accessed February 4, 2022. https://www.cnic.navy.mil/regions/cnrsw/installations/navbase_coronado/about/installations/nas_north_island.html.

Commander, Navy Region Northwest. “History.” Accessed February 21, 2022. https://www.cnic.navy.mil/regions/cnrnw/installations/ns_everett/about/history.html.

Commander, Navy Region Northwest. “Naval Base Kitsap.” Accessed February 21, 2022. https://www.cnic.navy.mil/regions/cnrnw/installations/navbase_kitsap.html.

Commander, Navy Region Northwest. “Naval Station Everett: About.” Accessed February 21, 2022. https://www.cnic.navy.mil/regions/cnrnw/installations/ns_everett/about.html.

Commander, U.S. Coast Guard Sector Puget Sound. Puget Sound Vessel Traffic Service 2021 User’s Manual. Seattle, WA: U.S. Coast Guard. 2021. (https://www.pacificarea.uscg.mil/Portals/8/District_13/sectpugetsound/VTSpugetsound/2021_UsersManual.pdf.

Commanding Officer, Naval Base San Diego. Policy Governing Port Operations and Laydowns, Naval Base San Diego Instruction 3170.1. San Diego, CA: Department of the Navy. January 2021. https://www.cnic.navy.mil/regions/cnrsw/installations/navbase_san_diego/about/policies.html.

Cybersecurity and Infrastructure Security Agency. *National Critical Functions: Status Update to the Critical Infrastructure Community.* Washington, DC: U.S. Department of Homeland Security, December 2021. https://www.cisa.gov/sites/default/files/publications/2021_ncf-status_update_508.pdf.

Dameron, Robert et al. "Seismic Analysis of the San Diego-Coronado Bay Bridge: Comparison of Dynamic Analysis Methods." California Department of Transportation. February 1999.

Department of Defense. *Department of Defense Climate Risk Analysis.* Washington, DC: Department of Defense. October 2021. https://media.defense.gov/2021/Oct/21/2002877353/-1/-1/0/DOD-CLIMATE-RISK-ANALYSIS-FINAL.PDF.

Department of Defense, *Department of Defense Climate Adaptation Plan.* Washington, DC: Department of Defense, September 2021. https://media.defense.gov/2021/Oct/07/2002869699/-1/-1/0/DEPARTMENT-OF-DEFENSE-CLIMATE-ADAPTATION-PLAN-2.PDF.

Department of Transportation. *An Assessment of the U.S. Marine Transportation System*. Washington, DC: U.S. Department of Transportation. September 1999. https://www.maritime.dot.gov/sites/marad.dot.gov/files/docs/resources/2386/assessmntoftheusmts-rpttocongrsep1999combined.pdf.

Dobyns, Stephen. "Tugboats of San Diego Bay." San Diego Reader. January 24, 2002. https://www.sandiegoreader.com/news/2002/jan/24/all-good-scenery-nice-sunsets-sunrises/#:~:text=Foss%20and%20Crowley%20have%20tugs,Navy%20uses%20six%20Chouest%20tugs.

Edison Chouest Offshore. "Highly Specialized Vessels Designed for Job-Specific Tasks." Accessed February 4, 2022. https://www.chouest.com/vessels.html.

Eisenberg, Daniel A. "How to Think About Resilient Infrastructure Systems." PhD diss., Arizona State University. 2018. https://core.ac.uk/download/pdf/158457105.pdf.

Eisenberg, Daniel. "The Four Horsemen of Critical Infrastructure Vulnerability." Lecture, Naval Postgraduate School, Monterey, CA, October 3, 2020.

E*nsuring the Future of Naval Power Projection: The Role of Carrier Aviation: Testimony for the House Armed Services Subcommittee on Seapower and Power Projection*, 114th Cong. 2 (2016) (statement of Michael C. Horowitz, University of Pennsylvania Associate Professor), https://docs.house.gov/meetings/AS/AS28/20160211/104318/HHRG-114-AS28-Wstate-HorowitzM-20160211.pdf.

