Maritime Corridor Trace Analysis for Addressing Safety, Security, and Asset Management of Inland Waterway Transportation Networks

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Abstract

Worldwide population increase, the associated expansion of consumer demand, and the distribution of natural resources, manufacturing capabilities, and regionally unique and desired goods have driven the growth of international shipping. The primary method of intercontinental shipment is by maritime vessels. Shipping growth trends have given rise to the production of more and bigger vessels to meet the demand. Cascading effects include intensified demand on intermodal infrastructure for domestic transportation of these goods and commodities. The most widely used of these are roadway transportation networks, followed by rail, and then maritime. Maritime transportation networks may be the most suited for accommodating the growing demand. Research has described the maritime transportation on inland waterways as the safest, most cost efficient, and most environmentally sustainable of the three intermodal transportation modes. The safety assessment of inland waterway transportation networks may be reflected in the underutilization of this mode compared to the others. An increased reliance on maritime transportation as well as other emergent and future conditions may disrupt this desirable status. A move to use of cleaner fuels for maritime vessels may promote greater environmental sustainability, but may be accompanied by an increase in hazardous commodities transiting the waterways for import and export. The introduction of autonomously capable vessels may limit maritime accidents by reducing the effects of human error, but could impact the use of the waterway by other stakeholders and have security implications in the face of potential threats. This dissertation develops and tests a methodology (the "Maritime Corridor Trace Analysis") that supports enterprise risk management along an inland waterway transportation corridor, with particular emphasis on the shoreline assets, variety of stakeholders, and other features of the

system environment for maritime commerce. Demonstrations facilitate a sequential introduction of (i) safety risk factors, (ii) security risk factors, and (iii) methods for risk and resilience-based asset management. The approach extends previous, roadway transportation network applications of the corridor trace analysis methodology. The approach is of interest to enterprise operators associated with the shipment of freight on maritime transportation networks. The methodology is transferable across applications of systems engineering and risk analysis with multiple factors impacting a flow or otherwise linearizable system operation. Fields include commerce, environment, public utilities, technological development, project management, and others.

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Chapter 1. Introduction

1-1. Overview

This chapter introduces the content of the dissertation. The motivation for the research is discussed. Research questions addressed by this dissertation are stated. The chapter concludes with a discussion of the purpose, scope and contributions of following chapters.

1-2. Motivation

The estimated length of navigable waterways in the United States is over 21,500 nautical miles (25,000 miles) (USDOT, 2019). In 2011, the Maritime Administration (MARAD) of the United States Department of Transportation (USDOT) delivered a report to Congress titled “America’s Marine Highway” (MARAD, 2011). The intent of the report was to address inadequacies in the

U.S. transportation system for future needs by highlighting the underutilized potential of navigable waterways, including intercoastal networks, to move freight and passengers. The report identifies twenty potential marine highways, some of which were already recognized before the report's publishing, which could supplement routes used by land-based freight haulers. The land routes identified are all a part of the interstate highway network. The marine highways are named for the land routes for which they are intended to alleviate. Examples include M-580, a supplement to Interstate 580, or commonly I-580, in the San Francisco/Oakland region of California, and part of the inland waterway corridor demonstrated in Chapter 2. Other examples are M-64, the James River in Virginia and subject of the demonstration in Chapter 5, M-95 an intercoastal network running along the length of the eastern shore of the U.S., M-70 for the Ohio River valley, and M-5 along the length of the U.S. western shore. The subject of the demonstration of Chapter 3, the St. Johns River in northeastern Florida, is not identified as among the twenty marine highways.

The MARAD report identifies nine benefits to the overall transportation of the United States by greater utilization of the inland waterway transportation networks.

1. Support for new and existing mariner jobs.
2. Maintaining national shipbuilding capabilities.
3. Immediate relief of surface transportation congestion, particularly on routes providing landside access to urban ports.
4. Abundant new freight capacity.
5. Reductions in highway and bridge maintenance and repair costs.
6. Creation of a diverse and more resilient transportation system.
7. Improved environmental sustainability of the surface transportation system.

8. Benefits to public safety and security by the potential to avoid congestion and transportation of hazardous materials in heavily populated urban areas.
9. Low-cost freight and passenger services.

Though not explicitly organized in this manner, the report has two main sections. The first half discusses each benefit in detail, citing research supporting the benefits of maritime transportation over surface transportation. The second half discusses the role of the legislature in fostering growth of the marine highway program, including regulatory and de-regulatory actions, marketing of the program and garnering support of the public, and funding of related research. At the end of the first half of the report, four key issues are identified. The report does not discuss means for addressing them however.

1. Future increases in water traffic and expanded infrastructure.
2. Changed nature of vessels and their combined use and interaction on America's Marine Highway.
3. Larger cargo capacities.
4. Changed and expanded cargoes and products and the nature of accidental releases.

In its expanded discussion of the transportation of hazardous materials, the MARAD report highlights five additional benefits. Familiarity with waterway corridor characteristics allows reasonable doubt and need for further investigation with two of these: the ability to carry hazardous cargo at sea or on rivers creating significant separation from residences and businesses in the event of accidental release, and little vulnerability to bridge or tunnel failures including acts of sabotage targeting these structures. The report mentions public safety and security, including the use of this phrase as the title of a five-page section, but the treatment of security is limited. The only security related hazards and benefits mentioned are related to the ability of maritime transportation to create distance from populated areas. As mentioned, corridor channel widths and shore-to-shore distances, as well as the location of maintained and heavily trafficked channels close to shorelines in populated areas, reveals the need for further treatment of security-related factors.

The investigation of inland waterway transportation corridors presented in this dissertation began as a study of safety considerations for military maritime operations on inland waterway corridors. During this work, consultation with maritime system subject matter experts, combined with a familiarity of military operations, identified a need to assess the operational environment, provide a tool for visualization of risk in the environment, and a means to analyze the effect of emergent and future conditions on the disruption of safety and security factors.

U.S. Armed Forces doctrine supports the need for this type of analysis. Joint Publication 4-0 (JP 4-0) is the keystone logistics document at the joint level for the U.S. military. It opens chapter one by recognizing sustainment as one of the seven joint functions. A quote, also in chapter one, from Rear Admiral Henry E. Eccles in 1959 sets the stage at the strategic level for consideration of the operational environment in logistics operations. Eccles informs, “the logistics system must be in harmony, both with the economics system of the Nation and with the tactical concepts and environment of the combat forces.”

Doctrine, techniques, and procedures at the service branch level of the military also describe the imperatives of addressing the operational environment, the ability to visualize operations, and the ability to respond to future and emergent conditions. The Army Techniques Publication (ATP) 4-13, Army Expeditionary Intermodal Operations, identifies Military Sealift Command (MSC) as responsible for providing ocean transportation of equipment, fuel, supplies and ammunition to sustain U.S. forces worldwide. MSC lists the adoption of commercial maritime best practices, active management of risks, recognizing and addressing emergent challenges, and maintaining operational security among its key processes (MSC, 2017). In preparation for Operation Iraqi Freedom from November 2002 to May 2003, MSC loaded over 16 million square feet of military cargo at ports in Texas, Georgia, and Florida, and delivered the equipment to Ash Shuayba Port in Kuwait (Wissler, 2018). These operations required the safe and secure navigation through inland waterways in the United States and foreign waters to include the Suez Canal, the Red Sea and the Persian Gulf.

Themes of environment, visualization capabilities, and future and emergent conditions appear again in Army Doctrine Publication (ADP) 4-0, Sustainment. This document describes the similarities between the principles of sustainment and the principles of logistics. ADP 4-0 lists anticipation, survivability, and improvisation among the eight logistics principles. According to ADP 4-0, anticipation requires commanders and staffs of logistics operations to understand and visualize operations, identify threats, and assess those threats. Survivability consists of the capability to avoid or withstand hostile actions or environmental conditions while retaining the ability to fulfill the mission. Key to the survivability principle is the recognition of the ability of hostile actions and environmental conditions to disrupt the flow of logistics. Finally, improvisation is the ability to adapt sustainment operations to unexpected situations or circumstances. To operate with the improvisation principle, commanders must create methods to permit adaption in a changing operational environment, apply operational art to visualize and understand complex operations, and improvise operational and tactical actions when enemy actions or unexpected events disrupt sustainment operations.

Another motivation of this work is on-going research in support of enterprise operations for the Port of Virginia and deep-water port operations in general. There has been an evolving focus by all researchers involved in the work for the port. Published work includes scenario analysis for strategic investment project schedules (Collier et al., 2018), mapping of stakeholder perspectives for port initiatives (Almutairi et al, 2019), investigation of truck turn times within the port terminal due to activities at various stations throughout the terminal (Thorisson et al., 2019a), and investigation of cost and delay involved with the assignment of vessels to berths (Thorisson et al., 2019b). On terminal port operations have grown increasingly efficient and focus has shifted to associated operations outside of the terminal gates. Research in this area has investigated rail crossing locations and incident and probability of round-trip deliveries by truck drivers from the deep-water ports to inland warehouse locations. This dissertation is motivated in part to support the port's efforts for continued improvement of operations and regional growth in jobs and commerce.

1-3. Research Questions

In the chapters of this dissertation, the following research questions will be addressed.

1. What are the characteristics (factors) of inland waterway transportation corridors impacting the safe operation of vessels? (Chapter 2)
2. How are these factors associated with safety related hazards? (Chapter 2)
3. What are the characteristics (factors) of inland waterway transportation corridors impact the security of vessels, freight, and populations? (Chapter 3)
4. How are these factors associated with security related hazards? (Chapter 3)
5. What are the combined effects of factors on safety and security? (Chapter 3)
6. What are applicable risk considerations for safety and security of asset management systems? (Chapter 4)

7. What is the influence of emergent and future conditions associated with inland waterway transportation corridors on the prioritization of corridor segments? (Chapter 5)
8. How can understanding gained from corridor trace analysis influence the management of enterprise assets? (Chapter 5)
9. What is the influence of emergent and future conditions associated with inland waterway transportation corridors on stakeholder initiatives for management of an inland waterway corridor as an asset to enterprise operations and the community? (Chapter 5)

In a more general context, a purpose of this dissertation is to address a colloquial topic. Assuming international trade and the domestic transportation of goods and commodities continues to grow, and assuming an increase in the utilization of inland waterway transportation corridors is desirable, what methods can contribute to effective management of risk in safety and security and the resilience analysis of inland waterway transportation corridors so they do not succumb to undesirable conditions experienced on land-based corridors, and continue to be a legitimate asset to all stakeholders interested in enterprise operations on and use of inland waterway transportation corridors?

1-4. Research Contributions

This dissertation contributes to and extends previous analysis of maritime corridors and the development and application of corridor trace methodologies for transportation systems. Aspects of individual efforts in these bodies of literature are described and referenced in the background sections of applicable chapters. General observations of previous literature are discussed in this section to provide a basis for describing the contributions of this dissertation.

Previous work focuses largely on accident causation and the determination of conditions present during accidents contributing to their occurrences. Conditions among the various studies are related to weather, sea-state, channel configuration, vessel dynamics, human factors and others. The literature review of maritime corridor and accident analysis is applied in this dissertation to the selection of relevant safety risk factors associated with maritime hazards. The results of the previous efforts, in conjunction with expertise from maritime system operators, are considered and refined to achieve a register of factors relevant to inland waterway corridors. The register includes risk threshold levels representing the likelihood of contribution by each factor to collision, allision, and grounding incidents along the length of the corridor. Though the reviewed work is often set in a specific geographic location, a specific river or port for example, discussion of variation along the waterway corridor is sparse. This dissertation applies systems analysis techniques to the management of an inland waterway transportation corridor with risk factors as a basis for describing the transportation system. The focus of the dissertation shifts analysis from determining accident causation to the visual analysis of multiple causal factors in a segmented, linearized corridor and the coincident implications of factor risk thresholds to maritime operations.

Previous corridor trace analysis methods have been applied to roadway transportation systems. This dissertation demonstrates the application of the general framework of corridor trace analysis to other transportation modes and the adaptations required for the unique system characteristics of maritime corridors. Current challenges associated with the extension of surface transportation methods are identified and addressed. These challenges include differences in risk factor data collection and the need for out-scoping of the physical boundary of the transportation corridor. This dissertation also demonstrates the ability for expansion of methods in terms of the number of corridor risk factors considered compared to analyses of roadway transportation corridors. More than fifteen factors are visualized for inland waterways, doubling the considerations of previous analyses. The consideration of a large number of factors compels a need for a prioritization of corridor segments through the aggregated assessment of risk factors. Previous analyses rely upon visual inspection of the corridor trace to identify possible areas for investment in mitigation strategies and acknowledge benefits of increased accuracy in prioritization in future work. This dissertation addresses this need and demonstrates two methods for weighting the relevance of risk factors: (i) by the distribution of segment risk thresholds among risk factors and (ii) by stakeholder preferencing of corridor risk factors. The method of visual inspection is retained and demonstrated to capture a benefit of the corridor trace methodology by maintaining discernability of contributing risk factors. Lastly, this dissertation extends previous corridor trace methodology by demonstrating its ability to inform a scenario-based resilience analysis. Understanding of the transportation corridor system risks gained from the corridor trace analysis is applied to the development and prioritization of corridor segments and asset management initiatives subject to the influence of emergent and future conditions. Research contributions of each chapter are outlined in the following section.

1-5. Organization and Scope

1-5-1. Organization of this dissertation

The remaining sections in this chapter provide an overview of subsequent chapters and the progression of development of the maritime corridor trace methodology and asset management. The contributions of each applicable chapter are described. Figure 1-1 illustrates the organization of this dissertation by topic.

OVERVIEW

Chapter 1. Introduction
- The motivation, research questions, organization, and overview of topics and contributions by chapter.

THEORY, METHODS & DEMONSTRATIONS

Chapter 2. Safety Risk Factor Analysis for Inland Waterway Corridors
- Introduction of methodology for maritime corridor trace analysis for the identification and selection of safety risk factors on a Central California corridor.

Chapter 3. Security Risk Factor Analysis for Inland Waterway Corridors
- Application of the maritime corridor trace analysis method to the identification and selection of security risk factors on the St. Johns River corridor.

Chapter 4. Risk Management and Resilience Analysis for Asset Management Systems
- Introduction of methods for resilience analysis of asset management systems with risk-based initiatives

Chapter 5. Asset Management of Inland Waterway Transportation Corridors
- Application of methods developed in Chapters 2 through 4 to the asset management of the James River corridor. Includes additional methods for maritime corridor trace analysis.

CONCLUSIONS

Chapter 6. Extended Applications and Future Work
- Discussion of applications of the maritime corridor trace methods to other systems, and future work.

Chapter 7. Discussion and Conclusion
- Discussion of risk consequence of maritime systems, model validation, limitations, and a brief review of the dissertation.

REFERNCES

APPENDICES

Appendix A: Raw Data for Corridor Segments
Appendix B: Sensitivity Analysis
Appendix C: Risk Register

Figure 1-1. Organization of dissertation by topic.

1-5-2. Chapter 2. Safety Risk Factor Analysis for Inland Waterway Corridors

Chapter 2 introduces the maritime corridor trace analysis methodology through safety risk factor analysis of a Central California corridor network from the Port of Oakland to the Port of Stockton and from the Port of Oakland to the Port of West Sacramento. The steps introduced include (i) corridor definition and visualization, (ii) risk factor selection, (iii) risk factor data collection, (iv) risk factor threshold determination, and (v) maritime corridor trace production. The steps are provided in detail to facilitate the replication of the method. The detail steps also aid in the understanding of the visually centered, decision-aiding aspects of the maritime corridor trace analysis.

Contributions of chapter 2 are:

(1) The extension and adaptation of the corridor trace analysis methodology to analysis of inland waterway transportation corridors, including consideration of segment areas of interest to capture factors of the operational environment, factors of the natural environment and the built environment;

(2) Explicit connection of inland waterway corridor trace factors to risk hazards, establishing a potential for future extension to inclusion of risk consequence;

(3) Extension of compounded risk segment determination by inspection of multiple factors to include the lateral consideration of impacts of multiple adjacent segments and the aggregation and weighting of factors for inland waterway corridor segment prioritization; and

(4) A methodology to contextualize a maritime corridor and associated risks in a common frame of reference, meaningful to a variety of stakeholders, whether versed in maritime operations or unfamiliar with maritime terminology.

Chapter 2 and Chapter 3 include collaborative work completed with Zachary A. Collier for a sponsored project on the safety analysis of military maritime operations on inland waterway corridors.

1-5-3. Chapter 3. Security Risk Factor Analysis for Inland Waterway Corridors

Chapter 3 extends the maritime corridor trace methodology to include consideration of security factors for vessel operations. Risk factor selection, risk factor data collection, and risk factor threshold determination steps are applied to identify and classify security factors along the St. Johns River corridor for twenty-four nautical-mile long segments from the Port of Jacksonville to the Atlantic Ocean. Security threat hazards are discussed and associated with the security risk factors. Possible defensive tactics for maritime vessels are introduced and used as an opportunity to address the introduction of autonomous capable vessels and vessel motion dynamics. Specific segments are selected to discuss the interaction of safety and security considerations during possible threat scenarios.

Contributions of chapter 3 are:

(5) Extension of the corridor trace analysis to consider security risk factors for defensive operations; and

(6) Application of maritime corridor trace analysis to address combined impacts of safety and security risk factors.

Chapter 3 is an extended version of a paper accepted for publication in the conference proceedings for the 14th Annual IEEE International Systems Conference, titled “Systems Evaluation for Defense Operations of Maritime Transport.”

1-5-4. Chapter 4. Risk Management and Resilience Analysis for Asset Management Systems

Chapter 4 is a one-chapter departure from the investigation of inland waterway corridor systems, to introduce concepts in the risk and resilience analysis of an asset management system. The subject of this chapter is the acquisition of a technology-based tool control system for a state-level department of corrections. The acquisition and deployment of this asset has implications for the safety and security of the corrections officers, staff, inmates, and the community. The methodology for determination of success criteria and initiatives (termed requirements in Chapter 4) is introduced. Schemes for the relative importance weighting of criteria and the assessment of initiatives against criteria or discussed. Resilience analysis of initiatives is addressed by the process of (i) identification of emergent and future conditions relative to the life cycle implementation of the tool control system, (ii) the formation of scenarios by the inclusion of one or more emergent and future conditions, (iii) the reweighting of criteria under each scenario, (iv) ranking of initiatives under each scenario, (v) the assessment of disruptiveness of scenarios by their influence on initiative prioritization, and (vi) the identification of highly ranked and robust initiatives.

A contribution of Chapter 4 is:

(7) A framework for the association of enterprise initiatives to five risk dimensions for the management of assets.

1-5-5. Chapter 5. Asset Management of Inland Waterway Corridors

Chapter 5 is the application of methods developed in Chapters 2 through 4 to the analysis of the James River corridor in Virginia. The James River corridor is utilized by the Port of Virginia to transport containerized freight and bulk commodities from deep-water ports in Norfolk and

Portsmouth to the Richmond Marine Terminal. Two additional methods are introduced: (i) the development of a factor trace for identification of industrial and commercial parcels along the shoreline characterized as developed or available for development and (ii) a nomenclature framework for the naming of corridor segments other than by segment number referencing each segment's relative geographic location. A demonstration of methods from Chapter 4 for the management of the James River corridor as an asset to stakeholders is provided. Success criteria and enterprise initiatives are developed using the maritime corridor trace analysis to identify initiatives for the mitigation of safety and security related hazards. The influence of emergent and future conditions on both initiatives and corridor segment rankings are discussed.

Contributions of Chapter 5 are:

(8) Development of a nomenclature system to identify relative geographic location of segments adaptable for use in management of transportation corridors for other modes of transportation.

(9) Integration of maritime corridor trace analysis to system risk and resilience analysis by identifying risk mitigation requirements and incorporating those requirements with enterprise initiatives for the management of assets.

(10) Assessing the influence of emergent and future conditions on the prioritization of corridor segments.

Chapter 5 is an extended version of a paper accepted for publication in the conference proceedings for the 2020 ASCE International Conference on Transportation & Development, titled "Segmented Identification of Disruptive Settings on Transportation Corridors."

1-5-6. Chapter 6. Extended Applications and Future Work

Chapter 6 includes a discussion of possibilities for adaptation of the maritime corridor trace analysis for other engineering systems. The chapter describes how the five steps introduced in Chapter 2 for the development of the maritime corridor trace might be applied to other applications. Potential future work regarding the continued development of the maritime corridor trace methods and resilience analysis are proposed.

1-5-7. Chapter 7. Discussion and Conclusion

Chapter 7 concludes the dissertation with a discussion of model validation, limitations of the maritime corridor trace methodology, the context of discussion of risk absent consequence throughout the dissertation. A brief review of the content of the dissertation is provided.

1-5-8. Scope of Risk Analysis

The term risk is used ubiquitously throughout this dissertation. Kaplan and Garrick (1981) applied three components to the definition of risk, an incident, the incident's likelihood of occurrence, and the consequences of an occurrence. This dissertation adopts an interpretation of risk as the influence of scenarios to priorities (Karvetski and Lambert, 2012; Quenum et al., 2019; Hassler et al., 2020). The scope of this dissertation does not include the quantification of consequences for individual incidents on inland waterway transportation systems, or for the tool control system demonstrated in Chapter 4. For inland waterway transportation systems in this dissertation, the risk threshold levels applied to corridor factors can be expressed in two senses. First, threshold levels represent the likelihood of a single incident. In this sense, it would be appropriate to quantify a consequence of an incident. Still, each risk factor could lead to a variety of incidents with a range of severity. Second, threshold levels represent a characteristic of the corridor contributing to the likelihood of sufficiently many occurrences of a type of incident.

The consequences to port operations of lost cargo and loss of trust in port operations by business partners and the community, the consequences to the environment from a fuel commodity spill, and the consequences to domestic commerce and daily life in the event of a terrorist attack on a cargo vessel or liquefied natural gas tanker all require significant calculation involving a vast number of considerations. The scope of this dissertation in terms of risk is the identification of hazards and assessment of the likelihood of types of incidents occurring under consideration of the associated corridor risk factors.

Methods to appropriately manage inland waterway corridor systems to retain desired conditions of safety, environmental sustainability, and cost-effective freight transportation relative to other modes is the primary focus of this work. The failure to mitigate hazards related to the increased use of inland waterway corridors, resulting in no added benefit or resulting in a detriment to the corridor system or the environment is considered a sufficiently severe consequence. Management of inland waterway corridors is intended to project over long time horizons, and the accumulated consequence of all incidents are considered to have the same effect, abandonment of the inland waterway as value-added to the community. The determination of high, moderate, and low-risk levels is related to likelihood of types of incidents occurring, and the potential contribution of corridor factors to contribute degradation of beneficial aspects of inland waterway corridors under the influence of emergent and future conditions. A discussion of risk under assumed or undetermined consequence is presented in Chapter 7.

Chapter 2. Safety Risk Factor Analysis for Inland Waterway Corridors

2-1. Overview

This chapter introduces and develops the maritime corridor trace analysis methodology to explore the impact of inland waterway corridor factors on maritime system safety. Logistics systems operations, such as maritime shipping, utilize transportation corridors serving multiple and varied users. Risk management and resource allocation of freight operations must consider a set of corridor attributes related to system goals for the safe, reliable and efficient movement of freight. The transportation corridors are segmented into system-appropriate intervals. Each segment is evaluated using selected attributes to identify corridor sections with high relative risk and those potentially vulnerable to disruptions. The method is demonstrated for maritime corridors utilized for the movement of commodities to inland ports in California with lengths over seventy-five nautical miles.

2-2. Introduction

Rising populations and acceleration of global economic development drive increasing demand for goods and commodities (Hossain and Zakaria, 2017). Demand drives requirements for increased shipping capacity to deliver these goods to population centers. Increased shipping capacity requirements drive the building of more and bigger ships. More and bigger ships necessitate navigational improvements such as the deepening of waterways (Almaz and Altiok, 2012) and vessel traffic management (Zhang et al., 2014) to improve navigational efficiency. In 2016, movement of goods in the United States along waterway corridors comprised only three percent of the more than thirteen million tons of freight transported (USDOT, 2019). If shipping growth trends continue, the percentage will necessarily increase due to limitations on the other modes of freight transportation. Safety risk factors along an inland waterway corridor represent hazards for collision, allision, and grounding of vessels. A method is needed to identify these factors and assess their individual and collective impacts to the transportation of goods and commodities from deep water ports to inland terminals.

For U.S. waterways, the National Oceanic and Atmospheric Administration (NOAA), United States Army Corps of Engineers (USACE), the United States Coast Guard (USCG) and other organizations are a valuable source of information. The NOAA maintains detailed charts for navigable waterways and supplemental documents, a series of nine nautical volumes providing a wide range of information relevant to navigation in U.S. waters titled as the *United States Coast Pilot*. The controlling volume for the demonstration in this chapter is *United States Coast Pilot 7*, *Pacific Coast: California, Oregon, Washington, Hawaii and Pacific Islands*. This document is an existing and detailed record of key features of the waterways including some of the safety risk factors proposed in this work. Both the Coast Pilot documents and navigational charts provide precise, coordinate-based locations of factors such as buoys and lights, bridges, and obstructions. Though available resources are detailed and descriptive, there is a need to present the information available from various sources in a consolidated and more broadly applicable way. Latitudinal and longitudinal coordinates are undoubtedly useful for vessel pilots, but they lack significance for port operations, business leaders, and policy makers. An example of the narrative format and relative locating of factors highlights this need. In a description of key characteristics of nautical chart 18661, one of the charts used in the demonstration of this chapter, U.S. Coast Pilot 7 reads, "Threemile Slough meets the San Joaquin River 5.8 miles above Antioch Bridge and joins the Sacramento River at the north end of Decker Island" (NOAA, 2019). A more efficient and standardized method is desirable. A goal of this work is the development of methods to provide common reference to a variety of stakeholders interested in the use and impacts of inland waterways.

2-3. Background

Port management operations for the use of inland waterways for freight transport have been explored. Zhang et al. (2014) has demonstrated effective management of vessel congestion along the Yangtze River by the identification of multiple safety-critical factors most likely to lead to congestion and the monitoring of critical risk index scores based on the probability and severity of an accident given the factors. The management tool is suggested to be adaptable to other inland waterways. The safety-critical factors are heavily tied to weather and climate. Another congestion management method involves the optimization of shipping routes to maximize profit for operating barges between a seaport and a number of inland ports when subjected to varying levels of demand (Braekers et al., 2013). Lalla-Ruiz et al. (2018) suggest an optimization model to minimize ship waiting time in order to control congestion problems along inland waterways. This method accounts for factors of ship size and tidal effects. Elcheikh and Burrow (2017) discuss the importance of effective maintenance operations for inland waterways utilizing canal systems and characterized by the passage of ships underneath road and rail bridges. The method notes the importance of increased vessel traffic to the prioritization of lock and bridge assets based on asset condition and estimated maintenance costs. A related case is made for prioritization of improvements to sustain water transport on the Danube River. Analysis of existing infrastructure related to the waterway and other forms of land transport connected to the waterway, as well as future projects, including information systems, are to be considered in the prioritization. (Mihic et al., 2011).

Various analyses discussing the safety of inland waterway transport provide an expanded catalog of vulnerabilities and safety-related factors to consider. Automatic identification systems (AIS) data is used to develop vessel collision scenarios and assess collision avoidance processes in terms of vessel maneuverability characteristics and human decision-making factors (Wang et al., 2013). Wood et al. (2018) develop a mental model to combine the factors associated with the capabilities of the vessel and crew with external factors associated with vessel traffic, sea-state, and channel configuration. This analysis examines maritime transport on sea channels leading to the Port of Houston. An inland waterway study also recommends the use of channel configuration factors, such as width and depth, as well as factors of population density and accident history to measure limitations of specific waterways (Vidan et al., 2012). This method labels waterways with various coefficients developed from the prescribed factors, where each coefficient is intended to characterize the entire length of the waterway. Alternatively, an accident probability model predicts the number of accidents on the river Waal for each one-kilometer section (Roeleven et al., 1995). The model uses least squares estimation to assess the accident-explanatory capabilities of waterway characteristics which include channel configuration and weather factors. The single output of accident probability offers an opportunity to enhance the analysis by communicating the values of the many factors simultaneously along a corridor. Berle et al. (2011) propose the need for a methodology to support the quantification of risk factors related to the ability to move goods utilizing maritime transportation systems. Such methodologies should relate vulnerabilities to the ability to use navigable waterways to move goods and the ability to maintain safety and security. The methodologies should incorporate expert elicitation from stakeholders to assess the infrastructure, equipment, and processes of the system.

Prior work has demonstrated a corridor trace analysis methodology as a decision-support model with application to roadway transportation networks. Thekdi and Lambert (2015) introduced corridor trace analysis to assess highway segments vulnerable to adjacent land development by considering factors of access point density per mile, average daily traffic and future land development likelihood. An extension of the method demonstrated usefulness in big-data integration to aid decision makers in the visualization of various metrics and road attributes for a large number of roadways encompassing tens of thousands of kilometers (Thorisson and Lambert, 2017). Additional factors of volume-to-capacity ratio, crashes per mile, truck traffic, pavement condition, and planned projects were considered. A third application of corridor trace analysis established a basis for facilitating the prioritization of roadway access management projects (Alsultan et al., 2019).

This chapter extends the corridor trace analysis methodology to inland waterway corridors demonstrating its applicability to modes of freight transportation beyond highways. Application to inland waterways further expands the number of corridor factors under consideration. The framework can inform port operations on the potential for volume expansion and identify critical segments related to the safe and efficient movement of commodities.

2-4. Methods

This section outlines the steps required to implement the methods applied in the demonstration. Most steps are described in detail to facilitate the replication of the analysis presented in this chapter and in Chapters 3 and 5. Table 2-1 provides links for web-based access to applications and products used in the presented method.

Table 2-1. Applications and products used in the development of maritime corridor trace.

Applications and Products	Access Link
United States Coast Pilot	https://nauticalcharts.noaa.gov/publications/coast-pilot/index.html
Google Earth Pro	https://www.google.com/earth/versions/
Raster nautical charts	https://seamlessrnc.nauticalcharts.noaa.gov/arcgis/rest/services/RNC/NOAA_RNC/MapServer
PDF nautical charts	https://www.charts.noaa.gov/ChartCatalog/MapSelect.html
Vessel transit counts	https://coast.noaa.gov/arcgis/rest/services/OceanReportingTool/
Sea-state factor data	https://www.wunderground.com/

2-4-1. Corridor Definition and Visualization

A critical aspect of the application of corridor trace analysis methodology to inland waterways is the need to define the water transportation corridor for the system under investigation in terms of length and width. The method adopts the practice of defining numbered segments, like those of highway mile points. Maritime corridors differ conceptually from roadway corridors in terms of width. Whereas the width of a road transportation corridor typically varies only slightly, by additional or fewer traffic lanes, along its length, waterway corridor widths tend to vary significantly. Even where a well-maintained channel exists along the entire length of a waterway corridor, factors such as inflow current, cross-channel traffic, and shore-to-shore distance associated with the waterway width will impact safety along the navigable channel.

Thus, the first step of this methodology is to define and visualize the maritime transportation corridor. Geographic information system (GIS) software, such as ArcGIS packages or Google Earth Pro are useful for this step. GIS software contains linear measuring functions and graphic tools for placing paths, points, and polygons, which help to define the corridor. Google Earth Pro is the platform used to demonstrate the methods of defining inland waterway corridors in this and following chapters.

The ability to overlay navigational charts on top of satellite imagery assists in identifying existing vessel paths and maintained channels. NOAA provides GIS services in various formats. Among these services is access to raster nautical charts (RNCs). This service allows the user to view selectable outlines of available nautical charts within the GIS platform. This service is downloadable at the website included in Table 2-1. For Google Earth Pro, clicking the option Generate KML in the Supported Operations list will add the service to the user's Places menu. The service includes the option of selecting one or multiple chart scale groupings. Demonstrations in this dissertation use charts from the 1:25,000 scale grouping for waterway sections when available, and from the 1:50,000 scale grouping otherwise. Hovering over a desired chart outline highlights the outline and clicking on the outline produces a menu for chart selection. This step is depicted in Figure 2-1. The Collarless Preview option is desired. The collared option returns the full nautical chart with borders, legends, descriptive information, etc. The collarless option includes some of this information, but extraneous information, such as chart insets, are excluded. Like all GIS graphics used in this method, the RNCs offer the ability to select opacity percentage. Viewing the collected nautical charts at approximately fifty percent opacity is advantageous.

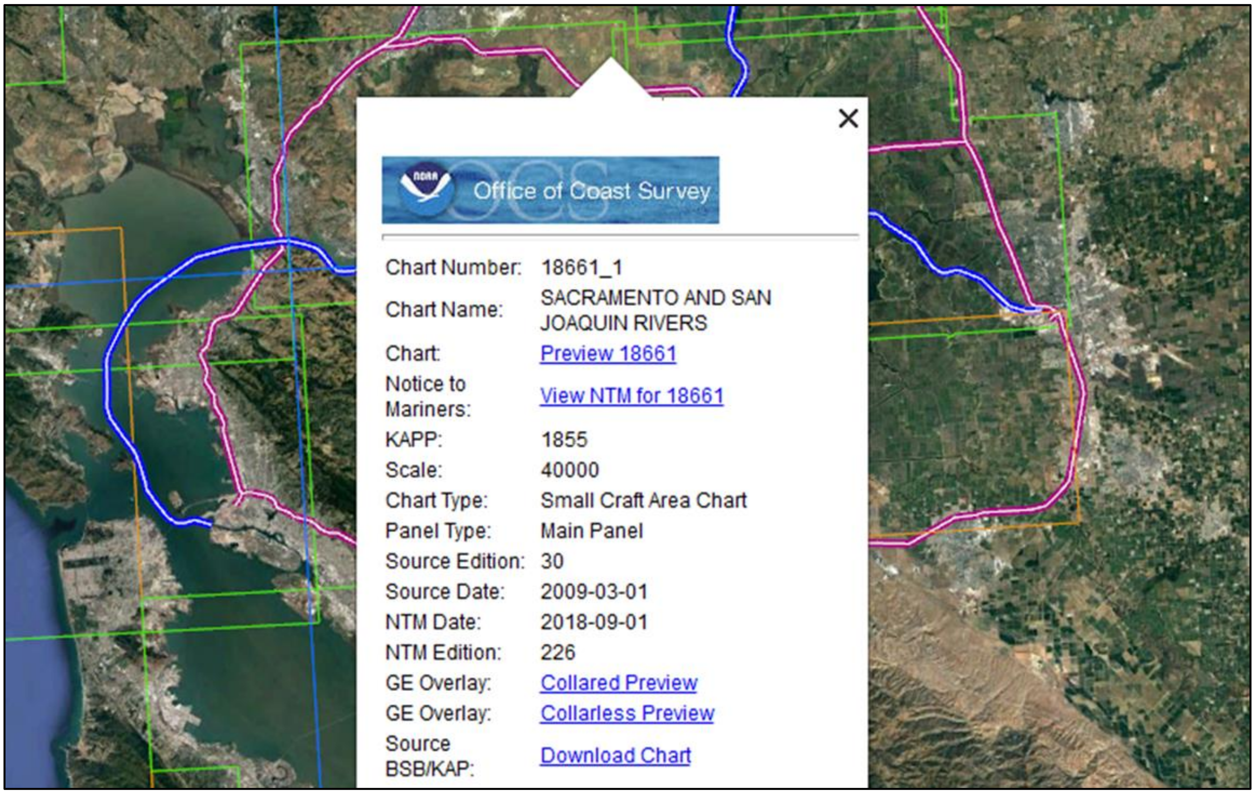


Figure 2-1. Nautical chart overlay selection.

Nautical charts depict maintained channels and aids to navigation, such as buoys and lights which help to define the path of travel of vessels. In some instances, when there are no defined channels or when there appear to be multiple paths available, vessel traffic overlays are useful to determine the established path of commercial vessels. NOAA also provides GIS products for visualization of vessel traffic. The link to this service is in provided in Table 2-1. Vessel transit count overlays are available for a number of vessel types: cargo, fishing, passenger, pleasure and sailing craft, tanker, and tug and tow. Each overlay can be uploaded to Google Earth Pro by clicking the link for the desired vessel type and then selecting the Generate KML option in the

Supported Operations list on the subsequent page. This vessel transit dataset is located in the OceanReportingTool folder of the parent NOAA services directory and offers data for 2016. As recently as May 24, 2020, Google Earth Pro supported overlays were available for vessel transit counts from years 2011 to 2017 from the MarineCadastre folder of the same parent directory. After May 24, 2020, the option to generate .kml formatted overlays was removed from the MarineCadastre folder. Google Earth Pro compatibility for data from the OceanReportingTool folder remained available as of June 1, 2020. Figure 2-2 provides a screen capture of a portion of San Francisco Bay with a section of the trafficked route marked on the nautical chart, where it is a maintained channel, and a section of the route not clearly identified on the nautical chart. The designated channel is indicated by the parallel, dashed black lines in the top-left quarter of the figure signifying the width of the maintained channel. The figure demonstrates the use of vessel traffic data to define the centerline of the waterway, indicated by the white line. In this figure, the opacity of the vessel traffic overlay is set to approximately thirty-five percent.

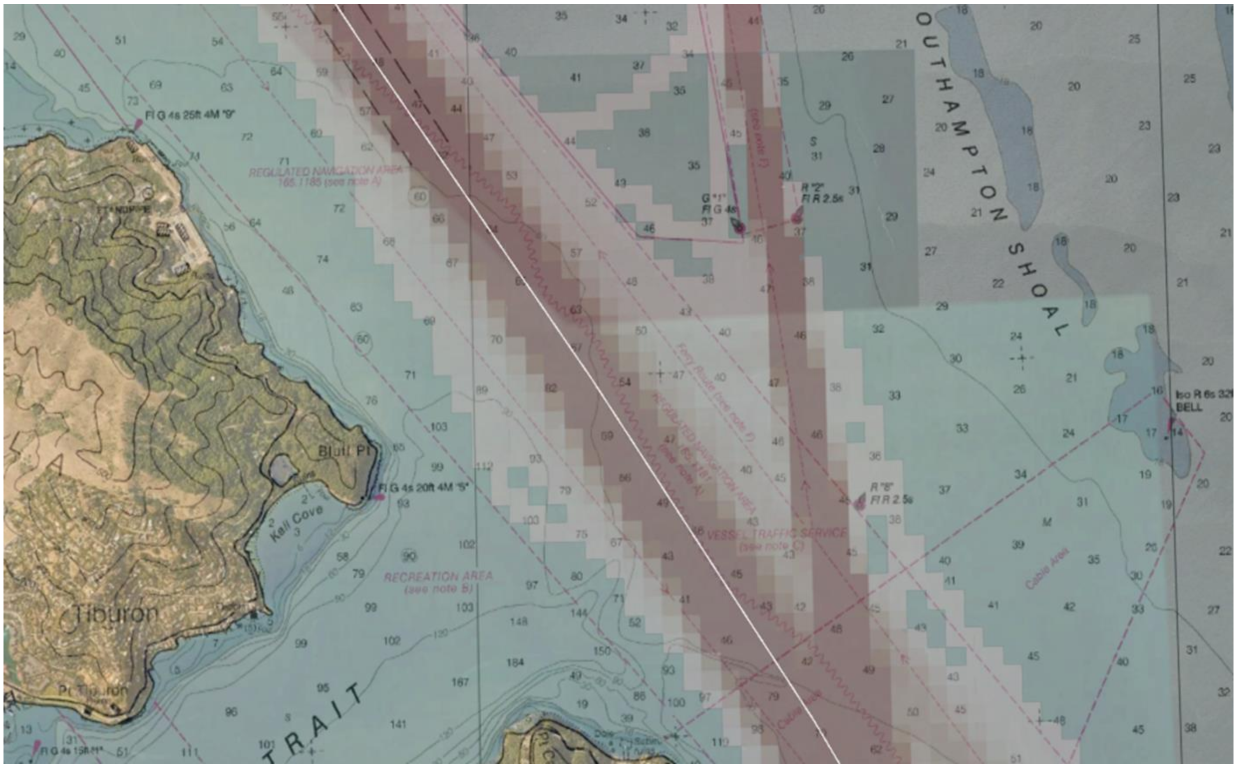


Figure 2-2. Combined use of nautical chart and vessel traffic overlays to define the vessel path.

The route is sectioned into one-nautical mile segments. For all inland waterway corridors throughout this dissertation the first segment is placed at the western most meaningful starting point of the corridor. Segment numbers increase from west to east, and from left to right on the page. Acknowledging the convenience of this standard to the corridors demonstrated in this dissertation, for future work and wider applicability, an alternate standard may be desirable. For example, first segment placement oceanside and last segment inland. Enterprise operators may also describe a preferred numbering method for their use. The method of defining and segmenting the path of travel of commercial vessels is a repeated two-step process. Using the nautical chart and vessel traffic overlays as described, the general centerline of the corridor is marked and segmented using embedded GIS tools to add a path and add placemarks. The add path option allows the user to build an overlay consisting of straight-line segments. Each one-nautical mile segment could be created separately, however the method employed is to create one path extending the entire length of the corridor. Both options would require a similar number of operations. The add path tool includes style options for color, width, and opacity. The default style of white, width 1.0, and one-hundred percent opacity is selected for this dissertation. Placemarks are added at the end of each nautical mile segment of the path to identify and name the previous segment of the corridor. Placemarks also include style options for the type of icon used, the color and size of the icon, icon opacity and the color, size, and opacity of the placemark label. A circle icon in orange, 1.0 scale, and fifty percent opacity with default settings for icon labels are selected for placemarks in this dissertation.

The first step of the two-step process of defining and segmenting the vessel path is use of the path option to follow the approximate center of vessel traffic or maintained corridor for a measured distance of one nautical mile. The GIS application measures the total length of the path as straight-line sections are added. For the first segment the user clicks at the starting point and clicks to create a segment at the end of the first straight-line section. This might be the entire length of one nautical mile, or the point at which a vessel must begin to turn to remain centered in the corridor. The path is saved upon reaching the next integer nautical mile distance of the corridor. The second step is to create a placemark to mark the boundary of the created corridor segment. Visually placing the icon as close to the most recent ending point of the path is reasonable accuracy for purposes of this analysis. Another option is to manually assign longitude and latitude to each placemark. The placemark is then named with the appropriate segment number, the nautical mile length of the last section of corridor created. For example, the length of the corridor path preceding placemark 30 is the thirtieth nautical-mile section of the corridor, or the length of the corridor measures thirty nautical miles at placemark 30. A useful procedure is to create and save placemarks in a separate folder. The process of adding a one-nautical mile segment followed by adding the appropriate placemark is repeated for the entire length of the corridor. The length of the path is amended by selecting the properties option for the path and clicking to add new straight-line segments. Placemarks can be quickly added by copying the previously created placemark, pasting into the placemark folder, renaming the new placemark with the next segment number and dragging the new placemark to the new end of the path. Figure 2-3 demonstrates the two-step process of adding a one-nautical mile segment length to the corridor.

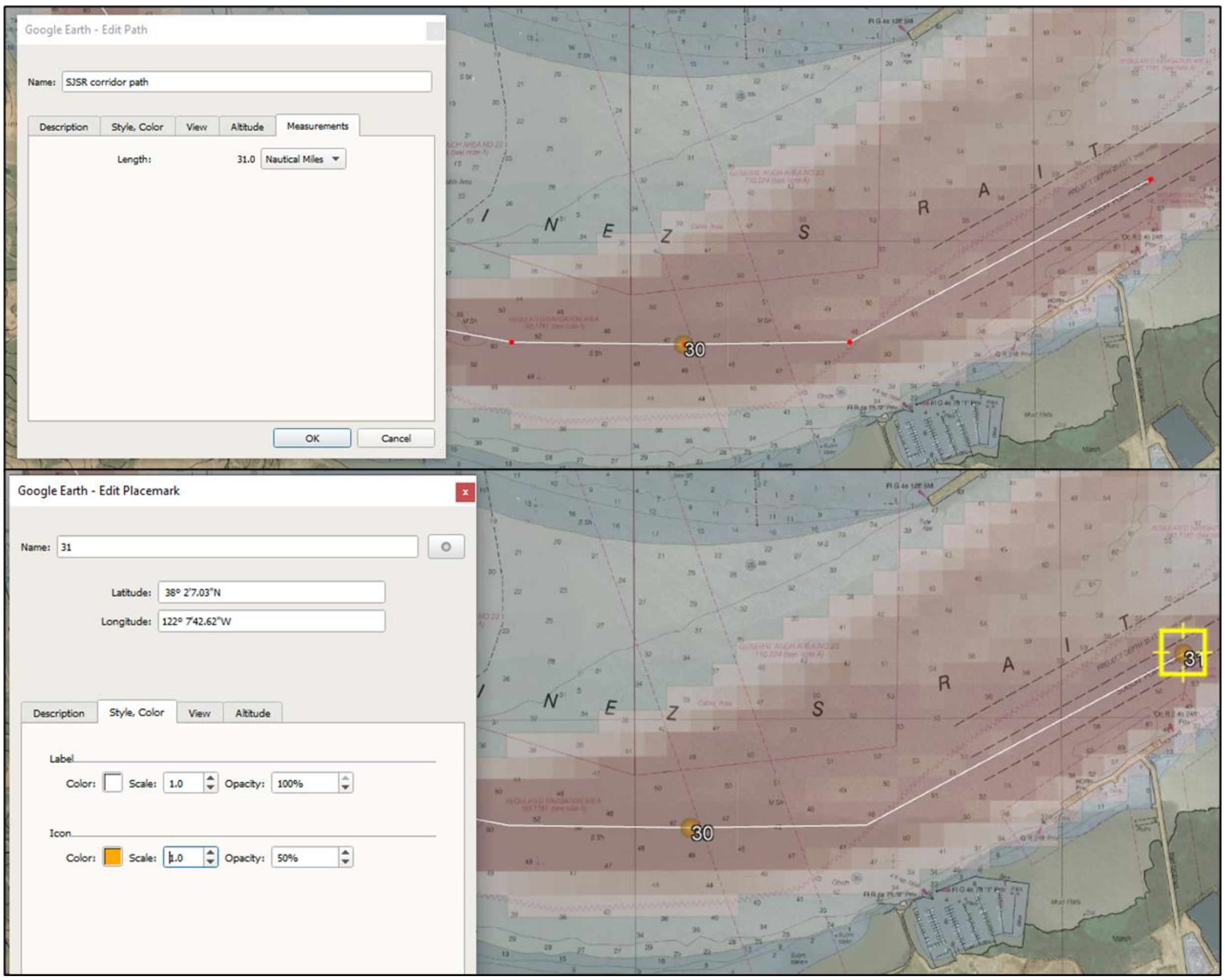


Figure 2-3. Process of adding one segment length to the corridor path. Adding one nautical mile of length to the corridor, generally centered in the defined channel or path of vessel traffic (top) and defining the newly added length with an appropriately labeled placemark (bottom).

Areas of interest are defined for each segment of the waterway transportation corridor to capture the influence of selected safety factors. The intent is to describe waterway corridors as two-dimensional systems, in which factors outside of the defined channel impacting safe operations can be accounted for. GIS software provides the ability to create polygon overlays to define the area limits within which the relevant factors will be considered for each segment. The polygons take the shape of parallelograms for relatively straight segments and resemble a pie-slice shape for segments with curvature. The determination of the width of the area of interest is largely subjective. Generally, each area is drawn to stretch from shore to shore while incorporating some width of the shoreline. This permits the inclusion of factors such as commercial docking and piers and tributary inflows. Additional factors will be collected based on segment areas of interest for the security analysis discussed in Chapter 3. To maintain a sense of smoothness of adjacent segment area boundaries do not always stretch shore to shore. This usually occurs when there is a dramatic change in shore-to-shore distance from one segment to the next, or when the distance from the corridor path to a shoreline is sufficiently long, more than a nautical mile for instance.

Segment area overlays are drawn by placing the first vertex at a desired point on the shore and drawing a line through the placemark at the beginning of the segment, generally perpendicular to the corridor path leading from the placemark, to a desired location on the opposite shore. The third vertex and second side, are drawn by selecting a point on the shore generally perpendicular to the corridor path leading into the placemark marking the end of the segment. The segment area is usually then completed by selecting the final vertex on the opposite shore, creating the generally perpendicular line through the segment ending placemark. If desirable based on corridor path or shoreline curvature, additional vertices can be added to the polygon. In this dissertation, segment area polygons are created with line styles of orange color, width of 2.5, and opacity of one-hundred percent. Outlined is selected as the polygon area style as area shading is an unnecessary feature. As with segment placemarks, a useful procedure is to create and save segment areas in a separate folder. Subsequent segment areas can be created by copying and pasting the previous segment area within the segment area folder. Selecting the properties option of the pasted area allows for renaming the area to the appropriate segment number and editing of vertex locations by clicking and dragging them to new locations. This operation allows the side of the new polygon shared with the previous segment to remain in the exact same position. This aids in the smoothness of segment area borders and coverage of the entire corridor. For example, creation of the segment area for segment 31 is executed by copying segment area 30, and dragging the two vertices forming the side passing through placemark 29 to new points forming a side passing generally perpendicular through placemark 31. Figure 2-4 depicts the creation of a corridor segment area. The red and blue dots are the vertices of the active polygon. The blue vertex is the vertex most recently manipulated.

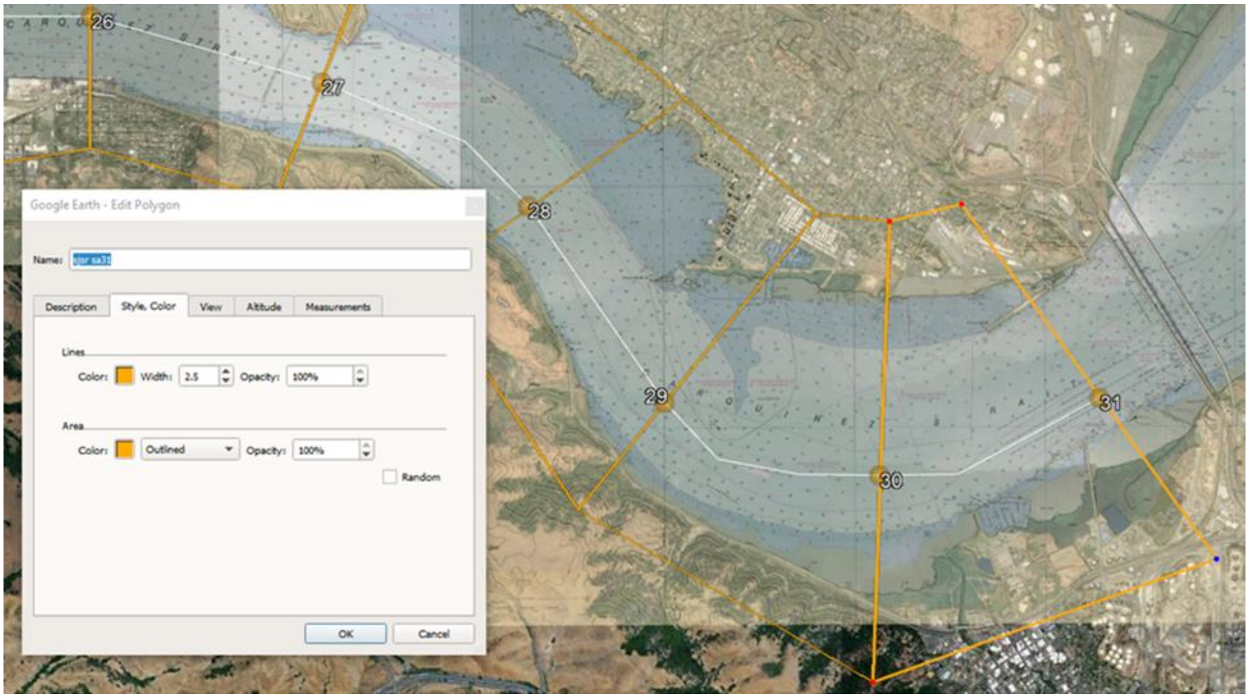


Figure 2-4. Process of creating a segment area.

2-4-2. Safety Risk Factor Selection

The second step of the maritime corridor trace analysis is identification and selection of factors relevant to the safe and efficient operation of the water transportation system. Safety factors relate to unintended vessel hazards of collisions, allisions, and groundings. Collisions refer to contact between two or more vessels. Allisions refer to contact between a vessel and a fixed object. Groundings refer to contact between a ship and the riverbed or shoreline. Estimation of the likelihood of occurrence of these hazards is limited to the classification of three risk threshold levels for each factor: high, moderate, and low.

Identification of safety risk factors can be aided by a number of sources, including the following: (i) previous waterway transportation studies, such as those described in the background section, (ii) the expertise of system operators, such as tug boat pilots or port managers, and (iii) review of waterway regulations and navigation manuals, such as the NOAA Coast Pilot documents discussed in the introduction of this chapter. Factor selection for this study included all three of these sources. The set of factors should be collectable, measurable if quantitative in nature, and definable if qualitative in nature.

Table 2-2 provides a listing of safety risk factors selected for analysis, groups the factors into general categories, and identifies sources which have considered these factors in a safety risk analysis of maritime operations. Expert interview and survey sources include port managers and barge system operators from the Port of Virginia (POV) and leadership from a private defense-sector company with expertise in maritime operations. In this dissertation, the company is referred to with the pseudonym Maritime Operations Company (MOC). Safety risk factor terminology is tailored to the analysis of this dissertation. Many of the cited sources do not use the verbatim terms listed in the Table 2-2. For example, some sources describe factors of traffic intensity or set of incoming ships, which is translated to the terminology used by NOAA's AIS data of vessel traffic cargo, vessel traffic tanker, etc. Alternatively, some sources limit their factor consideration to specific vessel traffic categories, such as cargo or tug traffic. Some sources considered sea-state factors of current and visibility. Data for these factors was not able to be attained for the corridors demonstrated in this dissertation. Factors of inflows and fog have been selected to for their contribution to current and visibility conditions in a waterway corridor. Current is also impacted within a segment by precipitation. The factors listed in Table 2-2 are not inclusive of all safety risk factors identified by the sources. Examples of factors considered by some of the sources but not selected are presence of locks and weirs, underwater and overhead cables, time of day, season, and wildlife.

Table 2-2. Selected safety risk factors for maritime corridor trace analysis.

Safety Risk Factor	Category	Source(s)
Channel width	Geometry	Lalla-Ruiz et al. (2018); Vidan et al. (2012); Wood et al. (2018); NOAA (2019); MOC (2019); POV (2020)
Channel depth	Geometry	Lalla-Ruiz et al. (2018); Vidan et al. (2012); NOAA (2019); POV (2020)
Shore-to-shore distance	Geometry	Vidan et al. (2012); Wood et al. (2018);
Turning angle	Geometry	Montewka et al. (2014); Roeleven et al. (1995); MOC (2019);
Vessel traffic tug/tow	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic cargo	Traffic	Akhtar and Utne (2014); Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic tanker	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic passenger	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic fishing	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic pleasure	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Bridges	Infrastructure	Akhtar and Utne (2014); Elcheick et al. (2017); Roeleven et al. (1995); Vidan et al. (2012); NOAA (2019); MOC (2019); POV (2020)
Commercial pier	Infrastructure	POV (2020)
Buoys and lights	Obstacle	NOAA (2019); MOC (2019);
Obstructions	Obstacle	Vidan et al. (2012); NOAA (2019);
Inflows	Sea-State	Akhtar and Utne (2014); Roeleven et al. (1995); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); POV (2020)
Wind	Sea-State	Akhtar and Utne (2014); Roeleven et al. (1995); Trucco et al. (2008); Wood et al. (2018); MOC (2019); POV (2020)
Precipitation	Sea-State	Montewka et al. (2014); Trucco et al. (2008); NOAA (2019); POV (2020)
Fog	Sea-State	Akthar and Utne (2014); Roeleven et al. (1995); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);

2-4-3. Safety Risk Factor Data Collection

The third step of the maritime corridor trace analysis is the data collection of safety risk factors. The GIS-based corridor definition and visualization is the primary source for the data collection of safety risk factors in the geometry, traffic, infrastructure, and obstacle categories, as well as the inflows factor. Values for each factor are collected for each nautical-mile segment within the segment area of interest. Data for wind, precipitation, and fog are available from wunderground.com.

Safety risk factors in the geometry category relate to the ability of vessels to maneuver along the corridor and also to capacity of the corridor. Channel width is a measure of the width of the corridor where commercial vessels routinely travel and represents collision hazards. In a narrow channel, opposing traffic is presumed to pass at closer distances and contribute to a higher likelihood of collision. There are two circumstances relevant to the determination of channel width in a given segment. When a nautical chart depicts a channel within a segment maintained by USACE, the width of the marked channel at its minimum distance is taken as the value of the channel width for such a segment. When a segment does not contain a maintained channel, vessel traffic overlays assist in determining the trafficked width of the channel. Measurement tools in the GIS application assist in measuring the straight-line widths. Figure 2-5 represents measurements for a section of the corridor where both circumstances exist. The yellow line represents the measurement of a maintained channel marked on the nautical chart overlay. The red line represents the measurement of channel width using a navigational aid buoy shown on the map and the limit of regular vessel traffic depicted by a cargo vessel traffic overlay. When both circumstances exist, the minimum width dictates the recorded segment channel width. Measurements are taken in meters.