Flagship Cruises and Events. "Best Fall Activities in San Diego." Accessed February 21, 2022. https://flagshipsd.com/blog/fall-things-to-do.

Geiger, James. "Strategic Shaping Capability of the Amphibious Force: The Case for Capital Ship Statues for the Amphibious Fleet." Master's Thesis, Fort Leavenworth, Kansas. U.S. Army Command and General Staff College. 2019. https://apps.dtic.mil/sti/pdfs/AD1085020.pdf.

Global Security. "Naval Station Bremerton." Accessed February 23, 2022. https://www.globalsecurity.org/military/facility/bremerton.htm.

Godried, Michael et al. "Hazard Mitigation Plan 2018." Seattle, WA: University of Washington Department of Urban Design and Planning. 2018. https://www.everettwa.gov/DocumentCenter/View/13998/EverettHMP_2018.

Gokey, Jonathan et al. "Development of a Prioritization Methodology for Maintaining Virginia's Bridge Infrastructure Systems*." Systems and Information Engineering Design Symposium,* (2009). https://ieeexplore.ieee.org/abstract/document/5166190.

Gonzalez, M. M. and Trujillo, L. "Efficiency Measurement in the Port Industry: A Survey of the Empirical Evidence." *Journal of Transport Economics and Policy*, 43, no. 2 (2009): https://www.researchgate.net/publication/46557334_Efficiency_Measurement_in_the_Port_Industry_A_Survey_of_the_Empirical_Evidence.

Graham, Stephen. *Disrupted Cities: When Infrastructure Fails.* New York: Rutledge, 2010.

Hampton Roads Planning District Commission. *Hampton Roads Hazard Mitigation Plan*. Hampton Roads, VA: Hampton Roads Planning District Commission. 2017. https://www.hrpdcva.gov/uploads/docs/2017%20Hampton%20Roads%20Hazard%20Mitigation%20Plan%20Update%20FINAL.pdf.

Hampton Roads Planning District Commission. "The Potential Economic Impact of Hurricanes on Hampton Roads." Hampton Roads Planning District Commission. July 2006, https://www.hrpdcva.gov/uploads/docs/Hurricanes.pdf.

Hampton Roads map. Google Maps. Accessed January 19, 2022. https://www.google.com/maps/place/Norfolk,+VA/@37.0462908,-76.2973368,10.72z/data=!4m5!3m4!1s0x89ba973a5322ca45:0xab99107fce7a1e0a!8m2!3d36.850505!4d-76.2856293.

Hayuth, Yehuda. "Containerization and the Load Center Concept." *Economic Geography* 57, no. 2 (April 1981): 160–17. https://www.jstor.org/stable/144140?seq=9#metadata_info_tab_contents.

Hoyle, Brian S. “The Port-City Interface: Trends, Problems and Examples.” *Geoforum*, 20 no. 4, (1989): 429–435. http://dx.doi.org/10.1016/0016-7185(89)90026-2.

Hubbard, Douglas W. *The Failure of Risk Management.* Hoboken, New Jersey: John Wiley and Sons, Inc. 2009.

Hurley, Brad. “State Lands Sea Level Rise Vulnerability Assessment.” *ICF*. July 2019. https://www.sandiego.gov/sites/default/files/state-lands-sea-level-rise-vulnerability-assessment.pdf.

Hsieh, Cheng-Hsien, Hui-Huang Tai & Yang-Ning Lee. “Port Vulnerability Assessment from the Perspective of Critical Infrastructure Interdependency.” *Maritime Policy & Management* 41:6, (2014): 589–606. https://www.tandfonline.com/doi/full/10.1080/03088839.2013.856523.

ICF International. *Climate Change Vulnerability Assessment*. San Diego, CA: City of San Diego. 2020. https://www.sandiego.gov/sites/default/files/climate-change-vulnerability-assessment.pdf.

Jellicoe, Michaela. “Marine Cargo Economic Impact Analysis.” Community Attributes, INC. January 2019. https://www.portseattle.org/sites/default/files/2019-01/CAI_NWSA_Marine_Cargo_Economic_Impacts_190122.pdf.

Kapur, Kailash and Michael Pecht. *Reliability Engineering* Hoboken, New Jersey: John Wiley and Sons, Inc, 2014.

Leggett, Theo. “Egypt’s Suez Canal Blocked By Huge Container Ship.” *BBC.* March 24, 2021. https://www.bbc.com/news/world-middle-east-56505413.

Lepore, Brian . *Defense Infrastructure: The Navy’s Use of Risk Management at Naval Stations Mayport and Norfolk.* GAO-12-710R. Washington, DC: Government Accountability Office, 2012. https://www.gao.gov/assets/gao-12-710r.pdf.

Linder, Bruce. *San Diego’s Navy.* Annapolis, Maryland: Naval Institute Press, 2001.

Mahan, Alfred. *The Influence of Sea Power Upon History, 1660–1783*. New York: Dover Publications, 1987.

Mahan, Mark. “Seismic Retrofit Guidelines for Bridges in California: Memo to Designers 20–4.” California: Caltrans, June 2016. https://dot.ca.gov/-/media/dot-media/programs/engineering/documents/memotodesigner/f0002889_20-4_a11y.pdf.

Mansouri, Mo, Alex Gorod, Thomas H. Wakeman, and BrianSauser. "Maritime Transportation System of Systems Management Framework: A System of Systems Engineering Approach." *International Journal of Ocean Systems Management I* 1, no, 2 (2009): 200–226. https://www.researchgate.net/profile/Brian-Sauser/publication/228675041_Maritime_Transportation_System_of_Systems_management_framework_a_System_of_Systems_Engineering_approach/links/0c96051598e3b79d5c000000/Maritime-Transportation-System-of-Systems-management-framework-a-System-of-Systems-Engineering-approach.pdf.

Maritime Administration. "About Us." U.S. Department of Transportation. December 1, 2021. https://www.maritime.dot.gov/about-us.

Maritime Administration. "National Port Readiness Network (NPRN)." U.S. Department of Transportation. December 7, 2021. https://www.maritime.dot.gov/ports/strong-ports/national-port-readiness-network-nprn.

Maurer, Diana. *Aircraft Carriers, Homeport Changes Are Primarily Determined by Maintenance Requirements*. GAO-21-345. Washington, DC: Government Accountability Office, 2021. https://www.gao.gov/assets/gao-21-345.pdf.

McAllister Towing and Transportation. "Fleet Location." Accessed January 6, 2022. https://www.mcallistertowing.com/fleet-information/tug-fleet/.

McAllister Towing and Transportation. "Virginia." Accessed January 6, 2022. https://www.mcallistertowing.com/ports-and-rates/virginia/.

McFadden, Janine, Andrew Barrows, and Clara Reschovsky. "2016 Highlights of Ferry Operations in the United States." Bureau of Transportation Statistics, November 2, 2017. https://www.bts.gov/2016-highlights-ferry-operations-united-states-0.

Moran Towing. "Tug Fleet." Accessed January 6, 2022. https://www.morantug.com/fleet/.

Mueller, T. J., T. M. Weishar, J.M. Hallworth, and T. F. Lillywhite. "Occupational Radiation Exposure from U.S. Naval Nuclear Plants and their Support Facilities." Report NT-19-2, May 2019. https://www.energy.gov/sites/prod/files/2019/09/f66/NT-19-2.pdf.

National Oceanic and Atmospheric Administration. *Puget Sound: Seattle to Bremerton.* Accessed January 31, 2022. https://www.charts.noaa.gov/OnLineViewer/18449.shtml.