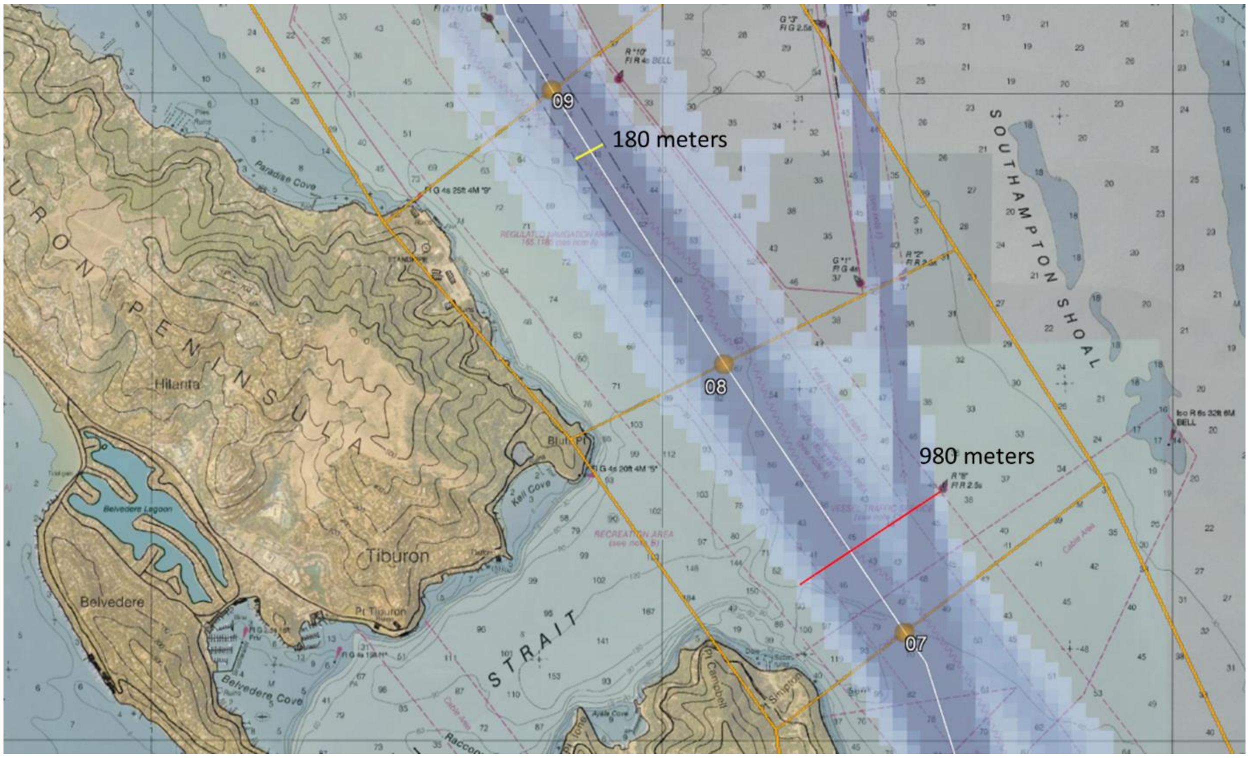


Figure 2-5. Channel width factor data collection. A maintained channel indicated on the nautical chart overlay is depicted by the yellow measurement line. Vessel traffic data and a navigational buoy is used to measure unmarked channels as shown by the red measurement line.

The channel depth factor represents the hazard of potential for grounding and relates to the draft and load capacity of commercial vessels. The same two circumstances for channel width measurement apply to channel depth data collection. Depth of maintained channels are either tabulated in the nautical chart or indicated in writing within the channel as a channel project depth. When no maintained channel exists, a commercial vessel traffic overlay is again used as a stand-in for helping to define the depth of the channel. Water depth soundings are indicated on the nautical chart at irregularly-spaced locations where depth has been measured. In these segments, depth is determined by the lowest depth sounding within the overlay shading. Figure 2-6 depicts instances for both circumstances. In the top portion of the figure, a capture of the channel depth tabulation has been inset into the image. Depth tabulations are not always included in the collarless version. When this is the case, the data can be obtained by either selecting the Collared Preview option for nautical chart overlays, or by viewing a pdf version of the chart of interest. These are available from the access link provided in Table 2-1. The bottom portion relates to the circumstance when there is no maintained channel within a segment. It highlights some level of subjectivity in determining channel depth for segments with this circumstance. Low depth soundings on the fringes of the vessel traffic are sometimes disregarded. In the corridor segment shown, segment 42, there are depth values of 38 and 39 feet near the edge of the vessel traffic overlay. In this case, the value of 45, located more closely to the center of vessel traffic density, is chosen to better represent the minimum channel depth for this segment. The NOAA nautical charts provide depth values in feet. These values are converted to meters for analysis.

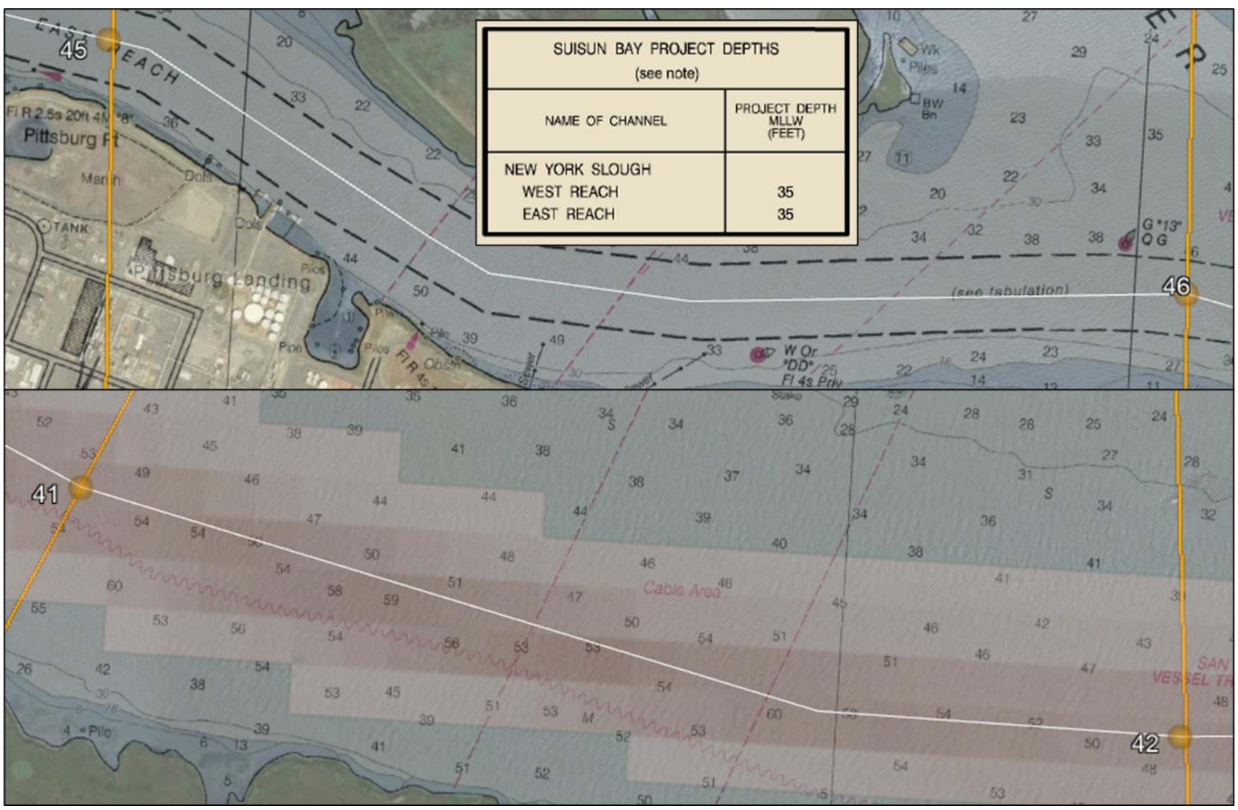


Figure 2-6. Channel depth factor data collection. Tabulated project depths for maintained channels (top). Use of vessel traffic overlay to determine minimum channel depth (bottom).

Shore-to-shore distance is related to the hazard of grounding. It is selected to represent the ability of vessels to maneuver throughout the width of the waterway. Shore-to-shore distance reflects the assumption of a wider shore-to-shore distance offering a greater margin of error for vessels maneuvering outside of the defined channel width. Inspection of nautical charts supports general applicability of this assumption to corridor segments, as acceptable depths tend to extend greater distances beyond the routinely navigated channels in segments with greater distances between shorelines. Shore-to-shore distance is recorded by embedded GIS application measuring tools to determine the minimum distance between shorelines within a given segment. Distances are measured in meters. Any shore-to-shore distance over 1850 meters, or approximately one nautical mile, is recorded as 1850 meters. This is a data-scale related decision to achieve a meaningful presentation of shore-to-shore factor data in the corridor trace chart.

The turning angle safety risk factor is selected for contribution to collision, allision, and grounding hazards. A greater turning angle within a corridor segment is associated with decreased vessel control and travel heading predictability by nearby vessels. Turning angle data could be determined mathematically by determining straight-line path segment vectors using geospatial locations for beginning and end points of adjacent path segments. However, the most efficient method for finding turning angles is manual measurement using a protractor on the screen. All angles created by the straight-line path segments of the corridor path within a given corridor segment are measured and summed to determine a corridor segment’s turning angle factor value. For instances in which the vertex of a turning angle is coincident with a segment placemark (begins at the beginning of a segment), the angle is attributed to the segment one greater than the coincident placemark.

The vessel traffic safety risk factors for the various vessel types are most closely applicable to the hazard of potential collisions. The process for determining factors values is essentially the same for vessel types. Spreadsheet-based, detailed AIS data is available from the NOAA at https://marinecadastre.gov/ais/. Data is available for download for multiple years and is sectioned into Universal Transverse Mercator (UTM) zones. The data represents the GPS-based location reporting of individual vessels within 100-meter grid squares for an entire year. File sizes of the downloadable datasets are upwards of four gigabytes. The procedure to attain GIS compatible vessel traffic overlays is discussed in Section 2-4-1. The vessel traffic overlays are color-scale representations of the vessel traffic density derived from the 2016 datasets. The use of vessel traffic overlays is suitable for the categorization of factors into risk threshold levels and is highly compatible with GIS-based corridor trace analysis methods presented. It does introduce a level of subjectivity to the factor value determination.

Figure 2-7 is a capture of a portion of the inland waterway corridor and the overlay for pleasure and sail craft vessel traffic. This section of the corridor contains a variety of the color scale intensity for vessel transit counts. Figure 2-8 provides the color-scale legend used to determine the factor level value for each corridor segment. Values are recorded as 1, 2, or 3, corresponding to the risk threshold levels of low, moderate, and high. The values for high levels in the legend correspond to vessel counts in a given 100-meter grid square over a yearly period, and do not exactly represent the number of vessels passing through the grid square. Vessel traffic overlays for each vessel type should be viewed at one-hundred percent opacity to best match with the overlay legend. The highest color intensity, and therefore vessel transit count, within a segment is the determinant of the segment value.

Figure 2-7. Vessel traffic factor data collection. Vessel type pleasure and sail craft is depicted.

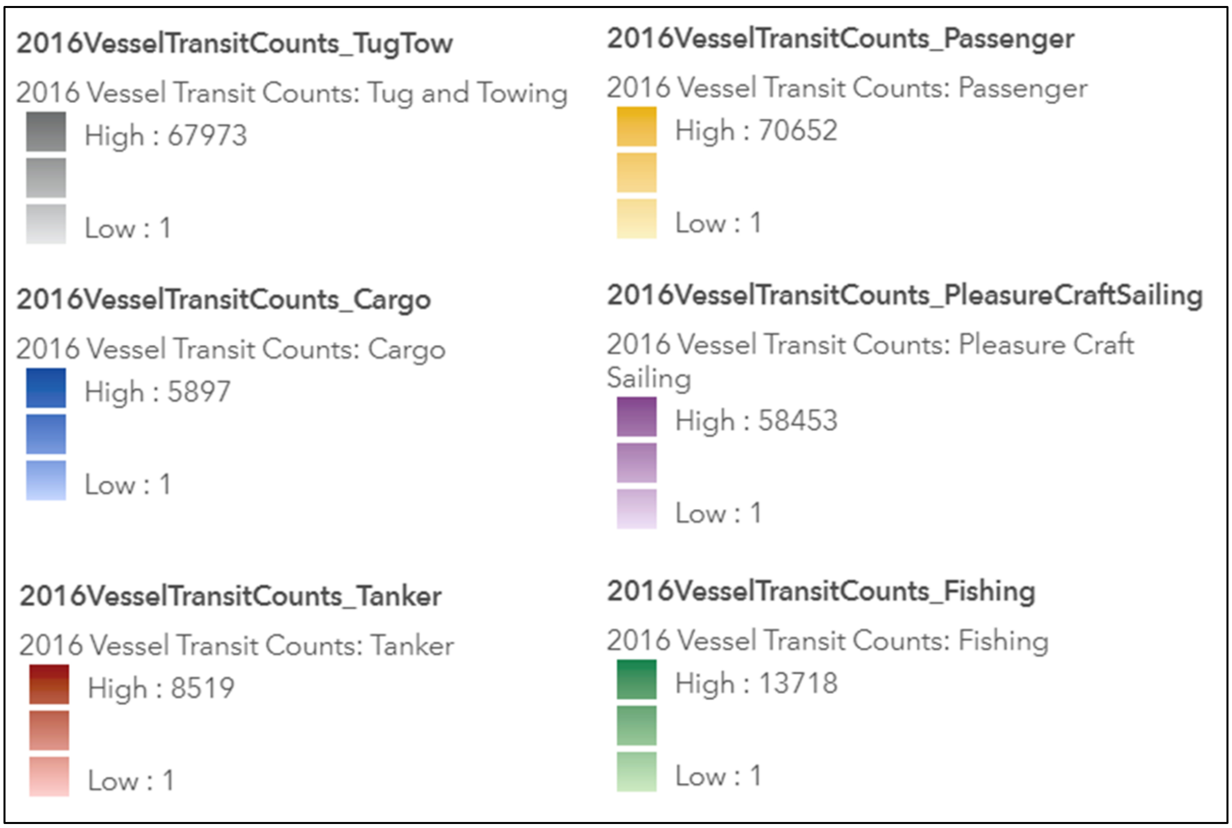


Figure 2-8. Vessel traffic factor color intensity legend. Source: NOAA.

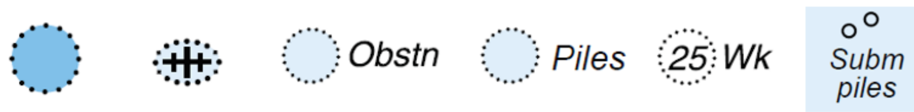
The bridges safety risk factor is indicative of the allision hazard primarily, though bridges are often a limiting factor for corridor segment channel width and could contribute to collision hazard. Only bridges crossing the corridor path are considered. Corridor segments are assigned a bridge factor value of 0, 1, 2, or 3 based on the following considerations. Segments containing more than one bridge greater than three-hundred meters apart are assigned a value of 3. Segments containing one bridge or consecutive bridges, such as generally parallel road and rail bridges within three-hundred meters, are assigned a bridge factor value of 2. Segments with no bridge, but adjacent to a segment containing at least one bridge are assigned a factor value of 1. The consideration for these segments is a likely requirement for vessels to maneuver before reaching the bridge to align with constricted channel width due to the bridge support structure. All remaining segments are assigned a factor value of 0.

The commercial pier safety risk factor considers both commercial piers extending into the waterway and shoreside ship docking for commercial or industrial operations. It is primarily considered to contribute to the collision hazard, representing the merging of large vessels (tanker, cargo, and tug and tow vessels) or the potential for cross-facing vessel traffic within the corridor channel. Piers secondarily pose an allision hazard though the extent of their reach typically ends outside of the routinely navigated channels. Factor values of 0, 1, and 2 are assigned. Segments with no commercial piers or docks are assigned a value of 0, segments with one or more piers or docks on only one shore are assigned a value of 1, and segments with these factors on both shores are assigned a value of 2. Figure 2-9 contains examples of infrastructure considered in assigning segment values for the commercial pier safety risk factor. In addition to piers and shoreside docks, reserve fleets anchorages exist on the James River in Virginia, the corridor demonstrated in Chapter 5 and pictured in Figure 2-9, and on Suisun Bay in California which is part of the inland waterway corridor demonstrated in this chapter.

Figure 2-9. Commercial pier factor infrastructure examples. A commercial pier for tanker vessels extending near the corridor path centerline (left). A shoreside dock with ship to shore cranes for cargo vessels (top right). Reserve fleet anchorage (bottom right).

Safety risk factors in the obstacle category are selected to represent the hazard of allisions. Buoys and lights are considered as fixed objects on the surface and obstructions are considered fixed objects below the surface. Corridor segment values for buoys and lights as well as obstructions are assigned by a count of each type of obstacle within a segment. Some subjectivity exists in the assignment of factor values in the obstacle category. Obstacles well outside of the routinely traveled width of a channel are not included in the factor value counts. Examples include lights marking the shoreline, lights marking the location of piers and docks, and obstacles including buoys, lights, and obstructions in depths of less than approximately four meters or twelve feet on the nautical charts. Table 2-3 includes examples of nautical chart symbols indicating the location of obstacles in the corridor. Figure 2-10 is a collection of some of these symbols on the nautical chart overlays in various corridor segments.

Table 2-3. Obstacle factor types and symbol examples.

Obstacle type	Symbols
Buoys and lights	
Obstructions Piles Wrecks	

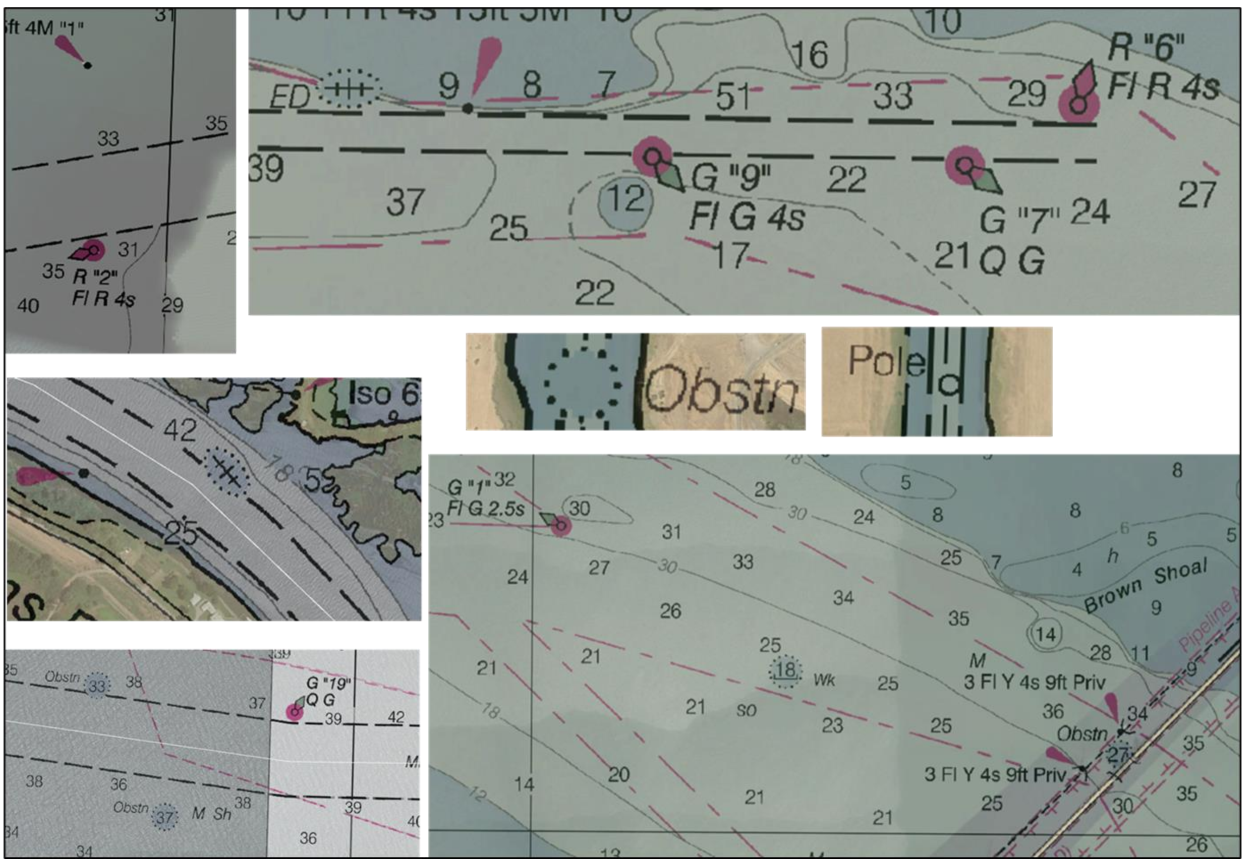


Figure 2-10. Obstacle factors mise-en-scene in various corridor segments.

Safety risk factors in the sea-state category represent collision, allision and grounding hazards. Many of the factor selection sources have included the use factors such as current, wind and visibility. Notably maritime system expert interviews noted the limiting impact of undesirable sea-states on operations. There are two primary limitations associated with the use of these factors, but they are included to acknowledge the relevance of sea-state to the hazards. These limitations are introduced here.

The first limitation is the availability of data for the desired factors. Data for current and visibility is largely unavailable. An extensive web-based data search revealed several options for retrieval of waterway related weather data. Among these are the United States Geological Survey (USGS), which operates a site called WaterWatch, available at https://waterwatch.usgs.gov/index.php. This source offers historical flow (current) and runoff data for a great number of locations in all fifty states. A Google Earth Pro compatible, kml file is providing a data collection station overlay with links to the collection station websites for data retrieval is available. However, the data is mostly limited to select streams and tributaries of the primary corridors of concern.

The NOAA provides access to a nationwide network of data buoys available at https://www.ndbc.noaa.gov/. There is a reasonable density of data collection coverage along the length of the corridors demonstrated in this dissertation. For example, there are at least ten data buoys along the forty-three nautical-mile section from San Francisco Bay to the end of Suisun Bay for the corridor demonstrated in this chapter. Some of the data fields included in the data are air temperature, wind speed, wind direction, wind gust speed, sea level pressure, and visibility (given in miles). For many of the data buoys, historical data is available for every day back to 2005. Temperature and wind related data from this source is robust and consistent, but visibility data is provided only for a sparing number of the data buoys. Figure 2-11 demonstrates the GIS based collection station selection capability of both the USGS and NOAA sources.

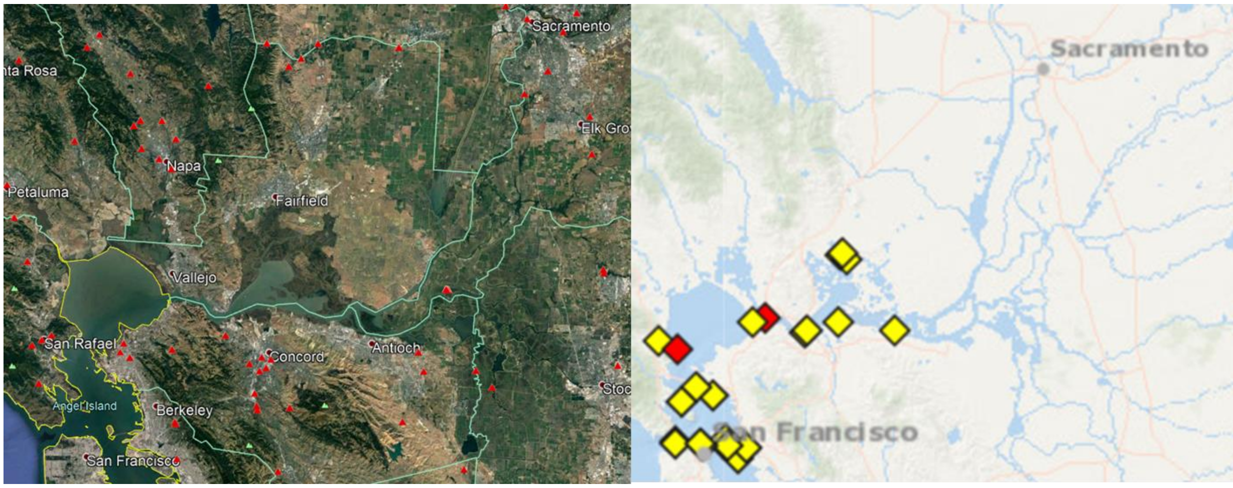


Figure 2-11. Sea-state factor data collection site location examples. USGS collection stations as a selectable GIS overlay (left). NOAA data buoys as a selectable inset available at https://www.ndbc.noaa.gov/ (right).

The Coast Pilot documents provide tabular data for selected areas. These documents provide summarized data in the form of various statistical measures for all months of the year of record of the data, which is presumed to be the year prior to the publication year of the document. Available data includes temperature, precipitation, wind speed, wind direction, and visibility (given as mean number of days with fog). In terms of coverage area however, the data available from Coast Pilot documents is sparse. For example, *United States Coast Pilot 7*, which covers the all three states on the Pacific coast, Hawaii, and the Pacific Islands, the tabular data is only available for twelve locations.

Sea-state factor data is available from a number of weather forecasting websites. From among these sites, https://www.wunderground.com/ was chosen as the source for the safety risk factors of wind, precipitation and fog. This source provides consistent data formatting and reporting with coverage locations available along the full length of corridors, though each chosen location is still used to represent conditions for tens of nautical miles. Regional airport locations offer the most consistent historical data in the form of daily maximum, minimum and average values for temperature, dew point, and wind speed, and total daily values for precipitation. For each chosen location, data is available for each day of each month and as far back as at least ten years for most locations.

The second limitation is the temporal nature of sea-state factors. Sea-states vary along the length of the corridor, but more importantly, they can vary hour-to-hour, day-to-day, and year-to-year. To conform with the segment-based corridor trace methodology, yearly average and maximum values in centimeters are presented for wind and precipitation. Borrowing from the Coastal Pilot documents, visibility is represented by fog, and is presented as percent of annual days with potential for fog development. Potential for fog development is calculated by determining the number of days in which the difference between the minimum temperature and the minimum dew point is less than 2.5 degrees Celsius. The number of days meeting this criterion is divided by three hundred and sixty-five days. Data for wind, precipitation and fog are from 2019.

Presenting factor data from the sea-state category in this manner results in an acknowledged loss of information and little usefulness for operational planning. These factors are included in the analysis to acknowledge their important relationship to collision, allision, and grounding hazards, as supported by source literature and especially by maritime system expert interviews. Potential means to address the limitations of these factors are presented in Chapter 7.

The safety risk factor of inflows is selected for the contribution of inflowing current from waterway corridor tributaries to current in conjunction with precipitation. Segment values for inflows are determined by the count of tributaries flowing into the corridor in a given segment. Some subjectivity is introduced in the determination of inlets not contributing a significant volume to the corridor, or those flowing away from the corridor, such as upstream flows around islands or flows from the corridor into a bay. Inflow data is collected in a manner consistent with the other, non-sea-state factors. For analysis discussed in the demonstration, including determination of compounded risk segments and calculation of segment rankings, the safety risk factor inflows is treated in the same manner as the non-sea-state factors.

The data for all factors are recorded in a spreadsheet. Rows correspond to the sequential corridor segments. Columns correspond to safety risk factors. It is desirable to designate five to six columns for each factor to facilitate creation of individual factor corridor traces as discussed in Section 2-4-5. Tables including the raw factor data are included in Appendix A.

2-4-4. Safety Risk Factor Threshold Determination

The fourth step of the maritime corridor trace analysis is the risk threshold determination of safety risk factors. Threshold values signify cutoffs between low, moderate and high-risk levels. Threshold values are derived from the various sources discussed previously, with most consideration given to maritime system expert judgment. Vessel traffic factor thresholds are based on the NOAA vessel traffic overlay legend values, divided generally into thirds. Table 2-4 indicates threshold values associated with low, moderate and high-risk levels for each selected factor. For channel width, channel depth, and shore-to-shore distance factors, the high threshold range is indicative of lower segment factor values. For all other factors, the high threshold range is indicative of higher segment factor values.

The classification of risk levels does not prescribe negligible risk to segments with low-risk levels for categories. Rather, the maritime corridor trace offers a prioritization feature to planners and decision-makers constrained by limited resources, including planning time available.

Table 2-4. Threshold values for safety risk factors.

Factor	Unit of measure	Threshold values		
		High	**Moderate**	**Low**
Channel width (cw)	meters	< 100	100 - 300	> 300
Channel depth	meters	< 6	6 - 10	> 10
Shore-to-shore distance	meters	< 500	500 - 1000	> 1000
Turning angle	degrees	> 60	30 - 60	< 30
Vessel traffic tug/tow	color-scale estimate of AIS vessel counts	> 46,000	23,000 - 46,000	< 23,000
Vessel traffic cargo	color-scale estimate of AIS vessel counts	> 4,000	2,000 - 4,000	< 2,000
Vessel traffic tanker	color-scale estimate of AIS vessel counts	> 6,000	3,000 - 6,000	< 3,000
Vessel traffic passenger	color-scale estimate of AIS vessel counts	> 50,000	25,000 - 50,000	< 25,000
Vessel traffic fishing	color-scale estimate of AIS vessel counts	> 10,000	5,000 - 10,000	< 5,000
Vessel traffic pleasure	color-scale estimate of AIS vessel counts	> 40,000	20,000 - 40,000	< 20,000
Bridges		bridge in segment	bridge in adjacent segment	no bridge
Commercial pier		present on both shores	present on one shore	none
Buoys and lights	number of buoys	> 2 if cw < 100 > 5 otherwise	2 if cw < 100 3 - 4 otherwise	< 2 if cw < 100 < 3 otherwise
Obstructions	number of obstructions	> 4	2 - 4 if cw < 100 3 - 4 otherwise	< 2 if cw < 100 < 3 otherwise
Inflows	number of inflows	> 1	1	0
Wind	knots	> 30	10 - 30	< 10
Precipitation	centimeters	> 10	4 - 10	< 4
Fog	% days / year	> 40	20 - 40	< 20

2-4-5. Maritime Corridor Trace Production

A uniqueness of the corridor trace analysis is to present a planning and decision-making framework associated with the operating environment of the maritime transportation system. The next step of the maritime corridor trace analysis facilitates decision-making through the production of individual factor corridor traces. The corridor trace depicts the relevant factor values and impact levels along the length of the maritime corridor with corridor segments plotted along the horizontal axis.

The data collection spreadsheet from the previous step facilitates the creation of factor corridor traces. For each factor, three additional columns are created for low, moderate and high risk-level thresholds. Conditional statements in each of the three columns determine if the factor raw value is within the range of values for the low, moderate or high threshold. A value of 1 is assigned in the risk-level column for which the conditional statement is true and a value of 0 for false, resulting in a sum across the three threshold columns in each segment row equal to 1.

It is desirable to present both the in-segment risk level and the in-segment raw value of each factor in its respective corridor trace. A combination chart facilitates the presentation of multiple data series with differing vertical axis scales. Each of the three risk-level columns and the raw data column are individual data series. The risk-level columns are chosen to appear as a clustered column chart type on the primary axis. The risk-level data series are colored consistent with Table 2-4. Low risk-level is colored green, moderate is colored yellow and high is colored red, with no border for any of the three risk-level data series. Other pertinent formatting includes a zero percent gap width and a one-hundred percent series overlap. The primary axis has a minimum value of 0 and a maximum value of 1. These format settings result in a continuously filled chart in which the color at each segment along the horizontal axis describes the risk level for the safety risk factor of interest. The raw value data series is chosen to appear as a line graph on the secondary axis. The minimum value of the secondary axis is zero and the maximum value is appropriate for each respective safety risk factor. Data labels for selected factors can be added to the raw data line chart to highlight key data points, such as values for the turning angle safety risk factor in segments associated with moderate and high-risk levels. Figure 2-12 is an example corridor factor trace for the safety risk factor channel width, aligned with a straightened GIS representation of a section of the corridor used as the demonstration in this chapter.

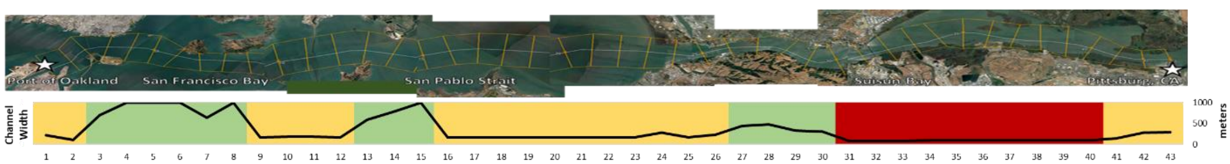


Figure 2-12. Example corridor factor trace for channel width.

The creation of corridor factor traces for the sea-state factors of wind, precipitation and fog is slightly adjusted, due to the current lack of fidelity in the data. Instead of indicating the factor threshold value for each segment as a clustered column chart, the three threshold levels are indicated for each segment in a stacked column format. The low threshold takes the value of the difference between zero and the minimum moderate threshold value. The moderate threshold takes the value of the difference between the minimum and maximum moderate threshold value. The high threshold takes a scaling value reasonable to permit a viewable band thickness for all three thresholds as well as the display of the sea-state factor values across all segments. For wind and precipitation, both the maximum and average values are plotted as line plots in different colors on the secondary axis. In this manner, the risk level of both the average and maximum values are presented for each segment. Figure 2-13 is an example corridor factor trace for the safety risk factor wind.

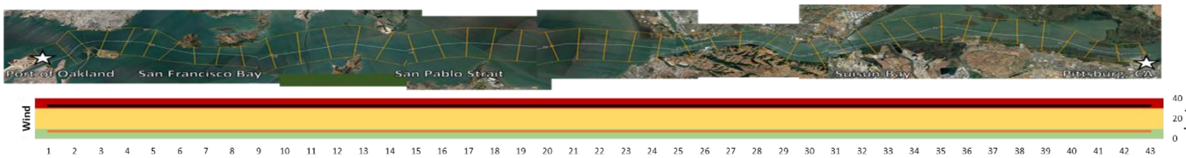


Figure 2-13. Example corridor factor trace for wind.

The simultaneous visualization of multiple factor traces allows decision makers to compare factors and identify corridor sections representing vulnerabilities for system operations. It is feasible to create factor traces for wind, precipitation, and fog more consistent with the other selected factors. For example, wind and precipitation could be separated into maximum and average factors, each on a separate trace permitting the indication of a single risk level for each segment. Considering the lack of information provided by the current characteristics of these values, it is reasonable to use the format described. The format is selected for the trade-off between presenting meaningful and as much data as possible, which would be supported by a consistent trace for wind, precipitation, and fog, and the ability to consolidate as many factor traces as possible in a single view. Based on both lack of consistency and information provided, wind, precipitation, and fog factor traces are separated from the other factors by the straightened GIS representation of the corridor when presented.

2-5. Demonstration

In this section, the methods described in Section 2-4 are applied to an inland waterway corridor network in the San Francisco Bay, Sacramento, and San Joaquin Valley region of California. In the rest of this chapter, the region is referred to as the Central California region, or just Central California. A description of some intended uses of maritime corridor trace analysis for operational planning and corridor management is presented. A set of visual, decision-aiding tools provides a basis for development of a risk register for maritime corridor segments. The risk register concept is discussed further in Chapter 4.

2-5-1. Demonstration Background

The starting point of the inland waterway corridor is chosen at the deep-water port in Oakland. The inland waterway corridor network extends north from the Port of Oakland through San Francisco Bay and the San Pablo Straight in the bay of the same name and then turns east. It includes the Carquinez Strait passing by the towns of Crockett and Benicia, Port Chicago, and the town of Pittsburg. At segment 43, (43 nautical miles), the maritime corridor divides at the confluence of the Sacramento and San Joaquin Rivers. From this point two corridors are demonstrated for vessel traffic to Stockton, utilizing the San Joaquin River and to Sacramento, utilizing the Sacramento River for about 7 nautical miles before entering the Sacramento Deep Water Ship Channel.

There are several intraregional road networks in this part of California. Interstate 80 connects Oakland to Sacramento over a distance of approximately 130 kilometers (82 miles). Interstate 580 connects Oakland and Stockton over a distance of approximately 114 kilometers (71 miles) including a portion of Interstate 5. Sacramento and Stockton are connected by Interstate 5 over a distance of 78 kilometers (49 miles). California Highway 12 is an alternate route, exiting Interstate 80 in Fairfield and joining Interstate 5 between Sacramento and Stockton. This region is depicted in Figure 2-14.

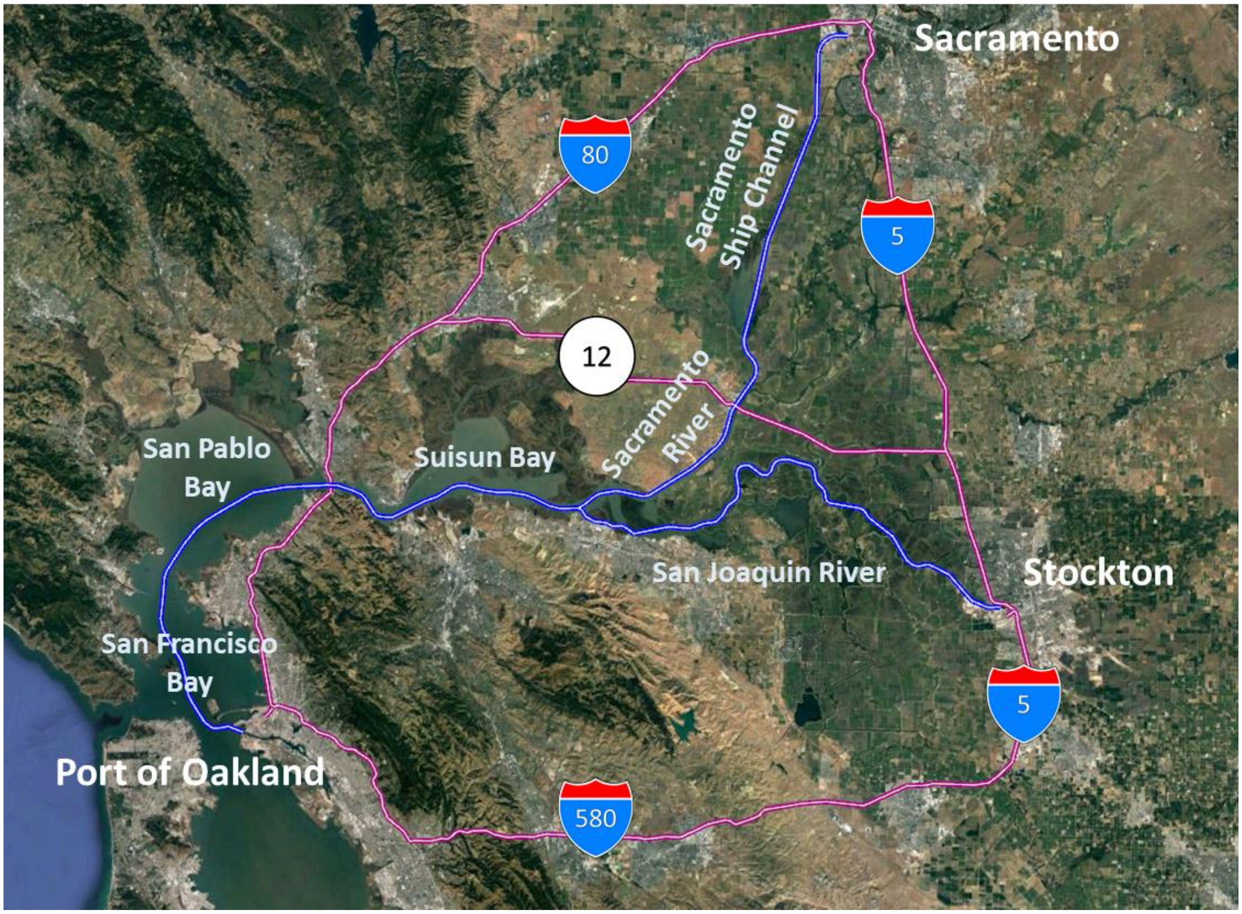


Figure 2-14. San Francisco Bay, Sacramento, and San Joaquin Valley region. Inland waterway corridors are highlighted in blue with roadway corridors highlighted in purple.

The Port of Stockton is a deep-water port located 78 nautical miles from the Port of Oakland along the defined inland waterway corridor. Its main commodities are dry bulk including coal, cement, sulfur, steel and agricultural products. It also handles hundreds of thousands of metric tons liquid bulk cargo including fertilizer, food grade oils and molasses (Port of Stockton, 2018). In 2018, the Port of Stockton reported its third consecutive year of record tonnage growth, and announced the commitment of at least $13 million in infrastructure improvements to rail, highway, and port complex systems to accommodate expected future growth. The port claims a regional economic impact of $1.6 billion. The port authority of the Port of Stockton is a port landlord. This designation means the port authority provides and maintains terminal infrastructure, but leases the land and infrastructure to tenants who conduct port operations for profit (USDOT, 2018).

The port authority for the Port of West Sacramento also operates as a landlord. The Port of West Sacramento is a deep-water port located 83 nautical miles from the Port of Oakland along the defined inland waterway corridor. Four companies operate terminals in the port complex. The major commodities are cement and agricultural products with rice chief of among them. As expected for private enterprise, the lessees anticipate continue growth in bulk tonnage handled at the Port of West Sacramento, citing the additional available capacity of the port as a growth opportunity (Yara, 2017).

Both the Port of Stockton and the Port of West Sacramento maintain relationships with international trading partners. Vessels arriving at both ports are ocean-going. Vessel calls include ships of the Panamax and “large Panamax” classes (Port of Stockton, 2018). Large Panamax is taken to refer to the class also known as Post-Panamax, which are approximately 335 meters (1,100 feet) long.

2-5-2. Maritime Corridor Trace Development

The maritime corridor trace for the Central California region is divided into three sections. The first component begins at the Port of Oakland and ends after 43 nautical miles at the approximate end of Suisun Bay near Pittsburg, California, where the Sacramento River and the San Joaquin

River meet. The second section is 35 nautical miles long and consists of the San Joaquin River from its confluence with the Sacramento River to the Port of Stockton. The third section is 40 nautical miles long and consists of a 7 nautical-mile portion of the Sacramento River and the entire 33 nautical-mile length of the Sacramento Deep Water Ship Channel.

The maritime corridor trace includes all eighteen maritime corridor factor traces for the selected safety risk factors. A purpose of this chapter is to highlight a particular application of the maritime corridor trace, the ability to visualize a broad set of data in a format usable by multiple stakeholders at the appropriate level of detail. Ideally, all traces would be included in an unbroken format allowing a simultaneous viewing of the complete set of data. Display limitations require the maritime corridor trace for each section to be divided into two sets of factor traces. The first set includes safety risk factors in the geometry and traffic categories. The second set includes safety risk factors in the infrastructure, obstacle and sea-state categories. Display considerations and limitations are addressed further in Section 2-6. The maritime corridor trace allows for visual analysis to identify compounded risk segments along the route. Additional tables are developed to augment the use of the maritime corridor trace during identification of these compounded segments.

2-5-3. Central California - Section 1: Port of Oakland through Suisun Bay

Figure 2-15 and Figure 2-16 include all eighteen maritime corridor factor traces for the selected safety risk factors for section 1 of the Central California region maritime corridor network. Figure 2-15 displays safety risk factors in the geometry and traffic categories while Figure 2-16 displays safety risk factors in the infrastructure, obstacle and sea-state categories. Table 2-5 displays the distribution of safety risk factor threshold levels within each segment. Table 2-6 displays the distribution of segments by risk level within each safety risk factor. The data in Table 2-5 and

Table 2-6 includes the separation of average and maximum values for wind and precipitation, resulting in a total of 20 safety risk factors. While understanding the limitations of sea-state data presented in a non-temporal manner, the separation of average and maximum values provides a sense, if only basic, of the impact of these factors during average and severe weather. Consolidation of average and maximum values in a single factor trace limits the number traces needed to be displayed while still providing the same information. These factors are included in the table, but they are given little consideration in identifying compounded risk segments and are given unique treatment in the calculation of segment rankings. This unique treatment is discussed later in this section with the introduction of segment ranking procedures. The sea-state factors of wind, precipitation, and fog continue to be included to provide a basis for improvements in presenting these factors in future work.

Identifying compounded risk segments allows enterprise mangers to understand the simultaneous effects of safety risk hazards along the maritime corridor. This can be accomplished by visual inspection of the corridor trace by scanning along the corridor trace for segments, or segment groupings where multiple safety risk factors are classified meet the moderate or high threshold. Table 2-5 is intended to assist in this assessment. The histogram and numerical indication of safety risk factors in each level help focus the user's attention to relevant segment groupings. The maritime corridor trace details which safety risk factors contribute to the compounding risk levels. The enterprise manager can then consider the contribution of those factors to the overall risk to operations.

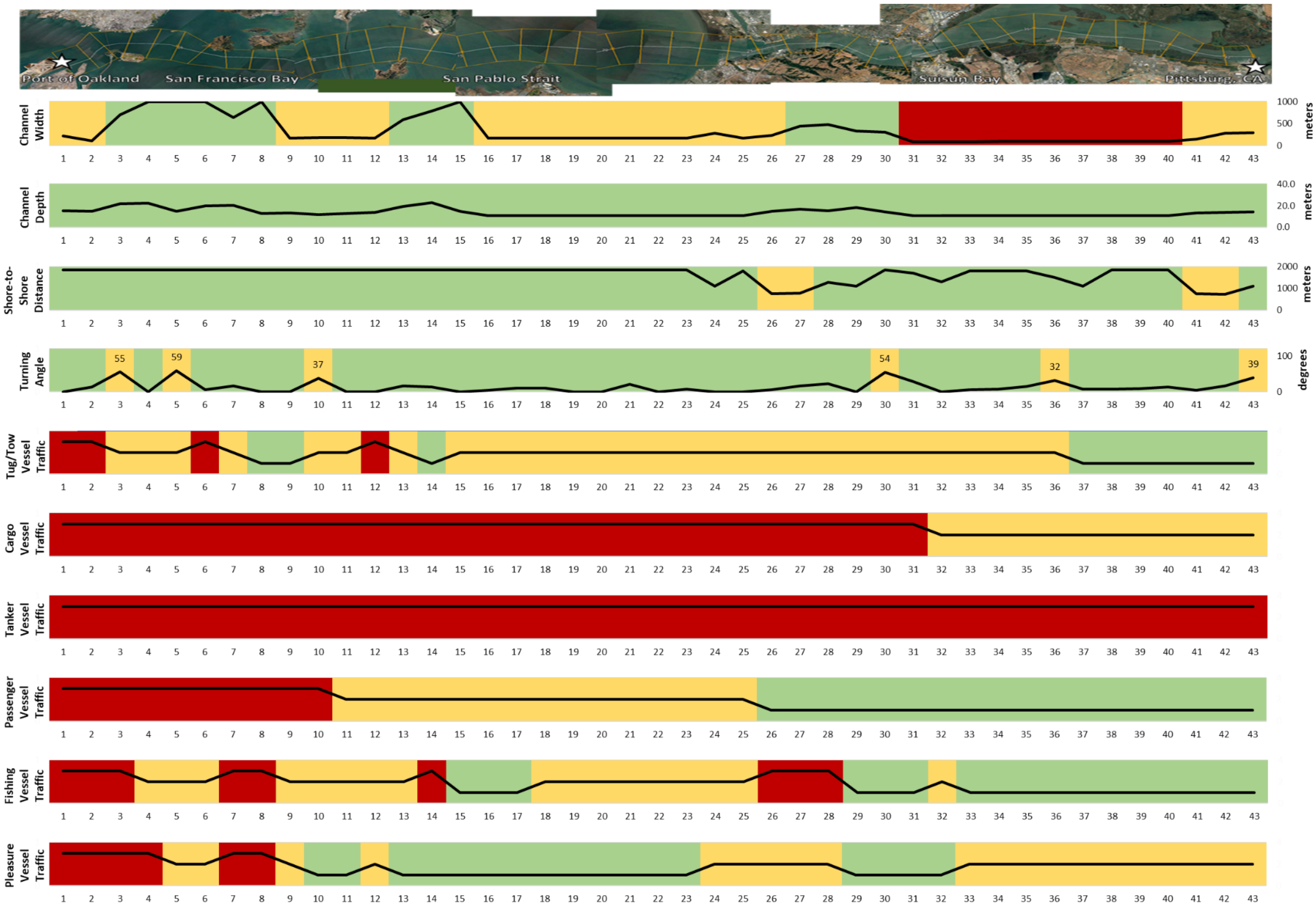


Figure 2-15. Maritime corridor trace of Central California - section 1 for geometry and traffic factor categories.

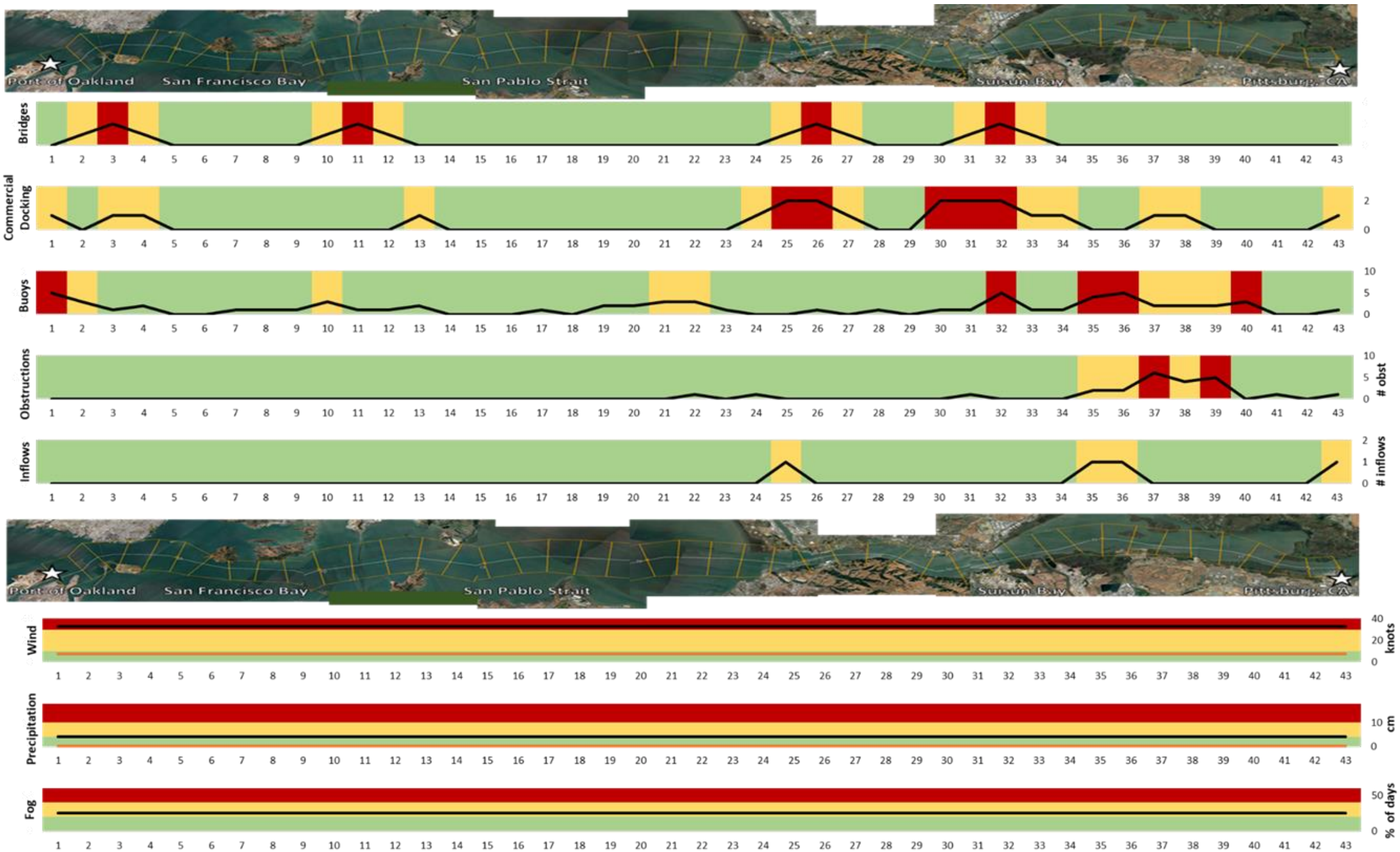


Figure 2-16. Maritime corridor trace of Central California - section 1 for infrastructure, obstacle, and sea-state factor categories.

Table 2-5. Distribution of safety risk factor levels in each segment for Central California – section 1.

Segment	Number of Factors Within Threshold		
	High	**Moderate**	**Low**
1	8	4	8
2	7	5	8
3	7	5	8
4	5	6	9
5	4	6	10
6	5	4	11
7	6	3	11
8	6	2	12
9	4	5	11
10	4	8	8
11	4	6	10
12	4	7	9
13	3	6	11
14	4	3	13
15	3	4	13
16	3	5	12
17	3	5	12
18	3	6	11
19	3	6	11
20	3	6	11
21	3	7	10
22	3	7	10
23	3	6	11
24	3	8	9
25	4	9	7
26	6	6	8
27	4	7	9
28	4	4	12
29	3	3	14
30	4	4	12
31	5	4	11
32	6	5	9
33	3	7	10
34	3	6	11
35	4	7	9
36	4	8	8
37	4	6	10
38	3	7	10
39	4	5	11
40	4	4	12
41	2	6	12
42	2	6	12
43	2	8	10

Table 2-6. Distribution of segments by risk level within safety risk factors for Central California – section 1.

Factor	Hazards	Number of Segments Within Threshold High	Moderate	Low
Channel width	Collision	10	20	13
Channel depth	Grounding	0	0	43
Shore-to-shore distance	Grounding	0	4	39
Turn angle	Collision, allision, grounding	0	6	37
Vessel traffic tug/tow	Collision	4	29	10
Vessel traffic cargo	Collision	31	12	0
Vessel traffic tanker	Collision	43	0	0
Vessel traffic passenger	Collision	10	15	18
Vessel traffic fishing	Collision	9	17	17
Vessel traffic pleasure	Collision	6	20	17
Bridges	Allision, collision	4	8	31
Commercial pier	Collision, allision	5	11	27
Buoys and lights	Allision	5	7	31
Obstructions	Allision	2	3	38
Inflows	Collision, allision, grounding	0	4	39
Wind (average)	Collision, allision, grounding	0	0	43
Wind (maximum)	Collision, allision, grounding	43	0	0
Precipitation (average)	Collision, allision, grounding	0	0	43
Precipitation (maximum)	Collision, allision, grounding	0	43	0
Fog	Collision, allision, grounding	0	43	0

Inspection of Table 2-5 suggests groupings of segments 1-4, segments 24-26 and segments 30-32 may warrant closer inspection in the corridor trace figures. Segments 1-4 have high and moderate level factors in buoys, vessel traffic of all types, commercial docking, a turning angle of 55 degrees in segment 3 and a moderate channel width in segments 1 and 2. This segment, at the beginning of the corridor, leads from the Port of Oakland into San Francisco Bay. This urban and industrial area would be expected to have high vessel traffic and the presence of multiple commercial docks. Highlights of segments 24-26 are commercial facilities on both shores, a tributary inflow, high vessel traffic, and a moderately narrow channel leading to a bridge constriction. Safety risk factor levels in segments 30-32 are indicative of commercial piers on both shores, high level cargo and tanker vessel traffic, moderate tug and tow vessel traffic, a combined turn angle of 82 degrees leading to a maintained, narrow channel width with a high-risk level for buoys as obstacles and a bridge in segment 32. The narrative description of these segment groupings highlights the possibility of enterprise operators may assessing a compounded risk for one direction of travel, but a lower risk for the other direction. Figure 2-17 provides a detail view of segments 30-32 with the relevant portions of the maritime corridor trace for the safety risk factors mentioned. The tanker vessel traffic overlay is shown at approximately 40% opacity.

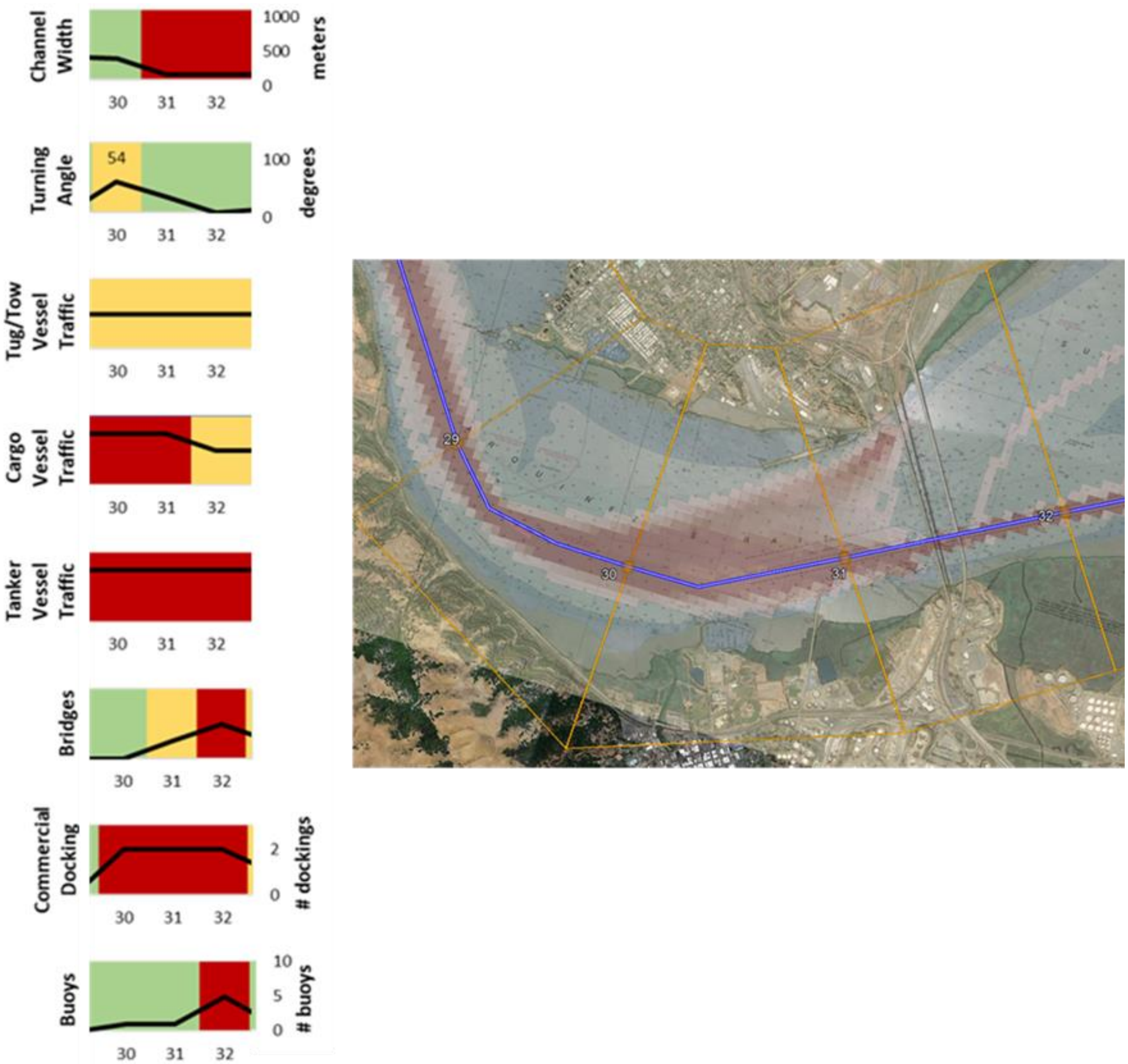


Figure 2-17. Detailed view of compounded risk segment grouping 30-32 for Central California – section 1 with associated factor trace portions for selected safety risk factors.

The distribution of segments by risk level in Table 2-6 gives an overview of the most prevalent safety risk factors in the maritime corridor. With inclusion of hazards associated with the safety risk factors as described in Section 2-4-3, the table also gives an overview of the most prevalent hazards.

An additional management tool facilitated by the maritime corridor trace is to establish a segment ranking. Establishing a safety risk factor rating through stakeholder assessment would provide a new set of information for operational planning and further support the usefulness of the maritime corridor trace to a variety of stakeholders. Vessel operators, port authorities, USACE, and recreational boaters may have varied perspectives on the relative importance of the safety risk factors which would result in a multiple set of segment rankings.

For this demonstration, the data included in Table 2-6 is used to establish the relative importance of safety risk factors and a common multi-criteria analysis approach is applied. A safety risk factor raw score, r_f, for each factor, f, is established according to

$$r_f = \sum T_i f_i,$$

Where T_i is the threshold weight for threshold i: {high, moderate, low}, T_i: {60, 30, 10} and f_i is the number of segments within threshold i for factor f, given in Table 2-6.

Considering an interest to continue acknowledging the importance of the weather-based sea-state factors, wind, precipitation, and fog, and the reduced reliability of these factors, safety risk factor raw scores are calculated in two separate groupings. Safety risk factor raw scores for geometry, traffic, infrastructure, and obstacle categories as well as inflows are calculated in group 1. Safety risk factor raw scores for sea-state factors wind, precipitation and fog are calculated in group 2. Once raw scores for both groups are determined, a scaling factor for group 2, u, is calculated. The maximum raw score value is set equal to half of the value of the minimum raw score value for group 1. The ratio of the decrease in this value is set as the scaling factor for the remaining group 2 factors. If $r1_f$ is the set of raw scores for group 1 and $r2_f$ the set of raw scores for group 2, the scaling factor for group 2 safety risk factor raw scores is determined according to

$$\max r2_{f,new} = 0.5 * \min r1_f,$$

$$u = \frac{\max r2_{f,new}}{\max r2_f}.$$

The remaining group 2 raw scores are then multiplied by the scaling factor to determine the incorporated group 2 raw scores, by

$$r2_{f,new} = u * r2_f.$$

Safety risk factor weighted scores, w_f, are determined by dividing each factor raw score by the summation of all factor raw scores.

Normalized segment raw-data factor scores, $d_{j,f}$ for channel width, channel depth and shore-to-shore distance are obtained by dividing the minimum value among all segments for factor f by the factor raw-data value for each segment, j. For all other factors, normalized segment raw-data factor scores are obtained by dividing the segment raw-data value by the maximum value among all segments for factor f. Segment factor weighted scores, $s_{j,f}$, are established according to

$$s_{j,f} = w_f d_{j,f}$$

and segment scores, S_j, according to

$$S_j = \sum_f s_{j,f}.$$

Figure 2-18 is a corridor trace-based representation of segment scores. The ranking of each segment based on those scores is indicated above the line-plot representing the segment scores. Safety risk threshold levels, replicating safety risk factor threshold levels, are also indicated for each segment. In this demonstration they are determined by dividing the number of segments in the corridor into quartiles and assigning segments ranked within the bottom quartile range as a high-risk level, segments ranked 1 through 10 for Central California – section 1. Segments ranked in the quartile below fifty percent and above the bottom quartile (including the boundary value of the bottom quartile) are assigned as a moderate risk level, segments ranked 11 through 21 for Central California – section 1. Segment rankings in the top two quartiles (including the fifty percent value) are assigned a low risk level. The classification scheme for segment rankings is selected to assist stakeholders in the analysis and decision-making process by focusing attention first on approximately half of the corridor. It is not intended to suggest corridors in the low risk level are of negligible risk.

Due to the use of data from Table 2-6 to establish relative safety risk factor weights, segment rankings in Figure 2-18 are expected to match closely with the analysis of compounded risk segments. Groupings of segments 1-4, segments 24-26, and 30-32 contain highly ranked segments. The figure also suggests further inspection is warranted for segments 10-12.

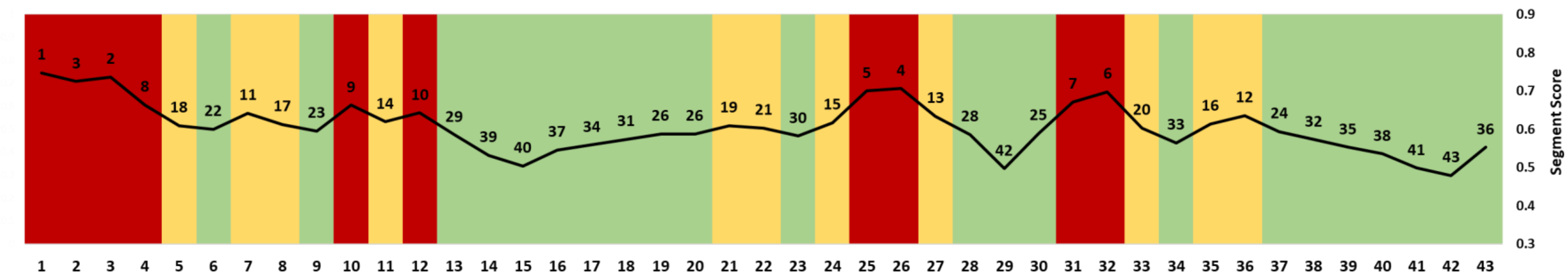


Figure 2-18. Aggregated safety risk factor assessment and resulting segment rankings for Central California – section 1.

2-5-4. Central California – Section 2: Suisun Bay to the Port of Stockton

Figure 2-19 and Figure 2-20 provide the maritime corridor trace for section 2 of the Central California region from Suisun Bay to the Port of Stockton. Inspection of the corridor trace describes multiple factors contributing to elevated levels of risk among segments in the corridor. Overall waterway width, both the channel width and shore-to-shore distance, show elevated potential for collision and grounding hazard along the whole length of the corridor with only one segment excepted. Traffic factor traces show elevated levels of cargo and especially tanker traffic along the whole length, leading to the deep-water port in Stockton. As the river winds through a rural section of the San Joaquin River in the middle segments of the corridor, it is distinguished by high turning angles. In these same segments, the pleasure and sailing vessel traffic of recreational boaters is also high. Figure 2-21 is a capture of the corridor in this rural section, segments 57 through 60. Pleasure vessel traffic is shown at fifty percent opacity.

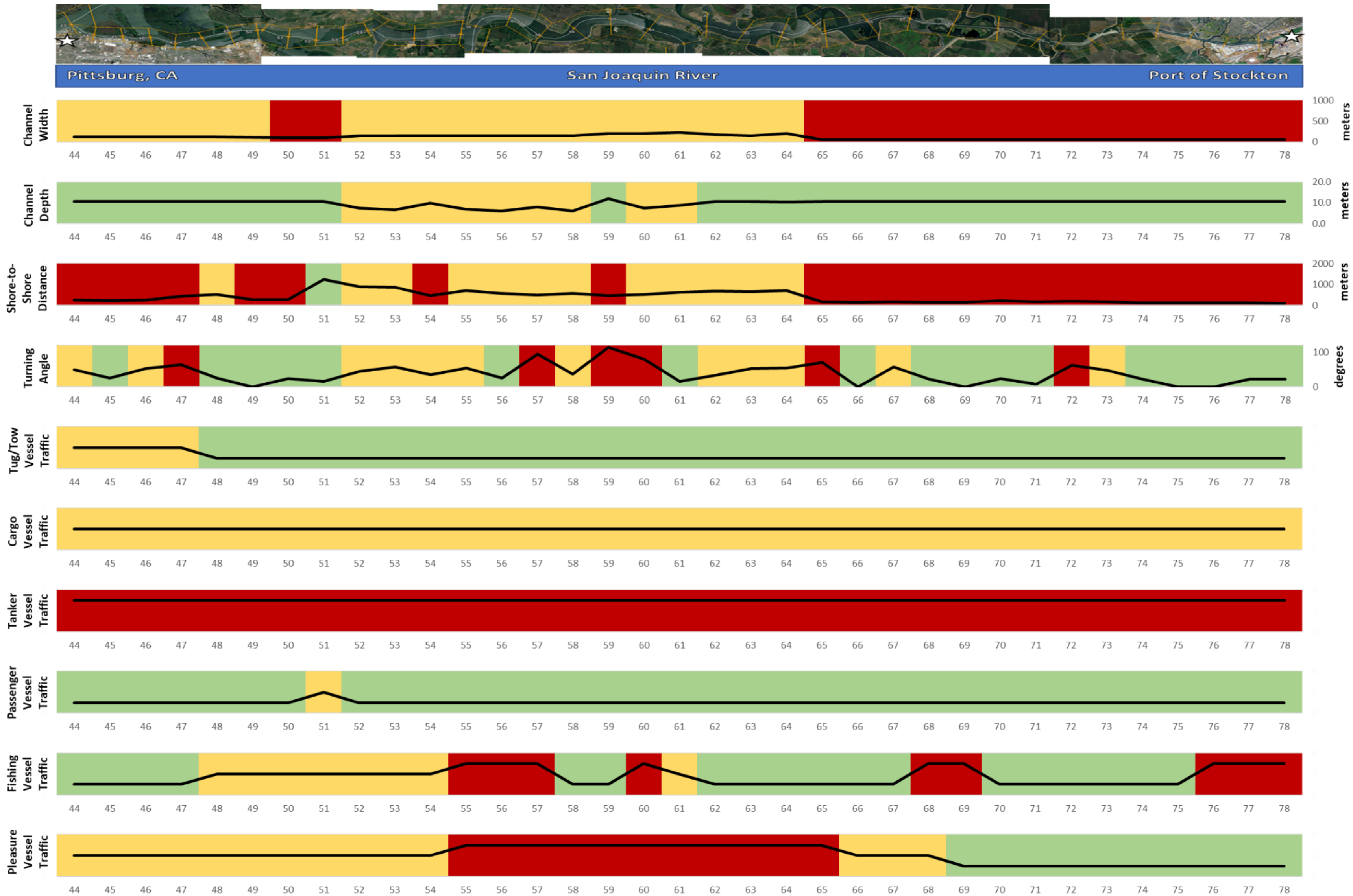


Figure 2-19. Maritime corridor trace of Central California - section 2 for geometry and traffic factor categories.

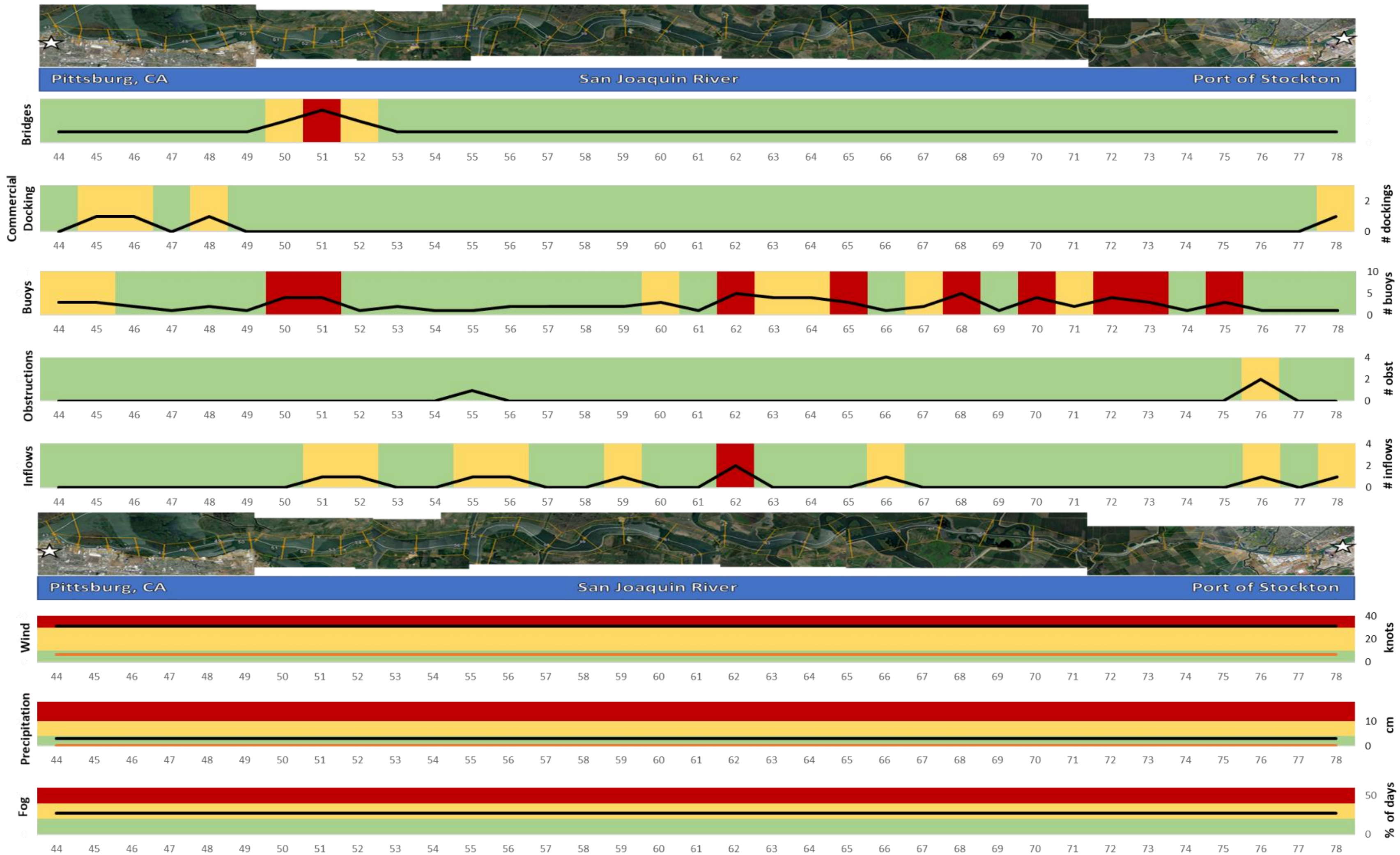


Figure 2-20. Maritime corridor trace of Central California – section 2 for infrastructure, obstacle, and sea-state factor categories.

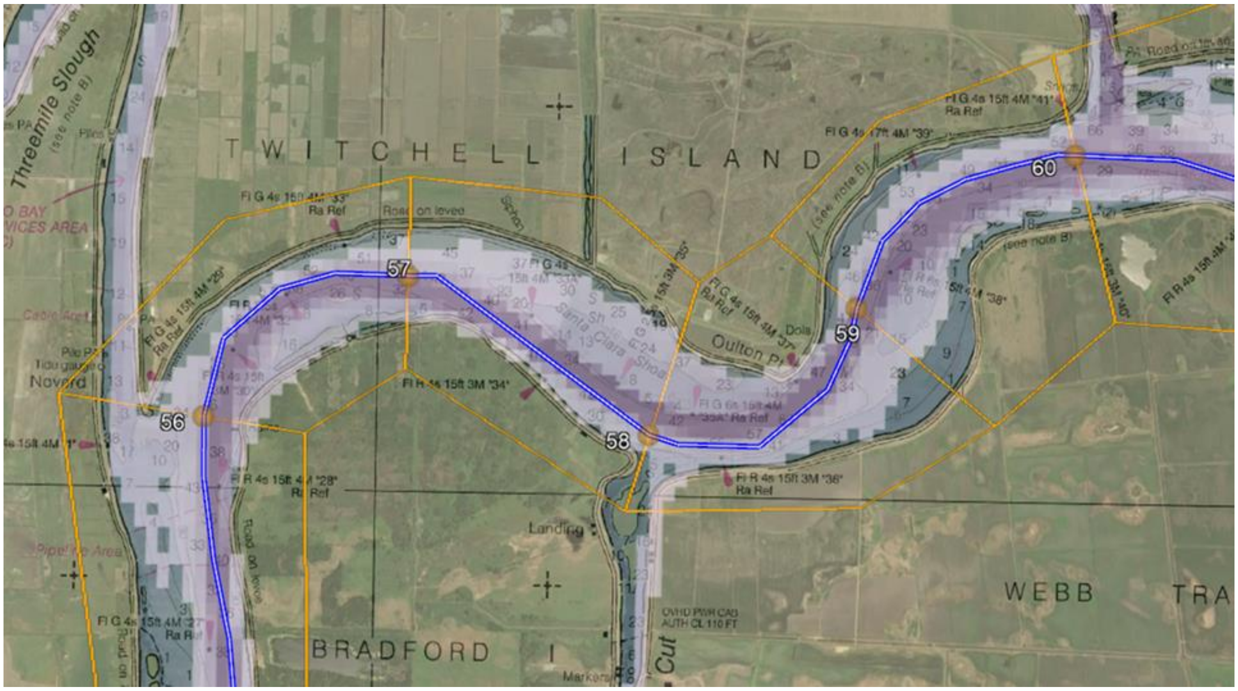


Figure 2-21. Detailed view of compounded risk segment grouping 57-60 for Central California – section 2.

A review of Table 2-7, Table 2-8 and Figure 2-22 support corridor trace observations of the contributions of individual factors to risk along the corridor. Highlighting segments 57 through 60 as a portion of the corridor with compounded risk is observant of possible pitfalls in using corridor wide values to determine segment rankings. Turning angle values fall mostly in the low threshold over the entire length of section 2. This is contributing to moderate to low rankings for these particular segments, especially segment 58 where the channel is generally straight between two segments with high turning angles. Use of relative importance values determined by stakeholders, such as vessel operators, may alter the current rankings and identify segments requiring more challenging vessel control operations as higher risk. The highlighting of these segments does promote the usefulness of the corridor trace in identifying areas of concern to a variety of stakeholders.

Table 2-7. Distribution of safety risk factor levels in each segment for Central California – section 2.

Segment	Number of Factors Within Threshold: High	Moderate	Low
44	3	7	10
45	3	7	10
46	3	7	10
47	4	5	11
48	2	7	11
49	3	5	12
50	5	5	10
51	5	6	9
52	2	10	8
53	2	8	10
54	3	7	10
55	4	7	9
56	4	6	10
57	5	5	10
58	3	6	11
59	5	4	11
60	5	6	9
61	3	6	11
62	5	5	10
63	3	6	11
64	3	6	11
65	7	2	11
66	4	4	12
67	4	5	11
68	6	3	11
69	5	2	13
70	5	2	13
71	4	3	13
72	6	2	12
73	5	3	12
74	4	2	14
75	5	2	13
76	5	4	11
77	5	2	13
78	5	4	11

Table 2-8. Distribution of segments by risk level within safety risk factors for Central California – section 2.

Factor	Hazards	Number of Segments Within Threshold		
		High	Moderate	Low
Channel width	Collision	16	19	0
Channel depth	Grounding	0	9	26
Shore-to-shore distance	Grounding	22	12	1
Turn angle	Collision, allision, grounding	6	12	17
Vessel traffic tug/tow	Collision	0	4	31
Vessel traffic cargo	Collision	0	35	0
Vessel traffic tanker	Collision	35	0	0
Vessel traffic passenger	Collision	0	1	34
Vessel traffic fishing	Collision	9	8	18
Vessel traffic pleasure	Collision	11	14	10
Bridges	Allision, collision	1	2	32
Commercial pier	Collision, allision	0	4	31
Buoys and lights	Allision	9	7	19
Obstructions	Allision	0	1	34
Inflows	Collision, allision, grounding	1	8	26
Wind (average)	Collision, allision, grounding	0	0	35
Wind (maximum)	Collision, allision, grounding	0	35	0
Precipitation (average)	Collision, allision, grounding	0	0	35
Precipitation (maximum)	Collision, allision, grounding	0	0	35
Fog	Collision, allision, grounding	0	35	0

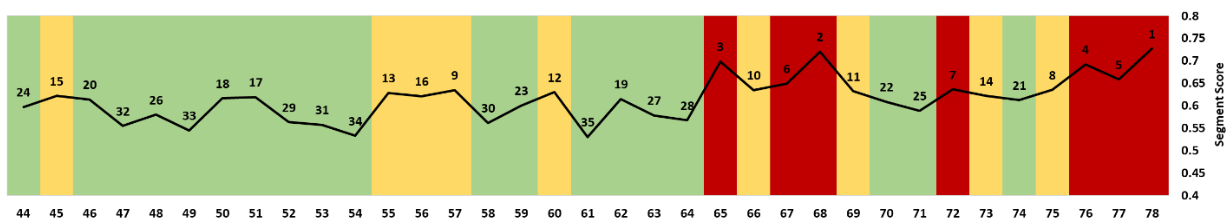


Figure 2-22. Aggregated safety risk factor assessment and resulting segment rankings for Central California – section 2.

2-5-5. Central California – Section 3: Suisun Bay to the Port of West Sacramento

Figure 2-23 and Figure 2-24 provide the maritime corridor trace for section 3 of the Central California region from Suisun Bay to the Port of West Sacramento. The risk characteristics of the corridor in section 3 are determined largely by the Sacramento Deep Water Ship Channel which makes up over half of the channel in this section. The ship channel was constructed in 1963 by the United States Army Corps of Engineers and is used exclusively by cargo and tanker vessels transiting to the Port of West Sacramento, beginning in segment 62. Though the ship channel is narrow with a uniform channel width of 60 meters and shore-to-shore distances less than 150 meters, it is intentionally straight for long portions, except a nearly 90 degree turn over two segments just before the port. Figure 2-25 indicates these last two segments as highly ranked in terms of aggregated risk. Table 2-9 and Table 2-10 provide the distribution of factor risk levels across segments and segment risk levels across factors, as with sections 1 and 2. A comparison of Table 2-5 (distribution of factor risks across segments for section 1) with Table 2-9 suggests the high aggregated risk ratings of some sections in section 3 (Figure 2-25) may be reduced by considering section 1 and section 3 as combined, single inland waterway corridor.

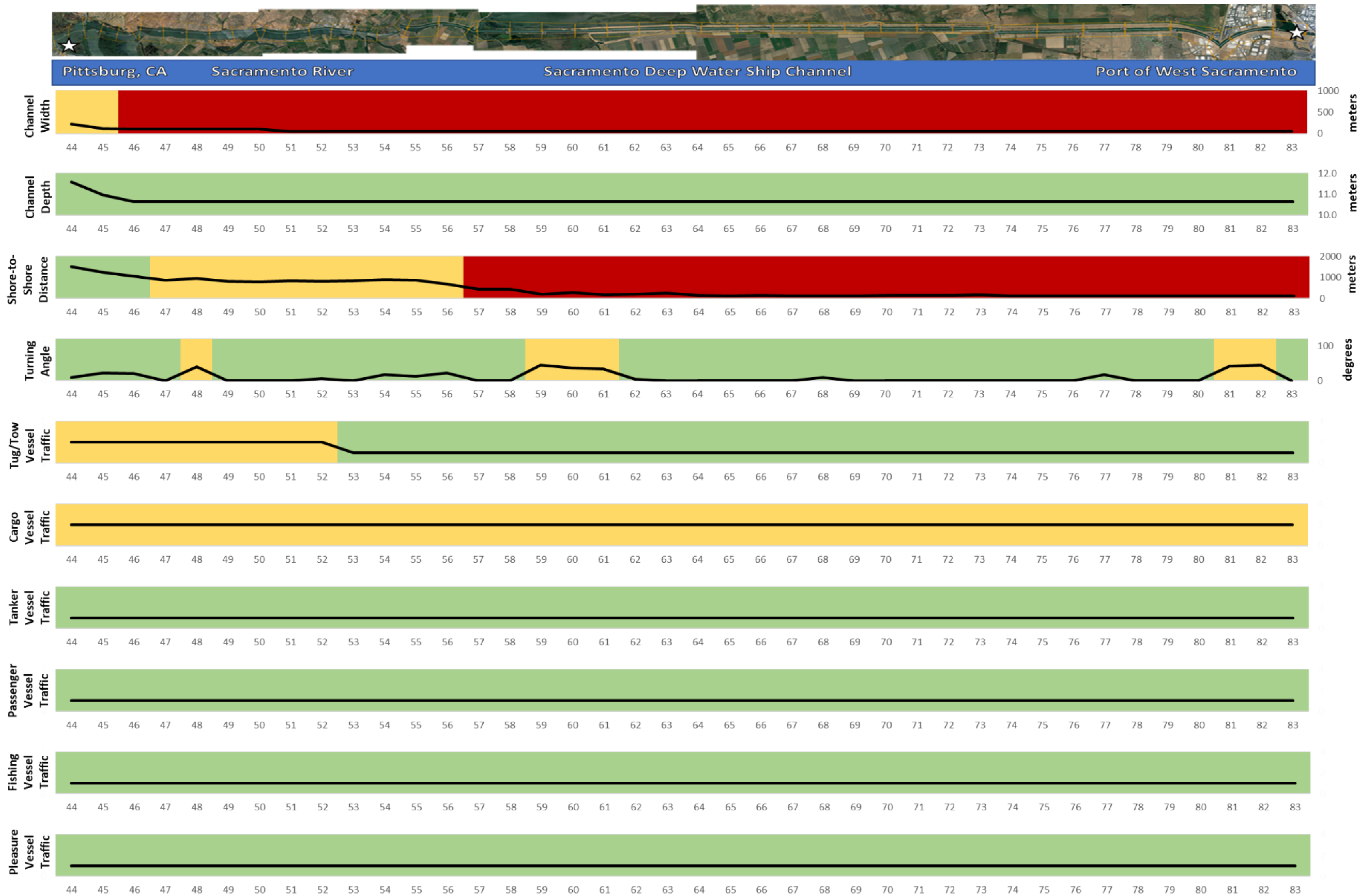


Figure 2-23. Maritime corridor trace of Central California – section 3 for geometry and traffic factor categories.

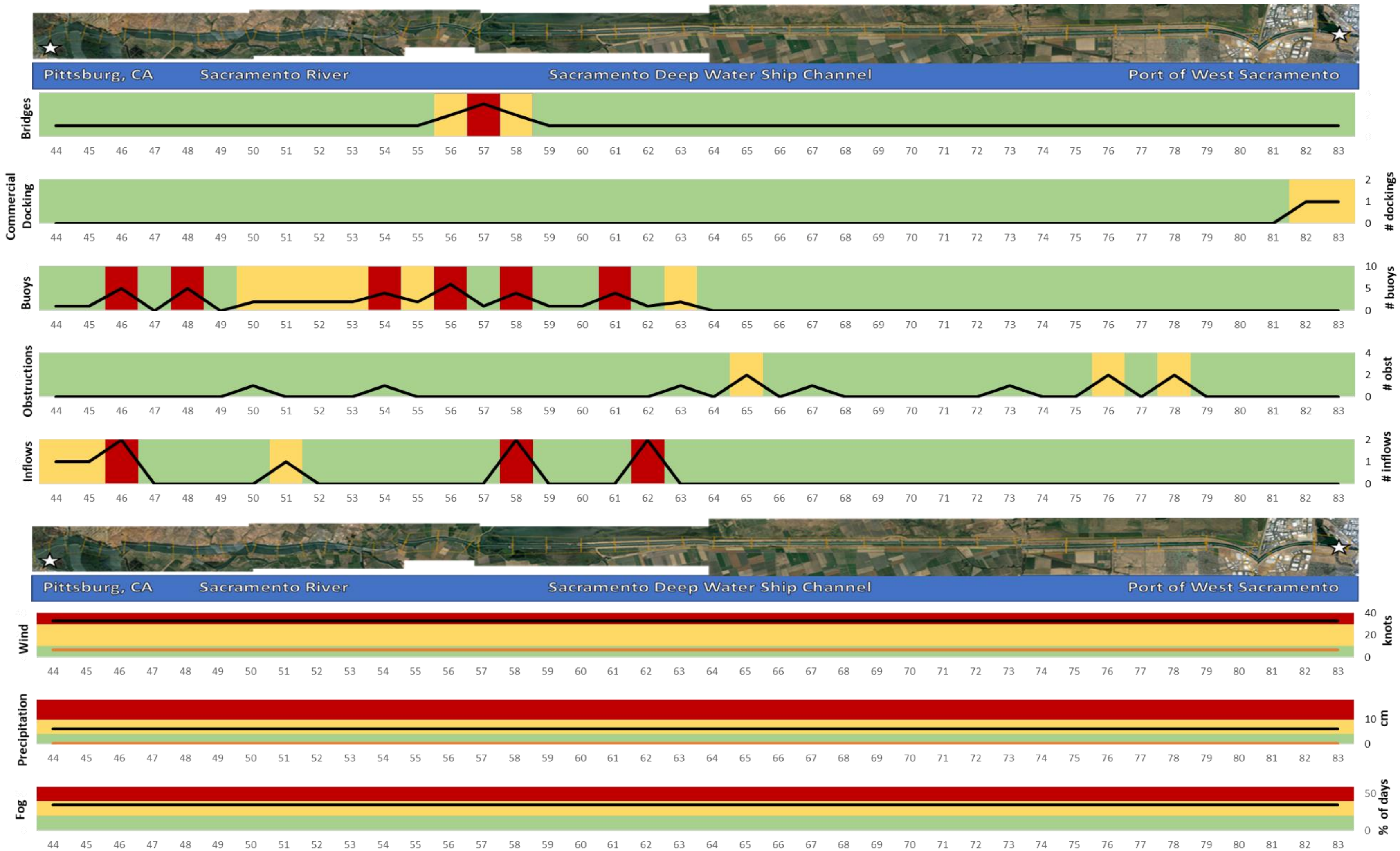


Figure 2-24. Maritime corridor trace of Central California – section 3 for infrastructure, obstacle, and sea-state factor categories.

Table 2-9. Distribution of safety risk factor levels in each segment for Central California – section 3.

Segment	Number of Factors Within Threshold		
	High	Moderate	Low
44	1	6	13
45	1	6	13
46	4	4	12
47	2	5	13
48	3	6	11
49	2	5	13
50	2	6	12
51	2	7	11
52	2	6	12
53	2	5	13
54	3	4	13
55	2	5	13
56	3	5	12
57	4	3	13
58	5	4	11
59	3	4	13
60	3	4	13
61	4	4	12
62	4	3	13
63	3	4	13
64	3	3	14
65	3	4	13
66	3	3	14
67	3	3	14
68	3	3	14
69	3	3	14
70	3	3	14
71	3	3	14
72	3	3	14
73	3	3	14
74	3	3	14
75	3	3	14
76	3	4	13
77	3	3	14
78	3	4	13
79	3	3	14
80	3	3	14
81	3	4	13
82	3	5	12
83	3	4	13

Table 2-10. Distribution of segments by risk level within safety risk factors for Central California – section 3.

Factor	Hazards	Number of Segments Within Threshold		
		High	Moderate	Low
Channel width	Collision	38	2	0
Channel depth	Grounding	0	0	40
Shore-to-shore distance	Grounding	27	10	3
Turn angle	Collision, allision, grounding	0	6	34
Vessel traffic tug/tow	Collision	0	9	31
Vessel traffic cargo	Collision	0	40	0
Vessel traffic tanker	Collision	0	0	40
Vessel traffic passenger	Collision	0	0	40
Vessel traffic fishing	Collision	0	0	40
Vessel traffic pleasure	Collision	0	0	40
Bridges	Allision, collision	1	2	37
Commercial pier	Collision, allision	0	2	38
Buoys and lights	Allision	6	6	28
Obstructions	Allision	0	3	37
Inflows	Collision, allision, grounding	3	3	34
Wind (average)	Collision, allision, grounding	0	0	40
Wind (maximum)	Collision, allision, grounding	40	0	0
Precipitation (average)	Collision, allision, grounding	0	0	40
Precipitation (maximum)	Collision, allision, grounding	0	40	0
Fog	Collision, allision, grounding	0	40	0

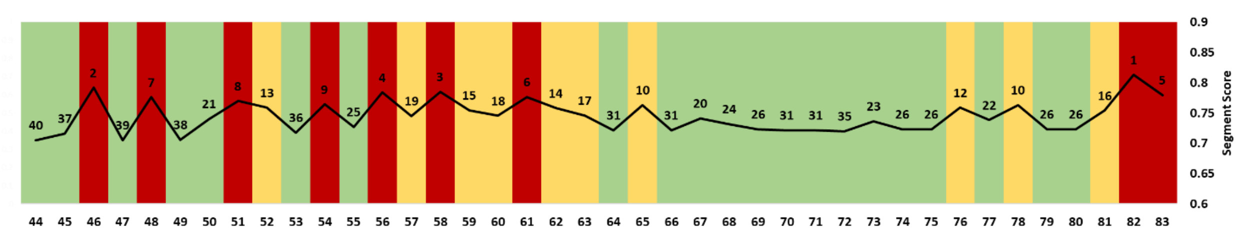


Figure 2-25. Aggregated safety risk factor assessment and resulting segment rankings for Central California – section 3.

2-6. Conclusion

Prior work has demonstrated a corridor trace analysis methodology as a decision-support model with application to roadway transportation networks. This chapter extends the analysis to applications on maritime corridor transportation networks for safety risk factors. It provides a decision-support methodology for maritime transport systems. When applied to freight transport operations, the methodology has the potential to facilitate continued efficient and sustainable growth of multimodal freight shipment.

The maritime corridor trace informs various stakeholders of safety associated risks to operations across defined segments of the inland waterway corridor. Vessel operators can plan for potential navigation and control requirements along the corridor to avoid collisions, allisions, and groundings. Enterprise operators can identify impacts to current operations and to initiatives for growth. The corridor trace can assist in planning for potential infrastructure improvements or management investments to improve safety and facilitate increased vessel traffic in support of economic development. The United States Corps of engineers can utilize the corridor trace methodology to prioritize dredging operations and mitigations to environmental impacts from use of the waterway. Federal, state and local agencies can use the corridor trace to assess risks to all users and as a planning tool for incident response. Local authorities may find usefulness in the understanding of safety conditions of the waterway where members of their community may rely upon the waterway for commerce or recreation, as well as a picture of the broader use of the corridor and those potential impacts on their localities.

There are real physical limitations to the presentation of data provided in the maritime corridor trace visualization. There is a trade-off between the ability to display data and the desire to view all data associated with an entire corridor in a single, consolidated setting, especially in a standard-letter paper format. One limitation is due to the length of corridors, extending upwards of eighty nautical miles if not sectioned as in this chapter's demonstration, or as in the demonstration of Chapter 5. As the number of segments increases, the width of data points in the corridor trace decreases and therefore the discernability of segment risk levels for a given factor decreases. A second limitation is due to the desire to include as many relevant safety risk factors as necessary to assess relevant risks to maritime operations. Page size limits the number of discernable corridor factor traces displayable on a single page. Landscape page orientation allows for greater discernment along the length of the corridor, but further limits the number of factors which can be viewed together. Enterprises could overcome this limitation with less restrictive printing techniques, with the use of wide format and plotter printers for example.

The segment ranking provides a basis for the resilience analysis of the maritime corridor system. The influence of future and emergent conditions on the risk concerned prioritization of corridor segments is explored further in Chapter 5.

Chapter 3. Security Risk Factor Analysis for Inland Waterway Corridors

3-1. Overview

This chapter extends the corridor trace analysis introduced in the previous chapter to include selection, development, and consideration of security factors. The mobility of personnel and cargo is subject to safety and security risks within a system corridor. Maritime transport has a critical role in the global economy but is subject to intentional attacks and site-specific risks. Previously, corridor analysis has been accomplished with innovative straight-line diagrams for land transportation but can be extended to evaluate disorganized corridors such as waterways. Attacks can originate from aerial, submerged, and surface origins with unique security risks associated with waterway channel geometry. The focus of this security analysis is on land and water surface attacks. A prioritization framework is required for defensive operations of maritime transport, which is achieved through a multi-factor security and safety corridor analysis. The analysis classifies corridor locations into critical locations to inform operators. This framework is demonstrated on a waterway corridor with multiple security and safety factors.

3-2. Introduction

The motivation for exploration of security considerations for maritime operations began with a study of safety considerations for military operations on inland waterway corridors. The study sponsor is referenced in Chapter 2 as a source of safety factor selection expertise. Due in part to classification concerns, the focus of the study remained on safety considerations and did not address security considerations. Therefore, none of the security factors addressed in this chapter were included in the study. However, an understanding of military offensive and defensive maneuvers, such as movement to contact and react to ambush, do inform the general analysis.

The study of military maritime operations considered a variety of perspectives on safety and incident prevention. The perspectives included mechanical, electrical and software system component failure, human factors in maritime accidents, and the role of organizational culture in maritime accidents. In the area of human factors, Fan et al. (2017) identified five critical human factors resulting in maritime accidents: mental workload, emotion, attention, stress and fatigue. An Analytic Hierarchy Process (AHP) model identifies causes and preventive measures of grounding accidents, citing between 80 and 90% of maritime accidents are attributable to human error (Ugurlu et al., 2015). The AHP model determined the most significant way to prevent grounding accidents is to improve the education and training of vessel operators. A Bayesian Network analysis assesses the influence of vessel operator characteristics of personality type, age, and professional experience in different stress conditions, or vessel maneuvers, to predict operator decision errors (Abramowicz-Gerigk and Hejmlich, 2015). Many of the reviewed and cited works on human factors reference the work of James Reason. Reason (1998, 1990) developed the “Swiss Cheese Model”, which illustrates how a hazard can ultimately cause harm. In this model, each “slice of cheese” represents a barrier or preventative measure aimed at blocking or mitigating harm, but deficiencies in these measures allow the hazard to propagate. Related to this is the Human Factors Analysis and Classification System (HFACS) developed by Wiegmann and Shappell (2003) to extend Reason’s model by identifying specific layers of defense and potential deficiencies. HFACS considers unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences as layers of defense, which when deficient, can allow a hazard to be realized. A similar model to the Swiss Cheese Model is the Bowtie Model (du Plessis, 2015). This model identifies a hazard which can cause a negative event, with various causes placed on one side, and consequences on the other. Between each cause and consequence, one or more controls are identified which can either prevent the cause from triggering the event, or to mitigate the impacts given the event has occurred.

In the perspective of organizational culture, a popular citation is the work of Jens Rasmussen. Rasmussen (1997) developed a risk management framework modeling accidents as a function of an organizational hierarchy, where failures at one level can propagate to other levels, eventually resulting an accident. Levels within the hierarchy include the government, regulators, company, company management, staff, and work. Rasmussen’s theory rests on an assumption of safety (or lack thereof) emerging as a function of interactions between actors at each of these organizational levels. Hanninen et al. (2014) propose a safety management model to prevent maritime accidents. The model highlights critical links among over twenty management subareas such as management commitment, communication, maintenance, planning, and feedback. The state of organizational culture within a maritime shipping company was assessed by means of questionnaire given to members at all levels of the company studied and combined with a set of measured safety metrics (Arslan et al. 2016). The assessment evaluated staff and crew member performance in ten key safety culture dimensions and improvement strategies. The dimensions included communication, problem identification, safety awareness, employer-employee trust, and mutual trust. Leveson (2004) developed the Systems Theoretic Accident Modeling and Processes (STAMP) model, which takes a hierarchical social view, similar to Rasmussen, showing how controls and constraints at higher levels affect processes at lower levels. The theory underlying the STAMP model is safety is an emergent property of complex systems with many nonlinear interactions between humans and the technology. Under this view, accidents are viewed as resulting from inadequate controls within the system. Using STAMP, systems can be viewed retrospectively (as in accident investigations) or prospectively (in terms of system design). Abrecht and Leveson (2016) developed Systems Theoretic Process Analysis (STPA) to analyze vessel dynamic positioning systems in terms of unsafe control actions and safety constraints.

Reason (2002) notes while the human, operating at the "sharp end" of the system, tends to receive the most blame for an accident, he or she is operating within an unpredictable environment which presents hazards can negatively affecting task performance. Though environmental factors are mentioned in several of the works among these other perspectives, there is opportunity for further analysis of the impacts of the operational environment on maritime safety and also maritime security. Corridor trace analysis is an approach to considering the operating environment. A goal of a formulation of corridor trace analysis by Thekdi and Lambert (2015), was to identify high-risk "hot spots" along Virginia's roadway system. In the example of roadway safety, three main safety factors were identified: likelihood of adjacent land development, access point density, and average daily traffic. While access point density was quantified through GIS applications, and average daily traffic along corridor segments is a statistic able to be found in various transportation databases, the likelihood of adjacent land development itself was determined from a number of other factors. Thorisson and Lambert (2017) adapted corridor trace analysis to integrate big-data sources of highway performance factors over many thousands of kilometers of highway and increased the number of factors considered. This application allowed for the identification of road segments under stress. By reframing corridor trace analysis and adapting the methodology to the analysis of inland waterway transportation networks, the corridor trace adds to the available perspectives of accident analysis (Figure 3-1). As demonstrated in this chapter, maritime corridor trace analysis is capable of considering both safety and security risk factors to plan for unintentional accidents and deliberate attacks.

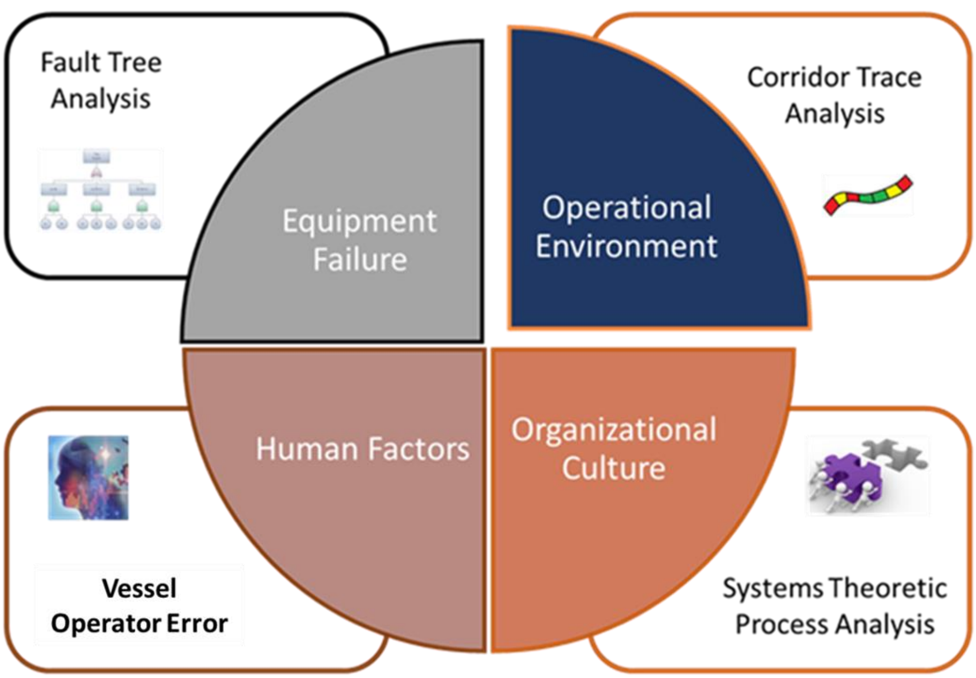


Figure 3-1. The operational environment perspective provided by corridor trace analysis as a complimentary component of maritime incident analysis.

3-3. Background

The inherent reliance of commerce on transportation corridors requires innovative approaches to the planning for safe, secure, and reliable logistics operations. In 2015, the U.S. Department of Transportation reported more than thirty-three thousand tanker, eighteen thousand container, and fifteen hundred liquified natural gas (LNG) vessel calls as U.S. ports (USDOT, 2019a). For 2018, the USDOT indicated over seventeen thousand hazardous material incidents over all modes of transportation resulting in seventy million dollars in property damage (USDOT, 2019b). These statistics represent two components of transportation corridor risk: probability or frequency, in terms of volume of vessel calls, and consequence, in terms of magnitude of property damage. A third component needed to appropriately address risk is the identification and evaluation of hazards or vulnerabilities. This is an intended goal of the maritime corridor trace analysis.

Recent work has modeled safety of water and road transportation systems and identified hazards associated with these systems. Liu et al. (2017) apply a brittleness theory to waterway navigation and identify hazards as components of a brittleness index. Among these are wind, wave, fog, channel, and traffic flow. Wan et al. (2019) identify safety factors as nodes of a Bayesian network analysis. A Cognitive Reliability and Error Analysis Method of tanker shipping safety gives hazards as descriptive characteristics of common performance conditions (Zhou et al., 2017). Hazards for road transportation systems are listed as sub-factors to direct and indirect factors in a quality function deployment analysis (Li et al., 2019). Du et al. (2015) extract influence factors to develop a safe ship speed control model.

An increasing volume of oil and LNG tankers, as well as an increase in LNG fueled vessels, indicates a need for expanding the system boundary to consider application of security factors as well as safety factors. A study on the future of oil and LNG shipping for East Asia provides a world-wide region-by-region outlook on the growth of oil and LNG imports and exports. Estimates out to 2040 predict a net growth in oil and LNG shipping (Kimura et al., 2016). Meanwhile, an International Maritime Organization (IMO) decision to limit the Sulphur content of fuel oil on ships to 0.50% mass/mass by January 1st, 2020 (IMO, 2008) is likely to prompt the build and use of LNG-fueled ships into the future (Fritelli, 2019). Jian et al. (2017) and Vidmar and Perkovic (2018) consider enhanced safety requirements of commodity tanker waterway navigation.

In addition to enhanced safety requirements, it is prudent to consider security vulnerabilities and possible defensive requirements for maritime corridors. A report from the U.S. Government Accountability Office (GAO) focusing on deliberate attack scenarios against energy commodity tankers (oil and LNG) identifies three main types of attack: vessel-borne suicide attacks, standoff attacks with weapons launched from a distance, and armed assaults (GAO, 2017). The GAO report recommends a general risk management approach to identify and mitigate risks to oil and LNG tankers of threat, consequence, and vulnerability assessment. The GAO report also addresses some risks related to spill and explosion of the fuel from tankers as a result of attack. A U.S. Department of Energy report provides experimental results of the consequences of LNG tank breach, spill, and pool fire events (DOE, 2012). While, the results indicate a pool fire is not likely to affect shore populations, depending on distances from the ship to the shore, it does describe potentially catastrophic consequences for the ship and crew. The emergent condition of increased energy commodity tankers trafficking U.S. inland waterways has led to a limited requirement for the Department of Homeland Security and the United States Coast Guard to escort prescribed classes of oil tankers on certain waterways. This requirement is outlined in the United States Code of Federal Regulation (CFR), Title 33, Chapter I, Subchapter P, Part 168 (OFR, 2013).

One method utilized in the escort of vessels at risk to deliberate attack is the use of dynamic positioning systems (DPS), with varying levels of autonomous capabilities, to maintain close distances between escort vessels and the at-risk vessel. This course of action provides an opportunity to highlight another emergent condition likely to impact inland waterway travel in the future, the increased deployment of autonomous navigation. Table 3-1 provides an example taxonomy for levels of vessel automation (NFAS, 2017). It is also an opportunity to address the characteristics of vessel control. Vessel control dynamics differ from land operating vehicles, which generally are able to influence velocity and direction of travel more readily.

Table 3-1. Example taxonomy for levels of vessel automation.

Level of Autonomy	Characteristics
Decision Support	Anti-collision radar Electronic charts Autopilots Crew in direct command of ship
Automatic	Continuous crew monitoring Automatic berthing Crew always available Crew can initiate direct control
Constrained Autonomous	Fully automatic in most situations Predefined actions (collision avoidance) Predefined constraints (maximum deviation from planned track) Crew can initiate direct control
Fully Autonomous	Ship handles all situations by itself No bridge personnel

The push for ubiquity of autonomous vehicles on road networks is well publicized. Autonomy of maritime vessels seems to be progressing slower, but predictions exist of varying levels of autonomy in ships on coastal waterways by 2020 and a possibility of unmanned shipping vessels on the ocean by 2030 (Kirchner, 2019). Vessels equipped with dynamic positioning systems capable of automatically maintaining position and heading are in use for military escort operations in coastal waterways (Abrecht, 2016). Recent work has developed control methods for autonomous vehicles on road networks based on environmental conditions and traffic control scenarios (Seal et al., 2019; Sippl et al., 2019) and has developed a functional decision architecture to enhance the safety of automated driving systems (Saberi, et al., 2019). Other recent work has extended the vehicular taxonomy of autonomous systems to build a similar framework for maritime vessels (Rodseth et al, 2018), developed steering and speed correction equations for automatic collision avoidance for a single ship (Su et al, 2019), and developed collision avoidance equations based on own-ship and target-ship data for head-on, crossing, and overtaking scenarios (Zhou et al, 2018).

Numerous technological advancements have been made to vessels, automating some or all of the navigational functions performed by ship pilots. One such technology is the dynamic positioning system (DPS), commonly used in conjunction with offshore drilling platforms. The DPS is comprised of three main subsystems – power, thrusters, and control (Thigpen et al., 2017). Vessels equipped with DPS employ thrusters to maintain vessel position and heading and allow for movement along a predefined track or movement relative to a target vessel (Sørensen, 2014; Holvik, 1998). Since the vessel is subject to dynamic forces from the environment such as waves, current, and wind, causing it to deviate from course, complex control algorithms are used to deploy the thrusters to maintain the desired position and heading (Sørensen, 2014; Holvik, 1998). This type of autonomous system is of particular relevance to vessels escorting other vessels at risk to deliberate attack.

External forces can affect ship motion in six degrees of freedom, three rotational and three translational. Rotational motions are pitch, roll, and yaw. Translational motions are heave, sway, and surge. Figure 3-2 is an illustration of external forces experienced by ships, three of the motion degrees of freedom, and an example control loop for a DPS system.

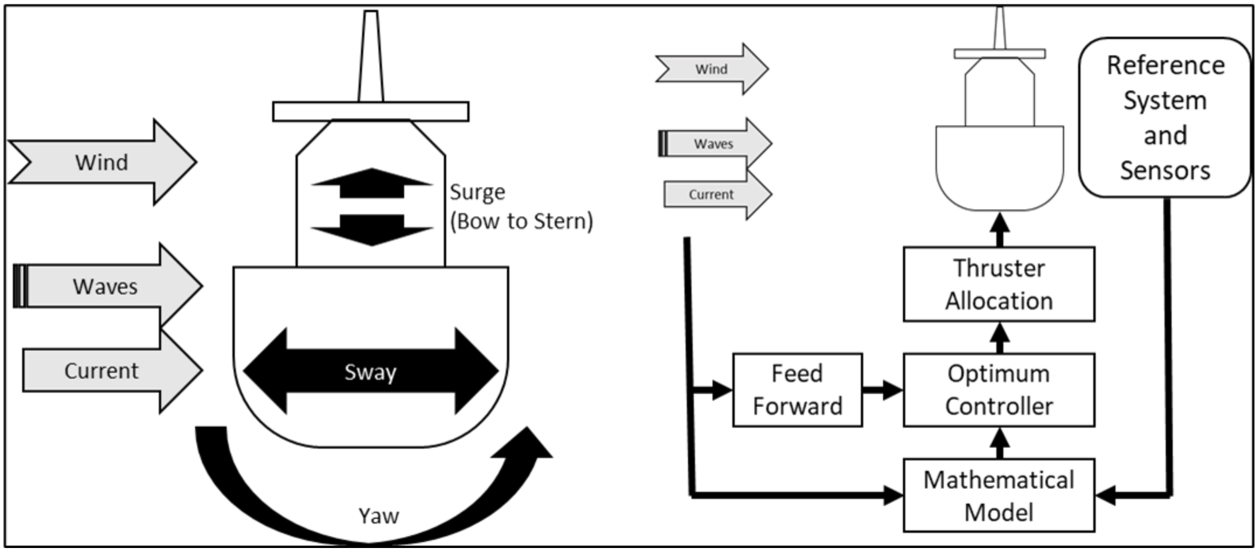


Figure 3-2. External forces, vessel motions, and example DPS control loop. (Adapted from Holvik, 1998.)

Review of related applications in which vehicles operate in close proximity and in high-risk contexts can assist in the understanding of difficulties in conducting defensive operations. Related applications also highlight risk assessment and management methods employed to mitigate security risks and the consideration of the operational environment factors impacting defensive operations. Among these situations are automotive vehicle platooning, aerial refueling, and aerial drone operations in formation. All of these use cases can encompass varying levels of autonomy.

During automotive platooning operations, semi-autonomous systems are engaged to allow follow vehicles to operate in close proximity to a lead vehicle. The goals of platooning operations are to improve safety, increase fuel efficiency of the platooned vehicles, and reduce emissions. A vehicle platoon is composed of a lead vehicle and follow vehicles. In this system configuration, the lead vehicle is at the front of the platoon, and sets speed and direction for the platoon. The control system provides supervision and coordination to the platooned vehicles by collection and dissemination of data. Supervision controls act to authorize the ability to platoon, dependent on weather, traffic, and road conditions. Platooning is permitted only when conditions are deemed safe. Coordination of the follow vehicles is achieved by passing data such as lead vehicle power and engine torque, lead vehicle speed and distance between vehicles to control the speed, braking, and steering corrections of follow vehicles. Platooned vehicles communicate by vehicle to cloud networks for supervision control and by vehicle to vehicle communications for coordination. On-board systems collect and transmit data through global positioning, radar, and over wi-fi networks. Platooning is claimed to reduce the safe follow distance for freight trucks from 545 feet under manual operation to approximately 40 feet under the semi-autonomous operations. Safe follow distance is described as a summation of driver perception, driver reaction, attention buffer to account for distractions during driving, a brake lag to account for the time between a driver applying brakes and the brakes actually engaging, and for differences in vehicular capabilities. The semi-autonomous system is claimed to make all of these components irrelevant except for vehicular capability differences. Recent advances in platooning control algorithms include efforts to correct for entry and departure of vehicles in the platoon and for negligent or malicious actions by a vehicle or operator within the platoon (Wu et al., 2019). Other work proposes incorporating inter-platoon controls and an override mode resulting in increased autonomy of the vehicle to assist in handling factors external to the platoon, such as slower vehicles and autonomous enforcement of speed limits on the platoon (Giordano et al., 2019). A broadcast forwarding algorithm has been suggested to ensure communication between all members of the platoon, ensuring only the latest and most accurate information is acted upon by its member vehicles (Larsson et al., 2016).

Uses of autonomous systems in aircraft may be more relatable to their implications for maritime vessels. Control systems and motion degrees of freedom for aircraft and the lack of friction with the ground as a means of controlling vehicle motion are more similar between aircraft and vessels than vessels and vehicles operating on land. Aerial refueling operations require aircraft to fly in close proximity at high speed and achieve a connection with the refueling components of the aircraft in a manner not damaging to those components. There are multiple methods of aerial refuel which are generally defined by the method of connection between the aircraft. Most methods dictate the tanker aircraft maintain a stable flight path while the receiving aircraft maneuvers to a position behind and below the tanker (Nalepka and Hinchman, 2005). In manned aircraft, auto-pilot systems assist in the maneuvering of the receiving aircraft into position. The development of fully autonomous control systems, or automated aerial refueling (AAR), is of interest in recent work (Wilson et al., 2015). AAR systems could be employed in unmanned aerial vehicles (UAV) as the receiving or tanker aircraft, or both. Tsukerman et al. (2018) compare two types of feedback and control processes for aerial refueling, an outer-loop system in which the aircraft guidance and rendezvous control data are separate, and an integrated single-loop system in which control data based on tanker flight dynamics are used directly to control the guidance system. Several works describe the use of vision-based sensors in AAR operations (Al-Kaff et al., 2018; Valasek et al., 2017). Pavitra and Clarke (2019) propose a control method for landing autonomous fixed-wing vehicles on the deck of a moving platform by building upon principles of aerial refueling and formation flying. Aerial refueling accidents, especially those involving military aircraft, could have large costs depending on the severity of a possible accident.

Noting the connection between aerial refueling and formation flying, another area of interest is the control and collision avoidance of unmanned aerial drones and drone swarms for use in logistics and advertising. Intel garnered much attention for the demonstration of choreographed drones to produce a lighting display during opening ceremonies for the 2018 Winter Olympics. While control systems for such displays are generally preprogrammed, there is interest for use of drone formations to deliver packages and to create advertisement displays in public spaces. Recent patents have been granted for the communication and control systems of drone swarms to display advertising signage (Marshall et al., 2019) and for the use of drones to rendezvous with and deliver packages to ground delivery vehicles while in route (Siegel et al., 2016). As with aerial refueling, studies have explored the required control systems and hardware for coordinating the safe operation of drones in formation (Kim and Ahn, 2016).

Research presented in this section describes the need to consider security risk factors as well as safety risk factors for maritime operations on inland waterway corridors. Vessels carrying hazardous materials are likely to be most at risk to deliberate attack by vessel-borne suicide attack or improvised explosive device, armed assault, or stand-off attacks. Other vessels may also be subject to the deliberate attacks mentioned or subject to hijack or targeted theft of certain goods. The recognition of the introduction of autonomous capabilities to maritime operations highlights the relevance of safety and security factors to vessel operations and identifies an emergent condition impacting the resilience of systems relying on the use of inland waterway corridors.

3-4. Methods

This chapter builds upon the methods described in Chapter 2 for maritime corridor trace development and analysis for safety risk factors. In this chapter, security risk factors are introduced and considered in combination with safety risk factors for the inland waterway corridor. The methods unique to this chapter and introduced in this section are security risk factor selection, security risk factor data collection, and security risk factor threshold determination.

3-4-1. Security Risk Factor Selection

This section contributes to the second step of the maritime corridor trace analysis, the identification and selection of risk factors. There are two primary sources for the selection of security risk factors. The first is a GAO Report to Congress in 2007 on the needs to address challenges in preventing and responding to terrorist attacks on energy commodity tankers (GAO, 2007). The second source is a number of military doctrine materials related to tactical operations. Army doctrine is relied upon due to accessibility and familiarity. Although the operating environment is a maritime setting, general doctrinal principles for situational understanding and identifying threat courses of action remain applicable. The general doctrinal principles discussed in this section are found across many available Army doctrine references as they apply to multiple levels (tactical, operational, and strategic) and many types of operations (offense, defense, civil support, etc.). The primary reference used here is FM 3-90-1: Offense and Defense, Volume 1 (HQDA, 2013). This document is approved for public release. The GAO report primarily identifies the type of hazard posed by threat actors to energy commodity tankers and other vessels. Concepts from FM 3-90-1 primarily considers the operational environment in terms of these hazards to identify possible security risk factors.

The GAO report acknowledges there were no specific credible threats to vessels in U.S. waters at the time the report was published, but does substantiate a valid concern for potential domestic attacks. Owing to the lack of historical incidents in the U.S., the report relies upon worldwide incidents to demonstrate threat tendencies and capabilities. The threat course of action of most concern to the authors of the report is suicide attack, the use of an explosive-laden vessel to ram a larger, target vessel. Suicide attacks are difficult to defend because the attack is undertaken with the attacker having no concern for their life or their ability to exfiltrate after the attack. Examples cited include a 2004 suicide attack on tankers docked at an offshore oil terminal in Iraq and a 2002 suicide attack on a French supertanker on approach to an oil terminal in Yemen. The GAO report highlights the prevalence of attackers to use small boats in suicide attacks. A second threat course of action is armed assaults. The primary goal of armed assault is financial gain rather than destruction. During armed assaults, attackers attempt to gain control of the vessel for the purpose of theft of goods or hijacking for purposes of ransoming the ship and/or crew. Widely profiled attacks of this type have taken place off the eastern shore of Africa, targeting vessels transiting to and from the Suez Canal (George, 2013). A third security related hazard is standoff attack. Standoff attack is described by the GAO as an attack using a rocket, mortar, or rocket-propelled grenade launched from a sufficient distance to evade defensive fire. In this dissertation, the definition of standoff attack is expanded to describe an attack in which the attacker does not intend to come into contact with the vessel and intends to avoid death and exfiltrate following the attack. This allows for the use of small arms fire in addition to rockets, mortars and rocket-propelled grenade. The definition permits standoff attacks conducted from vessels and from land. Considering these three types of attack, for this analysis, hazards are consolidated into two types. Vessel-based attacks (VBA), which include vessel-borne suicide attacks, armed assault, and water-based stand-off attacks, and land-based attacks (LBA) comprising stand-off attacks from the shore or bridges.