National Oceanic and Atmospheric Administration. *Strait of Juan de Fuca: Eastern Part.* Accessed January 31, 2022. https://www.charts.noaa.gov/OnLineViewer/18465.shtml.

National Terrorism Advisory System. “Bulletin.” U.S. Department of Homeland Security, February 7, 2022. https://www.dhs.gov/sites/default/files/ntas/alerts/22_0207_ntas-bulletin.pdf.

Naval Sea Systems Command. “Puget Sound Naval Shipyard and Intermediate Maintenance Facility.” Naval Sea Systems Command. Accessed February 13, 2022. https://www.navsea.navy.mil/Home/Shipyards/PSNS-IMF/.

NAVFAC Headquarters Public Affairs and Communications Office. “Navy Contracts with Five Companies to Compete for Future Possible Shipyard Modernization Projects in Hawaii and Washington.” Naval Sea Systems Command, November 15, 2021. https://www.navsea.navy.mil/Media/News/SavedNewsModule/Article/2842768/navy-contracts-with-five-companies-to-compete-for-future-possible-shipyard-mode/.

Newell, Gordon and Smith, Allan. *Mighty Mo: The USS Missouri: A Biography of the Last Battleship.* Seattle, Washington: Superior Publishing Company. 1969.

Office of Emergency Services, and Unified Disaster Council. “Multi-Jurisdictional Hazard Mitigation Plan.” San Diego, CA: County of San Diego, October 2017. https://www.sandiegocounty.gov/content/dam/sdc/oes/emergency_management/HazMit/2018/2018%20Hazard%20Mitigation%20Plan.pdf.

Oil Tankers—Restricted Waters—Requirements. RCW 88.16.190, (2019). https://app.leg.wa.gov/RCW/default.aspx?cite=88.16.190.

O’Rourke, Ronald. *Navy Nuclear Aircraft Carrier (CVN) Homeporting at Mayport: Background and Issues for Congress.* CRS Report No. R40248. Washington, DC: Congressional Research Service, 2010. https://apps.dtic.mil/sti/pdfs/ADA522947.pdf.

Perrow, Charles. *Normal Accidents: Living with High-Risk Technologies.* New Jersey: Princeton University Press, 1999.

PSNS and IMF Public Affairs. “Nimitz Completes Availability One Day Early.” Naval Sea Systems Command, December 22, 2021. https://www.navsea.navy.mil/Media/News/Article/2880890/nimitz-completes-availability-one-day-early/.

Port of San Diego. “Climate Action Plan.” San Diego, CA: Unified Port of San Diego, 2013. https://pantheonstorage.blob.core.windows.net/environment/Port-of-San-Diego-Climate-Action-Plan.pdf.

Port of San Diego. “Cruise and Cargo Ship Calls.” Accessed February 21, 2022. https://www.portofsandiego.org/events/cruise-and-cargo-ship-calls.

Port of San Diego. “Shipyards.” Accessed January 19, 2022. https://www.portofsandiego.org/maritime/shipyards.

Port of San Diego. “Vessel Entry and Clearance Procedures.” Accessed January 19, 2022. https://www.portofsandiego.org/maritime/mariner-resources/vessel-entry-and-clearance-procedures.

Port of San Diego. “What We Do.” Accessed January 20, 2022. https://www.portofsandiego.org/.

Port of Seattle. “Cruise Seattle.” Accessed February 20, 2022. https://www.portseattle.org/maritime/cruise#.

Port of Seattle. “Northwest Seaport Alliance.” Accessed February 20, 2022. https://www.portseattle.org/page/northwest-seaport-alliance.

Port of Seattle. “Our Mission.” Accessed February 20, 2022. https://www.portseattle.org/about/our-mission.

Port of Tacoma. “About.” Accessed February 20, 2022. https://www.portoftacoma.com/about.