In Army operations, the mission planning and orders production process involves multiple steps. Among these is a process termed intelligence preparation of the battlefield (IPB). A simplified description of this process is the identification of operational areas of interest and aspects of those areas impacting friendly and enemy operations. One of the conceptual tools used in this process is known as METT-TC. The acronym represents a set of mission variables for defining the tactical situation. The variables are mission, enemy, terrain and weather, troops and support available, time available, and civil considerations. The variables of mission, terrain and weather, and civil considerations align well with an intent of maritime corridor trace analysis to identify factors related to safe and secure operations. Among the safety factors identified in Chapter 2, the mission variable might be considered as relating to the various types of vessel traffic along the inland waterway corridor. Terrain and weather align well to factors of geometry, infrastructure, and sea-state. Civil considerations could apply to the presence of pleasure and sail craft (vessel traffic pleasure) on the waterway.

Seven security factors are selected and are listed in Table 3-2. Four of these factors have already been identified and treated in Chapter 2 as safety risk factors, but are selected as security factors due to their relevance to terrain, weather, and civil considerations for security operations: vessel traffic pleasure, bridges, shore-to-shore distance, and fog. The vessel traffic pleasure security risk factor relates to enemy tendencies for use of small crafts in the execution of vessel-based attacks and provides an opportunity for cover and concealment during approach to a target vessel. Bridges are considered as an important terrain variable, providing a platform from which to conduct land-based attacks, which could include dropping explosive devices from the elevated platform onto passing vessels. Conceivably, a bridge could also provide a base of armed assault attacks, though it would present significant risk to the attacker attempting to board a vessel, presumably by jumping or rappelling to the vessel from the bridge. Shore-to-shore distance is a relevant terrain associated variable applying to the hazard of land-based attacks. Fog is a weather-relevant factor, proving a threat with concealment during approach to the target vessel. The three unique security risk factors, inlets, civilian docks and piers, and shore cover type are addressed further in the security risk factor data collection and security risk factor threshold determination sections.

Table 3-2. Selected security risk factors for maritime corridor trace analysis.

Security Risk Factor	Category	Hazard
Inlets	Terrain	VBA
Civilian docks and piers	Enemy, civil considerations	VBA
Vessel traffic pleasure	Enemy, civil considerations	VBA
Bridges	Terrain	LBA
Shore cover type	Terrain	LBA
Shore-to-shore distance	Terrain	LBA
Fog	Sea-state (weather)	VBA

3-4-2. Security Risk Factor Data Collection

This section contributes to the third step of maritime corridor trace analysis, data collection of risk factors. As with safety risk factors, the GIS-based corridor definition and visualization is the primary source for the data collection of security risk factors.

Inlets are a measure of all tributaries and vessel-accessible water inlets to the inland waterway corridor. It is similar to the safety risk factor of inflows. However, the inflows factor is intended to relate to sea-state in terms of potential contribution to the speed of the current in the corridor. During data collection for inflows, and attempt is made to include only those tributaries flowing into the corridor, contributing additional volume and flow rate. As a security risk factor, inlets is associated with the terrain variable and attempts to capture access to the corridor not included in the inflows category. In military parlance, these would be considered possible enemy avenues of approach associated with the terrain of the corridor as well as possible hide positions, offering cover and concealment to the threat prior to the attack. Data for the inlets security risk factor is recorded as the total number of inlets within a given segments defined area of interest. If the border of a segment's area of interest bisects a particular inlet, the inlet is counted in both segments. Subjectivity for this factor lies in the judgement of the trafficability of an inlet by small boats and the degree of bisection along segment area of interest borders. Figure 3-3 is a demonstration of the data collection for inlets and including some of the inherent subjectivity. In the figure, segment 15 is attributed with 3 inlets and segment 14 with 2 inlets. There is a bridge in the top left of segment 14 and what appears to be an inlet. Closer inspection reveals the bridge is a land bridge and there is no water accessible path from the body of water to its north.

Figure 3-3. Inlets factor data collection.

Civilian docks and piers are associated with vessel-based attack hazards. Their selection as a security risk factor is derived from threat courses of action (enemy) and civilian considerations. The presence of civilian docks and piers provides the threat with concealment opportunities and a base from which to launch an attack. Values for this factor are recorded as 0, 1, or 2 and correspond to no presence of civilian docks in a segment, civilian docks on one shore of a segment, and civilian docks on both shores of a segment. Figure 3-4 provide an example of data collection for civilian docks and piers. Segment 12 is assigned a value of 1, having civilian docks on the south shore and a commercial facility on its north. Segment 13 is assigned a value of 2.

Figure 3-4. Civilian docks and piers factor data collection.

Shore cover type is associated with land-based attack hazards and is a terrain-associated consideration. Data collection for this security risk factor involves a qualitative assessment of the type of terrain associated with the shoreline, and values are assigned based on an assessment of accessibility by land-based threats and the amount of cover, concealment, and exfiltration mobility provided to those threats during a stand-off attack. Table 3-3 is a listing of each type of shore cover considered and their associated factor values. Segment values are determined by the highest factor value associated with either shore in the segment of interest.

Table 3-3. Shore cover types and associated factor values.

Shore Cover Type	Factor Value
Open water	0
Military facility	1
Commercial/industrial facility	1
Urban	2
Rural farmland	3
Rural forested land	4
Mountainous	5

Open water is considered to exist both when it occurs in a traditional sense, as in corridor segments extending through a maintained channel beyond the coastline, and in segments where the shore-to-shore distance is greater than one nautical mile, and land-based attacks are considered negligible. Military and commercial/industrial facilities are likely to have restricted access to the shoreline and present a low threat of land-based attack. Urban shores do offer substantial cover and concealment, however, the ability of the threat to operate covertly is reduced in heavily populated centers. Rural farmland presents the threat with easy mobility and potential concealment, as well as possible cover in ditches or behind low walls. Rural farmland includes agricultural areas as well as rural areas on which the shoreline consists of private residences. Rural forested land offers elevated levels of concealment, while still providing cover and permitting mobility. Mountainous areas may limit mobility, but offer highly effective cover and concealment opportunities. Figure 3-5 provides an example of shore type for three segments assigned different factor values. Segment 18 is classified as rural farmland, with rural residences lining its north shore. Segment 19 is classified as rural forested on its north shore and Segment 20 is classified as military facility, with Mayport Naval Station on its south shore and open water on its north shore.

Figure 3-5. Shore cover type data collection.

3-4-3. Security Risk Factor Threshold Determination

This section describes the application of the fourth step of the maritime corridor trace analysis, risk factor threshold determination, to the security risk factors described in the previous section. Threshold values signify cutoffs between low, moderate, and high-risk levels. Threshold values for security risk factors also identified as safety risk factors remain the same as they are in the safety context. The justification of those thresholds has changed for shore-to-shore distance and bridges.

The threshold levels for civilian piers and docks are similar to the threshold levels for commercial piers as a safety consideration. The presence of civilian docks on both shores signifies a segment of high risk, moderate risk for civilian docks on one shore, and low for no civilian docks in the segment. Threshold levels for bridges and shore-to-shore distance are based considerations of maximum effective range of small arms and rocket propelled grenades. Rocket propelled grenades have a maximum range of 700 to 950 meters. Small arms have effective firing ranges up to 500 meters. These ranges align well with the thresholds assigned to bridges and shore-to-shore distance factors for safety considerations, with a high threshold less than 500 meters (susceptible to small arms and rocket propelled land-based attacks), a moderate threshold out to 1000 meters (susceptible to rocket propelled grenades), and a low risk level greater than 1000 meters. For bridges, these ranges justify keeping the same categorization as for safety. Table 3-4 lists all the selected security risk factors and their associated threshold levels.

Table 3-4. Threshold values for security risk factors.

Factor	Unit of measure	Threshold values		
		High	**Moderate**	**Low**
Inlets	# of inlets	> 1	1	0
Civilian docks and piers		present on both shores	present on one shore	none
Vessel traffic pleasure	color-scale estimate of AIS vessel counts	> 40,000	20,000 - 40,000	< 20,000
Bridges		bridge in segment	bridge in adjacent segment	no bridge
Shore cover type	factor value	4 or 5	2 or 3	0 or 1
Shore-to-shore distance	meters	< 500	500 - 1000	> 1000
Fog	% days / year	> 40	20 - 40	< 20

3-5. Demonstration

In this section, the methods described in Section 3-4 are applied to an inland waterway corridor in northern Florida, the St. Johns River from the Port of Jacksonville to the mouth of the river on the Atlantic Ocean at Naval Station Mayport. The region and corridor for this demonstration is referred to as St. Johns River throughout this chapter. Maritime corridor traces for both safety risk factors and security risk factors are presented, along with the supporting risk register products, introduced in Chapter 2, for both safety and security risk factors. A discussion of combined safety and security considerations is presented.

3-5-1. Demonstration Background

The region selected for this demonstration is northeast Florida and focuses on operations associated with the Port of Jacksonville and vessel traffic on the St Johns River. The St Johns River is the longest river in Florida at about five hundred kilometers long. It originates in marshland near the east coast of the state, south of Cape Canaveral. Figure 3-6 is a depiction of the St Johns River corridor region and the corridor segmentation.

Figure 3-6. St. Johns River corridor region.

The Port of Jacksonville is a deep-water port. It handles a wide variety cargo at several terminals along the St Johns River corridor: Talleyrand, Dames Point, and Blount Island marine terminals. The Jacksonville Port Authority is a port operator. This designation means the port authority is responsible for and in charge of operations at some or all of the terminals in its jurisdiction (USDOT, 2018). The Port of Jacksonville transfers containerized cargo, bulk and breakbulk goods, and has extensive roll-on/roll-off facilities. The port announced $1.8 billion dollars of investment in infrastructure improvements to prepare for expected growth in their bulk shipping business (Port of Jacksonville, 2019). They loaded and off-loaded nearly seven hundred thousand automotive vehicles in 2019, and are a military port of embarkation loading a large volume of heavy equipment, including tanks and helicopters, for the U.S. Army for deployments abroad.

Most relevant to this demonstration, the Port of Jacksonville advertises itself as a leader in the movement to liquefied natural gas (LNG) in the maritime shipping industry (Port of

Jacksonville, 2018). Working with partner organizations, they have recently introduced and begun expanding their LNG services. One of these partners, Crowley Maritime, a shipping company, built two new LNG-powered vessels homeported at the Talleyrand Marine Terminal. These vessels are fueled by the Eagle LNG company which owns and operates a liquefaction plant and bunkering facility at Talleyrand, capable of producing two hundred thousand gallons of LNG per day. Eagle LNG has also started the production of a second liquefaction and storage plant at the Blount Island Marine Terminal with authorization to use this future terminal for the export of LNG by tanker shipment. A third company, JAX LNG, operates a liquefaction and storage facility at the Dames Point Marine Terminal. Lastly, TOTE maritime operates two LNG powered vessels homeported at Blount Island and established North America's first LNG bunkering barge which supplies LNG capable vessels at Dames Point.

In addition to these LNG facilities and capabilities, there are several petroleum-based fuel points along the St Johns River corridor, operated by Marathon Petroleum, Apex Oil, and Nustar Energy. Also of interest, and unique to this demonstration among the others presented in the dissertation, is a passenger cruise berth located northwest of Dames Point Marine Terminal. This port is called by Carnival Cruise Line and Norwegian Cruise Line vessels.

In the state of Florida, ship captains of vessels drawing 2.14 meters (7 feet) or more of water are required to notify and request piloting assistance from the Florida Harbor Pilots Association during approach to Florida inland waterways. Specifically, for the St. Johns River, the St. Johns Bar Pilot Association provides these services. The association describes case law, as well as authorities of the United States Coast Guard prohibiting ship captains from navigating their own vessels in Florida's waters (SJBPA, 2016). The piloting of vessels occurs in the form of escort tug operations and in having pilots board and pilot the vessel during high-risk sea-state conditions of wind, rain, and fog. Though the knowledge and experience of these pilots may reduce overall risk in terms of probability of hazard occurrence, the relative risk of safety and security risk factors remains. Pilots are not immune to the associated safety and security risks due to their knowledge and experience. Additionally, the maritime corridor trace remains a useful planning tool for assessing risks associated with stated commercial growth goals. As of writing, there are fourteen licensed pilot members of the St. Johns Bar Pilot Association, implying a maximum of fourteen vessels drawing 2.14 meters or more of water are permitted on the St. Johns River corridor at any time.

3-5-2. Maritime Corridor Trace Development

The starting point of the inland waterway corridor is chosen at the Port of Jacksonville’s Talleyrand Marine Terminal northeast of downtown Jacksonville. The corridor proceeds northeasterly for six nautical miles before turning southeast. After approximately three nautical miles, the corridor takes a nearly ninety degree turn just before Interstate 295 and continues east. There is a winding section from segments 13 through 18 as the corridor approaches Naval Station Mayport. The corridor extends four nautical miles into the Atlantic Ocean ending at segment 24, at the beginning of a maintained channel, the Jacksonville Harbor Barcut.

3-5-3. Safety Risk Factor Considerations

Figure 3-7 and Figure 3-8 present the maritime corridor trace for safety risk factors for the St Johns River corridor. Table 3-5 and Table 3-6 are supporting risk register products providing the distribution of safety risk factor levels across segments and the distribution of segment threshold levels across factors.

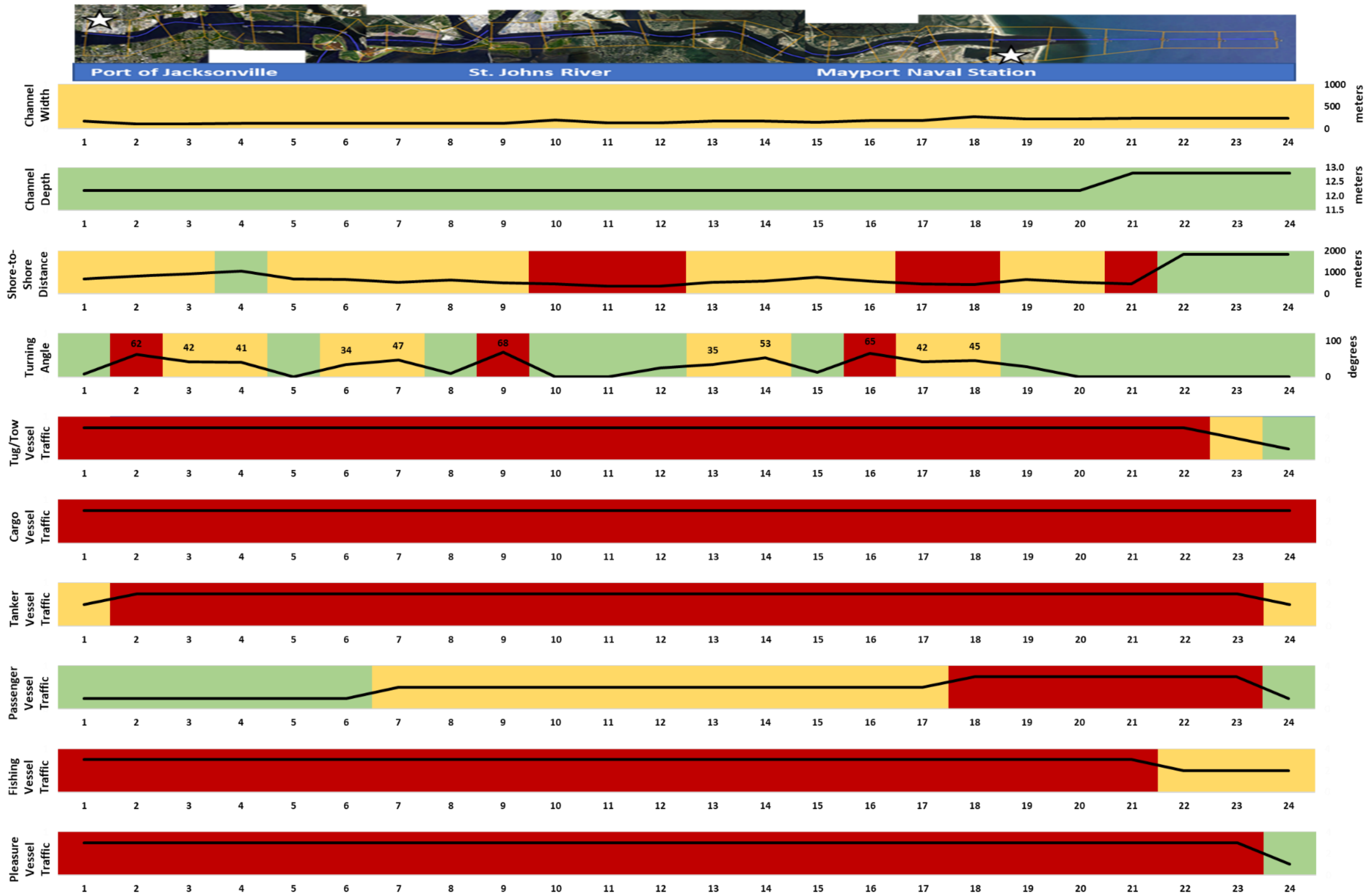


Figure 3-7. Maritime corridor trace of St. Johns River for geometry and traffic factor categories.

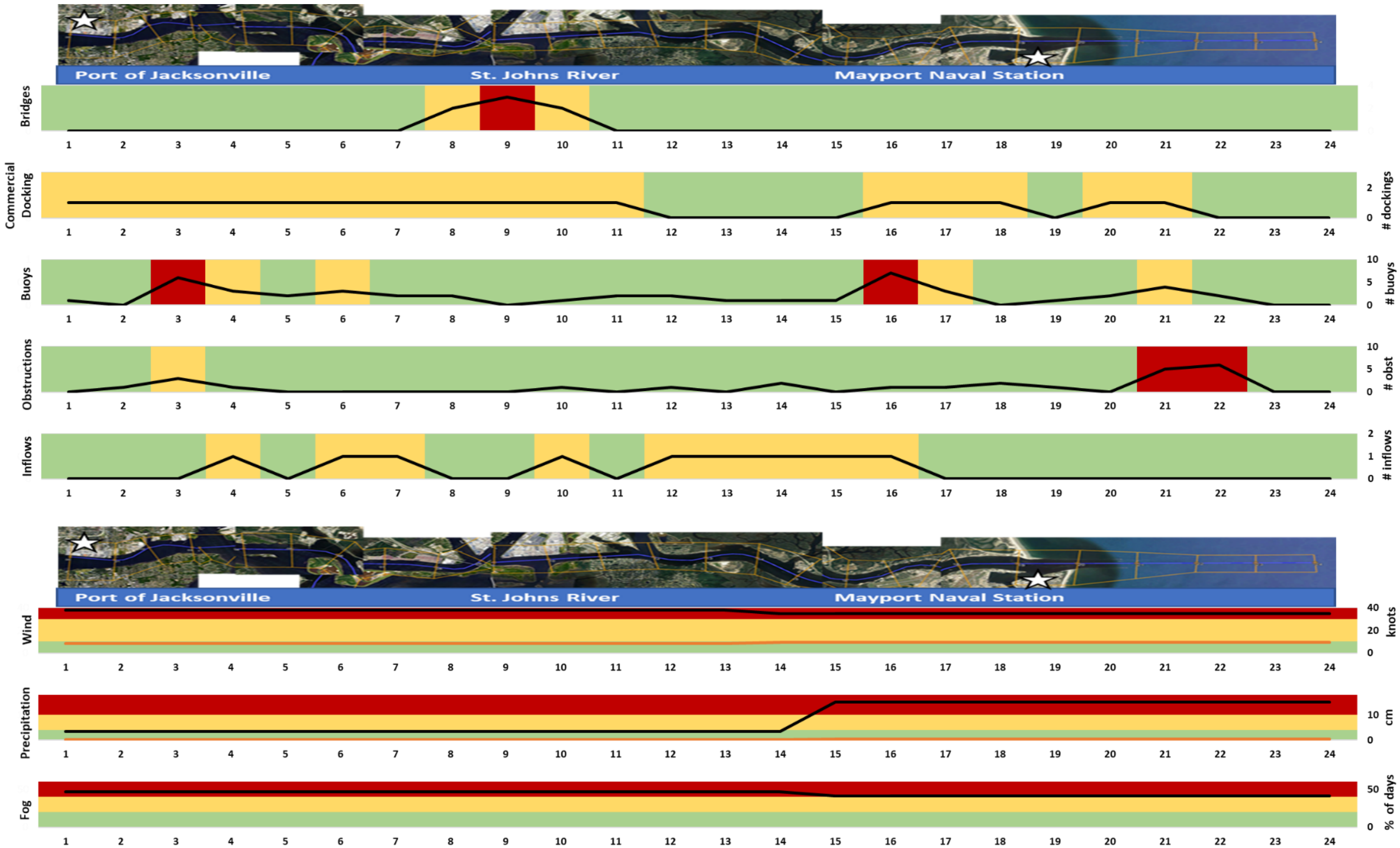


Figure 3-8. Maritime corridor trace of St. Johns River for infrastructure, obstacle, and sea-state factors.

Table 3-5. Distribution of safety risk factor levels in each segment for St. Johns River.

	Number of Factors Within Threshold		
Segment	**High**	**Moderate**	**Low**
1	6	4	10
2	8	3	9
3	8	5	7
4	7	5	8
5	7	3	10
6	7	6	7
7	7	6	7
8	7	5	8
9	9	4	7
10	8	5	7
11	8	3	9
12	8	3	9
13	7	5	8
14	7	5	8
15	8	4	8
16	10	5	5
17	9	5	6
18	10	3	7
19	9	2	9
20	9	3	8
21	11	3	6
22	9	2	9
23	7	3	10
24	4	3	13

Table 3-6. Distribution of segments by risk level within safety risk factors for St. Johns River.

Factor	Hazards	Number of Segments Within Threshold		
		High	Moderate	Low
Channel width	Collision	0	24	0
Channel depth	Grounding	0	0	24
Shore-to-shore distance	Grounding	6	14	4
Turn angle	Collision, allision, grounding	3	8	13
Vessel traffic tug/tow	Collision	22	1	1
Vessel traffic cargo	Collision	24	0	0
Vessel traffic tanker	Collision	22	2	0
Vessel traffic passenger	Collision	6	11	7
Vessel traffic fishing	Collision	21	3	0
Vessel traffic pleasure	Collision	23	0	1
Bridges	Allision, collision	1	2	21
Commercial pier	Collision, allision	0	16	8
Buoys and lights	Allision	2	4	18
Obstructions	Allision	2	1	21
Inflows	Collision, allision, grounding	0	9	15
Wind (average)	Collision, allision, grounding	0	0	24
Wind (maximum)	Collision, allision, grounding	24	0	0
Precipitation (average)	Collision, allision, grounding	0	0	24
Precipitation (maximum)	Collision, allision, grounding	10	0	14
Fog	Collision, allision, grounding	24	0	0

Inspection of the maritime corridor trace reveals areas of compounded risk among segment groupings 2 through 4, 9 through 11, and 16 through 18. Each of these groupings include a segment with a high-risk turning angle. Further, the turning angle risk level for all three segments in groupings 2-4 and 16-18 is high or moderate. Commercial docking is moderate in all segments of each grouping. Vessel traffic is consistently high across the entire corridor for all types of vessel traffic except passenger vessels. Passenger vessel traffic is moderate in segments 9-11 and high in segments 16-18. Shore-to-shore distance is moderate to low in segments 2-4, but moderate to high in segment groupings 9-11 and 16-18. The presence of buoy and light obstacles presents an elevated risk in segments 2-4 and segments 16-18. Finally, segment 9 contains the Dames Point Bridge carrying vehicular traffic on Interstate 295. Figure 3-9 is a GIS visualization of the maritime corridor in each compounded safety risk segment groupings discussed.

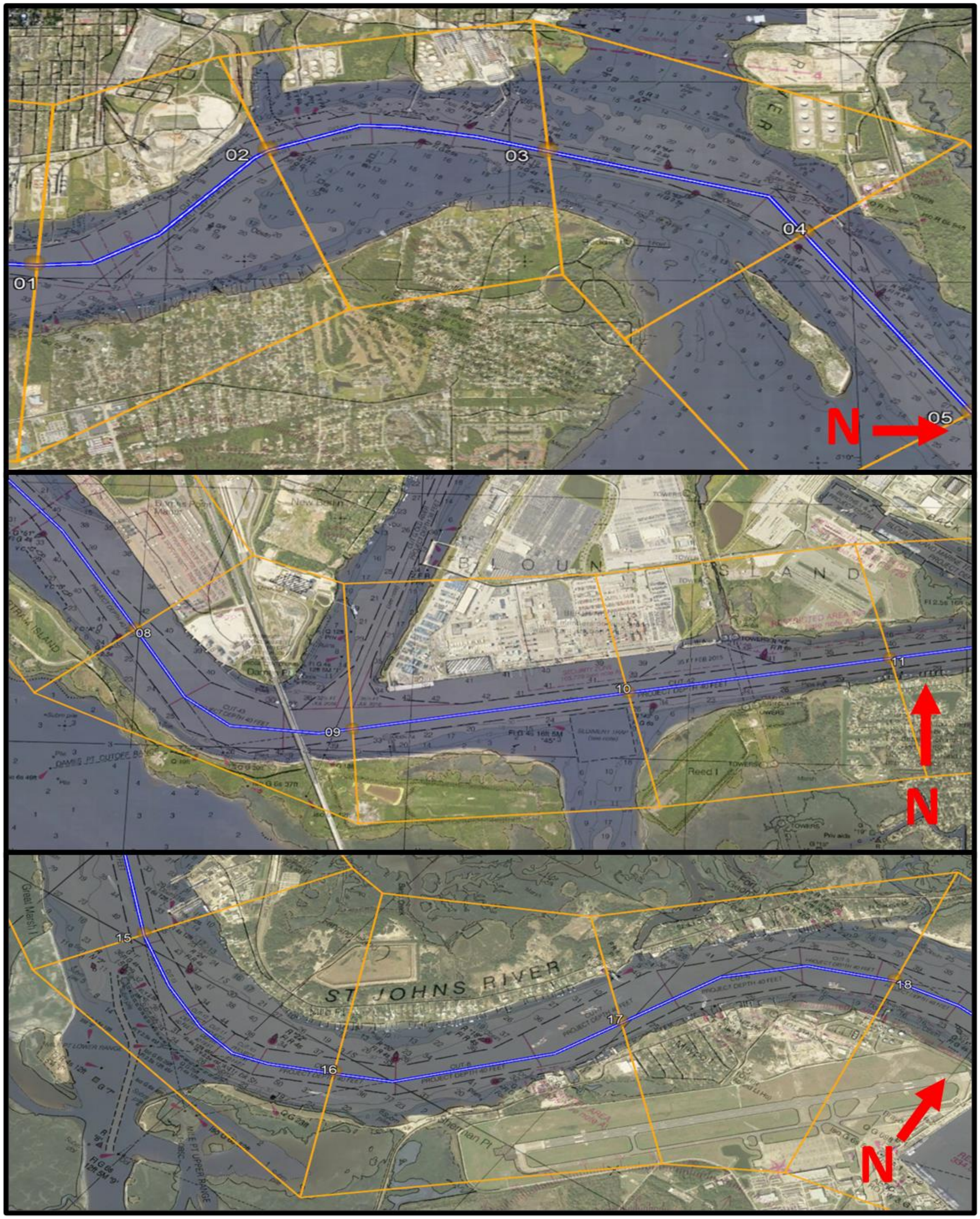


Figure 3-9. GIS visualization of compounded safety risk segment groupings for St. Johns River corridor.

Figure 3-10 gives the aggregated safety risk factor assessment and segment rankings for the St. Johns River corridor. The figure shows high to moderate segment rankings for the compounded segment groupings discussed, with exception for segment 2. It also reveals high segment rankings for segments 6 and 7 and a moderate ranking for segment 8, suggesting these three segments may be worthy of further investigation, or even consideration of the entire length of segments 6-11 as a single compounded risk area if meaningful.

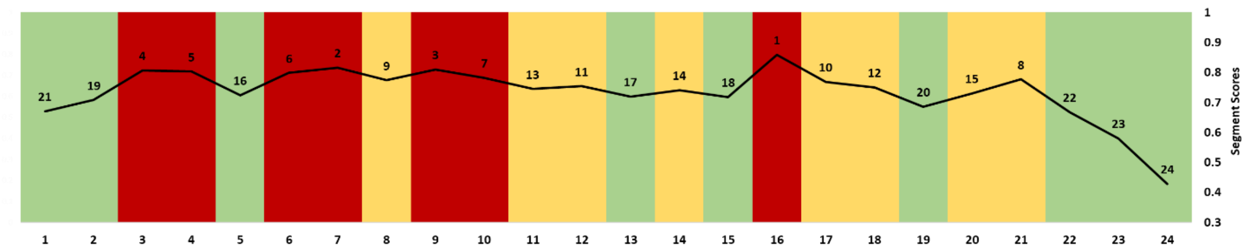


Figure 3-10. Aggregated safety risk factor assessment and resulting segment rankings for St. Johns River corridor.

3-5-4. Security Risk Factor Considerations

This section applies the same analysis approach to security risk factors applicable to the corridor as with safety risk factors. the maritime corridor trace for security risk factors is presented, with accompanying risk distribution tables. Compounded security risk areas are considered. The section is concluded with the presentation of the aggregated security risk factor assessment and segment rankings.

Figure 3-11 is the maritime corridor trace for security risk factors for the St Johns River corridor. Table 3-7 and Table 3-8 are supporting risk register products depicting the distribution of security risk factor levels across segments and the distribution of segment threshold levels across security risk factors.

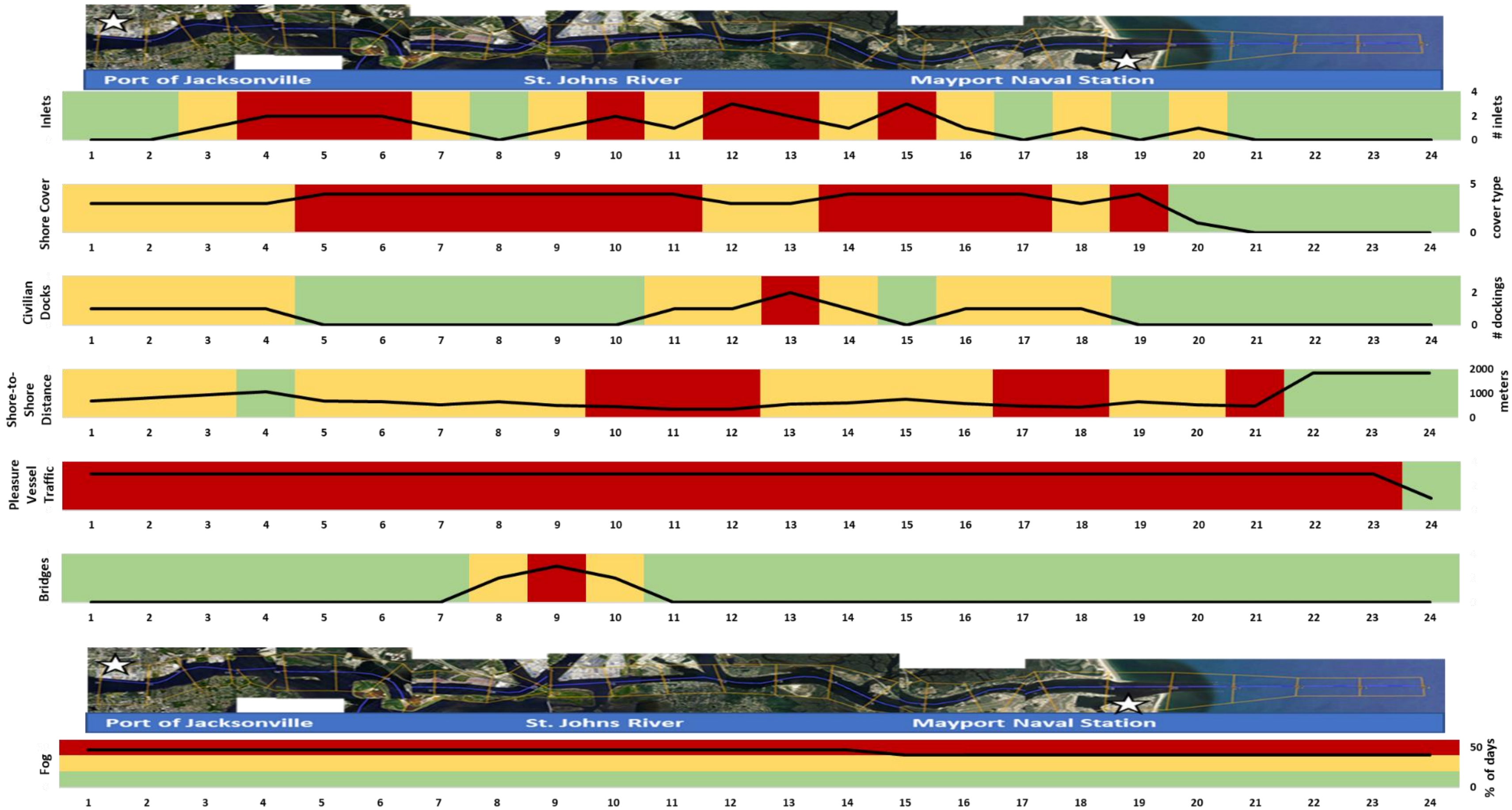


Figure 3-11. Maritime corridor trace of St. Johns River for security risk factors.

Table 3-7. Distribution of security risk factor levels in each segment for St. Johns River.

	Number of Factors Within Threshold		
Segment	**High**	**Moderate**	**Low**
1	2	3	2
2	2	3	2
3	2	4	1
4	3	2	2
5	4	1	2
6	4	1	2
7	3	2	2
8	3	2	2
9	4	2	1
10	5	1	1
11	4	2	1
12	4	2	1
13	4	2	1
14	3	3	1
15	4	1	2
16	3	3	1
17	4	1	2
18	3	3	1
19	3	1	3
20	2	2	3
21	3	0	4
22	2	0	5
23	2	0	5
24	1	0	6

Table 3-8. Distribution of segments by risk level within security risk factors for St. Johns River.

Factor	Hazards	Number of Segments Within Threshold		
		High	Moderate	Low
Inlets	VBA	7	8	9
Cilivilan docks and piers	VBA	1	10	13
Vessel traffic pleasure	VBA	23	0	1
Shore cover type	LBA	12	7	5
Shore-to-shore distance	LBA	6	14	4
Bridges	LBA	1	2	21
Fog	VBA	24	0	0

Inspection of the maritime corridor trace and the distribution of security risk factor levels in segments suggests segment groupings 9 through 13 and 16 through 18 are potential areas of compounded security risk. High-risk levels for small-craft traffic (vessel traffic pleasure) are associated with all corridor segments except the end of the Jacksonville Harbor Barcut, segment 24, near open water in the Atlantic Ocean where small-craft traffic disperses. Shore cover type is high or moderate in all segments of both groupings. The northern shore in segments 9-12 consist of the Dames Point Marine Terminal and the Blount Island Marine Terminal, and thus are commercial/industrial facilities. The southern shore in segments 9-11 consists of undeveloped forested or marsh land. Segments 12 and 13 classified as moderate based on the residential shorelines. The south shores of segments 16 and 17 contain undeveloped forested or marsh land. Segment 18 is residential. Segments in both groups, except segment 17, contain at least one inlet, providing a hide position and small-craft access to the corridor. Segments 10, 12, and 13 have multiple inlets. Shore-to-shore distance risk levels are high to moderate throughout, all less than 800 meters across, placing vessels within effective range of small arms fire from the shore. Segments in these groupings highlight a potential relationship between shore cover type and civilian docks. Where the shore is lined with residences, there is likely to be civilian dock access. This does not have to be the case, but it is in for the corridor segments considered here. The security risk factor levels for civilian docks is generally moderate to high in the segment groupings. Finally, segment 9 contains the one bridge in this corridor, providing a potential platform for a land-based attack from an elevated position.

Figure 3-12 is the aggregated security risk factor assessment and segment rankings based on security considerations for the St. Johns River corridor. It reveals a curious level of symmetry about the central portion of the corridor where the highly ranked segments coalesce. Similarly, moderately ranked segments are grouped on either side of the central portion with low ranked segments flanking at either end of the corridor. The general symmetry is also reflected in high-risk threshold column of Table 3-7. Low rankings at the eastern end of the corridor are due to the 4-nautical mile section of maintained channel extending into the Atlantic Ocean. Low rankings on the western end are due to wider shore-to-shore distances and the populated areas approaching metropolitan Jacksonville.

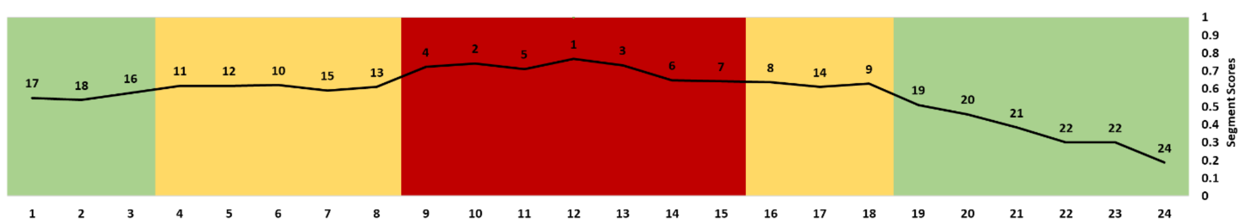


Figure 3-12. Aggregated security risk factor assessment and resulting segment rankings for St. Johns River corridor.

Another relationship highlighted by the discussion of compounded security risk segments is the relationship between segment risk levels for safety factors and segment risk levels for security factors. Both of the compounded security risk areas discussed overlap with compounded safety risk areas shown in Figure 3-9. This is expected for three reasons. First, four of the selected security risk factors are also safety risk factors, and a fifth, inlets, is highly related to the safety risk factor, inflows. All four of the shared risk factors maintain the same threshold, though bridges and shore-to-shore distance thresholds are evaluated with different reasoning. Second, the shared and similar risk factors make-up over seventy percent of the selected security factors. Third, in this demonstration, the calculation of risk factor weights is based on the distribution of segments by risk level within each risk factor. Since the thresholds remain unchanged between safety and security risk factors, the distribution of segments risk levels in these factors remains unchanged. Relative factor weights may be slightly different, since they are relative to a differing set of factors overall, the sameness in segment risk distribution will result in similarities between segment rankings for safety and security considerations. The overlap of safety risk levels and security risk levels may not be as prevalent when relative factor weights are assigned by system stakeholders. In chapter 5, system stakeholder values are used to assign relative risk factor weights.

3-5-5. Disaggregated Safety and Security Risk Factor Analysis for Threat Scenarios

This section discusses possible implications of safety and security risk factors on vessel operations in the corridor by considering specific threat scenarios. Possible responses to the threat scenario are considered from a security stand-point and possible impacts of those responses on safety considerations are discussed. The discussion involves some conjecture, but is informed by insight gained during dialogue with subject matter experts in naval operations, port authority leadership for barge operations, and United States Coast Guard (USCG) personnel. It is also informed by research discussed in Section 3-3 and by the GAO Report and military doctrine discussed in Section 3-4.

In each scenario, three primary means of defensive tactics employable by friendly vessels are considered: speed, maneuver, and blocking tactics. Blocking tactics are discussed in terms of the limited USCG escort mission mentioned in Section 3-3 and in the context of autonomous capable systems which could be employed in those operations. Defensive tactics involving weaponry are discounted as a means of defense for purposes of this discussion.

Speed is likely a preferred course of action against a land-based attack. During a react to ambush, an ideal situation is to move through the attack zone if able and as quickly as possible. Since the typical threat course of action is to use small craft, it is unlikely a large tanker or cargo vessel could outpace the threat vessel. However, increased speed may generate wake, which could have a disrupting effect on the path of travel of the threat vessel. Subject matter experts have also noted general vessel speed, moving as fast as possible through the corridor, is a possible deterrent.

Evasive maneuvering could apply to both vessel-based and land-based attacks. Primarily, maneuvering may allow a target vessel to limit the profile of the vessel facing the attack. Turning the broad side of the vessel away from the direction of a land-based attack would limit the target area of the vessel. Similarly, for a vessel-based attack, the contact area and heading of the attack vessel against the target vessel could have impact on the amount of damage inflicted on the target vessel. If the target vessel assesses and armed assault as the intent of a vessel-based attack, the ship could maneuver to derail the approach of the attack vessel, perhaps even attempting to capsize the smaller craft. Maneuvering during an armed assault attempt could also delay the threat's ability to reach the boat and begin boarding until a response is able to arrive.

Blocking tactics would include the use of escorting vessels to patrol and enforce an exclusionary zone around the target vessel, the use of vessels of sufficient size to block direct fire from land-based attacks, and the use of vehicles to make it difficult for a threat vessel to make contact with the target vessel. Maintaining close distance between blocking vessels and target vessels can be a difficult procedure for water craft given their control dynamics. Autonomous capabilities on the blocking vessels can assist in such procedures by automatically controlling the blocking vessel in response to speed and heading signals from the target vessel.

Vessel-based and land-based attacks in St. Johns River corridor segment 9.

Figure 3-13 provides a reference for discussion of threat scenarios in segment 9 of the St. Johns River corridor. Segment 9 is included in identified compounded risk areas for both safety and security considerations.

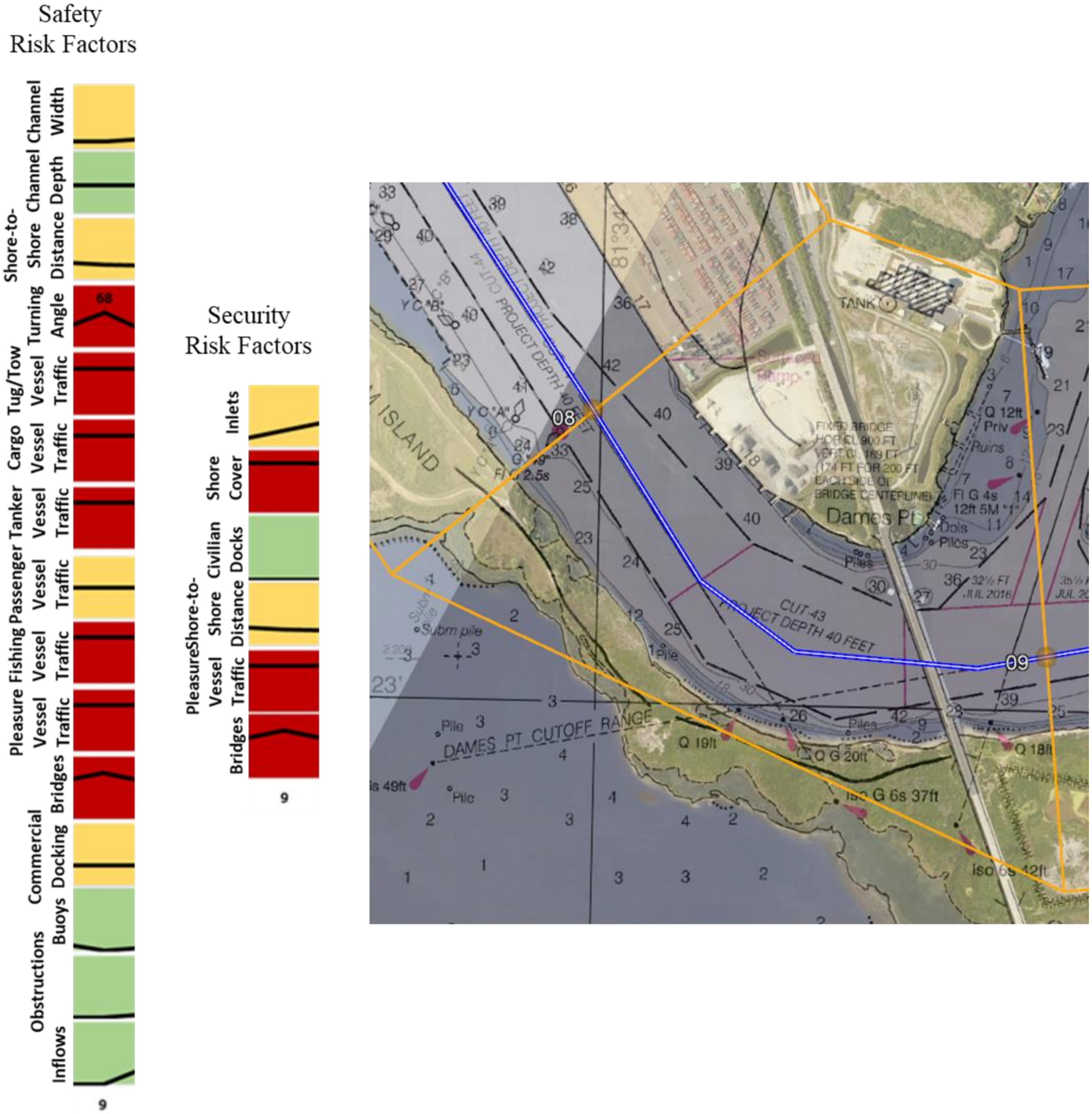


Figure 3-13. Safety and security risk factors and GIS visualization for threat scenario analysis of St. Johns River corridor segment 9.

For a vessel-based attack in this segment from the perspective of security risk factors, pleasure vessel traffic is a high risk, meaning a vessel-based threat may be able to disguise its intentions until committing to the attack by mingling among other small-craft vessels. There is only one inlet in this segment, but it may provide an advantageous staging position, especially for an attack against vessels heading from segment 8, using Dames Point as concealment from the approaching vessel.

To avoid an oncoming threat vessel, an unescorted vessel would look to employ speed and maneuver. The safety characteristics of the segment may limit the ability to take such actions. The 68-degree turning angle will limit the speed at which the vessel can travel, and if on approach to the bridge will need to proceed with elevated caution. Channel width and depth are at moderate risk levels indicating some room alter course headings to change the attack profile and some room to navigate outside of the maintained channel on the north side, depending on whether or not ships are berthed on the commercial piers on the north side of the channel. On the south side, depths drop immediately to 7.62 meters (25 feet) or below. Speed and maneuverability are also impacted by the presence of other vessels in the corridor. In segment 9, all types of vessel traffic aside from the moderate level for passenger vessels, are indicated as high-risk levels. Though not a safety risk factor, because it is deemed to be an outflow, the inlet on the north side at the east end of the segment may provide an opportunity for the vessel to turn sharply to assuage an attempted attack.

For blocking tactics, the escort vehicles are likely to be afforded more maneuverability than the larger target vessel. Blocking vessels may be able to operate outside of the maintained channel on both shores. The turning angle of the segment may impact the ability of autonomous systems to maintain ideal proximity with the target vessel, possibly allowing sufficient space for a threat vessel to close with the target vessel. Subject matter experts familiar with the operation of such autonomous systems have noted a tendency for vessel pilots to select out of autonomous operation in areas of elevated safety risk, believing they can operate the vessel more safely in manual mode. Though the marked channel at the bridge location is not the limiting distance on the determination of the channel width factor level, height restrictions may require a blocking formation to rearrange and leave the target vessel exposed during the approach.

A land-based attack is likely to come from the undeveloped forested land on the corridor segment's south shore or from the bridge at the east end of the segment. The shore-to-shore characteristics place a vessel within range of small arms and rocket-propelled explosives. Safety considerations for speed and maneuverability apply to land-based attacks in segment 9 as well. The turning angle and shore-to-shore distance play an additional role for land-based attacks from the bridge. As the corridor turns around Dames Point to the bridge, the angle places the target vessel closer to the potential attack location by the time line of sight to the bridge is established and places an unexpecting vessel at an angle to an attack from the bridge, exposing a larger surface area to direct fire.

Vessel-based and land-based attacks in St. Johns River corridor segment 19.

Figure 3-14 provides a reference for discussion of threat scenarios in segment 19 of the St. Johns River corridor.

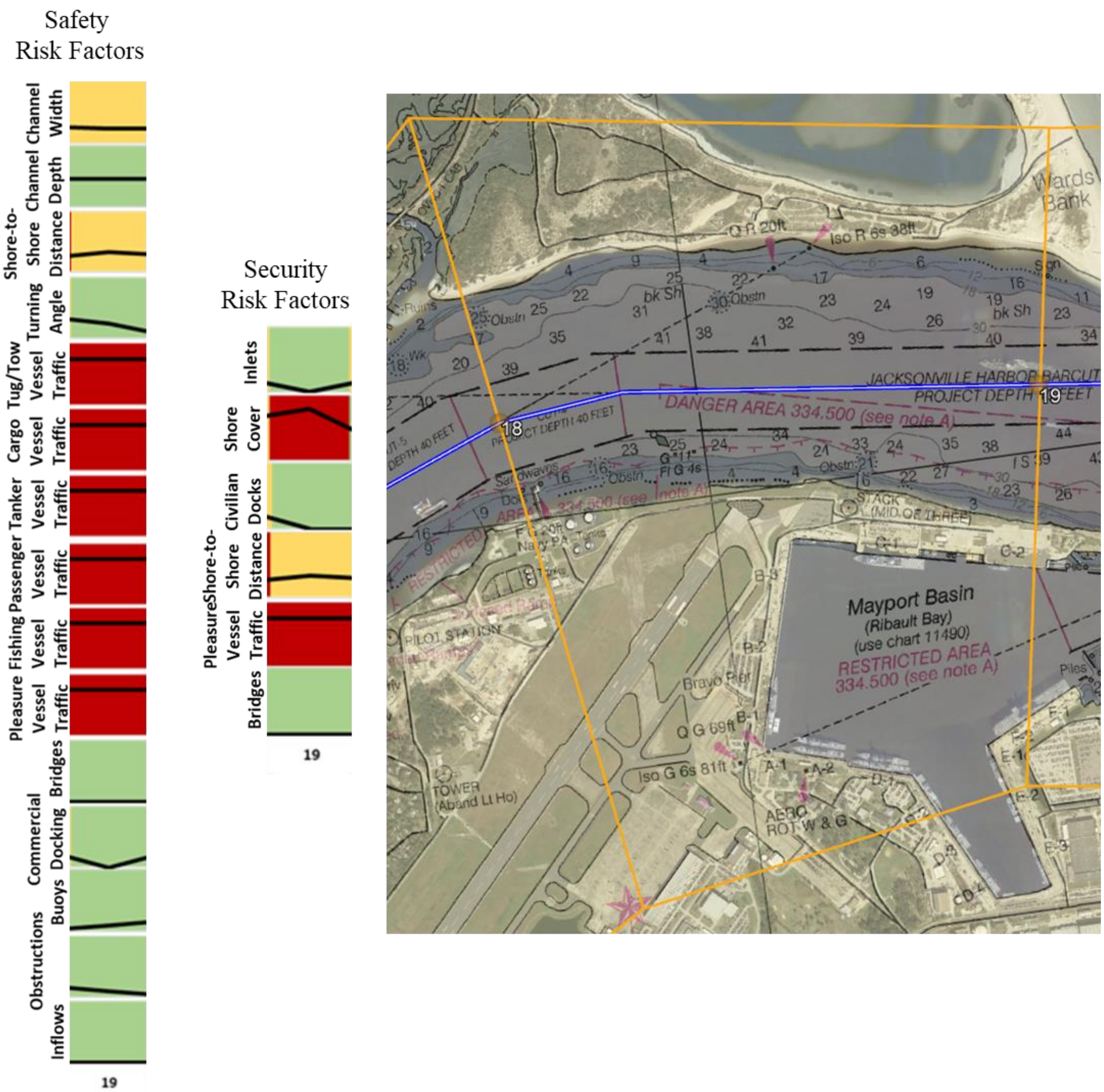


Figure 3-14. Safety and security risk factors and GIS visualization for threat scenario analysis of St. Johns River corridor segment 19.

Segment 19 is ranked as an aggregated low-risk level segment among both safety risk factors and security risk factors. The security risk factors for segment 19 related to land-based attacks have the highest risk levels. A land-based attack is likely to come from the north shore, where the mostly undeveloped shore is covered by vegetation offering cover and concealment and a method of egress for a potential threat, and is a high-risk level. Naval Station Mayport is located on the south shore. The shore-to-shore distance is moderate, but places vessels within range of rocket-propelled explosives and possibly small arms fire. Pleasure vessel traffic is high, as with most of the corridor, but there are no inlets or civilian docks which might provide a staging area for the threat. One consideration not captured by the current set of security risk factors is the location of this segment relative to the Atlantic Ocean and open water. Vessels moving toward the Atlantic Ocean are conceivably at higher risk of armed assault. A successful hijack in this part of the corridor could allow the threat force to quickly take the ship to open water and have gain greater control and defensive posture of the vessel than at segments farther inland.

The only safety factors limiting the use of defensive tactics in this segment are vessel traffic of all types, channel width and shore-to-shore distance. Channel width in this segment is 230 meters, less than the length of an LNG tanker at up to 300 meters. Still, vessels should have some ability, depending on the presence of other vessels, to vary heading along the segment. The turn angle in segment 19 is 29 degrees, but the majority of the segment is straight. Speed limitations will most likely be controlled by the capabilities of the vessel and not characteristics of the corridor. Escort vessels should be able to operate freely and in autonomous mode, depending on sea-state conditions.

3-6. Conclusion

This chapter extends the maritime corridor trace method developed in Chapter 2, to include consideration of security risk factors. Maritime corridor trace is argued as a necessary perspective to gain a full picture of the conditions potentially leading to maritime safety and security incidents along with perspectives on system component failure, organizational culture, and human factors. The trending growth in liquefied natural gas use in the maritime shipping industry and protected growth of autonomously capable vessels are presented to explore safety and security capabilities of autonomous systems in various types of vehicles and briefly discuss water-borne vessel dynamics. The maritime corridor trace methods for risk factor selection, data collection, and threshold determination are applied to security risk factors, using a GAO report on fuel commodity vessel security and military doctrine to select relevant security risk factors. The maritime corridor trace methodology for safety and security risk factors is applied to a 24-nautical mile long corridor on the St. Johns River in north-eastern Florida with the LNG related activities of the Port of Jacksonville being of special interest. Both safety and security risk considerations for the corridor are discussed. Two corridor segments are highlighted to explore possible defensive tactics against threat hazards in light of the safety and security risk factor characteristics in those segments.

The introduction of security factors to the maritime corridor trace analysis is necessary to achieve a full consideration of causal factors. Both safety and security risk factors have the potential to cause significant disruption to operations on the inland waterway corridor. Though some factors for safety considerations are included in security considerations, the inclusion of security provides the enterprise stakeholder with new information and a new analysis perspective. Inlets, shore cover type, and civilian docks and piers are introduced as security risk factors, and contribute to the scenario-influenced prioritization of corridor segments, as demonstrated in

Chapter 5. Discussions of disaggregated safety and security risk factor analysis for threat scenarios highlight competing concerns for operations planning. Vessel tactics employed to defend against a threat incident or to mitigate the potential of a threat incident, such as speed, maneuver, and use of blocking vessels, may exacerbate safety risks along the corridor. Segments where speed or maneuver are desirable for security considerations may be undesirable, or even infeasible, based on safety risk factor threshold levels associated with the segment. This analysis suggests a need to explore the dependency of safety factors in high risk security segments in future work. It is also of interest to explore segments with moderate or high safety risk rankings but low security risk rankings, and the converse. Inspection of aggregated safety and security risk rankings for the St. Johns River corridor reveals the existence of both of these situations.

Chapter 4. Risk Management and Resilience Analysis for Asset Management Systems

4-1. Overview

This chapter develops a risk and resilience-based method for the management of assets. Management of physical assets is a critical capability across many organizations and sectors. Within enterprises where safety is of particular importance, such as prisons, tracking and monitoring assets at the most granular level is a key enabler of safety, security, and trust. Various asset management systems can facilitate the tracking of physical assets, however different approaches may be more or less effective depending on emerging and future technological, social, economic, and environmental factors. This chapter describes a method for how security enterprises acquiring an asset management system can perform an analysis of system requirements under uncertainty. The methodology develops an analysis of emergent and future conditions with potential to disrupt the tool-control system. The conditions are across technologies, operating environments, regulations, workforce behaviors, user behaviors, prices and markets, organizations, etc. The methodology addresses the influence and interaction of the conditions on system requirement priorities, such as the influence of environmental conditions related to infectious disease epidemics on technological requirements and the influence of the adoption of technology on trust in these systems among stakeholders. The conditions most and least relevant to the development of an asset management request for proposals (RFP) are characterized. The analysis will be the basis for a risk register to identify and track sources of risk to project performance, schedule, and cost throughout the system acquisition and implementation.

4-2. Introduction

Asset management has been defined in several ways in the literature. For example, the ISO 55000 standard defines asset management as "coordinated activity of an organization to realize value from assets," while the Asset Management Council (2009) proposed the definition of "the life cycle management of physical assets to achieve the stated outputs of the enterprise". Asset management is not a single activity, but involves multiple processes including "organizing, planning and controlling the acquisition, care, refurbishment, and disposal of infrastructure and engineering assets" (Laue et al., 2012).

Effective asset management is an enterprise-wide activity, involving multiple business areas and processes (Al-Akruit and Dwight, 2013). Laue et al. (2012) identified the business process areas supporting asset management across the enterprise, across dimensions of time, organization, and space. Some of these areas include senior management, finance, accounting, IT, risk management, and sustainability management. Holland et al. (2005) describe asset management activities at BP, and show how an integrated approach to asset management can support functions including work management, requisition, data reporting and analysis, stock management, finance, and other supply chain management functions. Lin et al. (2006) describe how asset management can enable key business processes, including effective control of resources, work, costs, and change orders. Greyling and Wyhan (2017) apply business process modeling to improve an asset control system. Frolov et al., (2010) suggests a methodology for analyzing the functionality of components to build a physical asset management system.

Modern asset management strategies are enabled by data collection on the states of assets. To effectively utilize these data, Nel and Jooste (2016) define four necessary enablers:

- Asset information strategy
- Asset knowledge standards
- Asset information systems
- Asset data and knowledge.

These enablers facilitate a data-driven asset management strategy which allows the organization to engage in a number of analytics activities, which are described by Hampapur et al. (2011) as four categories: customer and usage analytics, work-management analytics, predictive maintenance analytics, and space-time analysis tools.

Leveraging predictive analytics in asset management systems can result in reduced risks and heightened system safety. For example, in the aerospace, nuclear power generation, advanced manufacturing, and other industries, foreign object damage (FOD) is a prevalent risk consideration. In some of these industries FOD is replaced by the term foreign material exclusion (FME). The most common example of FOD may be debris on an airfield capable of being drawn into an engine or damage a tire, placing the integrity of the aircraft and lives of passengers at risk.