Port of Virginia. “Facilities.” Accessed January 31, 2022. https://www.portofvirginia.com/facilities/.

Professional Mariner Staff. “Hampton Roads.” Professional Mariner, Journal of the Maritime Industry. November 2018. https://professionalmariner.com/hampton-roads/.

Puget Sound, National Oceanic and Atmospheric Administration, Accessed January 31, 2022, https://charts.noaa.gov/PDFs/18440.pdf.

Puget Sound map, Google Maps, Accessed January 19, 2022, https://www.google.com/maps/@47.706495,-122.4594233,9z.

Puget Sound Naval Shipyard and Intermediate Maintenance Facility. “History.” Naval Sea Systems Command. Accessed February 23, 2022. https://www.navsea.navy.mil/Home/Shipyards/PSNS-IMF/History/.

Puget Sound Pilots. “A Public Resource.” Accessed February 20, 2022. https://www.pspilots.org/what-we-do/a-public-resource/.

Reilly, James. “Load Testing Deteriorated Spans of The Hampton Roads Bridge-Tunnel for Load Rating Recommendations.” Master’s thesis, Virginia Polytechnic Institute and State University, November 29, 2016. https://vtechworks.lib.vt.edu/bitstream/handle/10919/74302/Reilly_JJ_T_2017.pdf?sequence=1&isAllowed=y.

Ready San Diego. “Tsunami.” Accessed February 18, 2022. https://www.readysandiego.org/tsunami/.

Richardt, Timothy. “Security and Defense of America’s Ports: An Assessment of Coast Guard and Navy Roles, Capabilities and Synchronization.” *Homeland Security Digital Library*. Army War College (U.S.), 2006. https://apps.dtic.mil/sti/pdfs/ADA448833.pdf.

Roberts, James E. “Highway Bridges.” in *Practical Lessons from the Loma Prieta Earthquake (1994).* Washington, DC: National Academy Press, 1994. https://www.nap.edu/read/2269/chapter/8.

Rubel, Robert C. “The Future of Aircraft Carriers.” *Naval War College Review* 64, no. 4 (2011): 12–27. http://www.jstor.org/stable/26397241.

San Diego Bay 18773. National Oceanic and Atmospheric Administration. Accessed January 19, 2022. https://www.charts.noaa.gov/OnLineViewer/18773.shtml.

San Diego Bay map, Google Maps, Accessed January 19, 2022, https://www.google.com/maps/@32.6672632,-117.1762958,12z.

San Diego Fire Foundation. “It’s Not a Matter of If a Tsunami is Coming, It’s When and How Large?” Accessed February 16, 2022. http://www.sdfirefoundation.org/commandpost/spotlight/its-not-a-matter-of-if-a-tsunami-is-coming-its-when-and-how-large/#:~:text=Obey%20firefighters%2C%20lifeguards%20%26%20police.,has%20trained%20for%20tsunami%20evacuation.&text=Have%20a%20contact%20out%20of,responders%20give%20the%20all%20clear.

Schank, John F. et al. *Refueling and Complex Overhaul of the USS Nimitz (CVN 68)*, MR-1632, Santa Monica, CA: RAND, 2002. https://www.rand.org/content/dam/rand/pubs/monograph_reports/MR1632/RAND_MR1632.pdf.

Sea Traffic Management. “Defining Sea Traffic Management.” Brussels, BE: European Union Sea Traffic Management. Accessed on August 6, 2021, 7.4. http://s3-eu-west-1.amazonaws.com/stm-stmvalidation/uploads/20160420153415/Act_2_MONALISA20_lowres.pdf.

Stavridis, James. Sea Power: The History and Geopolitics of the World’s Oceans. Penguin Books: New York, NY. 2017.

Thekdi, Shital A. and Joost R. Santos. “Supply Chain Vulnerability Analysis Using Scenario-Based Input-Output Modeling: Application to Port Operations.” *Risk Analysis,* 36, no.5, 2016: https://doi.org/10.1111/risa.12473.