Risks to airplanes, power generation plants, precision-manufactured products and other systems includes any loose item capable of interacting with the system in an undesirable manner, including tools, assembly parts, utensils, clothing, and others (Becker, 2008). Debris may enter a system during manufacturing, shipment, maintenance, or in operation. Hussin et al. (2016) identify circumstances with the potential to introduce foreign debris into a system, during maintenance or in operation, as insufficient accountability protocols, improperly sanitized working environments, general disorganization, or insufficient technology to identify potential debris.

Foreign object debris is estimated to cost the aerospace industry approximately 4 billion dollars annually (Khan et al., 2017; Patterson, 2008). Kenger and Karlsson (2007) categorize FME mitigation in the nuclear and advanced manufacturing industries into proactive and reactive methods. Proactive is described as processes and products resulting in a decreased possibility of personnel errors while reactive is described as detection processes which provide feedback to personnel. FOD detection systems in the aerospace industry possibly categorized as reactive, include the use of radar, high resolution cameras, and human visual inspection (Patterson, 2008). Detection systems may be stationary or mobile. Examples include radar-based detection systems to identify FOD as small as 2 centimeters in diameter (Ni et al., 2020) and a roving platform incorporating light detection and ranging (LiDAR) (Elrayes et al., 2019).

Much of the literature discussing FOD origin and mitigation relates to circumstances of unintentional or accidental debris. Some enterprise operations harbor more evident security concerns for asset control, as well as safety considerations. Nuclear power generation is among these, as are physical security of military weapons and ammunition, and tool and equipment control for corrections facilities. Security considerations may result in system requirements with unique attributes. Some attributes of security requirements will also apply to safety considerations.

In addition, asset management concerns are not limited to safety and security, and the cross-over of attributes may apply across all relevant dimensions.

Organizations issuing requests for proposals (RFPs) for data-driven asset management solutions need to define clear system requirements. For example, as with any data-intensive process, it is important to define data quality guidelines (Lin et al., 2006, 2007). Defining such requirements up-front in the systems acquisition process enables desired functionality and lower costs. The system life cycle is shown in Figure 4-1.

However, system priorities are subject to change, especially under situations of deep uncertainty. There will never be a complete prediction of what system needs will exist in the future (Hamilton et al., 2015; Teng et al., 2012). Changes in system operating environments, technologies, regulations, workforce behaviors, end-user behaviors, prices and markets, organizations, etc., can disrupt the effectiveness of these requirements once the asset management technology is fielded. Recent experience with the COVID-19 pandemic shows how easily "business as usual" forecasts can radically change, necessitating an approach adaptive to emergent and future conditions.

A method for analyzing system requirements for an asset management system under uncertainty is presented here, allowing users to identify disruptive conditions on the asset management system acquisition process, consistent with a "learn-as-you-go" system acquisition process (Horowitz & Lambert, 2006).

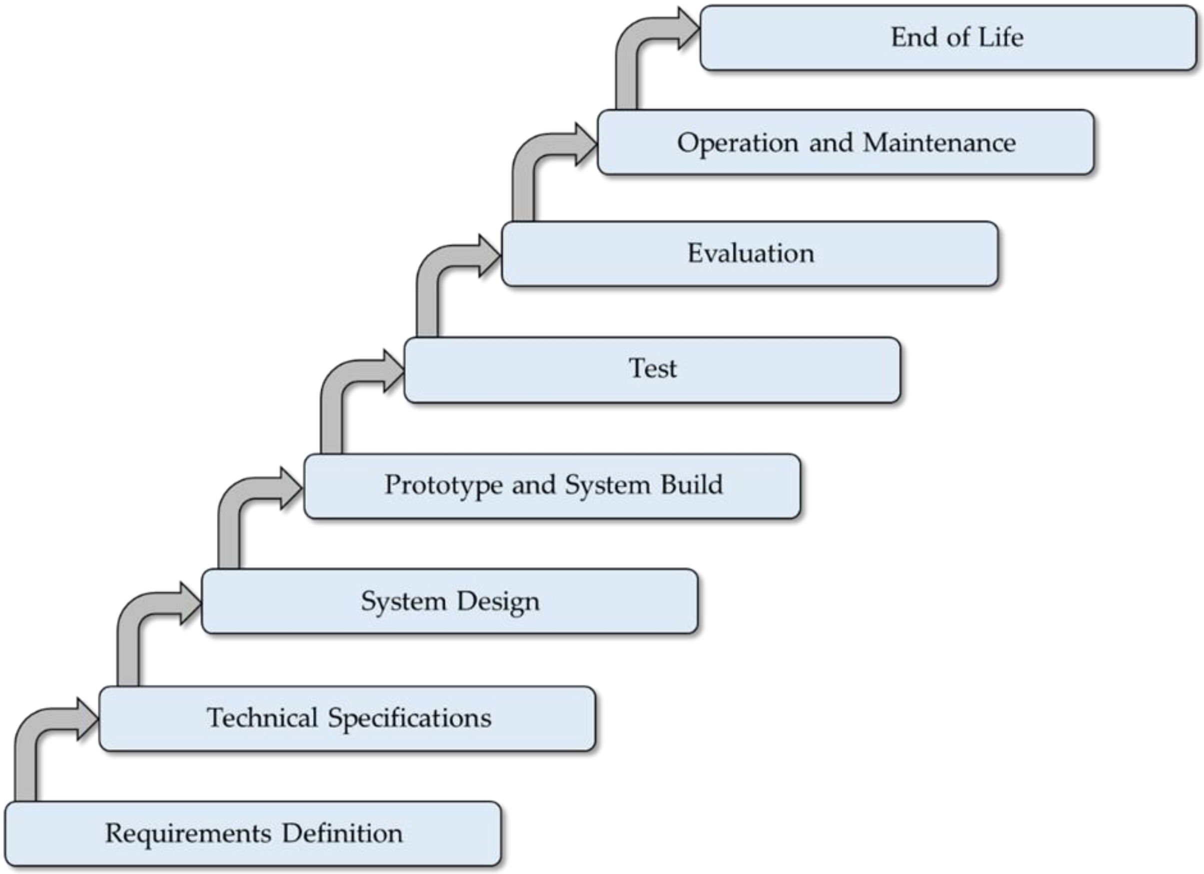


Figure 4-1. Life cycle stages of an asset management system.

4-3. Background

4-3-1. Technological Overview and Trade-Space Considerations

A number of asset management enabling technologies exist. Popular among them are RFID and optical tracking technologies. RFID tags can be either active or passive. The former is useful to regularly track location while the latter can only be located when near a scanner. However, active RFID requires installation of expensive detection equipment. Low energy Bluetooth tags are an alternative allowing location tracking without installation of fixed detectors. Alvarez (2018) summarizes the trade-offs among optical trackers and two frequencies of RFID tags, and notes RFID decreases risk of falsely identifying assets with similar appearance. However, RFID false positives can occur when near medical equipment, metallic objects, liquid, glass, and in moist environments.

The key benefit of ultra-high frequency (UHF) tags, relative to traditional RFID, is the larger reading range. For certain applications the tradeoff is increased cost for the benefit of long-range tracking which would allow reading of the tags in a much wider area of the facility. RFID scanners must be located a sufficient distance from other readers to limit false readings, and this may necessitate exclusion of any mobile scanners within range of stationary ones. Paaske et al. (2017) state RFID has the ability to be scanned without line of sight as would be required for a barcode.

Gladysz and Santarek (2017) compare tracking technologies across a broad set of criteria including accuracy, coverage area, interference potential, security and privacy, among others. Bisio (2016) identified a key tradeoff between various technologies is between energy consumption and location precision. Energy consumption is a useful proxy for lifespan of the tags.

Furthermore, technologies able to more closely track position will need to be replaced more regularly.

For the case of large-spatial scale tracking of assets, joint technology trackers may be required. An RFID scanner can be used to identify assets, which the scanner joins with data from its GPS sensor to define the asset location (Wang et al., 2018). This may be relevant for tracking of tool carts and other large mobile assets.

A further consideration regarding data-driven asset management systems is cyber security. Operators of distributed systems lack a method to observe system abnormalities, which would allow classification of an event as either an attack, an operational hazard to learn from, or low priority which need only be logged for potential future analysis. An emerging orientation within cyber security is to recognize the inevitability of systems infiltrated by attackers, and rather than relying upon perfect exclusion of such attacks, it is critical to put in place internal mitigation strategies to protect critical data. Cyber security is a continual advancement between defenders and attackers; as one improves techniques, the other responds by widening the scope of intervention and creating increasing uncertainty (Collier et al. 2014).

Islanding is the condition where even in the absence of power from the grid, the local or distributed generator continues to power the location. Circuit breakers (CBs) along the network help reduce the number of outages. Cyber-physical systems (CPS) with high vulnerability have shown reduced outage duration due to islanding and the rate is reduced even with high security level CPS.

For wireless networks, the same power distribution network can be created by using internal servers and browser isolation (Webgap) or Air Gap (Kara, 2017). Browser isolation is a cyber security model which aims to physically isolate an internet user's browsing activity (and the associated cyber risks) away from their local networks and infrastructure. Browser isolation technology effectively isolates the web browser and a user's browsing activity as a method of securing web browsers from browser-based security exploits and threats such as ransomware and other malware. Browser isolation or Webgap typically leverages virtualization technology to isolate the user’s web browsing activity from the endpoint device thus significantly reducing the attack surface for rogue links and files. Browser isolation is a way to physically isolate web browsing hosts and other high-risk behaviors away from mission-critical data and infrastructure isolating malware and browser based cyber-attacks in the process. Browser isolation although effective, is really difficult to apply. Air Gap systems consist of three parts: an external site (a secure network), internal site (a secure server), and shared disk system. This system provides a secure network traffic flow between two different security level networks in order to realize critical operations fundamentally by preventing transit IP traffic. Security comes from physical, electromagnetic or electrical separation of these networks. Air Gap security could be equal to offline data transfer security such as diskette, CD, USB, etc. The separated systems can be attached discontinuously for data transfer and storage to the central server, while a local Air Gap backup keeps storing the data to be sent when connected (Kara, 2017).

Related to the risks associated with cyber security is the issue of user trust in and acceptance of technology. Technological solutions are characterized by embedded hardware and software. Acceptance of technology is characterized by trust in hardware and software to perform as designed for a promised length of time and to be protected from cyber security vulnerabilities. These vulnerabilities include ease of physical access to hardware, obsolescence and counterfeit hardware, interaction with portable devices, ease of logical access to software, obsolescence and counterfeit software, and lack of antivirus coverage (Ganin et al., 2017). Trust and acceptance of technology is influenced by user perceptions of risks and benefits (Siegrist, 2019). Technological asset management systems will require some level of access for maintenance to hardware and updates to software to mitigate obsolescence and lack of antivirus coverage, demonstrating a trade-off between security and performance, risk and benefit. Gurriet et al. (2016) describe trust considerations in remotely programmable systems. They define these systems as allowing some component of their software to be changed by an external entity. Benefits are the mitigation of vulnerabilities, adaptability of the system to emerging threats or to improve performance from analysis of collected data, and expansion of capabilities. Due to access requirements, trust of programmable systems will require a method allowing for automated and efficient verification of the system following the software change. They suggest a continued move toward automation of systems shifts the burden of safety and security from operators to designers and contracted service providers. Trust is crucial in relationships between users and producers of technology and in the manner each interacts with the adopted technology (Siau and Wang, 2018).

Factors of technological systems influencing trust include understandability, direct-ability, reliability, utility, robustness and false-alarm rate (Hoffman et al., 2013). Direct-ability is described as the ability of the user to assert control or influence on the system if something goes wrong. False-alarm rates represent a trade-space for users. Some evidence suggests false alarms can result in an increase of user trust in the system (White and Eiser, 2006). This might be due to user perception of the system erring with caution, though it is reasonable to assume excessive false alarms would likely diminish the trust of the user in the system. Kaur and Rampersad (2018) consider performance, security, and privacy as factors of automated systems resulting in user trust. This analysis focuses on the adoption of driverless cars and also includes reliability and understandability, phrased as ease of use and learning. Privacy is related to trust through collection of data by automated systems making the user susceptible to location tracking, behavior pattern analysis, surveillance, and targeted marketing. The user must have a level of trust in those with access to not use the data for purposes not beneficial to the user.

4-3-2. Example Asset Management Use Cases

In Val Verde County, the sheriff's office was working with RFID experts to produce an asset tracking solution to monitor equipment in order to prevent theft or criminal activity. Using passive RFID (pRFID) in aggregation with data-collection systems, the goal is to ensure the safety and protection of an officer's vehicle and equipment. The program remains in the pilot stage, but if it provides visibility into the movements of equipment, the program could potentially be implemented in other law enforcement precincts and set a standard for RFID asset tracking (ConnectedWorld, 2014).

In the healthcare field, the loss of surgical equipment in the 90,000 square foot Greenville Hospital was resulting in loss of time and money due to the time wasted looking for and/or replacing equipment. The staff incurred the greatest number of tool losses after usage in patients' rooms and operating rooms. Hospital rooms are thoroughly cleaned after the patient leaves, so portal systems developed by Jamison and ThingMagic were placed in all laundry and decontamination rooms. The tools were tagged and when a tagged tool was read at a portal location, an alert notified the staff of a tool assigned to the wrong location. Handheld readers deployed to staff members were designed to locate specific tagged equipment and read the usage history of each tool (ThingMagic, 2009).

In another example, time and money spent staffing the equipment/tool room with employees in order to maintain inventory and prevent lost or stolen tools was a recurring problem for Motorola’s Engineering Shared Services Electrical Lab. Pressure-sensitive mats were used to trigger the RFID reader to scan the employees’ badge, which then allowed the employee access to the tool room if the badge had authorization. When the employee left the room, the doorway reader and antenna system scanned the employees’ badge as well as the tools RFID tag. With an initial $250,000 return on investment, and growing, Motorola has seen boosted productivity, fewer employee hours in equipment rooms, and no equipment losses (MetalCraft, 2019).

Holt-Cat’s Machine Division was in charge of maintaining an array of tools ranging in price from a few dollars up to $18,000. With 16 separate facilities in the state of Texas, the movement of these tools without proper tracking was resulting in loss of money and employee productivity. Ultra- UHF RFID tags on tools and High Frequency RFID tags on employee badges enabled Holt-Cat’s software to read and associate the employee with the tool removed from the tool room. With the use of a portal-type RFID system at each entrance/exit of the tool rooms, Holt-Cat monitored the employees and tools without slowing down productivity. A return on investment in less than eight months was seen due to the use of an RFID tracking system (Swedberg, 2008).

Additional use of tracking technology and other automation include non-pharmaceutical interventions (NPIs) to protect users of managed assets from infectious disease. These technologies find application in healthcare, food service, food processing, manufacturing, hospitality, and tourism industries among others. RFID, Bluetooth, GPS, computer vision via video and thermal sensors, and other technologies provide capabilities of area monitoring for crowding detection, social distancing data mining and analysis, workforce scheduling, and contact tracing (Nguyen et al., 2020). Self-service kiosks, voice-activated and facial recognition technologies, and hotel room-and seat-assignment optimization can promote social distancing and increase customer and employee confidence in the travel and tourism industry (Ivanov et al., 2020). COVID-19 was found to have spread among crew and passengers aboard a cruise ship in February 2020. The earliest confirmed cases were detected among food service crew members (Kakimoto et al., 2020), indicating the increased risk of spread among employees working in close proximity and sharing food preparation equipment. Corporations, universities, and other enterprises providing food and health care services to employees or students may also need to acquire NPI assets for future operations. In corrections facilities, which often encompass health-care, food service, and vocational and educational programs, NPIs will also be of interest. Challenges for these enterprises arise from inherent constraints to social distancing (Akiyama et al., 2020; Hawks et al., 2020) and a prevalence of vulnerable populations among offenders (Maruschak et al., 2015).

4-3-3 Trust Considerations for Contractor Selection

An organization seeking a technology-based asset management system through an RFP will exhibit a level of trust in the selected contractor to deliver promised capabilities. Henderson (2016) describes the influence of trust in seller and vendor transactions, including the role of evolving technology in creating trust. Platforms for creating trust between customers and vendors have been created over time through warranties, binding contracts, communications technologies, and block-chain. E-commerce platforms like eBay provide trust vehicles through payment verification, dispute resolution, and instruments for consumers to provide feedback about seller performance. Feedback instruments manifest in trust-measuring rating systems. Similarly, Yelp ratings have been shown to impact selection of deals offered on the Groupon platform (Wang et al., 2018). Before the proliferation of these type of trust vehicles, acquisition choices were heavily influenced by manufacturer- and retailer-controlled variables such as price, signaling messages in advertising, and strength of brand name (De Langhe et al., 2015).

Factors influencing the perception of trust between consumers and firms include competence, integrity, benevolence (firms acting in the user's best interests and positive response to requests for assistance from the user), privacy and security (Oliveira et al., 2017). Positive trust perceptions have a corresponding influence on the intention of consumers to purchase from a particular vendor, or select a particular contractor. Positive perceptions of competence, integrity and benevolence indicate willingness of an organization to place themselves in a vulnerable position with respect to a technology (Kaur and Rampersad, 2018). Privacy and security relate to the organization's level of trust in the service provider's concern and ability to protect information from misuse and the technology's ability to monitor system conditions. Trust provides a subjective measure of the organization's belief in both the contractor and the acquired technology to behave as promised, to genuinely care about the organization, and achieve favorable results by satisfying the asset management system requirements (Liu et al., 2019).

4-4. Methods

The methodology is based on a scenario-based preferences framework, described by Karvetski et al. (2009), who analyzed emergent conditions to international development priorities within the Afghanistan power network. Rogerson and Lambert (2012) applied the framework to disruption of priorities caused by runway near-miss events. Teng et al. (2012, 2013) described a generic business process model to systematically define priorities within a safety critical enterprise, and identify steps in recognizing relevant priority in a risk framework. Collier and Lambert (2019, 2018) and Collier et al. (2018) demonstrate the framework with respect to project management priorities of cost minimization, schedule duration minimization, and quality maximization under uncertain project environments. User requirements are considered under deep uncertainty regarding future operational conditions in which preferences may change, in all the examples discussed.

The model is formulated as follows. Let $S_c = \{c_1, \ldots, c_m\}$ be the set of m evaluation criteria. Let $S_r = \{r_1, \ldots, r_n\}$ be the set of n system requirements. Further, let $S_e = \{e_1, \ldots, e_p\}$ be the set of p emergent and future conditions, and $S_s = \{s_1, \ldots, s_q\}$ the set of q scenarios, where a scenario contains one or more conditions. Given these elements, a linear-additive value function can be defined to assign a score to requirement r_i under scenario s_k:

$$V(r_i)_k = \sum_{j=1}^{m} w_{jk} * v_j(r_i)$$

where w_{jk} is a scaling coefficient (weight) assigned to criterion j criterion under scenario k.

The procedure begins by identifying system criteria. Criteria can be identified by stakeholders, or taken from relevant documents such as RFPs, mission statements, etc. Some authors have identified generic criteria sets, (see e.g., Quenum et al. (2019) for system acquisition success criteria).

Similarly, a set of system requirements must be identified. System requirements may also be identified by a group of relevant stakeholders, RFP documents, and so forth. When a set of criteria and requirements have been identified, a qualitative assessment is conducted in which stakeholders are asked to state the degree to which each criterion is addressed by each requirement. The qualitative assessments can then be converted to numerical scores.

Next, a list of emergent conditions is generated from a review of the literature or by brainstorming. Heuristics exist to aid the generation of emergent and future conditions, such as "PESTLE" (political, economic, social, technological, legal, environmental) (Chartered Management Institute, 2013). Emergent conditions are stakeholder beliefs or values, future events, or trends impacting how requirements are evaluated. Scenarios are constructed by selecting emergent conditions, alone and in combination, which represent possible and relevant futures in which stakeholder preferences may change, or be disrupted.

In this formulation of the scenario-based preferences model, preferences are represented by the criteria weights in the linear additive model. A baseline weighting is first developed, which can be accomplished using a number of different weighting procedures, such as even weighting, point-allocation, rank-sum weighting, swing weighting, etc. Given a baseline set of weights, the weights are adjusted within each identified scenario. A scaling constant, α, is defined such that if c_j "increases", "increases somewhat", "no change", "decreases somewhat" or "decreases" under scenario s_k, a new weight, w_{jk} is defined as:

$$w_{jk} = \alpha * w_j \mathrm{w'}_{\mathrm{jk}} = \mathrm{\alpha} * \mathrm{w_j}$$

where w_j is the baseline weight for criterion c_j (Karvetski et al., 2009). Here we let the values of α equal {8, 6, 1, 1/6, 1/8} for "increases", "increases somewhat", "no change", "decreases somewhat", "decreases", respectively. The weights are then normalized within each scenario. The sum of the normalized weights equals 1.

Using the linear-additive value function, a value score is computed for each requirement across each scenario. This value score is used to rank requirements within each scenario.

Finally, disruptiveness of scenarios is calculated. Disruptiveness is conceptualized as the degree of change in rankings or requirement within a scenario s_k, relative to the ranking under the baseline scenario. A higher level of re-prioritization designates higher disruptiveness.

4-5. Demonstration

This section describes a demonstration of the methodology applied to the acquisition of an asset management program for an enterprise with elevated safety, security, and trust concerns. The setting is the consideration of a tool control and inventory system to augment or replace current systems for a state-level corrections department. The demonstration will inform other enterprise functions in which safety, security, trust, and management of equipment is important to mitigate potential for injury or death, or damage to manufactured products or operational assets.

In the acquisition of the asset management system, the enterprise is interested to reduce risk across five key dimensions:

1. Tool (asset) control – security vulnerability (safety, security, and trust)
2. Tool (asset) management – tool (asset) life cycle and reliable availability for use
3. System integrity – cohesion (data uniformity), responsiveness (incident and audit management), efficiency (dependability of system and peripheral devices), integration (policy and other systems)
4. System protection – mitigation of operable risks in a distributed environment

5. Capacity and contingency – planning as additional tools and facilities (and future system requirements) are added

The selection of an asset management system should address the particular success criteria important to the enterprise, the requirements of ideal tool control, and the sources of risk to the enterprise. A risk register aids in the decision process for procurement of asset management systems by tracking the performance criteria and requirements of these systems in light of potentially disruptive conditions. The following describes steps involved in the development of the risk register and the determination of rankings for tool control requirements, and the robustness of those requirements to potential disruptions for a state-level corrections department. The criteria, requirements, and scenarios evolve primarily through documents sourced from corrections departments across the United States. However, the application of the methodology does not need to be limited to corrections departments or to enterprises within the United States.

Terminology varies among the various departments of corrections. First, not all states following the naming convention of department of corrections. Other nomenclature includes department of correction, department of public safety, department of public safety and corrections, department of correctional services, department of public safety and correctional services, department of criminal justice, corrections department, or division of corrections. Department of corrections is the most commonly used nomenclature. The nomenclature of department of corrections, corrections department, or the abbreviation DOC is used in this demonstration. Second, most all DOCs use terminology of either inmate or offender. Both terms are used in this demonstration. Third, DOCs refer to department employees with the various terms of employees, staff, corrections officers, or workforce. All of these terms appear in this demonstration.

Success criteria must be developed based on goals set by system stakeholders. Documents relevant to the development of stakeholder-based criteria are available for thirty-seven state corrections departments. These documents are in the form of multi-year strategic plans or annual reports (ADC (AZ), 2018; ADC (AR), 2019; ADOC, 2019; CDCR, 2016; CTDOC, 2014; FDC, 2018; HI PSD, 2017; IDOC (IA), 2017; IDOC (ID), 2017; IDOC (IL), 2018; IDOC (IN), 2010; KDOC, 2019; LaDPS&C, 2017; MADOC, 2015; MCE, 2019; MDOC (MI), 2019; MDOC (MS), 2019; MN DOC, 2020; MO DOC, 2020; MT DOC, 2019a; NC DPS, 2018b; NDCS, 2019; NDOC, 2016; NHDOC, 2018; NJDOC, 2019; NMCD, 2013; NY State Assembly, 2018; OR DOC, 2019; PA DOC, 2017; SCDC, 2018; SD DOC, 2018; TDCJ, 2019; TDOC, 2019; VADOC, 2018; WA DOC, 2019; WDOC, 2019; WVDOC, 2018). In a few instances, when strategic plans or annual reports are not available, declarations of departmental mission, vision, and values provide useful insight into stakeholder goals. Most all strategic plans and annual reports also provide mission, vision, and values statements, or these statements are available on the associated DOC's website. With few exceptions, the strategic plans outline four to six high-level goals, objectives, or strategies. Each high-level goal is subdivided into one, two, or three sub-levels with increasing specificity at each sub-level.

The review of strategic plans and associated documents identified over six hundred goals related to tool control, trust, offender and staff safety and security, and offender programs. From these goals, thirty-eight key topics emerged. Table 4-1 lists these topics and the number of goals associated with each. The number of associated goals in each topic reflects representation from all state DOC documents reviewed, regardless of similarity in wording.

Table 4-1. Criteria key terms and topics derived from review of 35 state-level department of corrections strategic plans.

Key Topics	Number of Associated Goals
Safe / safety	36
Staff training / development	34
Re-entry / rehabilitation / transition	34
Technology / modernize / IT	28
Secure / security / trust	28
Programs / programming	25
Professional / professionalism	24
Integrity	20
Accountable / accountability	18
Vocational / work / job skills	17
Supervision	17
Respect	17
Recruit / retain staff	16
Communication	16
Risk classification	16
Risk assessment / management	16
Data / records collection and management	15
Efficient / efficiency	15
Quality	15
Staff / employee wellness	13
Collaboration	13
Inmate tracking / surveillance / monitor	13
Data / statistical analysis	12
Innovation	12
Electronic / paperless / automation	12
Responsibility	12
Productivity / idleness reduction	11
Data sharing	11
Reporting	11
Community	11
Audit	11
Workplace stress / conditions	11
Trust / transparency	11
Vendor / contracts / partnerships	9
Maintenance	8
Equipment / tools / resources	7
Job satisfaction	6
Contraband	5

The significance of trust is previously described in two aspects, adoption of technology and contractor selection. These aspects of trust are represented explicitly in the key topic *secure / security / trust*, and implicitly in the key topics *data / records collection and management*, *data sharing*, and *vendor / contracts / partnerships*. A third aspect of trust, trust among stakeholders, emerges through discovery of DOC organizational goals. For DOCs, stakeholders include administration, employees, the public, and inmates. This aspect relates to the key topics, *trust / transparency*, *staff training / development*, *professionalism*, *supervision*, *respect*, *recruit / retain staff*, *staff / employee wellness*, *community*, *workplace stress / conditions*, and *job satisfaction* among others. These key topics manifest in employee motivation and performance, inmate behavior, and community support of DOC operations, especially during disruptive events. Factors impacting motivation and trust among stakeholders include respect, recognition, supervision, teamwork, management support, communication and feedback, and availability of resources (Okello and Gilson, 2015). Trust among stakeholders has been shown to help improve retention, motivation, and performance and is an important element in willingness to work during disruptive events, such as a public health crisis (Imai, 2020). As a public agency, DOCs are accountable to their respective communities. Acton et al., (2020), discuss the importance of trust between different stakeholder groups and within groups during the outbreak of COVID-19. Individual protection is supported by public trust and confidence in government institutions, inter-stakeholder trust, and social trust in peers to engage in protective behaviors out of concern for one another, intra-stakeholder trust.

The key topics guide refinement of the list of goals into a tractable set of success criteria. For example, included in the topic *Data / statistical analysis*, are goals of: (1) evaluate incident patterns; (2) track performance; (3) monitor outcomes; (4) track incident and injury data; (5) use data to drive decision making; and, (6) improve quality of intelligence data, among others. The final list of criteria from the *Data / statistical analysis* topic are: (1) evaluate incident patterns and (2) use data to track programs and drive decision making. The refinement process for each key topic involves discarding some goals from the initial list for similarity within topic and some for similarity to goals in other topics. Other initial goals were combined and some were set aside from consideration based on an assessment of relative importance within the topic. Phrasing of criteria is as consistent as feasible with the phrasing used in source documents. The initial list of all goals is maintained for consideration during possible future iterations of the analysis.

Though baseline weighting of criteria is determined by stakeholder values and assessment, noting number of initial associated goals in each topic can be beneficial in in the baseline weighting process. The number of associated goals is an indication of the collective importance placed on each topic by all state DOCs represented in the document analysis. The weighting of criteria drawn from each topic may reasonably be informed by this information. To establish baseline weighting, system stakeholders indicate the relevance of criteria (the relevance of a single criterion among all others) for the baseline scenario. In this demonstration, a relative value scale of highest, high, medium, low, and lowest relevance is utilized. The relevance scale corresponds to weights decided upon by stakeholders and experts. Table 4-2 provides the list of criteria selected from the initial list of goals and the baseline weighting assigned to each criterion.

Table 4-2. Baseline relevance of criteria for enterprise risk analysis.

the criterion c.xx has	-	relevance among the other criteria
c.01 - Provide program services has	highest	relevance
c.02 - Address offender needs has	high	relevance
c.03 - Skill sets through work experience has	high	relevance
c.04 - Expand secure use of technology with offenders has	medium	relevance
c.05 - Use technology to increase productivity has	medium	relevance
c.06 - Offer innovative training has	high	relevance
c.07 - Expand use of technology with staff has	high	relevance
c.08 - Promote proper conduct and performance has	highest	relevance
c.09 - Improve workplace facilities has	medium	relevance
c.10 - Increase job satisfaction has	low	relevance
c.11 - Reduce occupational workplace stress has	medium	relevance
c.12 - Increase data collection and access to data has	medium	relevance
c.13 - Use data to track programs and drive decision making has	medium	relevance
c.14 - Evaluate incident patterns has	low	relevance
c.15 - Present data sharing opportunities has	medium	relevance
c.16 - Expand organizational knowledge has	low	relevance
c.17 - Internally disseminate information has	lowest	relevance
c.18 - Foster innovative communication methods has	high	relevance
c.19 - Obtain feedback has	medium	relevance
c.20 - Foster current and timely reporting has	medium	relevance
c.21 - Document work processes has	medium	relevance
c.22 - Report behavior has	medium	relevance
c.23 - Seek collaborative opportunities has	medium	relevance
c.24 - Technology to enhance safety, security, and trust has	high	relevance
c.25 - Encourage innovative thinking has	medium	relevance
c.26 - Record behavior has	lowest	relevance
c.27 - Expand sustainability practices has	lowest	relevance
c.28 - Utilize technology for enhanced surveillance has	medium	relevance
c.29 - Monitor behavior has	medium	relevance
c.30 - Movement control has	medium	relevance
c.31 - Track security threats through monitoring systems and scanners has	medium	relevance
c.32 - Manage offender work detail has	high	relevance
c.33 - Document offender activity has	high	relevance
c.34 - Address offender risks has	high	relevance
c.35 - Link individual risk needs to resource access has	high	relevance
c.36 - Identification data has	high	relevance
c.37 - Offender accountability has	highest	relevance
c.38 - Accountable programs has	highest	relevance
c.39 - Comply with employment practices has	medium	relevance
c.40 - Maintain and comply with agency policies and procedures has	high	relevance
c.41 - Security audits has	high	relevance
c.42 - Demonstrate processes to stakeholders has	lowest	relevance

c.43 - Eliminate offender injuries and illness has	highest	relevance
c.44 - Safety through effective procedures and practices has	highest	relevance
c.45 - Maintain perimeter security has	highest	relevance
c.46 - Eliminate offender assaults has	highest	relevance
c.47 - Contracting efficiency has	low	relevance
c.48 - Partner with organizations has	low	relevance
c.49 - Reduction in repair and replacement needs has	low	relevance
c.50 - Operable technology has	high	relevance
c.51 - Operable safety equipment has	highest	relevance
c.52 - Efficiency through process improvements has	high	relevance
c.53 - Increase offender ability and motivation to be responsible has	high	relevance
c.54 - Technology to improve and track program effectiveness has	medium	relevance
c.55 - Provide ongoing assessment has	low	relevance
c.56 - Avoid single points of failure has	low	relevance
c.57 - Align resources with risk has	medium	relevance
c.58 - Ensure equipment needs are met has	high	relevance
c.59 - Proactive asset management has	high	relevance
c.60 - Eliminate contraband has	highest	relevance

Requirements represent a set of decision-making objectives for desirable aspects of potential assets to be acquired. Requirements are developed through elicitation of stakeholder and expert opinions and from the review of third-party analyses. In this demonstration stakeholder input for the development of requirements is informed by review of multiple sources. The primary source of stakeholder requirements is current regulations, policies, and operating procedures governing the issuance, control, and supervision of tools in corrections department facilities. Ten such documents are publicly available (ADOC, 2009; CDCR, 2009; FDC, 2018; GDC, 2020; MDOC (MI), 2018; MN DOC, 2014; MT DOC, 2019b; NC DPS, 2019a; ODOC, 2018; OR DOC, 2016). Review of industry catalogs and brochures provides requirements of technology-based alternatives for tool control and tool sanitation. The last source category includes literature describing disinfection and sanitation requirements to combat the presence of infectious disease on work surfaces and instruments (Weber et al., 2016; Weber et al., 2017; Boyce, 2018; Kampf, 2020).

The requirements identification process is similar to the process of identifying criteria. The document review provides over two hundred asset management requirements, which were categorized into twenty-one key topics. The key topics address the five risk dimensions for acquisition of the asset management system. Table 4-3 identifies the key topics and their relationship to the risk dimensions. Refinement analysis results in a list of sixty requirements to be assessed and included in the tool control asset management risk register. Table 4-4 provides these requirements.

Table 4-3. Requirements key topics derived from relevant documents review.

Risk Dimension	Concepts	Key Topics	Number of Associated Requirements
Control	Safety	Inventory procedures	11
	Security	Inventory records	10
	Trust	Issuance procedures	26
		Issuance records	6
		Ready accountability	17
		Storage areas	16
		Storage containers	16
		Supervision	17
		Tool classification	18
		Tool identification	13
		Training for staff and inmates	4
Management	Life cycle	Maintenance records	3
	Availability	Repair procedures	11
		Replacement procedures	5
Integrity	Audit management	Audit procedures	7
	Incident management	Incident management	13
	Data uniformity	Integrity	10
	Efficiency		
	Dependability		
	Integration		
	Policy		
Protection	Data distributed environment	Data protection	9
	Operable risks	User protection	4
	Privacy		
	Health and wellness		
Capacity	Expansion	Capacity	1
	Future systems	Surplus tool procedures	3

Table 4-4. Requirements for tool control asset management systems.

Index	Requirements
r.01	Routine inventory scheduling
r.02	Unscheduled / random inventories
r.03	Key and lock control and inventory capabilities
r.04	Anomaly detection
r.05	Maintain master inventory
r.06	Maintain inventory archives
r.07	Issue by hard-copy form
r.08	User maintains copy of issuance form while using tool(s)
r.09	Chit and key tag system
r.10	Electronic signature (smartcard / badge / barcode / QR code)
r.11	Bio-metric signature (face ID / fingerprint)
r.12	Record transaction variables (name / date / time / etc.)
r.13	Tool issue time limit and expiry capabilities
r.14	Maintain archives of issuance transactions
r.15	Video / photo / audio records of issuance
r.16	Tool groups and kits issuance capabilities
r.17	Shadow boards and tool-cutouts
r.18	Technology to easily determine presence or absence of tools
r.19	Tool status display (issued / missing / unserviceable / in repair)
r.20	Designated secure tool storage areas
r.21	Security lighting
r.22	Storage area entry control systems
r.23	Storage container locking devices and systems
r.24	Tool location tracking (GPS / RFID / etc.)
r.25	Surveillance systems
r.26	Tool control officer
r.27	Supervision requirements based on tool classification
r.28	Tool risk classification
r.29	Tool grouping threat analysis
r.30	Tool color-coding by classification
r.31	Color-coded shadow boards and cut-outs
r.32	Tools issued by authorized personnel only
r.33	Tool identification system
r.34	Tool engraving / stamping / etching
r.35	Training materials, videos, and manuals
r.36	Tool control and tool use training for inmates
r.37	Tool repair service contract
r.38	Unserviceable tools in separate storage areas
r.39	Turn-in procedures for unserviceable tools
r.40	Tool replacement ordering procedures
r.41	Separate storage for surplus tools
r.42	Fail safe

r.43	Lock-down capability
r.44	Alert and warning system
r.45	Uninterrupted power
r.46	Missing tool search and reporting procedure
r.47	Audit of tool inventories
r.48	Audit of tool security systems
r.49	Incident reporting
r.50	Firewall from public internet
r.51	Connectivity / network interfaces
r.52	Server capabilities
r.53	Interoperability with other asset management systems
r.54	OS upgrade capability / obsolescence
r.55	Data transmission security
r.56	User identity management
r.57	Disinfection by ultraviolet light
r.58	Disinfection by dry steam chemical application
r.59	Anti-microbial surfaced (copper impregnated) tools
r.60	Language selection capability

With a fully developed list of success criteria and requirements, a pairwise assessment is conducted. Each requirement is assessed for the degree to which it addresses each criterion. For each pairing stakeholders express the degree to which they agree with the statement, criteria c_m is addressed by requirement r_n. In this demonstration the possible responses are strongly agree, agree, somewhat agree, or neutral. These responses correspond to the numerical score set $\{1, 2/3, 1/3, 0\}$. Tables 4-5 through 4-13 provide the pairwise assessment of criteria against requirements. Each table presents a distinct grouping of thirty criteria and thirty requirements. In each table, strongly agree is represented by a filled circle (●), agree is represented by a half-filled circle (◐), somewhat agree is represented by an unfilled circle (○), and neutral is represented by a blank ( ). Some criteria and requirements phrasing has been shortened or otherwise altered slightly in these tables to maximize display of the assessment data.

Table 4-5. Assessment of requirements r.01 – r.20 against criteria c.01 – c.20: strongly agree (●), agree (◐), somewhat agree (○), and neutral (   ).

Requirements: r.01 – r.20 Criteria: c.01 – c.20	r.01 - Routine inventory	r.02 - Unscheduled inventory	r.03 - Key and lock control	r.04 - Anomaly detection	r.05 - Master inventory	r.06 - Inventory archives	r.07 - Issue by hard-copy form	r.08 - User maintains form	r.09 - Chit and key tag system	r.10 - Digital [tool] signature	r.11 - Bio-metric signature	r.12 - Transaction variables	r.13 - Tool issue time limit	r.14 - Issuance archives	r.15 - Video / photo / audio	r.16 - Tool groups and kits	r.17 - Shadows / cut-outs	r.18 - Tech tool status	r.19 - Tool status display	r.20 - Secure tool storage area
the criterion c.xx is address by this initiative																				
c.01 - Provide program services	○				○		○	○	○	○	○	◐				◐	◐	○		◐
c.02 - Address offender needs					○					○	○	○				●		○	◐	
c.03 - Skill sets through work experience										○						○				
c.04 - Expand secure tech with offenders										◐	◐		○							
c.05 - Use tech to increase productivity				○						◐	◐					○		○	◐	
c.06 - Offer innovative training																				
c.07 - Expand use of technology with staff				◐						◐	◐		◐		◐			○	○	
c.08 - Promote proper conduct	◐	◐	◐	○	○		◐	◐	◐	○	○	○	○		◐		◐			
c.09 - Improve workplace facilities				○														◐	○	○
c.10 - Increase job satisfaction																○		○		
c.11 - Reduce occupational workplace stress	○		◐	◐				○	◐		○		○		○		◐	●	○	○
c.12 - Increase data collection and access to data	○	○	○	◐		◐				○	◐	◐		◐	○				○	
c.13 - Use data to track programs												○							◐	
c.14 - Evaluate incident patterns				◐		○					○		○	○						
c.15 - Present data sharing opportunities												○							○	
c.16 - Expand organizational knowledge						○						○							○	
c.17 - Internally disseminate information					◐		◐		○	○	○	○							○	
c.18 - Innovative communication methods													○							
c.19 - Obtain feedback	○	○	○	○			○		◐			○	◐		○		●	●	◐	
c.20 - Foster current and timely reporting	●	○	●	◐	○	◐	○	◐		◐	◐	◐	◐	○					○	

Table 4-6. Assessment of requirements r.21 – r.40 against criteria c.01 – c.20: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Requirements: r.21 – r.40 Criteria: c.01 – c.20	r.21 - Security lighting	r.22 - Storage entry control	r.23 - Container locking	r.24 - Tool location tracking	r.25 - Surveillance systems	r.26 - Tool control officer	r.27 - Supervise by tool class	r.28 - Tool risk classification	r.29 - Tool grouping analysis	r.30 - Tool class color-coding	r.31 - Coded shadows / cuts	r.32 - Issue by auth personnel	r.33 - Tool id system	r.34 - Tool engraving	r.35 - Training materials	r.36 - Tool control training	r.37 - Repair service contract	r.38 - Unserviceable storage	r.39 - Unserviceable turn-in	r.40 - Tool replacement order
the criterion c.xx is address by this initiative																				
c.01 - Provide program services					◐	◐	◐	◐				◐	○		◐	◐	●	○	○	◐
c.02 - Address offender needs						◐	○	◐	○	○					◐	●	◐			◐
c.03 - Skill sets through work experience						●									●	◐			○	
c.04 - Expand secure tech with offenders				◐	◐															
c.05 - Use tech to increase productivity				○					◐						◐					
c.06 - Offer innovative training						○									●	●				
c.07 - Expand use of technology with staff				◐	◐				◐						○					
c.08 - Promote proper conduct				○	●	◐	◐	○	○			◐			●	◐			○	○
c.09 - Improve workplace facilities	◐	○	○	○	◐						○		○	○				○		◐
c.10 - Increase job satisfaction						◐			○			○			●	○	○			
c.11 - Reduce occupational workplace stress	○	○	○	◐	◐	○	◐	○	◐	◐	○	◐	○	○	○	◐		○		
c.12 - Increase data collection and access to data				◐	○															
c.13 - Use data to track programs				○		○														
c.14 - Evaluate incident patterns				●	○	○	○		●											
c.15 - Present data sharing opportunities				◐											○					
c.16 - Expand organizational knowledge				○					◐						●	○				
c.17 - Internally disseminate information				◐		○									○					
c.18 - Innovative communication methods				○																
c.19 - Obtain feedback				●	●		◐		○		◐			◐						
c.20 - Foster current and timely reporting				●	◐	○	○				○	○					○		○	

Table 4-7. Assessment of requirements r.41 – r.60 against criteria c.01 – c.20: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Requirements: r.41 – r.60 Criteria: c.01 – c.20	r.41 - Surplus tool storage	r.42 - Fail safe	r.43 - Lock-down capability	r.44 - Alert and warning system	r.45 - Uninterrupted power	r.46 - Missing tool procedures	r.47 - Audit of tool inventory	r.48 - Audit of tool security	r.49 - Incident reporting	r.50 - Firewall	r.51 - Connectivity / network	r.52 - Server capabilities	r.53 - Interoperability	r.54 - OS upgrade capability	r.55 - Data transmission	r.56 - User id management	r.57 - Disinfection - UV light	r.58 - Disinfection - dry steam	r.59 - Anti-microbial surfaces	r.60 - Language selection
the criterion c.xx is address by this initiative																				
c.01 - Provide program services	○				●		○	○			◐	◐	○	○			◐	◐	○	◐
c.02 - Address offender needs											○	○				○	◐	◐	○	◐
c.03 - Skill sets through work experience											○									○
c.04 - Expand secure tech with offenders		○		○		○			○	○	◐	◐	◐	◐		◐				○
c.05 - Use tech to increase productivity					◐					○	◐	◐	◐	◐		○				○
c.06 - Offer innovative training																				
c.07 - Expand use of technology with staff		○				○			○	○	◐	◐	◐	◐		◐	◐			○
c.08 - Promote proper conduct				○			◐	◐	◐							○				
c.09 - Improve workplace facilities	○	○			○		○	○		○			◐	●	○		◐	○	◐	○
c.10 - Increase job satisfaction											◐									○
c.11 - Reduce occupational workplace stress	○	●	◐	◐	○					◐							●	◐	◐	
c.12 - Increase data collection and access to data									●		◐	●	◐		○					
c.13 - Use data to track programs				◐			○	◐	◐			○	◐		◐	○				
c.14 - Evaluate incident patterns		○	◐	◐		○		○	●				○			○				
c.15 - Present data sharing opportunities									◐		◐	◐	◐		◐					
c.16 - Expand organizational knowledge							○	◐	●					○						○
c.17 - Internally disseminate information				○			○	○	◐		○	◐	○		◐					
c.18 - Innovative communication methods				◐									◐		◐					○
c.19 - Obtain feedback			○	○		◐	○	◐	◐				○		◐					
c.20 - Foster current and timely reporting			◐	●	○	◐	◐	◐	●			○	◐							

Table 4-8. Assessment of requirements r.01 – r.20 against criteria c.21 – c.40: strongly agree (●), agree (◐), somewhat agree (○), and neutral (   ).

Requirements: r.01 – r.20 Criteria: c.21 – c.40	r.01 - Routine inventory	r.02 - Unscheduled inventory	r.03 - Key and lock control	r.04 - Anomaly detection	r.05 - Master inventory	r.06 - Inventory archives	r.07 - Issue by hard-copy form	r.08 - User maintains form	r.09 - Chit and key tag system	r.10 - Digital [tool] signature	r.11 - Bio-metric signature	r.12 - Transaction variables	r.13 - Tool issue time limit	r.14 - Issuance archives	r.15 - Video / photo / audio	r.16 - Tool groups and kits	r.17 - Shadows / cut-outs	r.18 - Tech tool status	r.19 - Tool status display	r.20 - Secure tool storage area
the criterion c.xx is address by this initiative																				
c.21 - Document work processes	●		●		◐	○	●	○		◐		●		○	◐					
c.22 - Report behavior		○		◐					○		○		○		○					
c.23 - Seek collaborative opportunities																				
c.24 - Tech to enhance safety / security / trust			◐	●						◐	◐		○		◐			○	○	
c.25 - Encourage innovative thinking				○												○				
c.26 - Record behavior	○		○	○			○	○		○	○			◐	●					
c.27 - Expand sustainability practices										○	○					○				
c.28 - Utilize tech for enhanced surveillance				◐									◐		◐					
c.29 - Monitor behavior		◐		◐					○				○		○		○			
c.30 - Movement control			●						○								○	○		◐
c.31 - Track threats through monitoring systems							○						◐		●					
c.32 - Manage offender work detail	◐		◐						○	○	○	◐	●							
c.33 - Document offender activity							◐	○		○	◐			◐	◐					
c.34 - Address offender risks	○	○	◐						○	○	○		○			○				
c.35 - Link individual risk needs to access			●	○	◐	◐		◐	●	◐	◐					○		○		
c.36 - Identification data							○			●	●	○			○					
c.37 - Offender accountability	●	●		○			◐	●	◐	◐	◐	○	◐		○					
c.38 - Accountable programs	●	●	○	○	●	●			◐	○	○		○	○	○		◐		◐	
c.39 - Comply with employment practices	○	○	○		○														○	
c.40 - Comply with agency policies	●	◐	●		●	◐		◐	●			●		○			●	○		●

Table 4-9. Assessment of requirements r.21 – r.40 against criteria c.21 – c.40: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Requirements: r.21 – r.40 Criteria: c.21 – c.40	r.21 - Security lighting	r.22 - Storage entry control	r.23 - Container locking	r.24 - Tool location tracking	r.25 - Surveillance systems	r.26 - Tool control officer	r.27 - Supervise by tool class	r.28 - Tool risk classification	r.29 - Tool grouping analysis	r.30 - Tool class color-coding	r.31 - Coded shadows / cuts	r.32 - Issue by auth personnel	r.33 - Tool id system	r.34 - Tool engraving	r.35 - Training materials	r.36 - Tool control training	r.37 - Repair service contract	r.38 - Unserviceable storage	r.39 - Unserviceable turn-in	r.40 - Tool replacement order
the criterion c.xx is address by this initiative																				
c.21 - Document work processes				◐	◐		○		◐				○							
c.22 - Report behavior				◐	◐		◐													
c.23 - Seek collaborative opportunities						○	○		○							○	◐			
c.24 - Tech to enhance safety / security / trust			○	●	◐				◐											
c.25 - Encourage innovative thinking							○	○	●						◐	○				
c.26 - Record behavior				◐	●														◐	
c.27 - Expand sustainability practices																	○			
c.28 - Utilize tech for enhanced surveillance	○			●	◐				○											
c.29 - Monitor behavior	○			◐	●	◐	●	○	○	○				○						
c.30 - Movement control	○	●	○	●	○	◐						○	◐							
c.31 - Track threats through monitoring systems				●	●		○	○		○			◐	○						
c.32 - Manage offender work detail		○	◐	●	◐	●	◐	●	○			○	○	◐	○	○				
c.33 - Document offender activity				◐	◐															
c.34 - Address offender risks				○			●	●	◐	◐					◐	◐			○	
c.35 - Link individual risk needs to access			◐				●	◐	●	◐					◐					
c.36 - Identification data						○						◐	●	●						
c.37 - Offender accountability			○	◐	◐	◐	◐	◐		○	○		○		○	○				
c.38 - Accountable programs					○	●	◐	◐		○	○		◐	○	○	○	○	◐	◐	
c.39 - Comply with employment practices				○		○	○	○				◐	○		◐	◐	○	○		○
c.40 - Comply with agency policies		●	○			●		●	○	●	●	○	○	●		○		○	○	○

Table 4-10. Assessment of requirements r.41 – r.60 against criteria c.21 – c.40: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Requirements: r.41 - r.60 Criteria: c.21 - c.40	r.41 - Surplus tool storage	r.42 - Fail safe	r.43 - Lock-down capability	r.44 - Alert and warning system	r.45 - Uninterrupted power	r.46 - Missing tool procedures	r.47 - Audit of tool inventory	r.48 - Audit of tool security	r.49 - Incident reporting	r.50 - Firewall	r.51 - Connectivity / network	r.52 - Server capabilities	r.53 - Interoperability	r.54 - OS upgrade capability	r.55 - Data transmission	r.56 - User id management	r.57 - Disinfection - UV light	r.58 - Disinfection - dry steam	r.59 - Anti-microbial surfaces	r.60 - Language selection
the criterion c.xx is address by this initiative																				
c.21 - Document work processes				○			◐	◐												
c.22 - Report behavior			○	◐		◐			◐							○				
c.23 - Seek collaborative opportunities								○					●							
c.24 - Tech to enhance safety / security / trust		◐	◐	◐	◐	○				◐			◐	◐	●					○
c.25 - Encourage innovative thinking						○		○												
c.26 - Record behavior					○				○			◐				○				
c.27 - Expand sustainability practices					○														◐	
c.28 - Utilize tech for enhanced surveillance			○	◐	◐	◐			◐		○		◐	◐	○	◐				
c.29 - Monitor behavior			◐	◐	◐				◐			○				○				
c.30 - Movement control			●	◐		◐										◐				
c.31 - Track threats through monitoring systems			◐	◐	◐	○			○			○				◐				
c.32 - Manage offender work detail		○		◐		○			○							○				
c.33 - Document offender activity									◐			◐				○				
c.34 - Address offender risks		○								●						○	◐	◐	○	
c.35 - Link individual risk needs to access																◐				○
c.36 - Identification data									○	◐		○			◐	●				◐
c.37 - Offender accountability						◐										◐				
c.38 - Accountable programs	◐	○	◐			◐	●	●	◐				○							
c.39 - Comply with employment practices	○						◐	◐	◐			○		◐	◐		○	○	○	○
c.40 - Comply with agency policies	○					◐	◐	◐												

Table 4-11. Assessment of requirements r.01 – r.20 against criteria c.41 – c.60: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Requirements: r.01 - r.20 Criteria: c.41 - c.60	r.01 - Routine inventory	r.02 - Unscheduled inventory	r.03 - Key and lock control	r.04 - Anomaly detection	r.05 - Master inventory	r.06 - Inventory archives	r.07 - Issue by hard-copy form	r.08 - User maintains form	r.09 - Chit and key tag system	r.10 - Digital [tool] signature	r.11 - Bio-metric signature	r.12 - Transaction variables	r.13 - Tool issue time limit	r.14 - Issuance archives	r.15 - Video / photo / audio	r.16 - Tool groups and kits	r.17 - Shadows / cut-outs	r.18 - Tech tool status	r.19 - Tool status display	r.20 - Secure tool storage area
the criterion c.xx is address by this initiative																				
c.41 - Security audits	◐	●	◐	●	◐		◐			○	○	◐		●	○				◐	
c.42 - Demonstrate processes to stakeholders				○		○				○	○				○		○	○	○	○
c.43 - Eliminate offender injuries and illness	◐	○											○			○				○
c.44 - Safety procedures and practices	●	●	●	○	○		○	○	○			○					◐	○		◐
c.45 - Maintain perimeter security			●																	●
c.46 - Eliminate offender assaults	◐	○	◐										○							○
c.47 - Contracting efficiency																			○	
c.48 - Partner with organizations											○				○					
c.49 - Reduction in repair and replacement needs	○	○		○	○														○	
c.50 - Operable technology										○	○									
c.51 - Operable safety equipment																			○	
c.52 - Efficiency through process improvements			○	◐						○	◐					◐		○	○	
c.53 - Offender ability / motivation responsible		○					◐		○	○	○		○							
c.54 - Tech to track program effectiveness				◐						◐	○									
c.55 - Provide ongoing assessment	◐	○		○								○		○						
c.56 - Avoid single points of failure		◐	◐	○				◐	○				◐		○		○	○		○
c.57 - Align resources with risk					◐	○	○	○	◐	◐	◐		◐			○				
c.58 - Ensure equipment needs are met	◐					◐										●			●	
c.59 - Proactive asset management	◐	●		◐	◐														○	○
c.60 - Eliminate contraband	◐	◐	◐	○	○		○					○	○		○		○	○	○	◐

Table 4-12. Assessment of requirements r.21 – r.40 against criteria c.41 – c.60: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Requirements: r.21 - r.40 Criteria: c.41 - c.60	r.21 - Security lighting	r.22 - Storage entry control	r.23 - Container locking	r.24 - Tool location tracking	r.25 - Surveillance systems	r.26 - Tool control officer	r.27 - Supervise by tool class	r.28 - Tool risk classification	r.29 - Tool grouping analysis	r.30 - Tool class color-coding	r.31 - Coded shadows / cuts	r.32 - Issue by auth personnel	r.33 - Tool id system	r.34 - Tool engraving	r.35 - Training materials	r.36 - Tool control training	r.37 - Repair service contract	r.38 - Unserviceable storage	r.39 - Unserviceable turn-in	r.40 - Tool replacement order
the criterion c.xx is address by this initiative																				
c.41 - Security audits		○	○	○		○		○		○			●	○				◐	○	
c.42 - Demonstrate processes to stakeholders				○	○				○	○	○									
c.43 - Eliminate offender injuries and illness			○				◐	○	◐						◐	●	●	◐		
c.44 - Safety procedures and practices	○	◐	◐	○	○		○	◐	○	○	○	◐			◐	◐	○	○	○	
c.45 - Maintain perimeter security	◐	●	○	◐	◐		○						○							
c.46 - Eliminate offender assaults			○	○	○		◐	◐	◐										○	
c.47 - Contracting efficiency																	●			●
c.48 - Partner with organizations					○												●			●
c.49 - Reduction in repair and replacement needs															◐	◐				◐
c.50 - Operable technology				○																
c.51 - Operable safety equipment															◐		◐			○
c.52 - Efficiency through process improvements								○	○		◐				○		◐			○
c.53 - Offender ability / motivation responsible						○		◐					◐	◐	◐	●			○	
c.54 - Tech to track program effectiveness				○																
c.55 - Provide ongoing assessment				○			○		◐											
c.56 - Avoid single points of failure		◐	◐	○	○		◐	○	○			○			○	○		◐		
c.57 - Align resources with risk			○				●	●	◐	●	◐	○								
c.58 - Ensure equipment needs are met		○	○	◐		◐	○	○	○		○	○	◐				●		●	●
c.59 - Proactive asset management			○	◐		◐	◐	●	●	○	○	○	◐		◐	◐	◐	○	○	◐
c.60 - Eliminate contraband	○	◐		○	○	◐	○	○				◐		○				◐	◐	

Table 4-13. Assessment of requirements r.41 – r.60 against criteria c.41 – c.60: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Requirements: r.41 - r.60 Criteria: c.41 - c.60	r.41 - Surplus tool storage	r.42 - Fail safe	r.43 - Lock-down capability	r.44 - Alert and warning system	r.45 - Uninterrupted power	r.46 - Missing tool procedures	r.47 - Audit of tool inventory	r.48 - Audit of tool security	r.49 - Incident reporting	r.50 - Firewall	r.51 - Connectivity / network	r.52 - Server capabilities	r.53 - Interoperability	r.54 - OS upgrade capability	r.55 - Data transmission	r.56 - User id management	r.57 - Disinfection - UV light	r.58 - Disinfection - dry steam	r.59 - Anti-microbial surfaces	r.60 - Language selection
the criterion c.xx is address by this initiative																				
c.41 - Security audits	◐						●	●		○					○					
c.42 - Demonstrate processes to stakeholders								○					○			○	○	○		
c.43 - Eliminate offender injuries and illness		○			○	○			○								●	●	◐	
c.44 - Safety procedures and practices	○		◐	○		◐	○	○						○			●	◐	◐	
c.45 - Maintain perimeter security		○		◐	●					●		○			○					
c.46 - Eliminate offender assaults		◐	◐	●	○	○			○											
c.47 - Contracting efficiency					◐						○	◐		◐						
c.48 - Partner with organizations					◐			◐			○	◐		◐						
c.49 - Reduction in repair and replacement needs						○											○		○	
c.50 - Operable technology					●						◐	◐		●	◐	○				
c.51 - Operable safety equipment					●									◐			●	○	◐	
c.52 - Efficiency through process improvements																	○			
c.53 - Offender ability / motivation responsible			○	◐		○			○		○					◐	○	○	○	○
c.54 - Tech to track program effectiveness												○	○		◐	○				
c.55 - Provide ongoing assessment				◐			◐	◐	○											
c.56 - Avoid single points of failure	◐	●	◐	○	●		○	○		○		◐	◐	◐						
c.57 - Align resources with risk										◐						◐	○	○	○	
c.58 - Ensure equipment needs are met					◐	○	○					◐		○			◐	◐	○	
c.59 - Proactive asset management		○					○	○					○	◐						
c.60 - Eliminate contraband	◐	●	◐	◐	○	●			○							○	○	○	○	

Next, emergent and future conditions are identified. These emergent and future conditions could potentially disrupt the prioritization of requirements by exploiting vulnerabilities. Emergent and future conditions are developed from stakeholder input, industry prospectuses, and other sources. Corrections department strategic plans are a compelling source of emergent and future conditions for tool control. Sixteen of these documents address future challenges or conditions likely to effect corrections enterprise operations. A sample of the possible emergent and future conditions impacting an asset management system is provided in the Table 4-14.