Thomas, John E., Daniel A. Eisenberg, Thomas P. Seager, and Erik Fisher. “A Resilience Engineering Approach to Integrating Human and Socio-Technical System Capacities and Processes for National Infrastructure Resilience.” Journal of Homeland Security and Emergency Management 16, no. 2 (2019). https://calhoun.nps.edu/handle/10945/63114.

Tortorella, Michael. “Service Reliability Theory and Engineering.” Piscataway, NJ: Rutgers University, January 2005. http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=A268D4041A4CA1E1823E76BCF5C27263?doi=10.1.1.182.6433&rep=rep1&type=pdf.

U.S Coast Guard. *Navigation Rules and Regulations Handbook.”* Washington, DC: Department of Homeland Security. June 2019. https://www.navcen.uscg.gov/pdf/navRules/Handbook/CG_NAV_Rules_29Apr2020.pdf.

United States Coast Guard. *Ports and Waterways Safety Assessment Workshop Report Hampton Roads, Virginia*. Washington, DC: United States Coast Guard, July 2016. https://www.navcen.uscg.gov/pdf/pawsa/WorkshopReports/Hampton_Roads_PAWSA_workshop_report_July_2016.pdf.

U.S. Coast Guard. “Ports and Waterways Safety Assessment: San Diego.” San Diego, CA: U.S. Coast Guard, March 2003. https://www.navcen.uscg.gov/pdf/pawsa/workshopReports/San%20Diego.pdf.

U.S. Coast Guard Atlantic Area. “Prevention.” Accessed January 15, 2022. https://www.atlanticarea.uscg.mil/Our-Organization/District-5/District-Units/Sector-Virginia/Prevention/.

United States Coast Guard Atlantic Area. “Sector Virginia.” Accessed January 31, 2022. https://www.atlanticarea.uscg.mil/Atlantic-Area/Units/District-5/Sector-Virginia/.

U.S. Coast Guard. “District Eleven Units.” Accessed January 5, 2022. https://www.pacificarea.uscg.mil/Our-Organization/District-11/Units/.

U.S. Coast Guard. “Sector Puget Sound: Seattle, WA.” Accessed February 20, 2022. https://www.pacificarea.uscg.mil/Our-Organization/District-13/Units/Sector-Puget-Sound/.

U.S. Coast Guard Sector Puget Sound. “Marine Transportation System Recovery Plan (MTSRP) for Puget Sound.” Seattle, WA: U.S. Coast Guard Sector Puget Sound, 2018. https://homeport.uscg.mil/Lists/Content/Attachments/66938/SecPS%20Approved%20Marine%20Transportation%20Recovery%20Plan%20NVIC%2004-18.pdf.

U.S. Department of Homeland Security. *Maritime Transportation System Security Recommendations for the National Strategy for Maritime Security.* Washington, DC: U.S. Department of Homeland Security. April 2006. https://www.dhs.gov/sites/default/files/publications/HSPD_MTSSPlan_0.pdf.

U.S. Department of Transportation, *An Assessment of the U.S. Marine Transportation System*, Washington, DC: U.S. Department of Transportation, September 1999. https://www.maritime.dot.gov/sites/marad.dot.gov/files/docs/resources/2386/assessmntoftheusmts-rpttocongrsep1999combined.pdf.

U.S. Fleet Forces Command "Comprehensive Review of Recent Surface Force Incidents." Official memorandum. Norfolk, VA: Department of the Navy, 2017. https://s3.amazonaws.com/CHINFO/Comprehensive+Review_Final.pdf.

University of Washington Institute for Hazard Mitigation Planning and Research. *City of Everett Hazard Mitigation Plan*. Everett, WA: City of Everett, 2018. https://everettwa.gov/DocumentCenter/View/13998/EverettHMP_2018.