Scenarios developed from emergent and future conditions for enterprise risk analysis are provided in Table 4-15. The baseline scenario can be considered to represent either the current state or a default state. It serves as a means of measuring the impact of specific scenarios constructed from the combination of one or several emergent and future conditions.

Table 4-14. Emergent and future conditions for tool control asset management.

Index	Emergent and Future Condition
e.01	General offender population size growth
e.02	Offender population lacking English language proficiency
e.03	General offender population education level decrease
e.04	General offender population education level increase
e.05	Offender population with mental health concerns
e.06	Close-custody offender population size growth
e.07	Offender suicidal tendencies
e.08	Data transmission infrastructure innovations
e.09	Interior air quality and conditioning standards
e.10	Facility sustainability policy
e.11	Program environmental sustainability goals
e.12	Correctional facilities realignment
e.13	Correctional facilities repurpose
e.14	Recruitment of corrections professionals (reduction)
e.15	Retaining corrections professionals (reduction)
e.16	Post-release employment opportunities (availability)
e.17	Post-release employment opportunities (wage)
e.18	Remote offender work sites
e.19	Natural hazard events
e.20	Infections disease and illness
e.21	Mandated offender movement restrictions
e.22	Policy to reduce sentencing terms (reentry training time)
e.23	Business objectives / priorities / reentry mission changes
e.24	Collaboration requirements with state / federal / private agencies
e.25	Public awareness and support of reentry programs
e.26	Budgetary constraints
e.27	Economic downturn affecting vendors and suppliers
e.28	Technological innovation
e.29	Enterprise-wide adoption of technology solutions
e.30	Cyber security threats
e.31	Communications systems interference
e.32	Active shooter
e.33	Threats to physical infrastructure

Table 4-15. Scenario definitions for tool control asset management.

Index	Scenario	Emergent and Future Conditions
s.00	Baseline	--
s.01	Economic downturn	e.17 - Post-release employment opportunities (wage) e.22 - Policy to reduce sentencing terms (reentry training time) e.23 - Business objectives / priorities / reentry mission changes e.26 - Budgetary constraints e.27 - Economic downturn affecting vendors and suppliers
s.02	Offender population change	e.01 - General offender population size growth e.02 - Offender population lacking English language proficiency e.03 - General offender population education level decrease e.06 - Close-custody offender population size growth
s.03	Infrastructure superannuation	e.08 - Data transmission infrastructure innovations e.09 - Interior air quality and conditioning standards e.10 - Facility sustainability policy e.13 - Correctional facilities repurpose e.33 - Threats to physical infrastructure
s.04	Infectious disease epidemic	e.16 - Post-release employment opportunities (availability) e.20 - Infections disease and illness e.21 - Mandated offender movement restrictions e.26 - Budgetary constraints
s.05	Community perception change	e.14 - Recruitment of corrections professionals (reduction) e.15 - Retaining corrections professionals (reduction) e.25 - Public awareness and support of reentry programs
s.06	Technological innovation	e.08 - Data transmission infrastructure innovations e.28 - Technological innovation e.30 - Cyber security threats e.31 - Communications systems interference

The impact of scenarios on requirements is reflected through the assessment of the relevance of each criterion in each scenario. This assessment for the baseline scenario has been described following the identification of success criteria. For the baseline scenario, each criterion is ascribed the stakeholders' belief of its relevance among the other criteria. For scenarios comprised of emergent and future conditions, a change in relevance method is used. Stakeholders assess how the relevance of a criterion changes under a given scenario using the *increases*, *increases somewhat*, *no change*, *decreases somewhat*, and *decreases* scaling factors. Tables 4-16 through 4-21 provide the assessment of the relevance of criteria in each scenario by reweighting from the baseline.

Table 4-16. Reweighting of criteria under each scenario. Criteria c.01 – c.20 and Scenarios s.01 – s.03.

Scenarios: s.01 – s.03 Criteria: c.01 – c.20	s.01 - Economic downturn	s.02 - Offender population change	s.03 - Infrastructure superannuation	s.00 - Baseline
c.01 - Provide program services	Decreases Somewhat	-	Decreases Somewhat	highest
c.02 - Address offender needs	-	Increases Somewhat	Increases Somewhat	high
c.03 - Skill sets through work experience	-	-	Decreases Somewhat	high
c.04 - Expand secure tech with offenders	-	Increases Somewhat	-	medium
c.05 - Use tech to increase productivity	Increases Somewhat	Increases Somewhat	Decreases Somewhat	medium
c.06 - Offer innovative training	Decreases Somewhat	-	Decreases Somewhat	high
c.07 - Expand use of technology with staff	-	Decreases Somewhat	-	high
c.08 - Promote proper conduct	-	-	-	highest
c.09 - Improve workplace facilities	Decreases Somewhat	Increases Somewhat	Increases	medium
c.10 - Increase job satisfaction	Increases	Increases	-	low
c.11 - Reduce occupational workplace stress	Increases	Increases Somewhat	Increases	medium
c.12 - Increase data collection and access to data	-	Increases Somewhat	-	medium
c.13 - Use data to track programs	-	-	-	medium
c.14 - Evaluate incident patterns	Increases Somewhat	Increases Somewhat	-	low
c.15 - Present data sharing opportunities	Decreases Somewhat	Decreases Somewhat	-	medium
c.16 - Expand organizational knowledge	Increases Somewhat	Increases Somewhat	Decreases Somewhat	low
c.17 - Internally disseminate information	-	-	-	lowest
c.18 - Innovative communication methods	Decreases Somewhat	Decreases Somewhat	-	high
c.19 - Obtain feedback	-	-	Increases Somewhat	medium
c.20 - Foster current and timely reporting	-	-	-	medium

Table 4-17. Reweighting of criteria under each scenario. Criteria c.21 – c.40 and Scenarios s.01 – s.03.

Scenarios: s.01 - s.03 Criteria: c.21 - c.40	s.01 - Economic downturn	s.02 - Offender population change	s.03 - Infrastructure superannuation	s.00 - Baseline
c.21 - Document work processes	-	-	-	medium
c.22 - Report behavior	-	Increases Somewhat	-	medium
c.23 - Seek collaborative opportunities	Increases	-	Decreases Somewhat	medium
c.24 - Tech to enhance safety / security / trust	-	-	-	high
c.25 - Encourage innovative thinking	Increases	-	-	medium
c.26 - Record behavior	-	-	-	lowest
c.27 - Expand sustainability practices	Increases Somewhat	Increases Somewhat	Increases	lowest
c.28 - Utilize tech for enhanced surveillance	Increases Somewhat	Increases Somewhat	Decreases Somewhat	medium
c.29 - Monitor behavior	Increases Somewhat	-	-	medium
c.30 - Movement control	-	Increases	Decreases Somewhat	medium
c.31 - Track threats through monitoring systems	-	-	-	medium
c.32 - Manage offender work detail	-	Increases Somewhat	-	high
c.33 - Document offender activity	-	-	-	high
c.34 - Address offender risks	Increases Somewhat	Increases Somewhat	-	high
c.35 - Link individual risk needs to access	Increases Somewhat	-	-	high
c.36 - Identification data	Decreases	Increases Somewhat	Decreases	high
c.37 - Offender accountability	-	-	-	highest
c.38 - Accountable programs	-	-	-	highest
c.39 - Comply with employment practices	Decreases Somewhat	-	-	medium
c.40 - Comply with agency policies	-	-	-	high

Table 4-18. Reweighting of criteria under each scenario. Criteria c.41 – c.60 and Scenarios s.01 – s.03.

Scenarios: s.01 - s.03 Criteria: c.41 - c.60	s.01 - Economic downturn	s.02 - Offender population change	s.03 - Infrastructure superannuation	s.00 - Baseline
c.41 - Security audits	-	-	-	high
c.42 - Demonstrate processes to stakeholders	Increases Somewhat	-	-	lowest
c.43 - Eliminate offender injuries and illness	-	Decreases Somewhat	-	highest
c.44 - Safety procedures and practices	-	-	-	highest
c.45 - Maintain perimeter security	-	-	-	highest
c.46 - Eliminate offender assaults	-	Decreases Somewhat	-	highest
c.47 - Contracting efficiency	Increases	Decreases Somewhat	Increases Somewhat	low
c.48 - Partner with organizations	-	-	-	low
c.49 - Reduction in repair and replacement needs	Increases	-	Increases	low
c.50 - Operable technology	Increases Somewhat	Decreases Somewhat	-	high
c.51 - Operable safety equipment	-	-	-	highest
c.52 - Efficiency through process improvements	Increases Somewhat	Increases Somewhat	-	high
c.53 - Offender ability / motivation responsible	-	-	-	high
c.54 - Tech to track program effectiveness	-	-	-	medium
c.55 - Provide ongoing assessment	-	-	-	low
c.56 - Avoid single points of failure	-	-	Increases	low
c.57 - Align resources with risk	-	-	Increases Somewhat	medium
c.58 - Ensure equipment needs are met	-	-	-	high
c.59 - Proactive asset management	-	Increases Somewhat	-	high
c.60 - Eliminate contraband	Decreases Somewhat	-	-	highest

Table 4-19. Reweighting of criteria under each scenario. Criteria c.01 – c.20 and Scenarios s.04 – s.06.

Scenarios: s.04 - s.06 Criteria: c.01 - c.20	s.04 - Infectious disease epidemic	s.05 - Community perception change	s.06 - Technological innovation	s.00 - Baseline
c.01 - Provide program services	Decreases	Decreases Somewhat	Decreases Somewhat	highest
c.02 - Address offender needs	Increases Somewhat	-	-	high
c.03 - Skill sets through work experience	Decreases	-	-	high
c.04 - Expand secure tech with offenders	Decreases Somewhat	-	Increases	medium
c.05 - Use tech to increase productivity	Decreases Somewhat	Increases	-	medium
c.06 - Offer innovative training	Decreases Somewhat	-	-	high
c.07 - Expand use of technology with staff	-	Increases Somewhat	Increases Somewhat	high
c.08 - Promote proper conduct	-	-	-	highest
c.09 - Improve workplace facilities	Increases	Increases	Increases Somewhat	medium
c.10 - Increase job satisfaction	-	Increases	-	low
c.11 - Reduce occupational workplace stress	Increases	Increases	-	medium
c.12 - Increase data collection and access to data	Increases Somewhat	-	Decreases Somewhat	medium
c.13 - Use data to track programs	-	-	-	medium
c.14 - Evaluate incident patterns	Increases	-	Increases	low
c.15 - Present data sharing opportunities	Increases Somewhat	Increases Somewhat	-	medium
c.16 - Expand organizational knowledge	-	Increases	Increases Somewhat	low
c.17 - Internally disseminate information	Increases Somewhat	-	Increases	lowest
c.18 - Innovative communication methods	-	-	-	high
c.19 - Obtain feedback	-	Increases Somewhat	-	medium
c.20 - Foster current and timely reporting	Increases	-	Increases Somewhat	medium

Table 4-20. Reweighting of criteria under each scenario. Criteria c.21 – c.40 and Scenarios s.04 – s.06.

Scenarios: s.04 - s.06 Criteria: c.21 - c.40	s.04 - Infectious disease epidemic	s.05 - Community perception change	s.06 - Technological innovation	s.00 - Baseline
c.21 - Document work processes	-	-	-	medium
c.22 - Report behavior	-	-	-	medium
c.23 - Seek collaborative opportunities	Decreases Somewhat	Increases Somewhat	Increases Somewhat	medium
c.24 - Tech to enhance safety / security / trust	-	-	-	high
c.25 - Encourage innovative thinking	-	Increases Somewhat	Increases	medium
c.26 - Record behavior	-	-	-	lowest
c.27 - Expand sustainability practices	-	-	-	lowest
c.28 - Utilize tech for enhanced surveillance	-	-	-	medium
c.29 - Monitor behavior	Increases Somewhat	-	-	medium
c.30 - Movement control	Increases	-	-	medium
c.31 - Track threats through monitoring systems	Increases Somewhat	-	-	medium
c.32 - Manage offender work detail	Increases Somewhat	Decreases Somewhat	-	high
c.33 - Document offender activity	-	Decreases Somewhat	-	high
c.34 - Address offender risks	-	-	Decreases Somewhat	high
c.35 - Link individual risk needs to access	-	Decreases Somewhat	-	high
c.36 - Identification data	-	-	Increases Somewhat	high
c.37 - Offender accountability	Decreases Somewhat	-	Decreases Somewhat	highest
c.38 - Accountable programs	Decreases Somewhat	-	-	highest
c.39 - Comply with employment practices	Increases Somewhat	-	Increases	medium
c.40 - Comply with agency policies	-	Decreases Somewhat	Increases Somewhat	high

Table 4-21. Reweighting of criteria under each scenario. Criteria c.41 – c.60 and Scenarios s.04 – s.06.

Scenarios: s.04 - s.06 Criteria: c.41 - c.60	s.04 - Infectious disease epidemic	s.05 - Community perception change	s.06 - Technological innovation	s.00 - Baseline
c.41 - Security audits	Decreases Somewhat	Decreases Somewhat	-	high
c.42 - Demonstrate processes to stakeholders	Increases	Increases	-	lowest
c.43 - Eliminate offender injuries and illness	-	-	-	highest
c.44 - Safety procedures and practices	-	-	Decreases Somewhat	highest
c.45 - Maintain perimeter security	-	-	-	highest
c.46 - Eliminate offender assaults	Decreases Somewhat	-	-	highest
c.47 - Contracting efficiency	Decreases Somewhat	-	-	low
c.48 - Partner with organizations	Decreases Somewhat	-	Increases	low
c.49 - Reduction in repair and replacement needs	-	-	Decreases Somewhat	low
c.50 - Operable technology	-	Increases Somewhat	Increases Somewhat	high
c.51 - Operable safety equipment	-	-	-	highest
c.52 - Efficiency through process improvements	-	Increases Somewhat	Decreases Somewhat	high
c.53 - Offender ability / motivation responsible	-	Decreases Somewhat	-	high
c.54 - Tech to track program effectiveness	Decreases Somewhat	-	-	medium
c.55 - Provide ongoing assessment	Increases	-	-	low
c.56 - Avoid single points of failure	-	-	Increases	low
c.57 - Align resources with risk	Increases	-	-	medium
c.58 - Ensure equipment needs are met	Decreases Somewhat	-	Decreases Somewhat	high
c.59 - Proactive asset management	-	Decreases Somewhat	-	high
c.60 - Eliminate contraband	-	Decreases Somewhat	-	highest

The combination of scores for requirements against criteria and relevance scores for criteria in each scenario result in a score for each requirement in each scenario. Inspection of requirement scores among all scenarios provides a means of assessing the ranking of requirements and the robustness of requirements against the disruption potential of each scenario. Sample results are shown in Figure 4-2 and Figure 4-3. It shows the range of rankings of each requirement among all scenarios for a sample analysis. For example, the requirement *r.13 – Tool issue time limit and expiry capabilities*, ranges in rankings from 11th to 26th over all of the scenarios. The baseline scenario ranking of requirement *r.13* is shown by the black bar. In this sample, requirement *r.13* was ranked 21st among all requirements in the baseline scenario. Robustness is measured by the range of rankings of a requirement over all scenarios. Requirement *r.24 – Tool location tracking (GPS / RFID / etc.)* is among the most robust scenarios since the total change in rank from its highest ranking, 1st in the baseline scenario, to its lowest ranking, 3rd, is only 3 positions. Requirement *r.24* is highly ranked and the most robust requirement. Other highly ranked and robust initiatives are *r.25 – Surveillance systems*, *r.29 – Tool grouping threat analysis*, and *r.04 – Anomaly detection*. In this sample analysis, requirement *r.59 – Anti-microbial surfaced (copper impregnated) tools*, would be assessed as neither highly ranked, nor robust as its lowest rank is 55th out of 60 requirements and its baseline rank is also near the bottom at 45th. This requirement is also subject to a wide change in importance ranking over the six scenarios and the baseline with a total change in rank of 40 positions, from 15th to 55th.

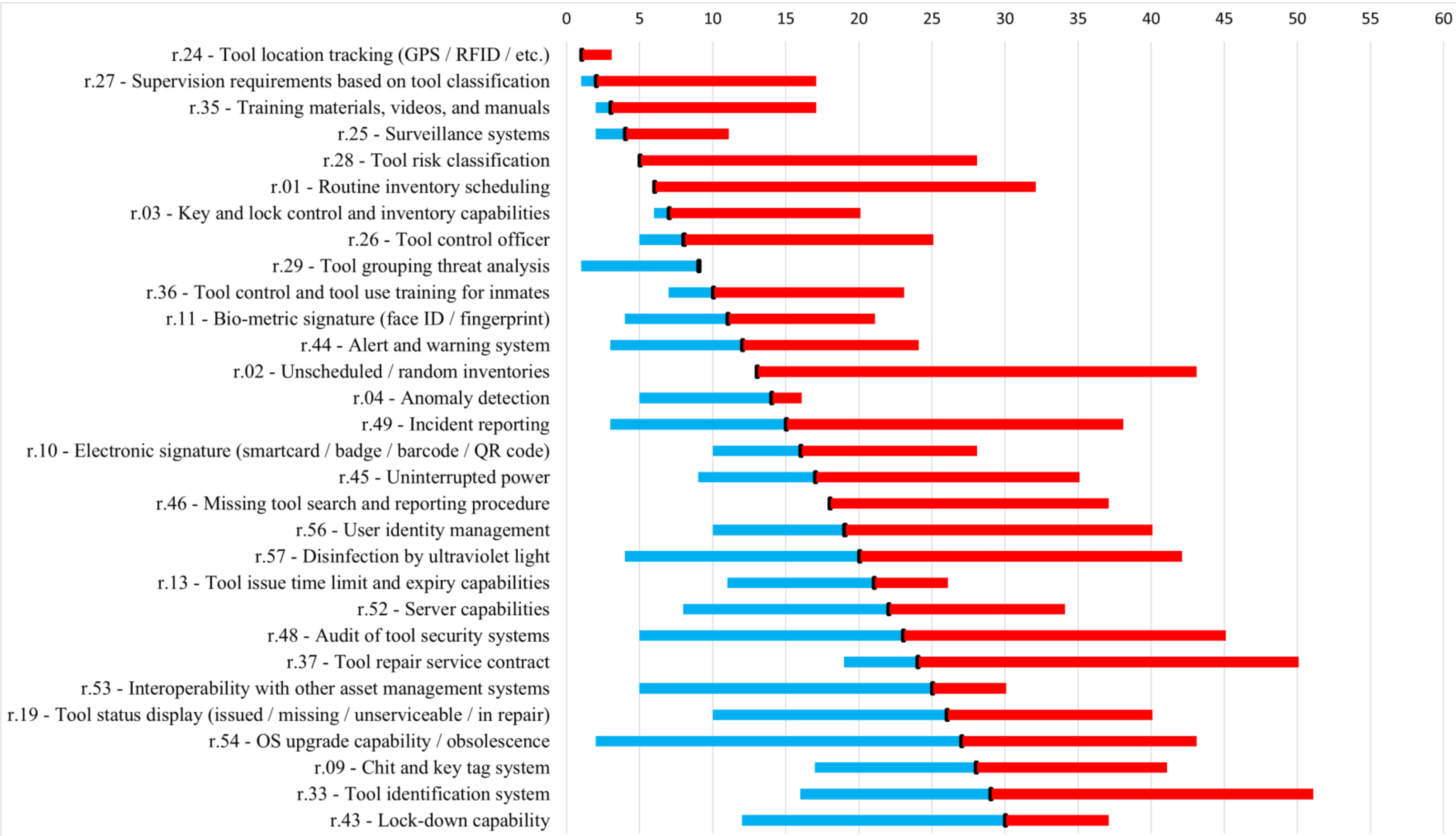


Figure 4-2. Sample results of requirements ranked across scenarios, part 1 of 2, for tool control asset management.

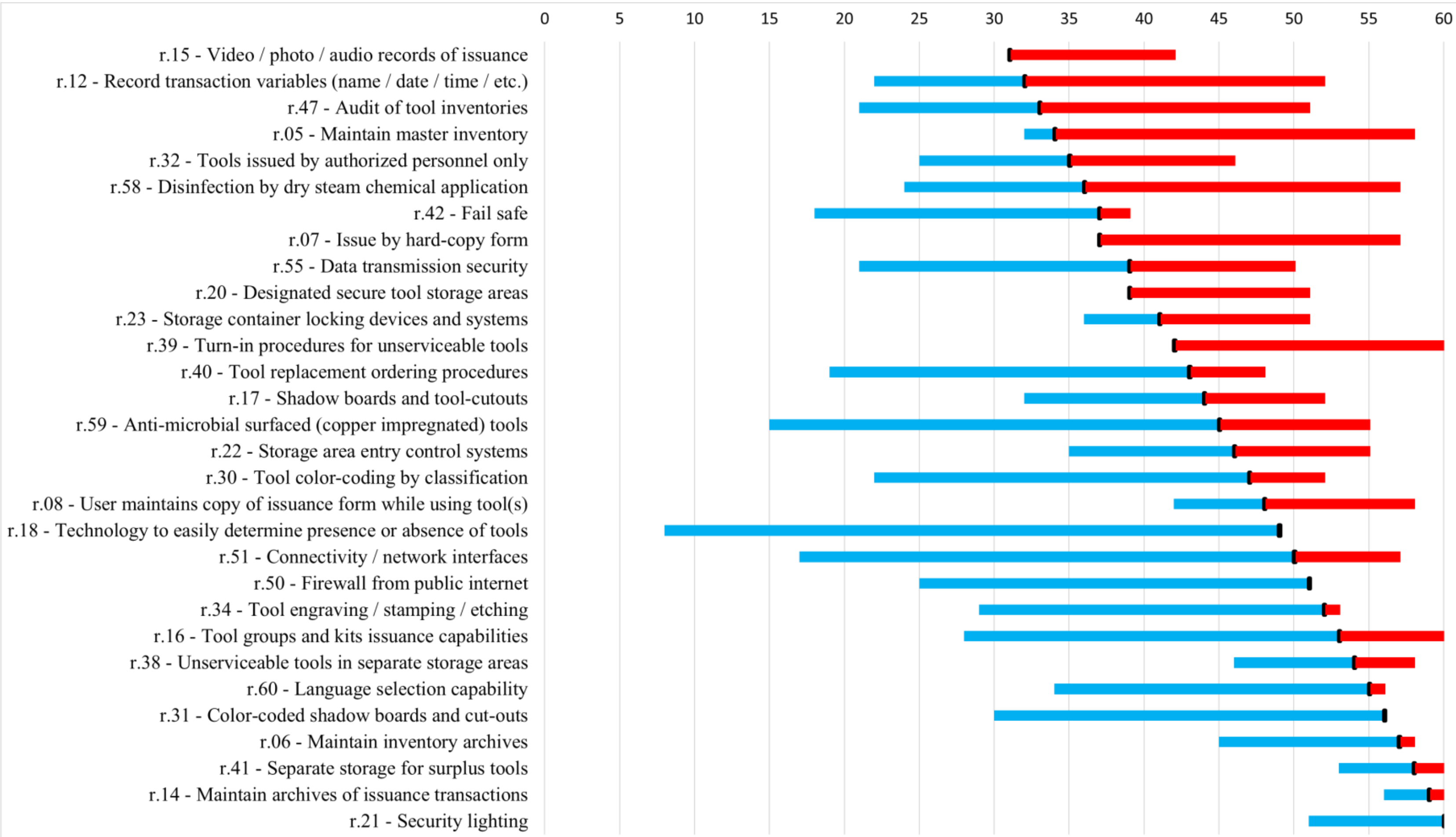


Figure 4-3. Sample results of requirements ranked across scenarios, part 2 of 2, for tool control asset management.

A calculation incorporating the changes in rankings of each requirement from the baseline scenario for all other scenarios can be used to identify which of the developed scenarios have the greatest potential to disrupt the system, and might therefore warrant increased consideration in the tool control asset procurement process. The change in requirement rankings for all requirements in each scenario are squared and summed. This value provides a measure of the magnitude of the overall disruption caused by the scenario (and its associated emergent and future conditions) from the baseline. This measure for each scenario is normalized by dividing by the maximum possible disruption, equal to the value of $n(n^2 - 1)/3$, where n is the total number of requirements considered. Figure 4-4 shows the disruptive score for each scenario developed in this analysis. A scenario in which no requirement changed rank from the baseline (the difference in rank for all requirements from the baseline scenario equal to zero), would have a disruptive score of zero. In the sample analysis, *Scenario 5, Community perception change* is the most disruptive of the three scenarios considered, with a disruptive score of 14.

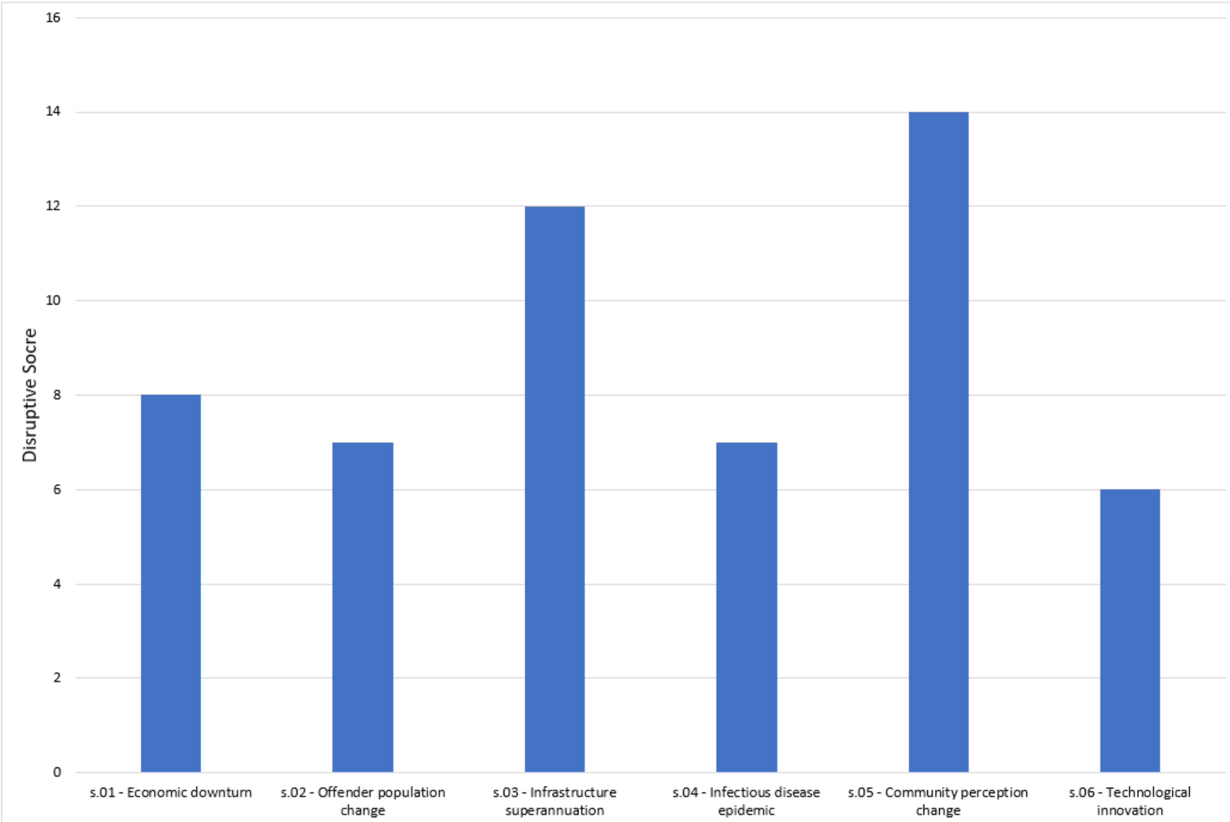


Figure 4-4. Most and least disruptive scenarios for tool control asset management.

This risk register methodology uses subject matter expert opinion to identify and rank business process requirements. By transferring feedback from subject matter experts into measurable system requirements, the risk register provides a method of evaluating responses to the RFP. Vendors would assess the suitability of their solution to meet the business process requirements previously identified by subject matter experts. As no vendor will fully satisfy each requirement having a ranking of these priorities enables selection from among the imperfect options.

The ranking of requirements can guide the selection and evaluation of vendors, and ultimately track the progress of a tool management system contract. Each vendor can be scored against their ability to meet the defined requirements. Each vendor will satisfy a unique subset of requirements and will score differently. A mathematical representation of the combination of requirement rankings and robustness can be used to identify a vendor’s ability to satisfy organizational goals, and their ability to address potential disruptions represented by scenarios developed from future and emergent conditions.

4-6. Conclusion

This chapter presents a methodology for identifying requirements relevant to enterprise asset management and identifying scenarios most and least influential in the stakeholder prioritization of those requirements. The model is applicable across various public and private enterprises. This chapter demonstrates the methodology in the context of the acquisition of a tool control system for a state-level department of corrections. Table 4-22 provides a summary of key results, describing resilient requirements and most and least disruptive scenarios for the demonstration.

Table 4-22. Summary of key results for enterprise asset management of tool control systems.

Type of Result	Description
Most resilient requirement	Requirement *r.24 - Tool location tracking (GPS / RFID / etc.)* is the most resilient requirement. The ranking of this requirement moves only two positions, between rank 1 and rank 3, over all scenarios, including the baseline scenario. It is also the highest ranked initiative in the baseline scenario, as well in scenario *s.02 - Offender population change*, *s.04 - Infectious disease epidemic*, *s.05 - Community perception change*, and *s.06 - technological innovation*.
Highly ranked and resilient requirements	Requirements *r.24 - Tool location tracking (GPS / RFID / etc.)*, *r.27 - Supervision requirements based on tool classification*, *r.35 - Training materials, videos, and manuals*, *r.25 - Surveillance systems*, *r.03 - Key and lock control and inventory capabilities*, *r.29 - Tool grouping threat analysis*, and *r.04 - Anomaly detection* are highly ranked and resilient among the other requirements. Each of these requirements are ranked within the top 15 requirements in the baseline scenario. None of these requirements are ranked below the top third of all requirements over all scenarios.
Most disruptive scenarios	Scenario *s.05 - Community perception change* is the most disruptive scenario. Emergent and future conditions related to workforce recruitment, workforce retainment, and public support of reentry programs comprise this scenario.
Least disruptive scenarios	Scenario *s.06 - Technological innovation* is the least disruptive scenario. This scenario relates to emergent and future conditions involving innovations in technology, data transmission, communications systems, and cyber security threats.

Probable overlap within the separate groupings of criteria, requirements, and scenarios highlights a current limitation of the methodology. Though the selection of success criteria considers similarity during the refinement process, all success criteria in the register are not entirely exclusive. Requirements addressing criteria *c.19 – Obtain feedback* may also address criteria *c.20 – Foster current and timely reporting*. This overlap is apparent among scenarios as well. Some emergent and future conditions are common to more than one scenario. For example, emergent and future condition *e.26 - Budgetary constraints* is a component of scenarios *s.01 – Economic downturn* and *s.04 – Infectious disease epidemic*. Scenario overlap has implications for their disruptive characteristics. The inclusion of emergent and future conditions *e.14* and *e.15*, pertaining to the recruitment and retention of corrections employees included in scenario *s.04 – Infections disease epidemic* could change the disruptiveness of scenario *s.04*. Ivanov et al. (2020) suggest customers and employees might feel more secure, reducing workplace stress, if their contacts with other human beings are minimized. A change in the disruptive assessment would manifest through stakeholder assessment of change in relative importance of criteria in the scenario based on a change in emergent and future conditions comprising a given scenario. This limitation can be addressed through an iterative approach facilitating revision of criteria and requirements and the reframing of scenarios (Hassler et al., 2020). During the value assessment process, stakeholders may discover ambiguity among criteria and requirements. Stakeholders may also find inconsistency between their intuition of criteria value changes for a scenario and justification for such change based on the current construction of the scenario. Additionally, future work can address this limitation by quantifying relationships among criteria or requirements and incorporating this relationship in the risk register.

A second limitation may be considered in the subjectivity of the semi-quantitative nature of the methodology. The analysis provides a decision aid to address and track sources of risk across five key dimensions and to describe the influence of scenarios on requirement priorities of stakeholders. It is not intended to be the final determination of the most important criteria and requirements for selection of an asset management system. Extended analysis could explore the relationship between the assignment of quantitative values to the qualitative assessments assigned by stakeholders. These include the numerical score set used to quantify assessment of requirements addressing criteria and quantitative values associated with the scaling constant, α, of the linear-additive value function. The distribution of relevance values assigned by stakeholders to criteria in the baseline scenario is also of interest.

A third limitation is the representation of a single stakeholder perspective as an enterprise consensus. In the corrections setting, stakeholder groups of administration, employees, inmates, and representatives of the community could provide differing perspectives of value to the prioritization of requirements. Future work may extend the analysis to incorporate perspectives of additional stakeholder groups through consideration of their values. One method is to assess the influence of multiple groups of stakeholders through stakeholder mapping (Almutairi et al., 2019). Another method is to apply an iterative analysis to incorporate benefits of disaggregation of stakeholder values (Hassler et al., 2020). Webler and Tuler (2018) provide historical context for the involvement of various stakeholders in risk decisions. They note an ethical responsibility of increased participation and benefits of potentially better decisions, a pathway to discover win-win solutions to risk challenges among competing interests, and a reduction in legal challenges due to wider stakeholder accountability for decisions, such as those related to the adoption of technology. This last point is applicable to the current demonstration. Wider stakeholder input may have an impact on the disruptiveness of scenarios, such as *s.05 – Community perception change*. Win-win solutions among competing stakeholder interests may lead to an increase in overall trust in the system.

This chapter and previous chapters pose the development of a risk register. A key capability for a data-driven asset management platform is the ability to visualize large quantities of data in an easy to understand format. Aggregation/disaggregation of asset management information at multiple levels within the organization should allow users to view and track assets at the appropriate level of detail. For instance, assets can be tracked by rooms/departments (e.g., assets in the kitchen), at the organizational level (e.g., the prison), and the enterprise level (e.g., all organizations statewide). Burns et al. (2003) describe a data visualization approach called ‘ecological interface design’ (EID). EID is based on principles from human-computer interaction and user interface design, and allows the user to view data at multiple levels within the system. In the example described by Burns et al. (2003), the status of internet networks was visualized across five levels, from a high-level system overview down to the status of particular physical components.

Some approaches apply the use of a risk register to project management systems for describing a record of identified risks for a particular project. These include assessments, responses, and current status produced through proprietary software packages or as a standalone document, spreadsheet, or database (Hillson and Simon, 2007). Risk registers exist in many forms. The various forms are comprised of a differing risk components and terminology, and provide a range of capabilities (Dunović et al., 2013). As presented in this chapter, the risk register is encompassed in the various tables and figures. The summary of key results for requirements and scenarios (Table 4-22), the high-low-baseline figures of requirements rankings (Figures 4-2 and 4-3), scenario composition (Table 4-15), and assessment of requirements against criteria (Tables 4-5 through 4-13) are important components of the risk register for this analysis. Additionally, the catalogue of criteria, requirements, and emergent and future conditions serve as an appropriate method for producing a request for proposals and tracking sources of risk to project performance, schedule, and cost during acquisition and implementation. Future work can incorporate additional components and develop improved visualizations for presenting the information to stakeholders.

Chapter 5. Asset Management of Inland Waterway Transportation Corridors

5-1. Overview

This chapter applies and extends the methods described in Chapters 2 through 4 to the James River inland waterway corridor in southeastern and central Virginia, from deep-water ports in Hampton Roads to the Richmond Marine Terminal in Richmond, Virginia. Three additions to the maritime corridor trace methodology are introduced: (i) the production of a safety risk factor trace for industrial and commercial land develop, and potential land development termed industrial zoned parcels, (ii) the production of a safety risk factor trace for maintained corridors, where they exist fully, partially, or not all within the corridor segments, and (iii) a nomenclature framework for segments to identify them by geographic location to further a broad applicability to stakeholders when considering factors outside of the straight-line representation of the corridor trace visualization. The asset management and resilience analysis methods introduced in Chapter 4 are applied to the James River corridor. The influence of scenarios on the prioritization of both enterprise initiatives, as well as segment rankings is discussed.

5-2. Introduction

From 2010 to 2018, world GDP increased by nearly 26 percent. During the same time period, world merchandise trade volume increased by approximately the same amount (WTO, 2019). This growth has propelled the development of the world container ship fleet. Both the number and size of vessels in the fleets of container shipping lines has increased. In 1996, the maximum size of a container ship was 7100 twenty-foot equivalent units (TEU). In 2015, the capacity of a single ship had ballooned to 18,000 TEUs. In the three decades leading up to 2015, the worldwide container fleet capacity increased by over 8 percent per year on average (Tran and Haasis 2015). Container port throughput, a primary metric of port performance, reflects this growth as well. World container throughput volume increased from approximately 470 million TEUs in 2010 to nearly 800 million TEUs in 2018 (UNCTAD 2019). U.S. domestic throughput measured 51.1 million TEUs in 2017, with inbound containers representing nearly 50 percent of traffic and 18 percent more than outbound. This volume was a 7.3 percent increase from the previous year (USDOT 2018). A continued trend of increased growth in containerized shipping will undoubtedly have consequences for transportation systems moving goods between a port and inland destinations.

The options for inland movement of containerized goods to and from deep-water ports are modes of truck, rail, and barge, though not all modes are available to all ports. In the United States, truck transportation comprises the vast majority of freight shipments. In 2016, trucks transported nearly 91 percent of the almost 14 million tons of freight shipments. Rail and water modes comprised 6 and 3 percent respectively (USDOT 2019). Yearly increases in container throughput will likely exacerbate congestion issues for the nation's highway system given the heavy reliance on the truck mode of freight transportation. Studies have demonstrated the potential for freight movement by rail to alleviate roadway congestion (Bryan et al. 2007, Cambridge Systematics 2010, Guo et al. 2010). Where available, the use of barge transportation on inland waterway networks provides the potential to reduce roadway congestion resulting from continued growth in international trade.

Additional impacts regarding the inland movement of containerized goods include transportation infrastructure maintenance, safety, modal energy efficiency, emissions, and cost. A 2017 report by the Center for Ports and Waterways of the Texas A&M Transportation Institute provides a detailed comparison of these impacts across the three modes of containerized freight transportation. The study compiles statistics from various U.S. government resources concerning each impact. The general trend of reported data suggests inland waterway transportation is generally less maintenance intensive, safer in terms of injuries and cargo loss, more energy efficient, and results in fewer greenhouse gas emissions than rail or truck. Typically truck freight transportation is the least desirable among the three modes. For example, in terms of ton-miles traveled for 2014 fuel standards, inland waterway transport was estimated to have emitted 15.6 metric tons of greenhouse gases compared to 21.2 metric tons for rail and 154.1 metric tons for highway transport (Kruse et al. 2017). Inland waterway transport may also provide cost savings for port operators. It is estimated an average tow barge trip could replace the equivalent of over 800 truck-loads for commodities (Camp et al. 2013).

The use of inland waterway corridors for transport is a promising measure to facilitate the trending increase of freight traffic, when these corridors are available. However, such use compels the need for analysis of relevant factors along inland waterway corridors impacting the navigation of barge traffic and will be suitable for assessing influence of future and emergent conditions for the sustainable use of these corridors.

5-3. Background

The trend of shipping growth has prompted many studies of the impact of such growth on the several freight transportation modes and their associated systems. The arrival of large vessels and their massive container capacity to port terminals is predicted to impact the intra-terminal operation of truck drayage with implications for truck turn times and roadway congestion near the port (Thorisson et al. 2019). Similar analysis may be applicable to barge or rail loading and availability during peak demand. Causal loop diagrams, cross-impact matrices, and hierarchical cluster analysis have been demonstrated for assessing impacts to highway transportation systems from influences such as freight alternatives, and safety considerations (Sadatsafavi et al. 2019). Collier et al. (2018) modeled the impact of disruptive scenarios to a port's large-scale capacity expansion projects in terms of cost, schedule, and quality. These impacts can lead to cost overruns and project failure if not managed properly.

Chapter 1 introduces the "America's Marine Highway" initiative described in a report by the Maritime Administration (MARAD) of the U.S. Department of Transportation (USDOT). One of the inland waterway corridors described in the report is the Central California region demonstrated in Chapter 2, named in the report as the M-580 highway. The projected benefits described by the MARAD report conform well with the state of California's vision for their intermodal transportation networks. In a document describing the state's interregional transportation strategic plan (ITSP), the California Department of Transportation outlines its mission to provide a safe, sustainable, and efficient transportation system to enhance economy and livability (CALTRANS, 2015). The ITSP outlines strategies to achieve its mission. Among these strategies are the following: maintain and enhance existing assets, apply new technologies and systems operations practices, and strategically add new capacity.

The M-580 highway, the inland waterway transportation network from the San Francisco Bay to ports in Stockton and West Sacramento was awarded a $30 million grant by the USDOT in 2010, divided among the Port of Oakland, the Port of West Sacramento, and the Port of Stockton to establish a container-on-barge service to alleviate container transport by truck on Interstates 580, 80, and 5 in the region (CALTRANS, 2019). With the grant money, the Port of Stockton purchased two 140-ton cranes and two barges to establish the container service from the Port of Oakland. The service ended after fourteen months of operation having experienced unsustainable cost overruns of approximately $1 million per month. An attempt to restart the M-580 program was made in the California legislature in 2017 by the proposal of legislation in AB-13 – 580 Marine Highway, for the appropriation of $85 million. The bill was voted down in January 2018.

5-4. Methods

The maritime corridor trace methodology described in Chapter 2 and Chapter 3 are applied to describe and analysis the safety and security risk factors of the inland waterway corridor in the demonstration of this chapter. The maritime corridor trace analysis is then applied to the asset management methodology presented in Chapter 4 to assess the influence of scenarios on the prioritization of enterprise initiatives as well as the risk-based ranking of corridor segments. Three new components of the maritime corridor trace methodology are described. In the asset management demonstration, segments are no longer ranked using the distribution of risk threshold segments among risk factors. In the demonstration of this chapter, the relative weighting of corridor risk factors is determined by stakeholder evaluation. In addition, all risk factors are aggregated in the relative weighting assessment, including both safety and security risk factors as well as the two factors described in this section. The corridor trace analysis is used to inform the selection of initiatives for asset management related to the defined risk dimensions.

5-4-1. “Maintained Channel” Safety Risk Factor

The maintained channel safety risk factor is selected based on consideration of corridor capacity management and is related to the hazards of collision and grounding. As discussed in Chapter 2, NOAA nautical charts depict the location of channels maintained by the United States Army Corps of Engineers. The channels are maintained to designated widths are periodically dredged by USACE to maintain specific project depths. These depths are typically tabulated on nautical charts. There is an acknowledged relationship between the selection of this factor and its risk represented by the factors of channel width, channel depth, and buoys and lights. The presence or absence of a maintained channel could be inferred without difficulty from the segment values associated with these three factors. Maintained channels usually have a smaller, regularly trafficked channel width, a uniform channel depth over several adjacent factors, and a higher presence of buoys and lights. Still, the introduction of this factor represents a risk in the absence of monitored and periodically maintained channel depth and the general reduction in aids to navigation in areas segments, and portions of segments, without a maintained channel. It is also useful in conjunction with the industrial zoned parcels safety risk factor described next, for consideration of expansion capacity impacts along the corridor.

The maintained channel safety risk factor is classified into risk threshold levels according to the presence or absence of a maintained channel is all or a portion of a segment. The high-risk threshold is assigned to segments with no portion having a maintained channel. The moderate-risk threshold classifies segments with some portion having a maintained channel. The low-risk classification is applied to segments in which the entire length is maintained. Figure 5-1 depicts a portion of the James River corridor demonstrated in this chapter, with all three conditions. The full length of segment 56 contains a channel maintained by USACE, a portion of segment 57 does, and no portion of segment 58 contains a maintained channel. The relative lack of aids to navigation in segments 57 and 58 is of note, since these buoys and lights are what indicate the presence of the channel to vessel pilots.

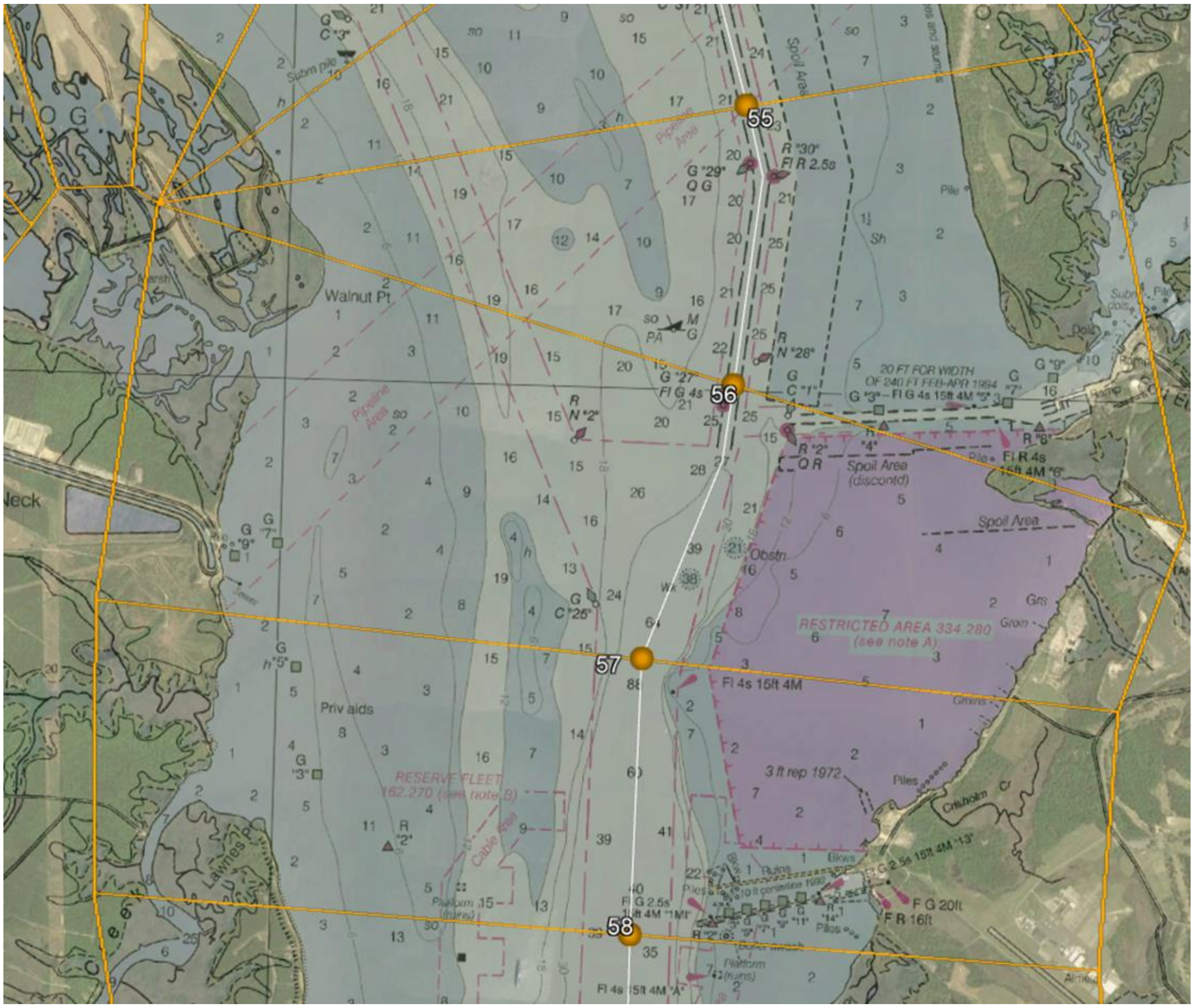


Figure 5-1. Maintained channel factor data collection.

5-4-2. "Industrial Zoned Parcels" Safety Risk Factor

The industrial zoned parcels safety risk factor identifies segments containing shoreline parcels zoned for commercial or industrial use. The selection of this risk factor has two intentions. As a safety risk factor, it is associated primarily with collision hazards, especially under conditions of greater utilization of the corridor. Similar to the maintained channel factor, there is an acknowledged relationship between the industrial zoned parcels factor and the commercial piers factor. In areas with already developed parcels, there is an associated likelihood for the presence of commercial piers. Because of this relationship, the industrial zone parcels will be associated secondarily with allision hazards. Segments with industrial zoned parcels do not necessarily predict the risk of commercial piers. The second intention of the parcels risk factor is to support the asset management of the inland waterway corridor by stakeholders interested in the promotion of regional economic growth by classify relevant parcels as developed and undeveloped. Industrial zoned parcels within a segment determined to be undeveloped are classified in the high-risk threshold. Developed parcels, indicating existing and evidently operational enterprise infrastructure on the parcel, are classified in the moderate-risk threshold. Parcels not zoned for industrial or commercial use are classified as low-risk.

There are three steps in the safety risk factor data collection process for industrial zoned parcels. The first step is to determine the location and zoning designation of parcels along the entire shoreline of the inland waterway corridor. Online resources assist in this step. The research for this dissertation did not determine if it is universally true in the United States, but generally, counties, cities, and towns in the U.S. maintain a zoning ordinance prescribing the allowable use of sectioned portions of land, or parcels, within their jurisdictions. For the localities concerned in the demonstration of this chapter, each offers a web-based GIS application or dataset identifying parcels. Table 5-1 provides the URL for each locality containing a shoreline of the James River. The listed order is counter-clockwise beginning on the north shore and moving west to Richmond and returning east on the south shore of the corridor to Norfolk. Figure 5-2 demonstrates the use of the websites, using Surry County as the example. The owner information is given, but is redacted in the figure.

Table 5-1. Parcel data URL's for localities bordering the James River corridor.

Locality	Parcel Data URL
City of Newport News	https://www.arcgis.com/home/item.html?id=e7794bc8b1e84ae7a5526b81f168ed26
James City County	https://opendata-jcc.opendata.arcgis.com/datasets/a0dfa59d3c4a442c9ebe3719762a407d_17
Charles City County	https://qpublic.schneidercorp.com/Application.aspx?AppID=1042&LayerID=22982&PageTypeID=1&PageID=9640#
Henrico County	https://data-henrico.opendata.arcgis.com/datasets/tax-parcels-cama-data?geometry=-77.462%2C37.372%2C-77.246%2C37.419&selectedAttribute=RESIDENTIAL_COMMERCIAL
City of Richmond	https://cor.maps.arcgis.com/apps/webappviewer/index.html?id=c3ed34c0fb38441fb95cd2d2d6a22d48
Chesterfield County	http://geospace.chesterfield.gov/datasets/d38f30b3216d45d4b5d779edfeff0b51_3
City of Hopewell	https://www.arcgis.com/home/item.html?id=0a445472e5904f3c889946304f047df1
Prince George County	http://maps.princegeorgeva.org/Html5Viewer/index.html?viewer=Mapviewer.htmlviewer
Surry Country	http://surry.mapsdirect.net/Account/Logon
Isle of Wight County	https://hub.arcgis.com/datasets/692bdbb512bf4b849a3273dace2d9335
City of Portsmouth	https://www.arcgis.com/home/item.html?id=45a6cef84dd243a79846d2ee559710dd
City of Norfolk	https://norfolkgisdata-orf.opendata.arcgis.com/datasets/parcel-boundaries?geometry=-76.364%2C36.871%2C-76.148%2C36.919

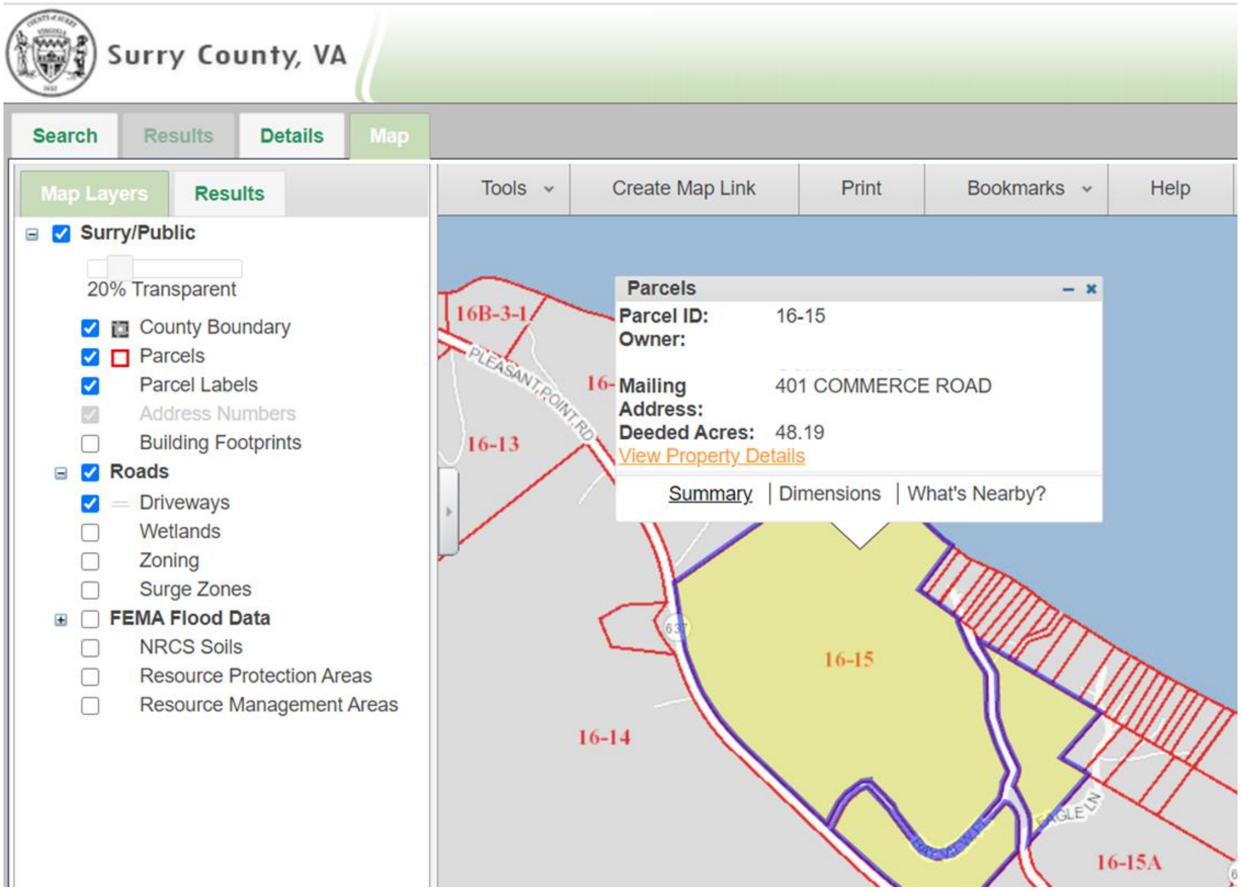


Figure 5-2. Identification of land parcels from locality-maintained web-based applications.

Most URLs provide a link for additional land use details. The additional details include the zoning code and may or may not provide the definition of the code. If the definition is not provided, review of the locality's zoning ordinance is required to determine the land use associated with the zoning code. In the example shown, the land use code is A-R, for agricultural rural, and thus, is not an industrial zoned parcel. Alternatively, some localities maintain a zoning map with a legend depicting all parcels and their associated land use.

The second step of the data collection is to determine the developed or undeveloped nature of identified industrial or commercially zoned parcels. Provided additional property details may be sufficient to determine current use. Otherwise, determination requires subjective judgment by the analyst to identify existing and evidently operational enterprise infrastructure. This dissertation relies on the satellite imagery capabilities of Google Earth Pro, or other GIS applications for the judgment basis.

The third step is the creation of an industrial zoned parcel overlay. The polygon feature is used to add parcel shaped features to the suite of overlays for the inland waterway corridor. Precision is not essential and adjacent parcels are conveniently represented by a single shape feature. Figure 5-3 is a portion of the parcel overlay for the James River corridor, consisting of the majority of industrial zone parcels. City names have been added for reference. The north pointing arrow is approximate.

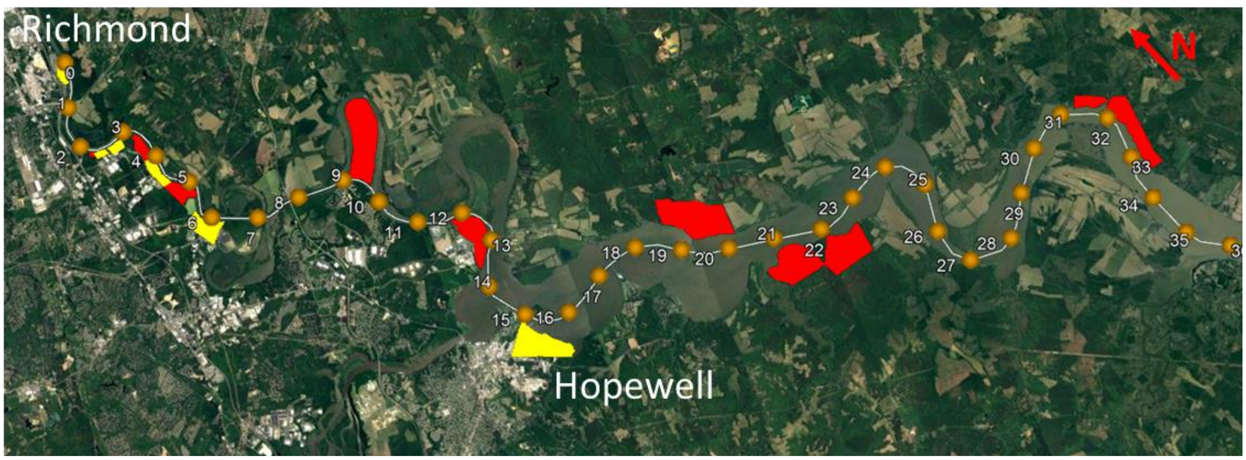


Figure 5-3. Industrial zoned parcel safety risk factor overly example. Locations of undeveloped industrial zoned parcels (red) and developed industrial zoned parcels (yellow) are indicated.

5-4-3. Segment Nomenclature Framework

The last component of the maritime corridor trace fully described in this dissertation is a nomenclature framework for corridor segments. The intent of the framework is to further the meaningful use and applicability of the maritime corridor trace to a variety of stakeholders. It can also be useful for discussion in a context other than the straight-line corridor trace visualization. In this context, referencing a segment simply by number may not provide the user with understanding of the place of the segment in the corridor, unless the user is continuously aware of the starting point and overall length of the corridor. Even then, it might only provide a general sense of relative placement between start and end points. The framework described could be adapted to other maritime corridors, rail and highway corridors, and other applications.

The nomenclature for segments includes two parts. Part one is a reference to a county or municipality associated with a segment. Part two is a second identifying feature of the natural or built environment, or perhaps a subordinate municipality. A particular feature of the James River corridor contributed to the motivation for this framework. For the length of the navigable corridor, the James River serves as a natural border for all counties and municipalities encompassing a portion of the shoreline. There are two exceptions for segment 10 and segment 13, where the actual river does serve as a county border for chesterfield county, but the trafficked corridor travels along a cutoff of two fingers of land, Jones Neck and Turkey Island. With the James River as a boundary, the framework was formulated by developing a shorthand for counties and municipalities and then assigning the first part of the nomenclature with a south shore/north shore pairing of the shorthand for the localities on the respective borders. Deviations exists at the deep-water harbors where the channel turns south and is bordered by Portsmouth and Norfolk, and in segment 1 which is labeled for part one only as Richmond. Table 5-2 provides the shorthand notation for the various counties and municipalities along the James River corridor.

Table 5-2. Shorthand notation for part one of the segment nomenclature for the James River corridor.

County or Municipality	Shorthand Notation
City of Newport News	NN
James City County	JCC
Charles City County	CCC
Henrico County	HC
City of Richmond	Richmond
Chesterfield County	CC
City of Hopewell	Hope
Prince George County	PGC
Surry Country	SC
Isle of Wight County	IWC
City of Portsmouth	Port
City of Norfolk	Norf

The second identifying feature for part two of the nomenclature could be a bridge, a commercial or industrial feature meaningful to stakeholders, a known landmark, a land feature indicated on the nautical charts, etc. In cases when there is no reasonable choice for a second identifying feature, the segment number is used for part two. Table 5-3 provides shorthand notation used for part two of the nomenclature.

Table 5-3. Shorthand notation for part two of the segment nomenclature for the James River corridor.

Feature	Shorthand Notation
Richmond Marine Terminal	RMT
Vietnam Veterans Memorial Bridge	VVM Bridge
Industries	Ind
Fulfillment center	FC
Benjamin Harrison Memorial Bridge	BHM Bridge
Country club	CC
Jamestown-Scotland Ferry	JS Ferry
Monitor-Merrimac Bridge-Tunnel	MM Bridge-Tunnel
Norfolk International Terminal	NIT
Virginia International Gateway	VIG

Table 5-4 provides some examples of the nomenclature for selected corridors.

Table 5-4. James River corridor segment nomenclature examples.

Segment	Nomenclature
Segment 6	CC/HC - Chesterfield Power
Segment 11	CC/HC - Amazon FC
Segment 18	PGC/CCC - BHM Bridge
Segment 25	PGC/CCC - Windmill Point
Segment 36	SC/CCC - Chippokes Creek
Segment 45	SC/JCC - JS Ferry Settlement
Segment 47	SC/JCC - JS Ferry Scotland
Segment 57	SC/NN - Fort Eustis
Segment 72	IWC/NN - NN Shipbuilding 1
Segment 80	Port/Norf - NIT North

The nomenclature framework for corridor segments may not apply directly to other maritime corridors or to road and rail networks. For example, in the Central California region of Chapter 2, Sacramento County, California does form a border with the Sacramento River, but does not border the Sacramento Deep Water Ship Channel. Yolo County is located on both sides of this section of the corridor. On the St. Johns River corridor, Duval Country is located both north and south of the river in the segments closest to the Atlantic Ocean. The two-part construction may still include enough distinguishing detail to provide a geographic reference frame. Road corridors are commonly referenced by mile-marker, or by exit numbers typically assigned with the roadway mile-maker number containing the exit, for non-toll highways. Exit numbers may be a good choice for the second identifying feature when present. Rail corridors may also require adaptation as they may exist in long stretches of rural land with few distinguishing features.

5-4-4. Additional Methods for Asset Management Analysis

In this chapter, methods introduced in Chapter 4 are applied for the asset management analysis of the James River inland waterway transportation corridor network. In Chapter 4, the term "requirements" as a system appropriate term to address prioritization of characteristics for a technology-based tool control asset management system. In the demonstration of this chapter, the term "initiatives" is used to address prioritization of potential stakeholder actions for the asset management of the James River corridor. In addition, the influence of scenarios on the risk-based prioritization of corridor segments is explored. Stakeholder values are solicited to assess relative weights of aggregated safety and security risk factors. The assessment of segments against factors is represented by the threshold risk value of each segment for each factor. For consistency of the methodology, the assessment is presented to stakeholders in table form in which a filled circle (●) indicates a high-risk value for a segment assessed against a factor, a half-filled circle (◐) indicates a moderate-risk value, and an unfilled circle (○) indicates a low-risk value. The symbols correspond to the numerical score set {1, 2/3, 1/3}.

5-5. Demonstration

In this section, methods introduced up to this point of the dissertation are applied to the James River inland waterway corridor in southeastern and central Virginia. Maritime corridor traces for both safety risk factors and security risk factors are presented, along with the supporting risk register products. The safety risk factors introduced in this chapter are presented separately from the previously identified factors. The maritime corridor trace products are provided without the additional exploration of compounded risk segments and combined safety and security considerations discussed in the previous chapters. The asset management methods from Chapter 4 are applied to the assess the influence of scenarios on corridor segment risk and stakeholder prioritization of asset management initiatives. The most and least disruptive scenarios are identified along with consideration of highly ranked and robust initiatives and the interpretation of highly ranked and robust segment risk. The nomenclature of segments developed in Section 5-4-3 is applied during the asset management analysis.

5-5-1. Demonstration Background

The region selected for this demonstration is southeastern and central Virginia, which consists of the James River from Norfolk to the Richmond Marine Terminal (RMT) in Richmond, Virginia. The eastern end of the corridor is referred to as Hampton Roads, and includes the cities of Norfolk, Portsmouth, Hampton and Newport News. It focuses on vessel traffic on the James River and operations associated the Port of Virginia (POV). Primary road networks in this region are Interstate 64 on the north side of the James River from Norfolk to Richmond. A significant feature of I-64 is the Hampton Roads Bridge-Tunnel (HRBT) connecting Norfolk to the cities of Hampton and Newport News. All ocean-going vessels berthing in the POV terminal complex, Norfolk International Terminal (NIT), Virginia International Gateway (VIG), and Portsmouth Marine Terminal (PMT), in Hampton Roads pass over the tunnel portion of the HRBT. The HRBT consists of two east-bound and two-west bound vehicle lanes and can be a bottleneck for the roadway network. As defined in this dissertation, the James River corridor is eighty-two nautical miles long from VIG to the wharf at RMT. Figure 5-4 depicts the region of the James River corridor.

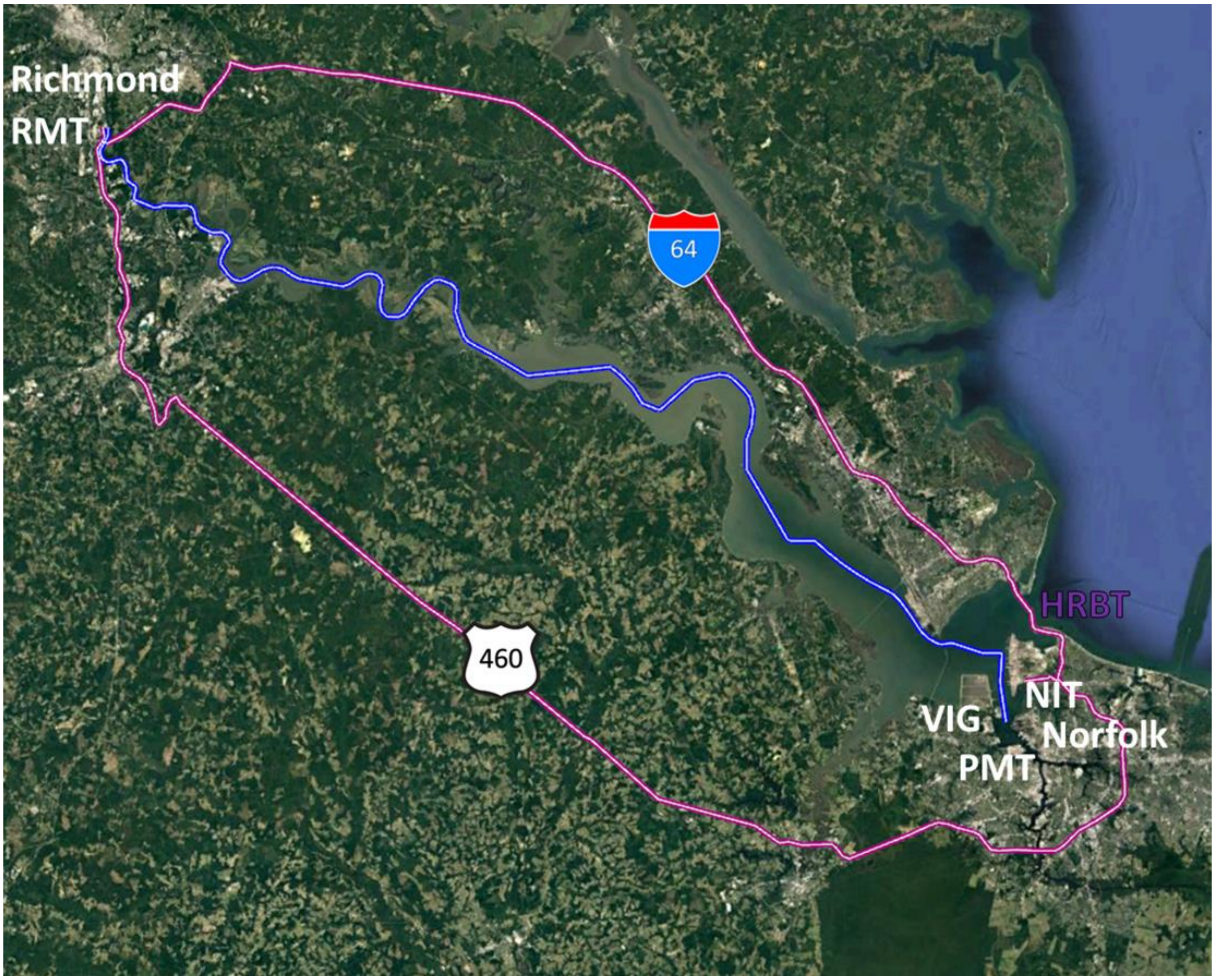


Figure 5-4. James River region. The inland waterway corridor is highlighted in blue with roadway corridors highlighted in purple.

The Port of Virginia is a port operator, which means they directly operate the terminals within their jurisdiction. With this designation, POV is enterprise responsible for the operation of the barge service for the movement of containerized freight as well as bulk agricultural exports and break-bulk (POV, 2017) from RMT to the Hampton Roads terminals. As of 2017, POV was the fifth largest container port in the United States and all freight from the City of Richmond ranked among the top twenty-five ports by tonnage (USDOT, 2018). POV handles large volumes of containerized freight and projects continued growth. The port advertises a partnership with USACE to deepen the shipping channel from the Atlantic Ocean to the Hampton Roads terminals to a depth of fifty-five feet, which allows ultra large container vessels to call the port. Along with larger vessels and more containers at the Hampton Roads terminals, a POV strategic goal is increased container throughput at RMT. In 2019, operations at RMT exceeded project container throughput by more than three thousand containers (POV, 2020). The port has received grants from MARAD and others to support the marine highway program, referred to as the “64 express” by POV (POV, 2016). The Port of Virginia includes sustainability, stewardship of resources, and improvement of navigable waterways in Virginia among its mission and values (POV, 2017).

5-5-2. Safety Risk Factor Considerations

Figure 5-5 and Figure 5-6 represent the maritime corridor trace for safety risk factors for the James River corridor.

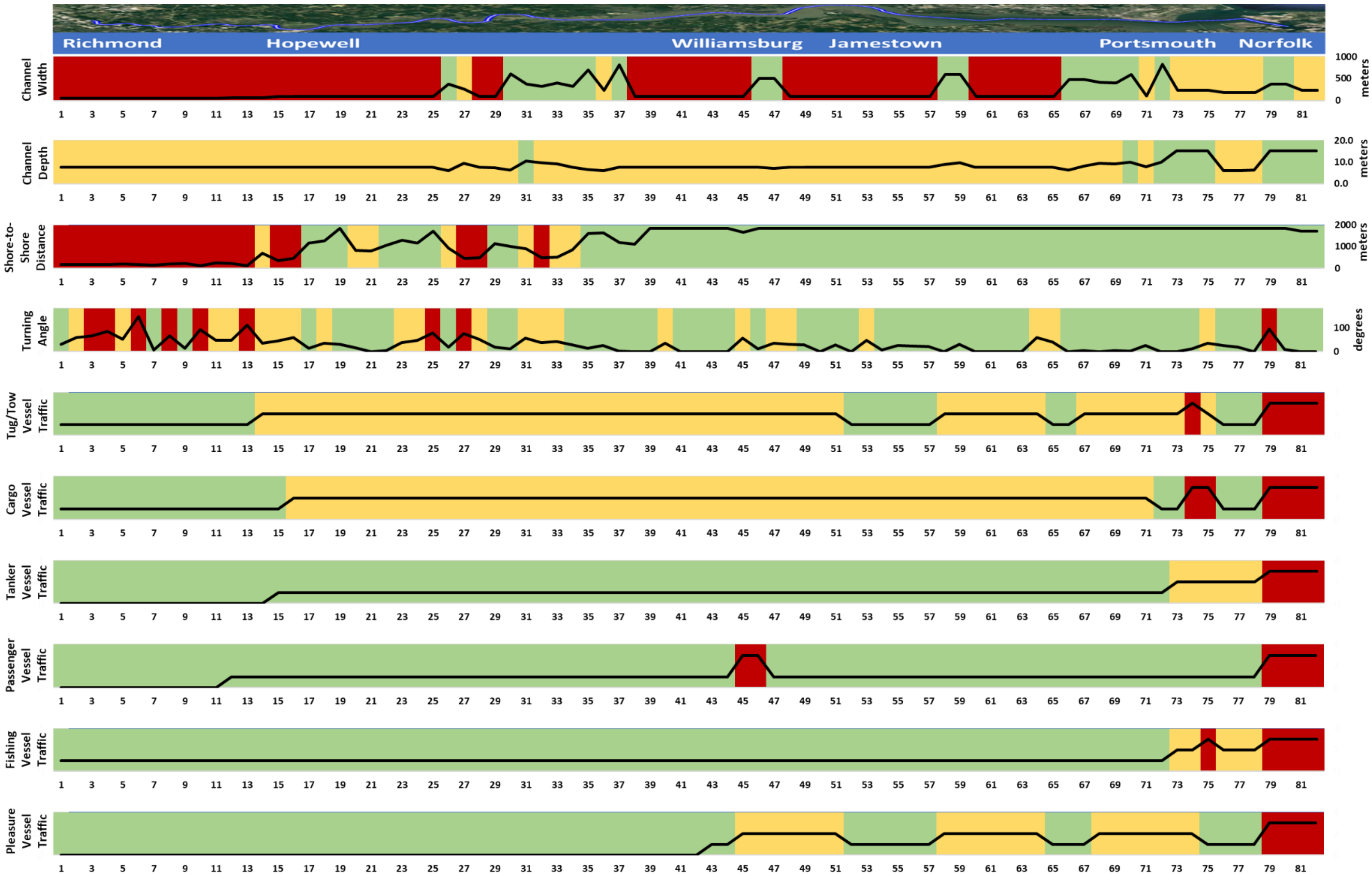


Figure 5-5. Maritime corridor trace of the James River for geometry and traffic factor categories.

Figure 5-6. Maritime corridor trace of the James River for infrastructure, obstacle, and sea-state categories.

Inspection of the maritime corridor trace shows generally low vessel traffic throughout the corridor compared to previous demonstrations, except for the final four segments in Hampton Roads at deep-water ports. The Richmond end of the corridor is characteristic of frequent high-risk value turns, some over 100 degrees. The trafficked channel as well as the general river width is narrow in this section as well. Vessels will need to contend with segments containing high-risk levels of buoys and lights as obstacles. Discussions with representatives from the Port of Virginia have identified bridges as a significant concern to barge operations. They do not only represent an allision hazard as described in Chapter 2. The Benjamin Harrison Memorial Bridge in segment 18 and the James River Bridge in segment 71 are vertical-lift bridges. These bridges must be raised to allow vessel passage. A lack of predictability has led to frequent delays for the barge service, which impacts operating costs and reliability for the port. It could also increase the risk for collision hazards due to vessel consolidation awaiting a bridge opening. Inflows in the narrow, winding segments near Richmond could represent a concern for sea-state conditions. Table 5-5 and Table 5-6 are supporting risk register products providing the distribution of safety risk factor levels across segments and the distribution of segment risk thresholds across factors. Aggregated risk factor ranking is addressed in the asset management analysis.

Table 5-5. Distribution of safety risk factors in each segment for the James River.

	Number of Factors Within Threshold				Number of Factors Within Threshold		
Segment	High	Moderate	Low	Segment	High	Moderate	Low
1	4	4	12	42	2	6	12
2	3	5	12	43	3	6	11
3	4	4	12	44	3	5	12
4	4	3	13	45	4	8	8
5	3	6	11	46	3	6	11
6	4	4	12	47	2	7	11
7	3	4	13	48	4	6	10
8	6	3	11	49	4	5	11
9	3	5	12	50	4	5	11
10	4	5	11	51	3	6	11
11	3	4	13	52	3	3	14
12	3	5	12	53	4	4	12
13	5	4	11	54	4	3	13
14	3	6	11	55	3	4	13
15	3	8	9	56	4	4	12
16	4	8	8	57	4	5	11
17	2	8	10	58	2	6	12
18	3	6	11	59	2	6	12
19	3	6	11	60	4	6	10
20	3	7	10	61	3	6	11
21	2	7	11	62	3	6	11
22	3	5	12	63	3	6	11
23	3	6	11	64	4	7	9
24	3	6	11	65	4	5	11
25	4	6	10	66	2	4	14
26	1	6	13	67	2	5	13
27	3	6	11	68	2	5	13
28	3	6	11	69	2	5	13
29	3	5	12	70	2	5	13
30	1	5	14	71	3	6	11
31	1	6	13	72	2	5	13
32	2	6	12	73	2	8	10
33	1	7	12	74	3	7	10
34	1	6	13	75	3	8	9
35	1	5	14	76	1	7	12
36	1	7	12	77	1	6	13
37	1	5	14	78	1	6	13
38	2	6	12	79	8	4	8
39	2	7	11	80	7	3	10
40	3	7	10	81	7	5	8
41	2	7	11	82	7	5	8

Table 5-6. Distribution of segments by risk level within safety risk factors for the James River.

Factor	Hazards	Number of Segments Within Threshold		
		High	Moderate	Low
Channel width	Collision	51	11	20
Channel depth	Grounding	0	72	10
Shore-to-shore distance	Grounding	18	7	57
Turn angle	Collision, allision, grounding	9	22	51
Vessel traffic tug/tow	Collision	5	53	24
Vessel traffic cargo	Collision	6	56	20
Vessel traffic tanker	Collision	4	6	72
Vessel traffic passenger	Collision	6	0	76
Vessel traffic fishing	Collision	5	5	72
Vessel traffic pleasure	Collision	4	21	57
Bridges	Allision, collision	4	7	71
Commercial pier	Collision, allision	0	20	62
Buoys and lights	Allision	20	18	44
Obstructions	Allision	1	3	78
Inflows	Collision, allision, grounding	2	22	58
Wind (average)	Collision, allision, grounding	0	0	82
Wind (maximum)	Collision, allision, grounding	82	0	0
Precipitation (average)	Collision, allision, grounding	0	0	82
Precipitation (maximum)	Collision, allision, grounding	30	52	0
Fog	Collision, allision, grounding	0	82	0

5-5-3. Security Risk Factor Considerations

Figure 5-7 presents the maritime corridor trace for security risk factors for the James River corridor.

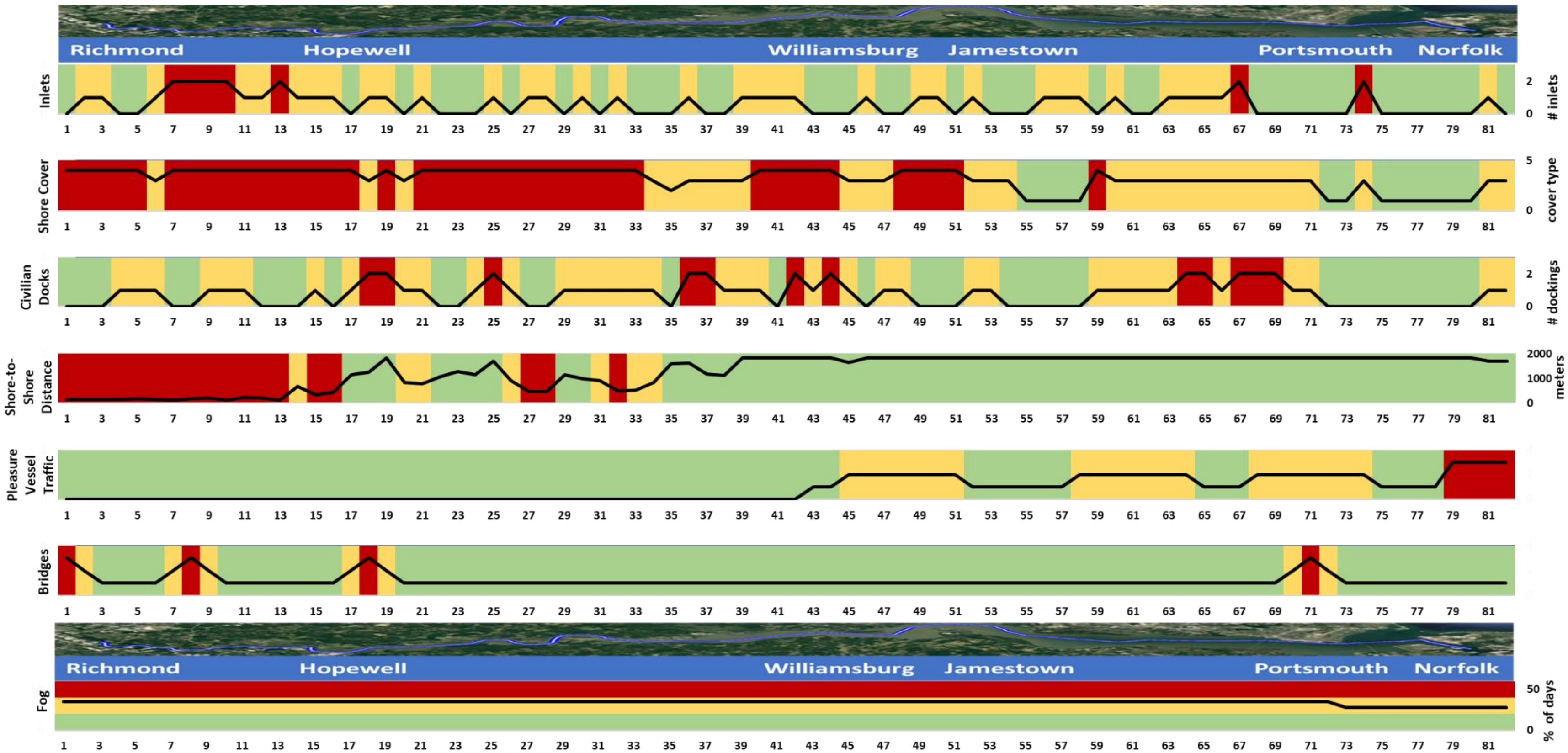


Figure 5-7. Maritime corridor trace of the James River for security factors.

Inspection of the maritime corridor trace for security factors high to moderate-risk levels for all the security risk factors associated with the land-based attack hazard over segments of the corridor closest to Richmond. The north shore of the James River in this area, Henrico County and Charles City County is rural forested, providing cover and concealment to a potential threat. Shore-to-shore distances are generally narrowest over the first sixteen segments. There are also three bridges from segment 1 to segment 18, the Vietnam Veterans Memorial Bridge in segment 1, the Varina-Enon Bridge in segment 8, and the Benjamin Harrison Memorial Bridge in segment 18. Pleasure vessel traffic is generally low throughout the corridor with a notable exception. As with other forms of traffic, pleasure vessel traffic is high in segments 79 through 82. This is where the large container and cargo vessels, including naval vessel stationed at Naval Station Norfolk will traffic. A threat may target a vessel in this area to have a large impact by attacking a large ship, or intending to scuttle a ship in the port's main channel to impact commerce throughout the region. Table 5-7 and Table 5-8 are supporting risk register products for the distribution of security risk factor levels across segments and the distribution of segment threshold levels across security risk factors.

Table 5-7. Distribution of security risk factor levels in each segment for the James River.

	Number of Factors Within Threshold				Number of Factors Within Threshold		
Segment	High	Moderate	Low	Segment	High	Moderate	Low
1	3	1	3	42	2	2	3
2	2	3	2	43	1	2	4
3	2	2	3	44	2	1	4
4	2	2	3	45	0	4	3
5	2	2	3	46	0	4	3
6	1	4	2	47	0	4	3
7	3	2	2	48	1	3	3
8	4	1	2	49	1	3	3
9	3	3	1	50	1	3	3
10	3	2	2	51	1	2	4
11	2	3	2	52	0	4	3
12	2	2	3	53	0	3	4
13	3	1	3	54	0	2	5
14	1	3	3	55	0	1	6
15	2	3	2	56	0	2	5
16	2	2	3	57	0	2	5
17	1	3	3	58	0	3	4
18	2	3	2	59	1	3	3
19	2	3	2	60	0	5	2
20	0	4	3	61	0	4	3
21	1	4	2	62	0	4	3
22	1	1	5	63	0	5	2
23	1	1	5	64	1	4	2
24	1	2	4	65	1	3	3
25	2	2	3	66	0	4	3
26	1	3	3	67	2	2	3
27	2	2	3	68	1	3	3
28	2	2	3	69	1	3	3
29	1	2	4	70	0	5	2
30	1	3	3	71	1	4	2
31	1	3	3	72	0	3	4
32	2	3	2	73	0	2	5
33	1	3	3	74	1	3	3
34	0	4	3	75	0	1	6
35	0	2	5	76	0	1	6
36	1	3	3	77	0	1	6
37	1	2	4	78	0	1	6
38	0	3	4	79	1	1	5
39	0	4	3	80	1	1	5
40	1	3	3	81	1	4	2
41	1	2	4	82	1	3	3

Table 5-8. Distribution of segments by risk level within security risk factors for the James River.

Factor	Hazards	Number of Segments Within Threshold		
		High	Moderate	Low
Inlets	VBIED	7	34	41
Shore cover type	LBA	40	30	12
Cilivilan docks and piers	VBIED	12	37	33
Shore-to-shore distance	LBA	18	7	57
Vessel traffic pleasure	VBIED	4	21	57
Bridges	LBA	4	7	71
Fog	VBIED	0	82	0

5-5-4. Capacity Category Safety Risk Factors

Figure 5-8 introduces the two corridor factor traces for industrial zoned parcels and maintained channels described in Section 5-4. The industrial zoned parcels corridor trace identifies sixteen undeveloped segments. Since there are no segments with undeveloped parcels on both shores, by inspection of the parcel overlay, an estimated ten percent of the land along the James River corridor has potential for the expansion of commercial and industrial activities. The real impact could be higher, acknowledging the access to additional undeveloped land potentially provided by shore-side parcels. Comparison to other risk factors does reveal a relationship between industrial zone shores with moderate-level risk and commercial piers with moderate level risk, for developed parcels as expected. The industrial zoned parcels safety risk factor does provide additional information not captured by the commercial piers factor trace. Comparison also highlights a reasonable relationship between industrial zoned shores and the security risk factor, shore cover type. This could also be expected, since high-risk levels for shore cover type reflect a less developed shoreline. Alternatively, shore cover type risk levels are dictated by the highest risk category on either shore, so there is also different information provided by each factor.

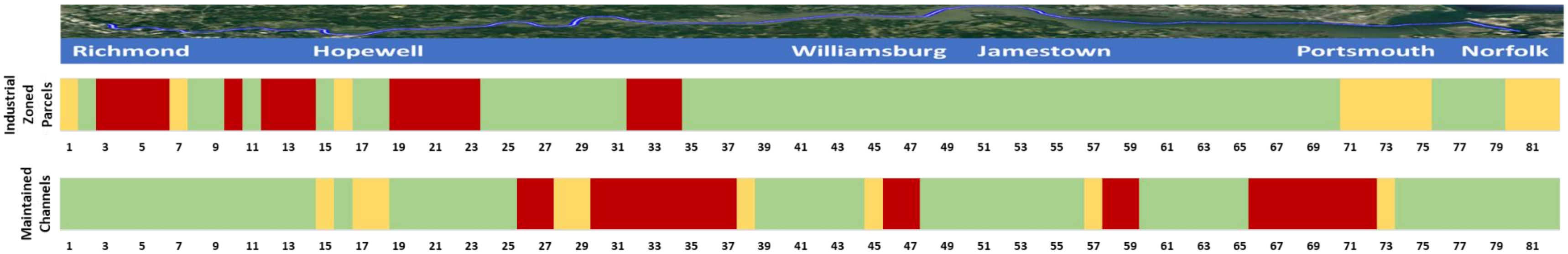


Figure 5-8. Maritime corridor trace of the James River for safety risk factors in the capacity category.

5-5-5. Asset Management Analysis for the James River Corridor

Port of Virginia leadership, a manager of Richmond Marine Terminal operations and a vice president for asset management and special projects, represent the system stakeholders for the analysis in this section. Their assessment is a consensus perspective. For the baseline ranking of segments in the asset management analysis of the James River Corridor, all risk factors have been aggregated, including sea-state factors. The stakeholders were informed of the limitations of this data and advised to weight these factors as low or lowest relative to the other factors for the baseline ranking. The relative value scale of highest, high, medium, low, and lowest is used for relative factor weights and relative criteria weights. The relative weighting of factors for the baseline segment ranking is provided in Table 5-9. The assessment of segments against factors is determined by the risk threshold level of each segment for each factor. Essentially, the data for the assessment of segments against factors is reflected in the maritime corridor trace. Tables providing the assessment of segments against factors are included in Appendix A.

Table 5-9. Baseline relevance of risk factors for the James River corridor.

the factor f.xx has	-	relevance among the other factors
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	high	relevance
f.03 - Shore-to-shore distance (safety) has	medium	relevance
f.04 - Turning angle has	high	relevance
f.05 - Vessel traffic tug/tow has	medium	relevance
f.06 - Vessel traffic cargo has	high	relevance
f.07 - Vessel traffic tanker has	high	relevance
f.08 - Vessel traffic passenger has	medium	relevance
f.09 - Vessel traffic fishing has	low	relevance
f.10 - Vessel traffic pleasure (safety) has	low	relevance
f.11 - Bridges (safety) has	high	relevance
f.12 - Commercial pier has	medium	relevance
f.13 - Buoys and Lights has	high	relevance
f.14 - Obstructions has	lowest	relevance
f.15 - Inflows has	medium	relevance
f.16 - Inlets has	high	relevance
f.17 - Civilian docks and piers has	low	relevance
f.18 - Vessel traffic pleasure (security) has	high	relevance
f.19 - Bridges (security) has	medium	relevance
f.20 - Shore cover type has	low	relevance
f.21 - Shore-to-shore distance (security) has	medium	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

For asset management of the James River inland waterway corridor, from the perspective of the Port of Virginia, the success criteria should be applicable to success criteria for the port enterprise. Success criteria to be used in the prioritization of management initiatives is derived from routine meetings with the stakeholders, available POV literature, including the port’s 2065 Master Plan Executive Summary, annual reports from 2018 and 2019, and the 2016 Port of Richmond Master Plan. The proposed list was vetted through the stakeholders and a set of twenty criteria was established. Table 5-10 provides the list of criteria and indicates the relative weighting of criteria to be used in the calculations for the baseline ranking of asset management initiatives.

Table 5-10. Baseline relevance of criteria for asset management of the James River corridor.

the criterion c.xx has	-	relevance among the other criteria
c.01 - Address customer needs has	high	relevance
c.02 - Improve operational efficiencies has	highest	relevance
c.03 - Barge service reliability has	high	relevance
c.04 - Barge turn times has	medium	relevance
c.05 - Sustainable growth operations has	medium	relevance
c.06 - Support innovation in operations has	low	relevance
c.07 - Fiscal responsibility has	highest	relevance
c.08 - Improve navigation waters has	medium	relevance
c.09 - Public/private/port integration has	medium	relevance
c.10 - Stewardship of grants and investments has	high	relevance
c.11 - Diversify business relationships has	medium	relevance
c.12 - Facilitate job growth has	high	relevance
c.13 - Human health conscious has	high	relevance
c.14 - Protect the environment has	high	relevance
c.15 - Unrestricted waterway access for all has	low	relevance
c.16 - Support natural disaster response has	lowest	relevance
c.17 - Address needs of communities has	high	relevance
c.18 - Vessel accident prevention has	medium	relevance
c.19 - Security of goods and commodities has	lowest	relevance
c.20 - Security of employees and community has	low	relevance

The key risk dimensions for asset management developed in Chapter 4 are used as a framework for the development of initiatives. Asset management initiatives are derived from a variety of sources. Of particular interest to this dissertation is the use of the maritime corridor trace to highlight risk areas along the corridor for inclusion in the prioritized initiatives. The inland waterway corridor is the primary asset to achieve the desired goals outlined in the marine highway initiative and shared by the operational goals of the Port of Virginia. The maritime corridor trace and the analysis conducted during its development provide and understanding of the needs for risk mitigation along the length of the corridor. POV Stakeholders are a primary source and provide their unique insight to current operations and already planned initiatives. Other sources include the MARAD report to Congress on the marine highway program, which offers potential actions for achieving for successful implementation of the program. The GAO report to Congress referenced in Chapter 3, addresses the risks of attacks on maritime vessels. Additionally, a report from the RAND Center for Terrorism Risk Management Policy (RAND, 2006) addresses risks to container vessels focused on deep-water navigation and the use of containers for trafficking. Table 5-11 lists the initiatives for asset management of the James River corridor and the associated asset management risk dimension.

Each initiative is assessed for the degree to which it addresses each criterion. For each pairing, stakeholders express the degree to which they agree with the statement, criteria c_m is addressed by initiative i_n. In this demonstration the possible responses are strongly agree, agree, somewhat agree, or neutral. These responses correspond to the numerical score set {1, 2/3, 1/3, 0}. Tables 5-12 and Table 5-13 provide the pairwise assessment of initiatives against criteria. In each table, strongly agree is represented by a filled circle (●), agree is represented by a half-filled circle (◐), somewhat agree is represented by an unfilled circle (○), and neutral is represented by a blank ( ). Initiatives phrasing has been abbreviated in these tables to maximize display of the assessment data.

Table 5-11. Initiatives for asset management of the James River corridor.

Index	Initiative	Source	Risk Dimension
i.01	More frequent maintenance dredging	CTA	
i.02	Expand width of maintained channels	CTA	Control
i.03	Active channel depth monitoring	CTA; POV	*vulnerability*
i.04	Coordinate barge departures and vessel schedule	POV	*safety and security*
i.05	Increase predictability of bridge raisings	POV	
i.06	Barge escort services	CTA; GAO	
i.07	Improved sea-sate data collection	CTA	
i.08	Improved vessel traffic data access	CTA	Management
i.09	Rehabilitate aging infrastructure	POV	*life cycle*
i.10	Replace obsolete infrastructure	POV	*reliable availability*
i.11	RMT wharf repairs/improvements	POV	
i.12	RMT fender repairs/improvements	POV	
i.13	USCG liaison with port	GAO; POV	
i.14	VDOT partnership	CTA; POV	
i.15	ISO-14000 environmental management system	POV	System Integrity
i.16	Increase licensed pilot availability	CTA	*incident*
i.17	Weather capable barge acquisition	CTA; POV	*management*
i.18	Dedicated barge wharf at HR terminals	POV	*audit management*
i.19	Port terminal as civilian evacuation point	MARAD	*policy integration*
i.20	Pre-load radiological container screening	POV; RAND	
i.21	Stakeholder barge service ride-alongs	POV	
i.22	Provide barge tracking data to customers	POV	
i.23	Balance routine and off-schedule shipments	ARDP	Protection
i.24	Maintain pilots on autonomously capable vessels	CTA	*cyber security*
i.25	Refrigerated container tamper proofing	RAND	*information security*
i.26	Use container loading to limit access	RAND	
i.27	Create additional turning basins on James River	POV	
i.28	Higher capacity barge acquisition	POV	Capacity
i.29	Multiple barges per tug vessel trip	POV	*future*
i.30	Increase barge frequency	POV	*system requirements*
i.31	Increase length of maintained channels	CTA	
i.32	Partner with VEDP	POV	
i.33	RMT on-terminal rail expansion	POV	
i.34	Establish additional inland ports	POV	
i.35	Warehouse expansion on/near RMT	POV	Other / Enterprise
i.36	Increase barge service marketing	POV	
i.37	Two-way cargo contract partnerships	POV	

Table 5-12. Assessment of initiatives i.01 – i.20 against criteria c.01 – c.20: strongly agree (●), agree (◐), somewhat agree (○), and neutral (   ).

Initiatives: i.1 - i.20 Criteria: c.01 - c.20	i.01 - Maintenance dredging	i.02 - Expand channel width	i.03 - Channel depth monitor	i.04 - Barge/vessel scheduling	i.05 - Bridge predictability	i.06 - Barge escort services	i.07 - Sea-state data collection	i.08 - Vessel traffic data access	i.09 - Rehab old infrastructure	i.10 - Replace infrastructure	i.11 - RMT wharf improvement	i.12 - RMT fender improvement	i.13 - USCG liaison	i.14 - VDOT partnership	i.15 - ISO-14000 EMS	i.16 - Increase # of pilots	i.17 - Weather hardened barge	i.18 - Dedicated barge wharf	i.19 - Civilian evacuation	i.20 - Radiological screening
the criterion c.xx is address by this initiative																				
c.01 - Address customer needs				○					◐	●	○			◐	○	◐	◐	○		
c.02 - Improve operational efficiencies			◐	◐	●		◐	○	◐	●	○	○	○	◐		◐	◐	○		
c.03 - Barge service reliability	●	◐	●	●	●		●	◐	◐	◐	◐	◐				◐	●	◐		
c.04 - Barge turn times	●	◐	◐	●	●		◐	●								●	○	●		
c.05 - Sustainable growth operations	●	◐	◐		○			◐	○	○	◐	◐		○	◐	◐	○	◐		
c.06 - Support innovation in operations						◐	○	○		◐			○	○						
c.07 - Fiscal responsibility	◐								●	○	○	○			○					
c.08 - Improve navigation waters	●	●	●		○			◐							◐					
c.09 - Public/private/port integration	◐	◐	◐	○	◐	◐	◐	◐	○	○			●	●		◐			●	◐
c.10 - Stewardship of grants and investments	◐								◐	○	○	○			○					
c.11 - Diversify business relationships			○											◐						
c.12 - Facilitate job growth		○				○				◐						◐		◐		○
c.13 - Human health conscious									○	○					●				◐	◐
c.14 - Protect the environment	◐	◐	○				◐		○		○	◐		○	●	○	◐			●
c.15 - Unrestricted waterway access for all	●	●	◐		○			●					◐		◐	○				
c.16 - Support natural disaster response		◐	○				●	○			○	○	◐	○	○		◐		●	◐
c.17 - Address needs of communities					○									◐	◐				●	
c.18 - Vessel accident prevention	●	●	●	◐	◐	◐	●	●	○	○	◐	●			◐	●	●	◐		
c.19 - Security of goods and commodities		○				●	○	○	○	○	○	○	◐			○	○	○		●
c.20 - Security of employees and community		○				●			○	○	○	○	●			○	○	○		●

Table 5-13. Assessment of initiatives i.21 – i.37 against criteria c.01 – c.20: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Initiatives: i.21 - i.37 Criteria: c.01 - c.20	i.21 - Barge ride-alongs	i.22 - Barge tracking data	i.23 - Randomize barge moves	i.24 - Pilots on automated ships	i.25 - Refer tamper proofing	i.26 - Container access security	i.27 - Additional turning basin	i.28 - Higher capacity barge	i.29 - Multiple barges per trip	i.30 - Increase barge frequency	i.31 - Increase channel lengths	i.32 - VEDP partnership	i.33 - RMT rail expansion	i.34 - New inland ports	i.35 - RMT warehouse expansion	i.36 - Barge service marketing	i.37 - Two-way cargo partners
the criterion c.xx is address by this initiative																	
c.01 - Address customer needs	◐	●			●	◐		●	●	●		●	◐	◐	◐		
c.02 - Improve operational efficiencies		○				◐	○	●	●			◐	◐		◐		●
c.03 - Barge service reliability	○	○			○		○			●	●						◐
c.04 - Barge turn times		○					◐			●	●			◐			○
c.05 - Sustainable growth operations							○	◐	◐	◐		◐	●	○	◐	●	●
c.06 - Support innovation in operations	○	○	○	●	○	○				○		○				○	◐
c.07 - Fiscal responsibility								○				○				○	●
c.08 - Improve navigation waters							●				●						
c.09 - Public/private/port integration	●	◐					◐	○			○	●	◐	○	◐	●	○
c.10 - Stewardship of grants and investments								◐			○	◐	◐	○	○		○
c.11 - Diversify business relationships	◐	○			◐			○	○	○		◐		◐	◐	●	●
c.12 - Facilitate job growth				○				◐	◐	◐		●	○	●	●	○	◐
c.13 - Human health conscious					●			○	○								
c.14 - Protect the environment			○				◐	◐	○								○
c.15 - Unrestricted waterway access for all	○			○			○										
c.16 - Support natural disaster response							○										
c.17 - Address needs of communities	○				○			○	○	○		◐		○			
c.18 - Vessel accident prevention				●			◐				●						
c.19 - Security of goods and commodities		◐	●	◐	●	●	○								○		
c.20 - Security of employees and community	○		●	○		◐											

Emergent and future conditions could potentially disrupt the prioritization of initiatives by exploiting vulnerabilities. The same sources used for the development of criteria and initiatives are also useful for identifying emergent and future conditions. These documents address future challenges posed to operations on inland waterway corridors. For example, the Port of Richmond Master Plan outlines a SWOT analysis (strengths, weaknesses, opportunities, and threats) for operations at RMT. A selection of the possible emergent and future conditions impacting an asset management system is provided in the Table 5-14.

Scenarios developed from emergent and future conditions impacting the asset management of the James River corridor are provided in Table 5-15. The baseline scenario can be considered to represent either the current state or a default state. It serves as a means of measuring the impact of specific scenarios constructed from the combination of one or several emergent and future conditions. Eight scenarios were developed for stakeholder consideration during the reweighting of criteria to address the emergent and future conditions.

Table 5-14. Emergent and future conditions impacting the James River corridor.

Index	Emergent and Future Condition
e.01	Sea-level rise
e.02	Active hurricane seasons
e.03	Heavy rain events near Richmond
e.04	Frequent flooding in Norfolk area
e.05	Increasing average temperatures
e.06	Low visibility events
e.07	Water level rise near RMT
e.08	Increased capacity on I-64
e.09	Decreased capacity on I-64
e.10	Toll requirements added to road networks
e.11	Increase ferry traffic Jamestown-Scotland
e.12	Required bridge repair: JRB, BHMB, VEB, VVMB
e.13	Vertical-lift bridge failure: JRB, BHMB
e.14	Vehicular accident requiring aquatic search and rescue
e.15	Reduction in fuel prices
e.16	Aggressive truck transportation pricing
e.17	Economic downturn affecting port customers
e.18	Train derailment
e.19	Redirecting of container volume to POV
e.20	Completion of deepwater channel dredging project
e.21	Commercial enterprise expansion in Richmond
e.22	Increased activity at Kinder Morgan facility north of RMT
e.23	Commercial development at Bachelor Point (north shore)
e.24	Commerical development at Mayocks Point (south shore)
e.25	Supply chain disruptions
e.26	Lack of federal funding contributions
e.27	Lack of state funding contributions
e.28	Lack of funding for USACE maintenance dredging
e.29	New grant sources for barge service
e.30	Private investment in barge service
e.31	Lack of public awareness of barge service
e.32	Lack of public awareness of barge benefits
e.33	Increased public support for barge operations
e.34	Autonomous vessels begin operating on James River
e.35	Improved container tracking capabilities
e.36	Container handling technology
e.37	Vessel accident on James River
e.38	Vessel accident on out-of-region corridor
e.39	Credible threat intelligence
e.40	U.S. domestic VBA hijacking of vessel
e.41	U.S. domestic VBA suicide attack on vessel
e.42	U.S. domestic LBA against vessel

Table 5-15. Scenario definitions for asset management of the James River corridor.

Index	Scenario	Associated Emergent and Future Conditions
s.00	Baseline	--
s.01	Economic downturn	e.17 - Economic downturn affecting port customers
		e.26 - Lack of federal funding contributions
		e.27 - Lack of state funding contributions
s.02	Increase in shipping demand	e.20 - Completion of deepwater channel dredging project
		e.21 - Commercial enterprise expansion in Richmond
		e.29 - New grant sources for barge service
s.03	Credible threat emergence	e.39 - Credible threat intelligence
		e.40 - U.S. domestic VBA hijacking of vessel
		e.41 - U.S. domestic VBA suicide attack on vessel
		e.42 - U.S. domestic LBA against vessel
s.04	Infrastructure degradation	e.09 - Decreased capacity on I-64
		e.12 - Required bridge repair: JRB, BHMB, VEB, VVMB
		e.13 - Vertical-lift bridge failure: JRB, BHMB
s.05	Pandemic	e.15 - Reduction in fuel prices
		e.16 - Aggressive truck transportation pricing
		e.17 - Economic downturn affecting port customers
		e.25 - Supply chain disruptions
s.06	Increased support for waterway utilization	e.09 - Decreased capacity on I-64
		e.33 - Increased public support for barge operations
s.07	Technological innovation	e.30 - Private investment in barge service
		e.34 - Autonomous vessels begin operating on James River
		e.35 - Improved container tracking capabilities
		e.36 - Container handling technology
s.08	Weather or climate changes	e.01 - Sea-level rise
		e.02 - Active hurricane seasons
		e.03 - Heavy rain events near Richmond
		e.05 - Increasing average temperatures
		e.06 - Low visibility events

Management of the James River corridor will require the prioritization of initiatives for the successful achievement of the Port of Virginia's enterprise goals and the efficient application of available resources to corridor segments. The asset management analysis assesses the initiatives and corridor segments where the dedication of resources may result in the resilience of the system to the emergent and future conditions incorporated into the different scenarios. To facilitate this assessment, stakeholders assess how the relevance of each criterion changes under a given scenario. Stakeholders indicate the change in relevance through application of scaling factors for each scenario against each criterion. Each criterion relevance *increases*, *increases somewhat*, is assessed as *no change*, *decreases somewhat*, or *decreases* for each scenario. This change in relevance method is used for both success criteria, which are addressed by initiatives, and corridor risk factors, which are addressed by corridor segments.

Table 5-16 through Table 5-18 provide the reweighting assessments for corridor risk factors across all eight scenarios. Table 5-19 through Table 5-21 provide the reweighting assessments for initiatives across all eight scenarios.

Table 5-16. Reweighting of risk factors under scenarios s.01 - s.03 for asset management of the James River corridor.

Scenarios: s.01 - s.03 Factors: f.01 - f.29	s.01 - Economic downturn	s.02 - Increase in shipping demand	s.03 - Credible threat emergence	s.00 - Baseline
f.01 - Channel width	Decreases Somewhat	-	-	highest
f.02 - Channel depth	Increases Somewhat	Increases Somewhat	-	high
f.03 - Shore-to-shore distance (safety)	-	-	-	medium
f.04 - Turning angle	-	Increases Somewhat	Increases Somewhat	high
f.05 - Vessel traffic tug/tow	-	Increases	-	medium
f.06 - Vessel traffic cargo	Decreases Somewhat	-	-	high
f.07 - Vessel traffic tanker	Decreases Somewhat	-	-	high
f.08 - Vessel traffic passenger	-	-	-	medium
f.09 - Vessel traffic fishing	Increases Somewhat	-	-	low
f.10 - Vessel traffic pleasure (safety)	-	-	-	low
f.11 - Bridges (safety)	Increases Somewhat	Increases Somewhat	Increases Somewhat	high
f.12 - Commercial pier	-	Increases Somewhat	-	medium
f.13 - Buoys and Lights	-	Increases Somewhat	Increases Somewhat	high
f.14 - Obstructions	-	-	-	lowest
f.15 - Inflows	-	-	-	medium
f.16 - Inlets	-	-	Increases	high
f.17 - Civilian docks and piers	-	-	Increases Somewhat	low
f.18 - Vessel traffic pleasure (security)	-	-	Increases Somewhat	high
f.19 - Bridges (security)	-	-	-	medium
f.20 - Shore cover type	Increases Somewhat	-	-	low
f.21 - Shore-to-shore distance (security)	-	-	Increases Somewhat	medium
f.22 - Industrial zoned shores	-	Increases	-	medium
f.23 - Maintained channels	-	Increases Somewhat	-	medium
f.24 - Wind (maximum)	-	-	-	low
f.25 - Wind (average)	-	-	-	lowest
f.26 - Precipitation (maximum)	-	-	-	low
f.27 - Precipitation (average)	-	-	-	lowest
f.28 - Fog (safety)	-	-	-	low
f.29 - Fog (security)	-	-	-	lowest

Table 5-17. Reweighting of corridor risk factors under scenarios s.04 - s.06 for asset management of the James River corridor.

Scenarios: s.04 - s.06 Factors: f.01 - f.29	s.04 - Infrastructure degradation	s.05 - Pandemic	s.06 - Increased support for waterway	s.00 - Baseline
f.01 - Channel width	-	-	-	highest
f.02 - Channel depth	Increases Somewhat	-	Increases Somewhat	high
f.03 - Shore-to-shore distance (safety)	-	-	Increases Somewhat	medium
f.04 - Turning angle	-	-	Increases Somewhat	high
f.05 - Vessel traffic tug/tow	-	-	Increases	medium
f.06 - Vessel traffic cargo	-	Decreases Somewhat	-	high
f.07 - Vessel traffic tanker	-	Decreases Somewhat	-	high
f.08 - Vessel traffic passenger	-	Decreases	-	medium
f.09 - Vessel traffic fishing	-	Increases	-	low
f.10 - Vessel traffic pleasure (safety)	-	Increases	-	low
f.11 - Bridges (safety)	Increases Somewhat	-	Increases Somewhat	high
f.12 - Commercial pier	Increases Somewhat	-	Increases	medium
f.13 - Buoys and Lights	-	-	Increases Somewhat	high
f.14 - Obstructions	-	-	-	lowest
f.15 - Inflows	-	-	-	medium
f.16 - Inlets	-	Increases Somewhat	-	high
f.17 - Civilian docks and piers	-	Increases Somewhat	-	low
f.18 - Vessel traffic pleasure (security)	-	Increases Somewhat	-	high
f.19 - Bridges (security)	-	-	-	medium
f.20 - Shore cover type	-	-	-	low
f.21 - Shore-to-shore distance (security)	-	-	-	medium
f.22 - Industrial zoned shores	-	-	Increases	medium
f.23 - Maintained channels	-	-	Increases Somewhat	medium
f.24 - Wind (maximum)	-	-	-	low
f.25 - Wind (average)	-	-	-	lowest
f.26 - Precipitation (maximum)	-	-	-	low
f.27 - Precipitation (average)	-	-	-	lowest
f.28 - Fog (safety)	-	-	-	low
f.29 - Fog (security)	-	-	-	lowest

Table 5-18. Reweighting of corridor risk factors under scenarios s.07 - s.08 for asset management of the James River corridor.

Scenarios: s.07 - s.08 Factors: f.01 - f.29	s.07 - Technological innovation	s.08 - Weather or climate change	s.00 - Baseline
f.01 - Channel width	-	-	highest
f.02 - Channel depth	-	Increases Somewhat	high
f.03 - Shore-to-shore distance (safety)	-	Increases Somewhat	medium
f.04 - Turning angle	Increases	Increases Somewhat	high
f.05 - Vessel traffic tug/tow	Increases	-	medium
f.06 - Vessel traffic cargo	-	-	high
f.07 - Vessel traffic tanker	-	Increases Somewhat	high
f.08 - Vessel traffic passenger	-	-	medium
f.09 - Vessel traffic fishing	-	-	low
f.10 - Vessel traffic pleasure (safety)	Increases Somewhat	-	low
f.11 - Bridges (safety)	-	Increases Somewhat	high
f.12 - Commercial pier	Increases Somewhat	-	medium
f.13 - Buoys and Lights	Increases Somewhat	Increases Somewhat	high
f.14 - Obstructions	-	-	lowest
f.15 - Inflows	-	Increases Somewhat	medium
f.16 - Inlets	Increases Somewhat	-	high
f.17 - Civilian docks and piers	Increases Somewhat	-	low
f.18 - Vessel traffic pleasure (security)	-	-	high
f.19 - Bridges (security)	-	-	medium
f.20 - Shore cover type	-	-	low
f.21 - Shore-to-shore distance (security)	-	-	medium
f.22 - Industrial zoned shores	Increases Somewhat	-	medium
f.23 - Maintained channels	Increases	Increases Somewhat	medium
f.24 - Wind (maximum)	-	Increases Somewhat	low
f.25 - Wind (average)	-	Increases Somewhat	lowest
f.26 - Precipitation (maximum)	-	Increases	low
f.27 - Precipitation (average)	-	Increases Somewhat	lowest
f.28 - Fog (safety)	Increases Somewhat	Increases	low
f.29 - Fog (security)	-	-	lowest

Table 5-19. Reweighting of criteria under scenarios s.01 - s.03 for asset management of the James River corridor.

Scenarios: s.01 - s.03 Criteria: c.01 - c.20	s.01 - Economic downturn	s.02 – Increase in shipping demand	s.03 – Credible threat emergence	s.00 - Baseline
c.01 - Address customer needs	Decreases Somewhat	Increases Somewhat	-	high
c.02 - Improve operational efficiencies	-	-	-	highest
c.03 - Barge service reliability	-	Increases Somewhat	Increases Somewhat	high
c.04 - Barge turn times	Decreases Somewhat	Increases	-	medium
c.05 - Sustainable growth operations	Increases Somewhat	-	-	medium
c.06 - Support innovation in operations	Increases Somewhat	Increases Somewhat	Increases Somewhat	low
c.07 - Fiscal responsibility	-	-	-	highest
c.08 - Improve navigation waters	Decreases Somewhat	Increases Somewhat	-	medium
c.09 - Public/private/port integration	Decreases Somewhat	Increases Somewhat	Increases	medium
c.10 - Stewardship of grants and investments	-	-	-	high
c.11 - Diversify business relationships	Increases	-	-	medium
c.12 - Facilitate job growth	Increases Somewhat	-	-	high
c.13 - Human health conscious	-	-	-	high
c.14 - Protect the environment	-	-	Increases Somewhat	high
c.15 - Unrestricted waterway access for all	-	Increases Somewhat	-	low
c.16 - Support natural disaster response	-	-	Increases Somewhat	lowest
c.17 - Address needs of communities	Increases Somewhat	-	-	high
c.18 - Vessel accident prevention	Decreases Somewhat	Increases Somewhat	Increases Somewhat	medium
c.19 - Security of goods and commodities	-	-	Increases	lowest
c.20 - Security of employees and community	-	-	Increases	low

Table 5-20. Reweighting of criteria under scenarios s.04 - s.06 for asset management of the James River corridor.

Scenarios: s.04 - s.06 Criteria: c.01 - c.20	s.04 - Infrastructure degradation	s.05 - Pandemic	s.06 - Increased support for waterway	s.00 - Baseline
c.01 - Address customer needs	-	Increases Somewhat	-	high
c.02 - Improve operational efficiencies	-	-	-	highest
c.03 - Barge service reliability	Increases	Increases Somewhat	-	high
c.04 - Barge turn times	-	Decreases Somewhat	Increases	medium
c.05 - Sustainable growth operations	Increases Somewhat	Decreases Somewhat	Increases	medium
c.06 - Support innovation in operations	Increases	Increases	-	low
c.07 - Fiscal responsibility	-	-	-	highest
c.08 - Improve navigation waters	Increases Somewhat	-	Increases	medium
c.09 - Public/private/port integration	Increases	-	Increases Somewhat	medium
c.10 - Stewardship of grants and investments	Increases Somewhat	-	-	high
c.11 - Diversify business relationships	-	Increases	-	medium
c.12 - Facilitate job growth	-	Increases Somewhat	-	high
c.13 - Human health conscious	-	Increases	-	high
c.14 - Protect the environment	-	-	Increases Somewhat	high
c.15 - Unrestricted waterway access for all	Increases	-	-	low
c.16 - Support natural disaster response	-	Increases	-	lowest
c.17 - Address needs of communities	Increases Somewhat	Increases Somewhat	Increases Somewhat	high
c.18 - Vessel accident prevention	Increases	-	-	medium
c.19 - Security of goods and commodities	-	-	-	lowest
c.20 - Security of employees and community	-	-	-	low

Table 5-21. Reweighting of criteria under scenarios s.07 - s.08 for asset management of the James River corridor.

Scenarios: s.07 - s.08 Criteria: c.01 - c.20	s.07 - Technological Innovation	s.08 - Weather or climate change	s.00 - Baseline
c.01 - Address customer needs	-	Increases Somewhat	high
c.02 - Improve operational efficiencies	-	-	highest
c.03 - Barge service reliability	-	Increases Somewhat	high
c.04 - Barge turn times	-	-	medium
c.05 - Sustainable growth operations	Increases Somewhat	-	medium
c.06 - Support innovation in operations	Increases	Increases Somewhat	low
c.07 - Fiscal responsibility	-	-	highest
c.08 - Improve navigation waters	-	Increases	medium
c.09 - Public/private/port integration	Increases Somewhat	Increases Somewhat	medium
c.10 - Stewardship of grants and investments	-	-	high
c.11 - Diversify business relationships	Increases	Increases Somewhat	medium
c.12 - Facilitate job growth	Increases Somewhat	-	high
c.13 - Human health conscious	-	-	high
c.14 - Protect the environment	-	Increases Somewhat	high
c.15 - Unrestricted waterway access for all	-	Increases	low
c.16 - Support natural disaster response	-	Increases	lowest
c.17 - Address needs of communities	-	Increases Somewhat	high
c.18 - Vessel accident prevention	Increases Somewhat	Increases	medium
c.19 - Security of goods and commodities	Increases	Increases	lowest
c.20 - Security of employees and community	Increases	Increases	low

The relative weights of risk factors and criteria across all scenarios leads to the calculation of segment rankings and initiative rankings in each scenario. A tie-break procedure is used in this demonstration for the ranking of corridor segments and asset management initiatives. For instances of ties among corridor segments, preference is given to the segment further upstream. For the James River corridor, this translates to segments closer to Richmond Marine Terminal. For ties among initiatives, a two-option weighting scheme involving the assessment of initiatives against criteria is used. A count, P_i, of the number criteria assessed by each initiative i, and a count, $p_{i,r}$, of each possible response, $r = \{\text{strongly agree, agree, somewhat agree, neutral}\}$, assigned to each criteria by each initiative is maintained, such that $P_i = \sum p_{i,r}$. The first tie break option gives preference to the initiative addressing more criteria, the initiative with the larger value of P. If ties remain, option two is considered. Weights, $w_r = \{0.4, 0.3, 0.2, 0.1\}$, are applied to each assessment response category. Initiatives with the larger value of Q, where $Q_i = \sum w_r p_{i,r}$, are given preference. If ties still remain, stakeholders would be asked to indicate a preference of initiatives.