Vice Chief of Naval Operations. "Command Investigation into the Circumstances Surrounding the Fire Onboard USS Bonhomme Richard (LHD 6) on or about 12 July 2020." Washington, DC: Department of the Navy, 2021. https://www.documentcloud.org/documents/21089014-for-release-bhr-command-investigation-20-oct-21?responsive=1&title=1.

Virginia Department of Transportation. "The Commonwealth's Transportation Agency." August 12, 2019. https://www.virginiadot.org/about_vdot/default.asp.

Virginia Department of Transportation. "Hampton Roads Tunnels and Bridges." December 3, 2021. https://www.virginiadot.org/travel/hro-tunnel-default.asp#the_tunnels.

Virginia Port Authority. "Facilities." Virginia Port Authority. Accessed January 31, 2022. https://www.portofvirginia.com/facilities/.

Washington Military Department. "Significant Earthquakes Experienced in Washington Since 1872." Accessed February 24, 2022. https://mil.wa.gov/asset/5ba41f67ab6be.

Washington Military Department, W*ashington State 2016 Cascadia Rising Exercise After-Action Report.* Camp Murray, WA: Washington Military Department, 2018. https://mil.wa.gov/asset/604b7fa186e5f.

Washington State Department of Natural Resources and NOAA Center for Tsunami Research. *Tsunami Hazard Map of Everett, Washington: Model Results for Magnitude 7.3 and 6.7 Seattle Fault Earthquakes.* December 2014. https://www.dnr.wa.gov/Publications/ger_ofr2014-03_tsunami_hazard_everett.pdf.

Washington State Department of Transportation. "Business with WSDOT." Accessed February 20, 2022. https://wsdot.wa.gov/business-wsdot.

Washington State Department of Transportation. "Climate Impacts Vulnerability Assessment." Olympia, WA: Washington State Department of Transportation, November 2011. https://wsdot.wa.gov/sites/default/files/2021-10/Climate-Impact-AssessmentforFHWA-12-2011.pdf.

Washington State Department of Transportation. “Construction and Planning.” Accessed February 20, 2022. https://wsdot.wa.gov/construction-planning.

Washington State Department of Transportation. “Emergency Support Function: ESF #1.” Washington State Department of Transportation, January 2017. https://mil.wa.gov/asset/5ba421155ca72.

Washington State Department of Transportation. “Engineering and Standards.” Accessed February 20, 2022. https://wsdot.wa.gov/engineering-standards.

Washington State Department of Transportation. “How Do You Want to Travel?” Accessed February 20, 2022. https://wsdot.wa.gov/.

Washington State Department of Transportation. “Real-Time Map.” Accessed February 17, 2022. https://wsdot.com/ferries/vesselwatch/default.aspx.

Washington State Department of Transportation. “Washington State Ferries.” Accessed February 20, 2022. https://wsdot.wa.gov/travel/washington-state-ferries.

Washington State Department of Transportation. “WSDOT Ferries Division Fleet Guide.” May 2020. https://wsdot.wa.gov/sites/default/files/2021-10/WSF-FleetGuide-May2020.pdf.

Watts, Robert. “Maritime Critical Infrastructure Protection: Multi-Agency Command and Control in an Asymmetric Environment.” *Homeland Security Affairs* 1, Article 3 (August 2005). https://apps.dtic.mil/sti/pdfs/ADA484165.pdf.

Wears, R. L. and L. K. Webb. “Fundamental on Situational Surprise: A Case Study with Implications for Resilience.” in Resilience Engineering in Practice Volume 2: Becoming Resilient, London: CRC Press, December 2016. 61–74.

Woods, David D. “Four concepts for resilience and the implications for the future of resilience engineering.” Reliability Engineering & System Safety, 141, 2015. https://www.researchgate.net/publication/276139783_Four_concepts_for_resilience_and_the_implications_for_the_future_of_resilience_engineering.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California