Figure 5-9 and Figure 5-10 depict the range of individual segment rankings across all eight scenarios. Segments are listed in order of their baseline ranking, indicated by the black bar. The beginning of the blue bar indicates the highest ranking of a given segment among all scenarios. The end of the red bar indicates the lowest ranking of the segment. Figure 5-11 depicts the range of rankings for enterprise initiatives across all eight scenarios. The total length of the blue, black, and red bars indicate the robustness of a segment or initiative to the suite of scenarios considered.

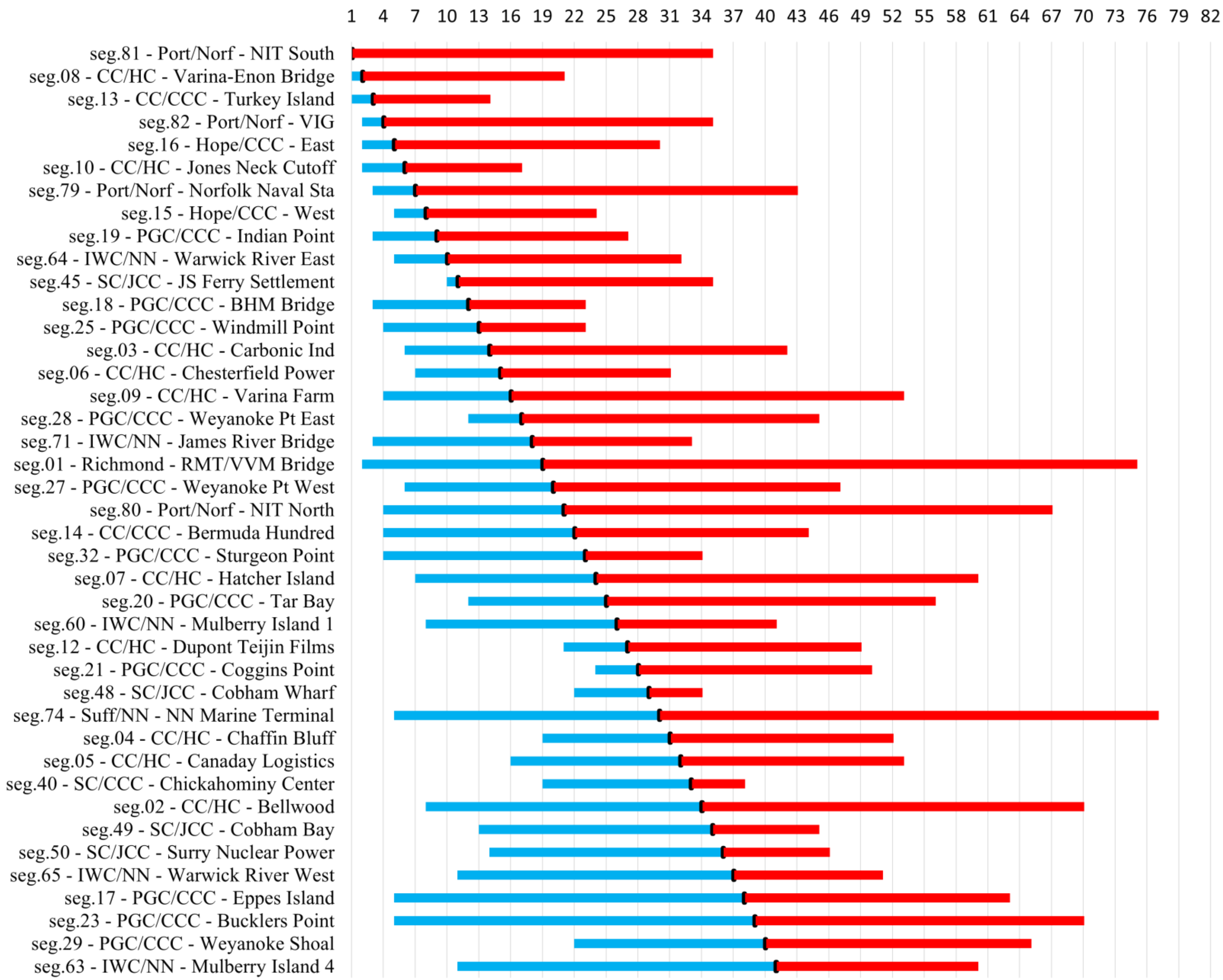


Figure 5-9. Corridor segments ranked across 8 scenarios, part 1 of 2, for asset management of the James River corridor.

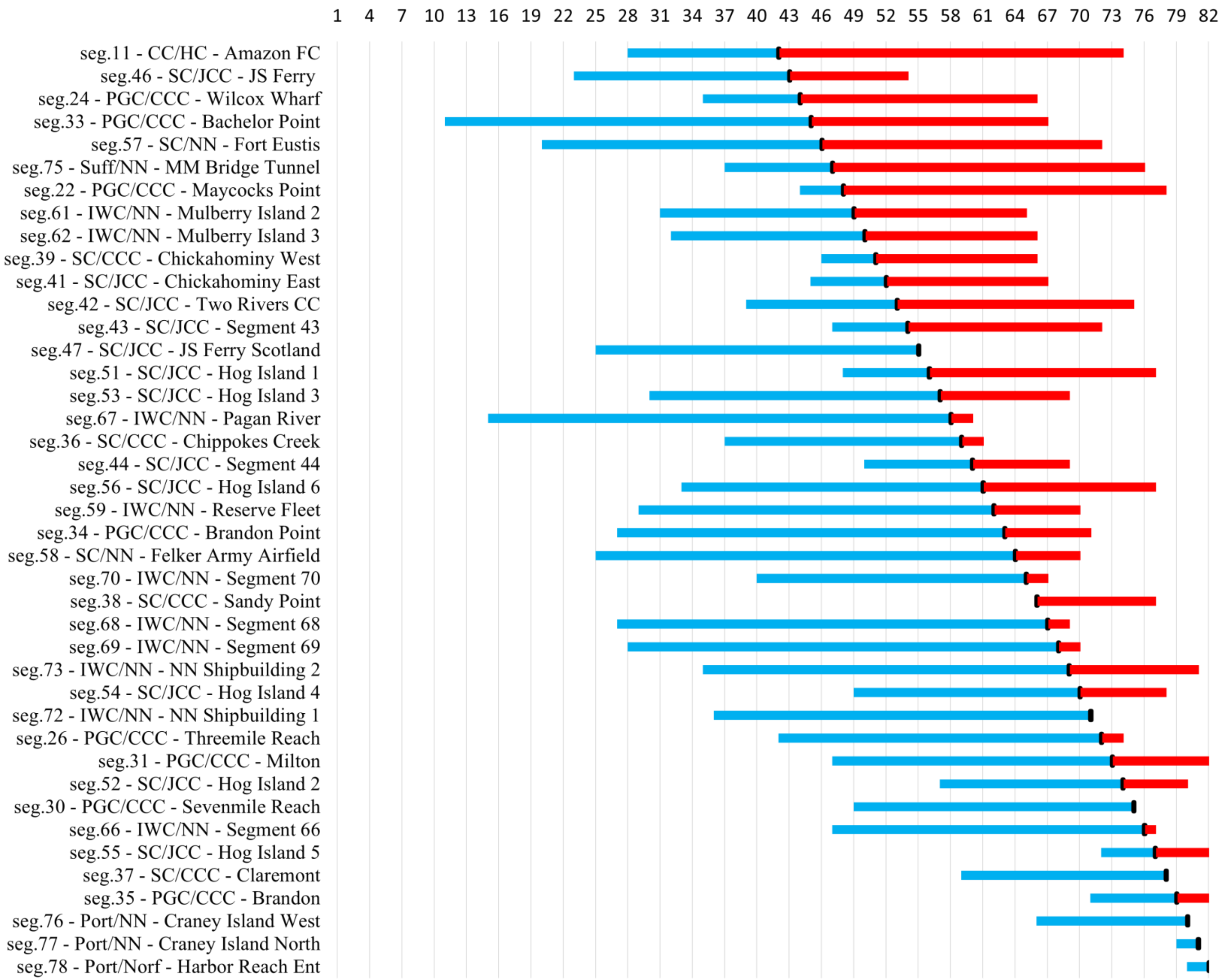


Figure 5-10. Corridor segments ranked across 8 scenarios, part 2 of 2, for asset management of the James River corridor.

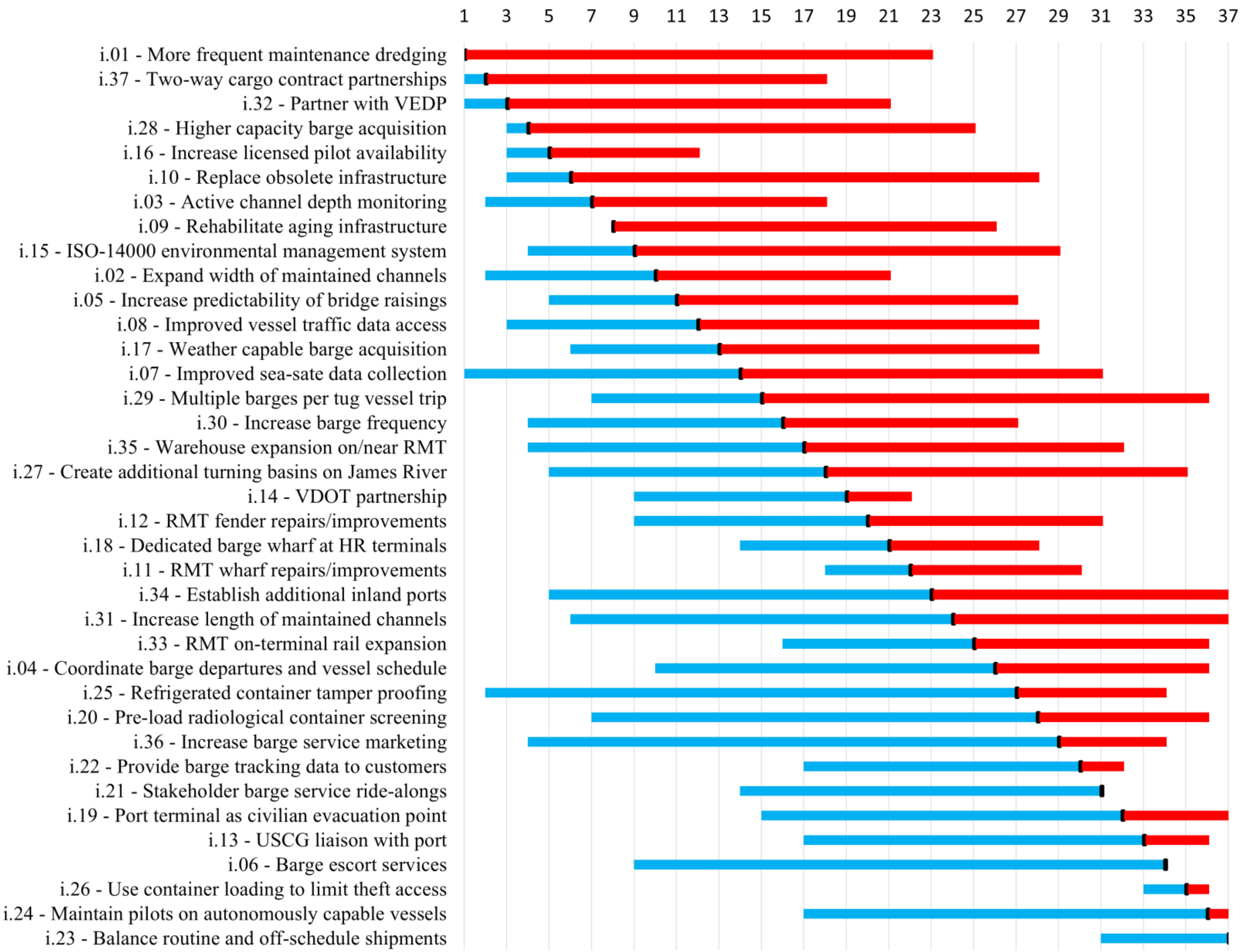


Figure 5-11. Initiatives ranked across 8 scenarios for asset management of the James River corridor.

The assessment of rankings for segments and initiatives is consistent. Contradiction may be discerned from the contrast between the positivity of a high ranking and the negativity of high-risk associated with highly ranked corridor segments. The consistency lies in context of the applicability to the stakeholder. The ranking of segments relates to the overall risk of the segment based on all risk factors. The blue bar of each segment indicates under one or more scenarios, the risks associated with safety and security hazards in the segment have increased relative to the baseline ranking. The ranking of initiatives relates to how well each initiative addresses the established success criteria for operations concerning the movement of freight along the inland waterway corridor. The blue bar of each initiative indicates under one or more scenarios, the potential for the initiative to address the success criteria is increased. For both segments and initiatives, stakeholders should seek to focus attention on segments and initiatives with rankings towards the left side of the ranking figures. The ranking figures reveal how baseline rankings will influence this management course of action. Under some scenarios, segments and initiatives with lower baseline rankings have greatly increased significance.

The disruptiveness measure of scenarios describes the potential for emergent and future conditions to impact the assessed risk of segments and effectiveness of initiatives, relative to the baseline ranking. These measures can serve as a management tool for stakeholders to explore which corridor segments and which initiatives with lower baseline rankings may warrant further consideration. Figure 5-12 and Figure 5-13 provide the disruptive scores for the eight developed scenarios under consideration of segment rankings and of initiative rankings. Since the disruptive score is a function of the number of segments or number of initiatives being ranked, the value of the disruptive score is relevant within each grouping.

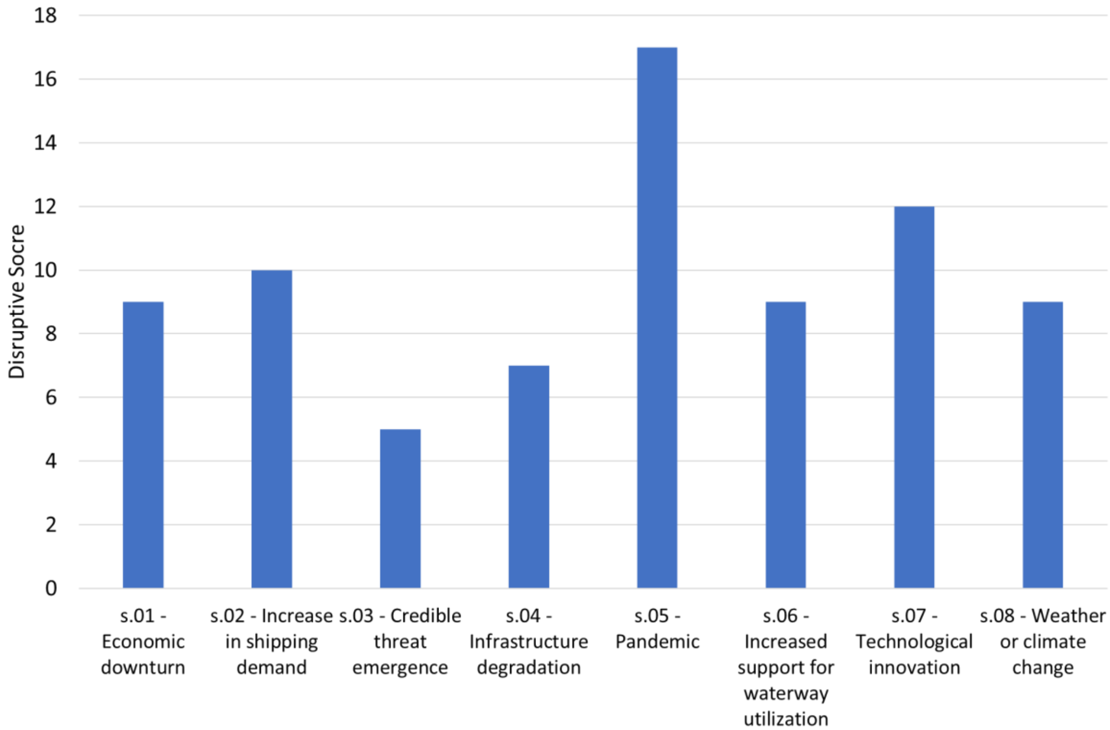


Figure 5-12. Scenario disruptive scores related to corridor segment rankings.

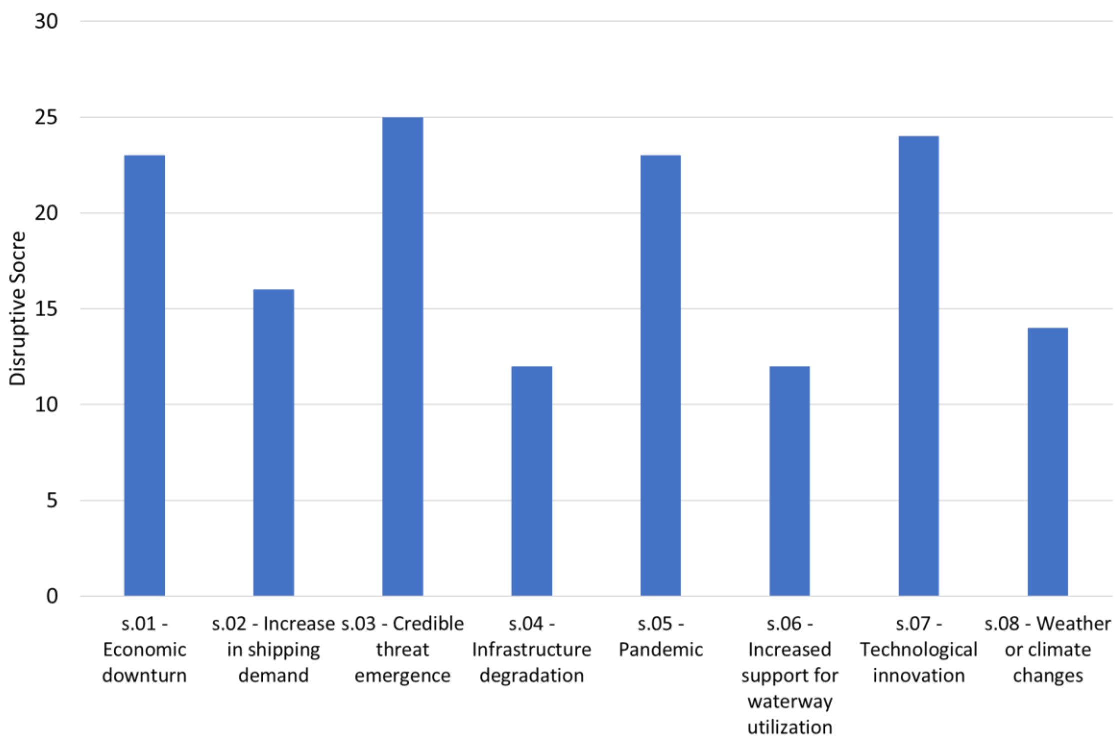


Figure 5-13. Scenario disruptive scores related to initiative rankings.

Relative to the ranking of corridor segments, *scenarios s.05 – Pandemic* and *s.07 – Technological innovation* are the most disruptive scenarios. Relative to the ranking of initiatives, *scenario s.03 – Credible threat emergence* is the most disruptive. Scenarios *s.05* and *s.07* are also highly disruptive along with scenario *s.01 – Economic downturn*.

It is desirable to discover highly ranked and resilient segments and initiatives during the analysis. Resiliency of segments in this context does not imply the accommodation of relative safe travel for vessels over a range of scenarios. Rather, resilient describes a consistency of the risk rankings over scenarios, and a measure of the effectiveness of contributing resources to waterway improvements in a particular segment. Inspection of Figure 5-8 reveals two segments always ranked in the top quarter of segments, *segment 13 – CC/CCC – Turkey Island* and *segment 10 – CC/HC – Jones Neck Cutoff*. Three more segments are always ranked in the top third of segments. Only one initiative is always ranked in the top third of initiatives when considering the influence of all eight scenarios, *i.16 – Increase licensed pilot availability*.

Given only one highly ranked and resilient initiative, it is of interest to assess the changes in ranking of segments and initiatives across a more limited set of scenarios. This course of action may unveil a broader set of segments and initiatives which remain resilient to a number of scenarios. Conducting the analysis by considering the influence of the least disruptive scenarios for initiatives is a recommended starting point. Multiple iterations can then be conducted by combining different sets of scenarios. The disruptive scores of each scenario within segments and within initiatives will not be affected by differing combinations of scenarios since the disruptive score of each is a function of the number of segments or initiatives and the baseline ranking. Figure 5-14 depicts the range of rankings for segments with baseline rankings from 1 to 41 under consideration of the following scenarios: *s.02 – Increase in shipping demand*, *s.04 – Infrastructure* *degradation, s.06 – Increased support for waterway utilization*, and *s.08 – Weather or climate change*. Figure 5-15 depicts the range of rankings for initiatives for the same selection of scenarios.

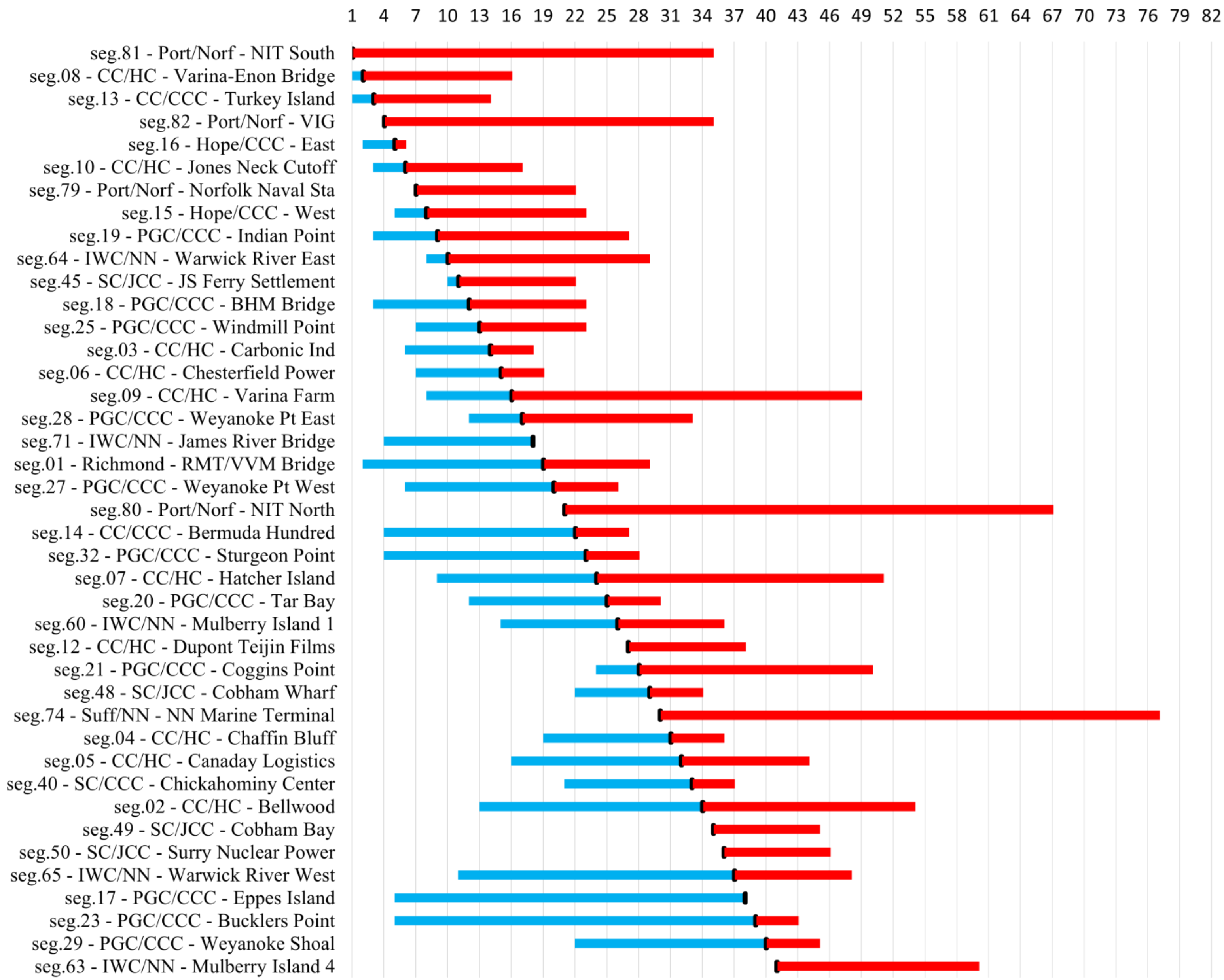


Figure 5-14. Corridor segments ranked across 4 scenarios for asset management of the James River corridor.

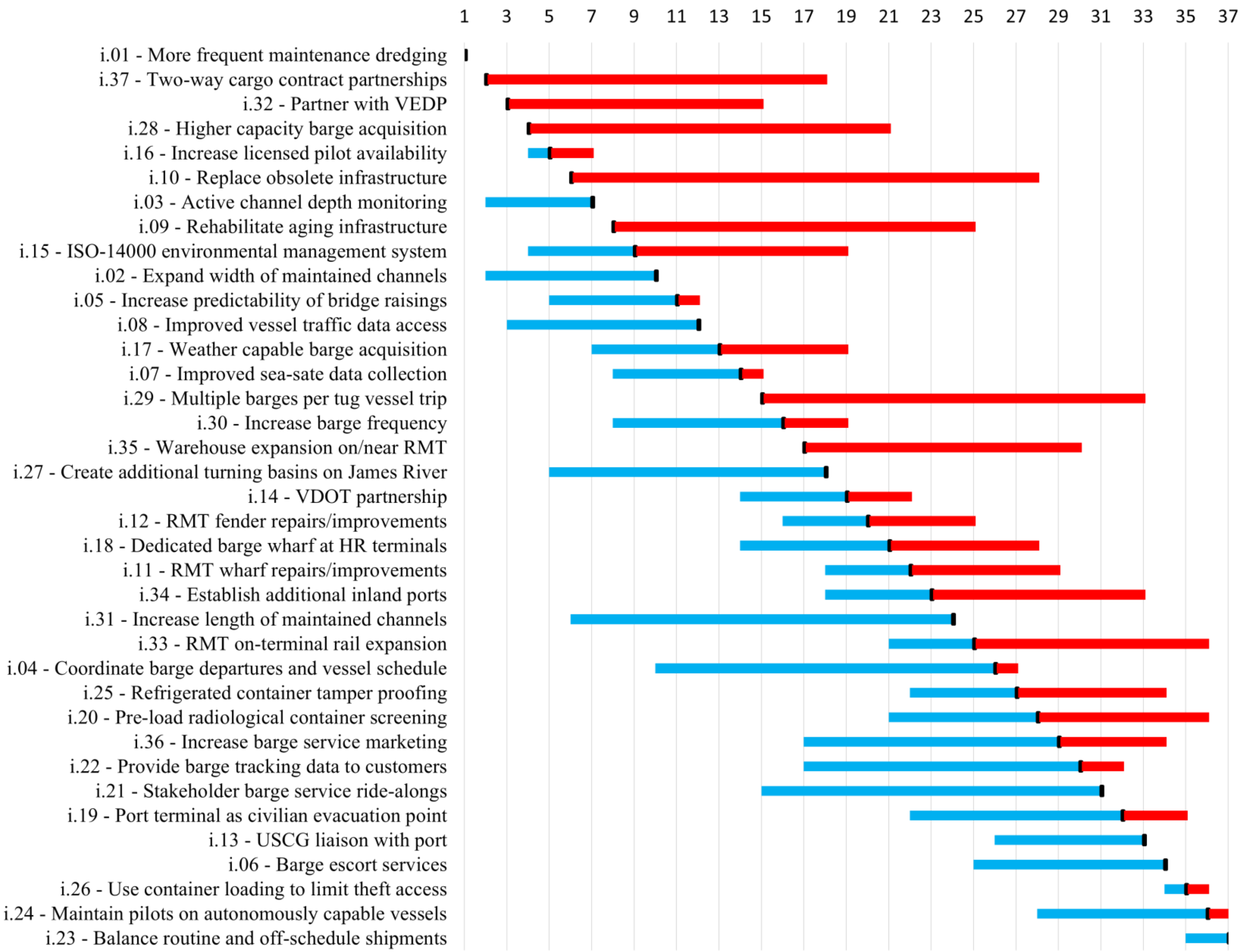


Figure 5-15. Initiatives ranked across 4 scenarios for asset management of the James River corridor.

The influence of just four scenarios on segment rankings results in seven segments always ranked within the top quarter of all segments and fifteen in the top third. The influence of just four scenarios on initiative rankings results in three initiatives always ranked in the top quarter of all initiatives and six initiatives in the top third. Initiative *i.01 – More frequent maintenance dredging* is ranked as the top priority initiative under all four scenarios considered. The goal of this analysis under a reduced number is scenarios is not to generate as many highly ranked and resilient initiatives as possible, rather the goal is to provide some level of discernability to the stakeholder under the influence of a range of scenarios. Given the four scenarios in the alternative analysis are the four least disruptive to initiative rankings, it is prudent to conduct additional iterations including the other scenarios. Stakeholders may have insight on which of the more disruptive scenarios are more likely, or are of interest to the enterprise.

5-6. Discussion

Table 5-22 provides key results from the asset management analysis for both segments and initiatives. This table represents a culmination in this dissertation of the progression of development of the maritime trace corridor methodology in the preceding chapters. The maritime corridor trace development for safety and security risk factors are incorporated with the asset management framework introduced in Chapter 4 to describe a method for the management of the James River corridor as an asset to all concerned stakeholders.

The risk register for maritime corridor trace analysis is expanded in this chapter with the inclusion of the industrial zoned parcels and maintained channel factor traces. The risk register also benefits from the inclusion of stakeholder relative weighting of factors and asset management initiatives for assessing segments across baseline and developed scenarios as well as the ranking of corridor segments and initiatives across scenarios.

Table 5-22. Key results from asset management analysis of the James River corridor.

Scenarios Considered		
s.01 - Economic downturn		
s.02 - Increase in shipping demand		
s.03 - Credible threat emergence		
s.04 - Infrastructure degradation		
s.05 - Pandemic		
s.06 - Increased support for waterway utilization		
s.07 - Technological innovation		
s.08 - Weather or climate change		
Category	**Result**	**Description**
Corridor Segments	Most resilient segment	The most resilient of the highly ranked segments is *seg.13 - CC/CCC - Turkey Island* . This segment is never ranked lower than rank 14 and is ranked as the highest risk segment under at least one scenario. The most resilient segments overall are *seg.77 - Port/NN - Craney Island North* and *seg.78 - Port/Norf - Harbor Reach Entrance* . Both of these segments are always ranked among the bottom three of all segments.
	Highly ranked and resilient segments	Highly ranked and resilient segments include *seg.08 - CC/HC - Varina-Enon Bridge* , *seg.10 - CC/HC - Jones Neck Cutoff* , *seg.13 - CC/CCC - Turkey Island* , *seg.15 - Hope/CCC - West* , *seg.18 - PGC/CCC - BHM Bridge* , and *seg.25 - PGC/CCC Windmill Point* . All of these highly ranked and resilient segments are within 25 nautical miles of Richmond Marine Terminal.
	Most disruptive scenarios	The most disruptive scenario is *s.05 - Pandemic* .
	Least disruptive scenarios	The least disruptive scenario is *s.03 - Credible threat emergence* .
Initiatives	Most resilient initiative	The most resilient initiative of the higher ranked initiatives is *i.16 - Increase licensed pilot availability* . This initiative is ranked in the top third of all intitiatives under consideration of all eight scenarios and is ranked as highly as rank 3. The most resilient of all initiatives is *i.26 - Use container loading to limit theft access* . This initiative changes only three positions in ranking under the influence of eight scenarios. All of these rankings are in the among the 4 lowest ranked initiatives however.
	Highly ranked and resilient initiatives	Under the inlfuence of eight scenarios *i.16 - Increase liscense pilot availability* could be considered as the only highly ranked and resilient initiative. Two other initiatives are always ranked in the top half of initiatives. They are *i.37 - Two-way cargo contract partnerships* and *i.03 - Active channel depth monitoring* . Four others of note are *i.01 - More frequent maintenance dredging* , *i.32 - Partner with VEDP* , *i.02 - Expand width of maintained channels* , and *i.14 - VDOT partnershp* .
	Most disruptive scenarios	The most disruptive scenario is *s.03 - Credible threat emergence . Scenarios s.07 - Technological innovation* , *s.01 - Economic downturn* , and *s.05 - Pandemic* also have disruptive scores nearly as high.
	Least disruptive scenarios	The least disruptive scenarios are *s.04 - Infrastructure degradation* and *s.06 - Increased support for waterway utilization* .

Chapter 6. Extended Applications and Future Work

6-1. Overview

Previous chapters of this dissertation develop a methodology, maritime corridor trace analysis, for the assessment of risk across safety and security factors for inland waterway transportation networks. This chapter discusses several systems to which the maritime corridor trace methods may be applicable for risk analysis and management. Following the discussion on possible extensions of the methods of this dissertation, future work to address limitations of the methodology are considered.

6-2. Maritime Corridor Trace Analysis Characteristics

The maritime corridor trace analysis methodology is an extension of previous work applying a similar method to the analysis of roadway transportation networks. The maritime version is distinguished by a wider range of factors collected and an effort to collect and analyze factors related to both the natural environment the systems operates in as well as the built environment encompassing its design. The discussion of extended applications of the maritime corridor trace analysis is limited to the steps of the method up to the production of the corridor trace visualizations. There are five general steps in this process:

1. Corridor definition and visualization,
2. Risk factor selection,
3. Risk factor data collection,
4. Risk factor threshold determination, and
5. Corridor trace production.

The order presented is the order followed in this dissertation. There would not be a prescribed requirement to proceed in the exact order presented for extended applications. The primacy of corridor definition and visualization was not an issue for application to inland waterway corridors. A familiarity of the general geography and an understanding of the operations of freight transport enterprises conducting operations on the corridors was the requirement for being able to define a generally linear system. For other systems, a need to understand the relevant risk factors required before a corridor can be defined and appropriately visualized is conceivable. Previously unknown or unexpected observations of factor data might initiate the need for a corridor trace analysis, and in a general sense, a portion of factor data collection could be the first step. Allowing for iterations and updates to the analysis, *step 5. Corridor trace production*, is the last step of the process.

Maritime corridor trace analysis is probably best adapted to systems involving a flow of one kind or another. The flow could be as in a physical engineering sense, the flow of air or water through conduits. The flow could also represent a process flow, as in a manufacturing assembly line, an engineering design process, or a construction process. Maritime corridor trace analysis could also provide a meaningful visual representation of a static system with a spatially defining aspect. A fanciful example of a landscaping enterprise representing various residential contracts in a locality with differing levels of service provided to each residence requiring the dedication of a variety of resources, such as manpower, equipment, and product, is imagined. A goal of the maritime corridor trace analysis is to provide stakeholders with a view of multiple system-relevant and operationally-impacting factors in as consolidated a format as possible while remaining useable.

Another aspect of the maritime corridor trace analysis to consider in application to extended systems is the linearized nature of the system. Primary transportation corridors are well-suited to this application. Other systems may have a more dispersed nature. A method including sets of subordinate corridor traces might be meaningfully applied to represent various branches of a two-dimensional system and retain some benefits of the methodology. Such a method could apply to transportation corridors as well.

The ability to discretize the candidate system is a desirable characteristic. Though the flow of water through an inland waterway corridor is continuous, the corridor is segmented into system-relevant units, nautical mile lengths in the case of the maritime corridor trace. In a manufacturing assembly line, the flow of the product could be discretized into different stages of assembly, each requiring different levels of manpower, robotics, tools, parts, quality control checks, and others.

Finally, a candidate system is one benefiting from consideration of multiple factors impacting performance or response. A usefulness of the visualizations is the disaggregation of multiple factors in a still consolidated and aligned fashion. This somewhat paradoxical statement describes the capability of stakeholders to identify compounding effects of factors while still having the ability to discern the varied sources of those effects. The focus of the following discussions on candidate systems for extension of the maritime corridor trace is on the system factors.

6-3. Water Supply and Sewer Systems

The analogy of maritime corridor trace to the flow of water supply and wastewater collection and treatment makes this a candidate system for discussion of extended applications. The maritime corridor trace methods might be applicable to the wastewater treatment process, but the discussion here is related to the quality of the water in the delivery and collection of water and waste. The risk factor selection for water supply and sewer systems is informed by literature discussing the vulnerabilities of these systems.

Mitchell (2005) describes hazards in urban areas from nonpoint pollution. Nonpoint pollution consists of runoff from non-discrete conveyances, such as agricultural areas, industrial facilities, construction sites, wooded areas, and others. Pollution can be in the form of fertilizers, herbicides, insecticides, petroleum and organic-based oils, and metals, which are the focus of the study. Point sources, for comparison are discernable conveyances, such as pipes, ditches, tunnels, concentrated animal feeding operations, vessels, and others. Mitchell uses GIS applications to determine land use types in the areas considered as well as visual interpretation of activity on the land using maps, satellite imagery and aerial photography. The use of GIS overlays provided by the European Environment Agency is also described. The risk factors described in this study focus on the content levels of various metals in water supply systems. Land use types might be a separate risk factor to supply additional information to the stakeholder. The study was also able to collect rainfall data for up to forty years from over six hundred collection sites. The total coverage area of the rainfall data is described as northwester Europe and the United Kingdom. Zhou (2014) studies the impact from the conversion of land use on the designed capabilities of sewer systems. Pollution "hot spots" are discussed.

Heaney et al. (2011) explore the vulnerabilities of underserved social justice communities unconnected from publicly maintained water supply and waste management systems. The focus of this study is on the vulnerabilities dependence by these communities on private septic systems and leach fields for waste and local wells for use. Age of systems and soil condition are described as system relevant factors. The study also explores the mitigation impacts of expanding the publicly operated water system corridors to serve these communities, indicating location of unserved residences may be a relevant factor.

The impacts of climate change on the sanitation systems of developing regions is studied in terms of system type (Sherpa et al., 2014). Eight types of waste systems are explored, including waterless pits systems, pour flush and cistern flush systems, and full flush sewage systems with disposal treatment and recharge. Focus is on the impact of weather-related factors and the vulnerabilities of these systems to periods of flooding from heavy rain events and to periods of drought. Fan et al. (2003) study the impacts of low-rainfall periods on robust sewer systems in terms of sediment from runoff. Sediment volume is the central factor and sources are described as residential rooftops, runoff from streets, parking lots, construction sites, and automotive maintenance facilities. Number and location of each of these sediment sources may also be a system-relevant factor for consideration.

GIS applications have been used to display vulnerable locations of water supply and sewer systems (Guidice et al., 2016; Mair et al, 2012). Both studies involve prioritization schemes for maintenance of these systems. Guidice et al. include factors of pipe size, soil type, pipe material, and sewer age, explicitly recognizing a relationship between the factors of sewer age and pipe material. Mair et al. consider the locations of conduits, pumps, potable water storage, and wastewater treatment facilities in the vulnerability assessment. Both studies produce a two-dimensional, networked vulnerability map of the system to highlight prioritized areas. The Guidice study also included access to a historical failure incident database.

Other factors mentioned include runoff of endocrine disrupting chemicals, the various sources of the pollutant, and infiltration characteristics of soil type (Zhou et al., 2019). Torres-Matallana et al. (2018) define different forms of flows: wet weather or rainfall flow, dry weather flow, combined sewage flow, and combined sewage overflow. The description of different flow regimes draws comparison to the consideration of safety and security factors in the maritime corridor trace analysis.

Risk factor threshold determination may have a scientific basis in terms of known risk based on level of contaminant. Many of the studies included discussion of field data collection for runoff volumes which could provide threshold values for a land type factor or commercial, residential, or manufacturing location factors. Threshold could be determined based on assessed failure likelihood related to system age, soil type, pollutant source, precipitation volume, etc.

Linearization, corridor definition, and visualization may present the biggest challenge to adaption of the maritime corridor trace methodology. Water supply and sewer systems are networked with branches and nodal connections. A subordinate trace method might be appropriate with a main corridor defined with subordinate traces representing the different branches. Studies producing visualizations presented a planar networked depiction, representing the aggregation of all factors. A drawback of this approach is the limited ability to discern impacts from multiple factors.

6-4. Smart Grids

Smart grids are described by the U.S. Department of Energy as local or regional electric power distribution systems characterized by digital technology facilitating sensing along transmission lines for enhanced system control, automation, and coordination of various equipment connected to the system (smartgrid.gov). Smart grids offer the potential benefits of efficient transmission of electricity, reduced operating costs, reduced peak demand, integration of large-scale renewable energy systems, integration of customer and commercially-owned power generation and storage systems, and improved security.

Deng et al. (2015) define smart grid systems as having two parts. The physical part consists of locations for generation, transmission, distribution, and consumption and represents the flow of power. The cyber part consists of locations representing wide area networks, neighborhood or field area networks, and home, business, and industrial area networks, representing the flow of information. They describe the system as having a supply-side and a demand-side, which could be located at opposite ends of the corridor. However, smart grids are distinguished by the two-way flow of both power and information, meaning components on both sides are capable of generating and consuming power and information. This study focuses on the components of the system, potentially representing a means of discretization, and the vulnerabilities to functionality presented by electricity demand and price. The factors of demand and price are related significantly to temporal considerations. The factors of demand and price are subdivided into factors determining the risk level of each. Demand subfactors include the ability of residences and businesses to accept power during off-demand times and provide additional power to the network during peak demand. The ability to generate and consume power suggest factors such as the number of homes with renewable power generation capabilities in a particular subdivision, the number of Internet of Things (IoT) devices in a defined segment, the number of businesses with renewable power generation capability, or the size and location of commercial electric vehicle fleets operated by businesses with bi-directional charging capability (Almutairi et al., 2018).

Vehicle-to-grid (V2G) technology represents a capability for electric vehicles and V2G service providers to offer a variety of benefits to the electrical grid, commercial enterprise operators, and electric vehicle owners. Segments of a smart grid corridor containing this capability would be introduced as both a supplier and consumer of power and information flow. This is facilitated by the connection of electric vehicles to the grid through bi-directional chargers and communications controllers. V2G service providers are able to monitor grid power and market conditions to identify opportunities for favorable corridor management. One of the multiple applications is the use of these systems for power grid frequency regulation (Fitzsimmons et al., 2016). V2G service providers, monitoring grid conditions, identify and aggregate corridor-connected electric vehicles able to provide power in instances of heightened demand or accept surplus to assist in maintaining a consistent grid frequency of 60 Hertz. A second application is the management of peak load usage for commercial and industrial enterprise (Walton et al., 2018).

Demand charges may be imposed by utility companies calculated from the maximum power draw of a building during a monthly billing cycle. V2G service providers can monitor these conditions and direct the timed draw of ancillary power from available electric vehicles to reduce the demand otherwise required from the grid for a commercial or industrial building. This application can decrease the maximum power draw by the enterprise which is used to calculate demand charges. V2G technology requires communications systems and complex algorithms, in the information flow of the corridor, to track and verify the grid corridor management facilitated by V2G service providers (Steward, 2017). The aggregation of these services and their locations along the grid represent multiple factors relevant to a defined corridor. These factors and vulnerabilities might be meaningfully grouped into physical and cyber security categories.

Ganin et al. (2017) provides a well-developed assessment of cybersecurity vulnerabilities across three domains: physical, information, and social. The physical domain applies to hardware-related components of the system and also power flow. Possible corridor factors in the physical domain could be points of physical access to the grid through power generating or consuming systems and locations and age of systems reflecting a hazard of obsolescence. An additional consideration is the connection to the smart grid corridor of manufacturers and technology developers of systems to be deployed in the grid. These businesses represent points of access and possible vulnerabilities in the physical and information domain. The information domain describes software-related vulnerabilities, including ease of logical access, obsolete software, counterfeit software and lack of antivirus and scan coverage. Safety and security of the smart grid corridor in the information domain would include factors such as ubiquity of antivirus coverage of connected devices, perhaps with threshold levels being assigned to type of location and ability to verify coverage, electrical company owned equipment, commercially owned equipment, and residentially owned equipment for example. The brand of the system components connected may also present a threshold distinguishable factor. Some brands may have better cyber security and reliability ratings and have different risks associated with counterfeit and obsolete software in the information domain and flow. These risks, as well as social domain vulnerabilities, relate to the concept of trust.

Developing concepts of trust in various forms throughout the smart grid network could represent an additional set of factors for consideration on a smart grid corridor. A National Institute of Standards and Technology paper (NIST, 2018) addresses trust concerns associated with IoT components. The study focuses on two aspects of trust: trust between connected devices and trust among humans in the system. Trust among humans could be divided further into acceptance of IoT devices by humans, their level of confidence in the services, data, and data protection offered by the devices, and trust between humans involved in the smart grid system. There are multiple potential factors related to trust of smart grid components. Heterogeneity results form market competition in the supply chain of smart grid components. Third-party vendors will need to develop trust with system managers and components of from third-party vendors will need to be assessed as they are adopted into the system. Additional factors include compatibility, certification, visibility, reliability, data integrity, cyber-security, and others.

6-5. Future Work

Future work will focus on the improvement of the corridor trace methodology by addressing current limitations and providing additional decision-aiding capabilities to stakeholders. Work to improve collection and display of sea-state data is a primary concern. Stakeholder feedback informs of the significant role of weather-related factors in barge operations on inland waterway corridors. Probability diagrams for corridor sections (a consolidation of a number of segments) may be appropriate. An alternative could be to develop a projected-state maritime corridor trace to represent defined scenarios related to various sea-state conditions. This would represent an alternate approach to scenario-based analysis, in which the corridor is built to reflect a scenario, and the "baseline" ranking of the alternate corridor could be used to prioritize segments for weather related mitigations.

Improvements for providing greater functionality include the use of software applications to permit enhanced interaction with the analysis by the stakeholder. An example of increased functionality demonstrated for roadway corridors is the ability to focus on a portion of the corridor through the use of a slider function or manual input of a desired range of segments. Scenario selection and automatic production of alternate maritime corridor traces would also provide greater functionality. Enhancements in visualization are also sought. Some effort has been made to utilize the capabilities of GIS applications to permit ground-level and other perspectives of the operating environment. Figure 6-1 is an example of a possible alternate perspective for segments on the St. Johns River corridor. Such perspectives could be present with selectable, focused segments of the corridor trace displayed. A video tour capability of the entire corridor in each direction would also provide desirable, enhanced functionality. Additionally, future work will more fully develop a risk register for stakeholders providing a record of the corridor trace products, visualizations, initiatives, emergent and future conditions, scenario-influenced rankings and other products presented in this dissertation or planned for future work. An example risk register of current products is provided in Appendix C.

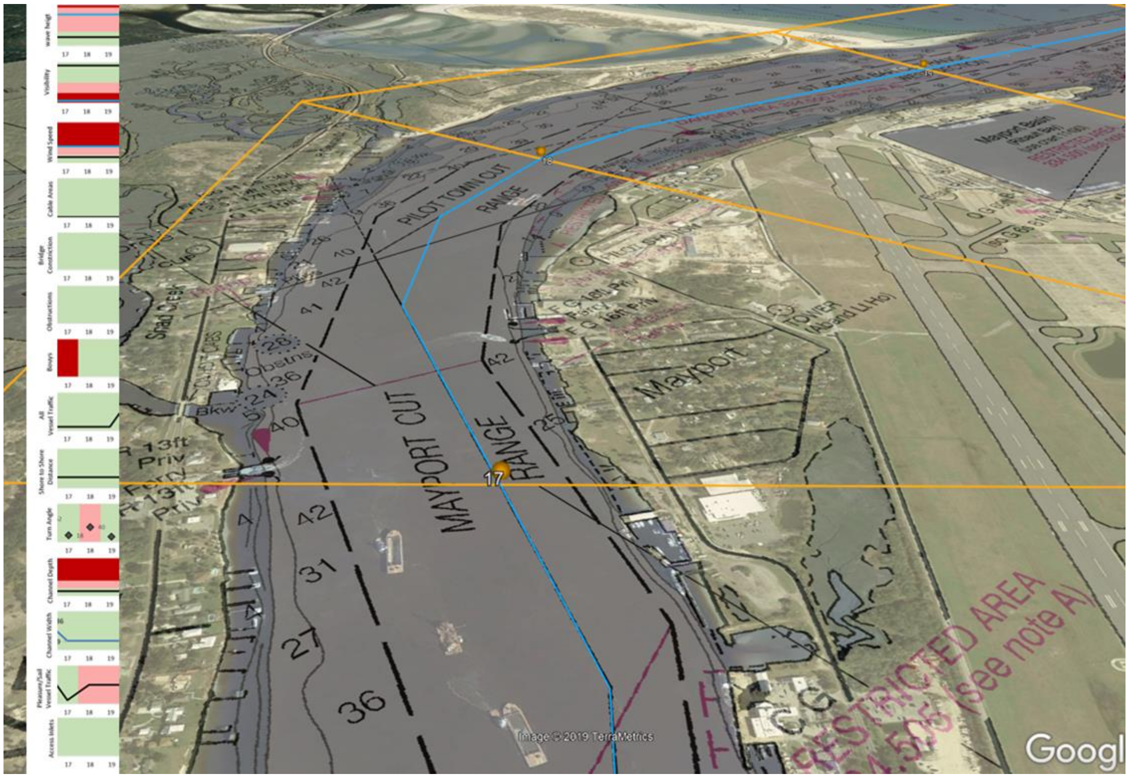


Figure 6-1. Example of an alternate corridor perspective enhancement for future work.

Lastly, on short-time scales, consequence of hazard occurrence could be evaluated to relate to enterprise operations. Consequence of individual occurrences, such as the effect of a single barge grounding in terms of recovery cost, delay, and loss of trust with business partners could be assessed to achieve a more complete description of risk for each corridor risk factor.

Chapter 7. Discussion and Conclusion

7-1. Overview

This chapter discusses limitations of the methods described and provides an overview of the content of the dissertation. A discussion of the description of risk to systems as described in the dissertation is presented. Model validation with use of expert knowledge and other limitations of the analysis is discussed. The conclusion consists of brief summaries of the other chapters in the dissertation.

7-2. Consequence Component of Risk

The term risk is used throughout this dissertation, but not without understanding of the composition of risk. Risk is generally understood to be a function of likelihood of an incident and the consequences of the occurrence of an incident. Quantification of consequence of possible incidents is not in the scope of this dissertation. The liberty taken in describing likelihood of incident occurrence as risk is acknowledged.

In Chapter 1, an assumption is made considering the consequences associated with hazard occurrence to be sufficiently severe. This assumption is made with the long-term goal of the management of inland waterway corridors in mind. The uncertainty of the outcome of any incident related to the hazards described is also in mind. Safety factors in the obstacle category are attributed to allisions. A maneuver by a vessel operator to avoid an obstacle in the presence of vessel traffic could result in a sufficiently severe collision, perhaps fatal depending on the circumstances of the type of vessels involved.

Other research referenced in the dissertation have addressed consequence. Berle et al. (2011) describe consequence in terms of percent reduction in stock price of a shipping company involved in a maritime incident over two years following the incident. They apply a hazard and mission focus methodology to their assessment of risk. Zhang et al. (2014) provide a risk severity matrix with severity categories of catastrophic, critical, major, and minor. The threshold for minor is 100,000 to 200,000 Ren Min Bi (RMB) or approximately 14,000 to 28,000 dollars. The critical threshold includes one or two deaths, and the catastrophic threshold involves three or more deaths and over one million RMB. Eicheikh and Burrow (2017) provide a three-tier severity rating for the consequences involving bridges, locks, and culverts on a waterway: minimum, medium, and maximum. The minimum threshold for bridge damage is 131 million dollars with a maximum threshold set to 185 million dollars. Vidan et al., (2012) discuss safety of inland navigation and discuss an increase in navigation safety leading to a decrease in the consequence of damages. Roeleven et al. (1995) study accidents on inland waterway transport and deals with the probability of occurrence irrespective of the extent of the damage. Thorisson et al. (2018) assess the consequence of disruption to ship berthing schedules at a container port in terms of cost and delay. The consequence of incident occurrence is also reasonably assumed to be dependent on the circumstances of individuals or organizations involved in the incident.

7-3. Model Validation

Validation of the maritime corridor trace analysis presented in this dissertation is heavily reliant on subject matter expertise for validation. This method of validation is sometimes referred to as face validity (Eddy et al., 2012). Face validity involves subjective evaluation from experts regarding whether the model structure, data sources, problem formulation, and results appear to be reasonable. Farr et al., (2016) describe considerations in the use of subject matter elicitation and suggest a framework model adjustment based on expert cognitive bias and model complexity. No adjustment is recommended if the subject matter expert has significant knowledge and expertise in the topic, some adjustment for some domain knowledge, and significant adjustment for limited domain knowledge. The same three-tier adjustment is applied to model complexity based on corresponding complexity scale. Methods and results of chapters 3 through 5, each building on the methods and results presented in the preceding chapters have been iteratively developed and presented to three groups of stakeholders representing different organizations, a military contracting company, the Virginia Department of Corrections, and the Port of Virginia. Two papers based on the content of these chapters have been accepted for publication in conference proceedings. The process of risk factor selection for the assessment of risk associated with navigation on inland waterway corridors is also based on prior research with varying methods of model validation described.

Wang et al. (2013) built their model based on information from an accident database for the Yangtze River which included over 1,600 accidents, 700 of which were collisions, the focus of their study. They used a data mining method on the database and associated AIS data to determine the characteristics of each accident when they occurred. From this data, they developed a flow chart to assess the probability of a collision based on the presence or absence of factors. (Zhang et al., 2014) use a data set of 663 accidents to develop a list of twelve factors leading to accident likelihood. Sensitivity analysis of the results was used to validate their model. Goerlandt and Montewka (2014) develop a Bayesian network model for determining cargo oil outflow resulting from a vessel collision incident. The states of the network describe different scenarios based on the varying conditions, or factors, present. They describe their process for model validation by comparing the results of the model, the estimated oil outflow, to a database of tanker collisions and groundings available from the National Research Council. Roeleven et al. (1995) also develop a set of waterway characteristics used in the calculation of probability of accident occurrence on the River Waal in The Netherlands. Among the characteristics are presence of a bridge, bend radius, navigable width, visibility, wind, and current. They compare the prediction of number of incidents in various locations from their model with a government agency dataset which included approximately 5,200 incidents over a ten-year period. Various accident models focused on human factors as the cause also validate models using datasets available from government agencies, such as the United Kingdom Marine Accident Investigation Branch (Batalden and Sydnes, 2017), the Transportation Safety Board of Canada (Abramowicz-Gerigk and Hejmlick, 2015), and the Australian Transport Safety Bureau (Ugurlu et al., 2015).

7-4. Limitations

Some limitations of this research have been addressed in previous chapters. These include the lack of consideration of consequence in reference to risk, the inability to present a complete set of factor traces to stakeholders in a single view, potential dependency between selected factors, dependency between criteria, initiatives, and scenarios, and the weakness of available data for sea-state factors.

A potential method to address the difficulty in addressing weather-related data in a geographic oriented representation is to develop a wind-rose diagrams, or radar charts for a given section of a corridor. For wind, probabilities of wind strength could be represented on radial spokes of the radar chart with wind direction represented as the orientation of the each spoke. Similar constructions could be developed for average and maximum precipitation with the radar chart divided into thirty-degree sections representing months of the year and average and maximum values plotted on the radial direction in each section. For fog, the radial direction could represent probability of fog with the thirty-degree section subdivided into twenty-four or twelve additional sections for time of day. Average monthly values for probability of fog, or visibility if available, could then be plotted on each of the twenty-four radii. Alternatively, as mentioned in Chapter 6, weather scenario-based sea-state traces could be developed for specific weather conditions along the corridor. Regardless, managers of the demonstrated inland waterway corridors will benefit from improved sea-state data collection methods.

A second limitation of this dissertation is the lack of temporal factor consideration. This especially applies to sea-state data. Ice formation has been mentioned by system stakeholders as a hazard during winter months on the James River corridor, especially near Richmond Marine Terminal. Vessel traffic is likely also related to time of day, and also likely to time of year.

Agricultural seasons will dictate levels of shipment of bulk commodities. These are likely to be among the heavier barge shipments and may affect travel time along the river. Agricultural seasons could also impact shore cover on farmland in relation to security concerns. Time-of-day variance in roadway traffic may impact waterway traffic as well. Bridge openings may be less permittable during traffic rush times and more permittable overnight. Vessel transit times along the corridors have also not been discussed. On average a one-way voyage from Hampton Roads to Richmond by barge is reported by stakeholders to take twelve hours. Certain sea-state conditions can cause travel times to be several hours longer up river and several hours shorter down river. Sea-state and vessel traffic conditions could change significantly over the course of twelve hours.

A third limitation is the reliance on verbal response value judgments for the relative weighting of criteria and the assessment of factors and initiatives against criteria. A brief sensitivity analysis is presented in Appendix B to assess the influence of varying baseline ratings on segment rankings and disruptive scores of scenarios.

A final limitation addressed in this chapter is the use of a limited set of scenarios to identify initiatives and segments for resource investment strategies. There is no guarantee, or even intent, to represent all possible future states. The scenario-based method presented is not intended to represent a complete probability space but an aid for stakeholder understanding of uncertainties associated with the system context and the influence of selected and vetted emergent and future conditions on their priorities.

7-5. Conclusion

This dissertation presents a methodology for risk management of inland waterway corridors through the development of a maritime corridor trace, decision-aiding tool. A methodology for prioritization of resources in the asset management of inland waterway corridors considering a risk framework for the development of initiatives is also introduced. Chapters 2 through 5 represent a progression of methods involved.

Chapter 2 introduces the maritime corridor trace for the develop of safety risk factors along the inland waterway corridor. The methods are applied to a transportation network in central California utilized for freight transportation operations from San Francisco Bay to ports in Stockton and West Sacramento. Compounded risk segments are identified and discussed.

Chapter 3 introduces the development of security risk factors and applies the new methods and those developed in the previous chapter to the St. Johns River corridor from Jacksonville, Florida to the Atlantic Ocean. This corridor is highlighted for the emergence of liquefied natural gas capable vessels and the intent to begin exporting via tanker. The import and export of petroleum also represents security risks for the corridor. The disaggregated assessment of security and safety factors is introduced and demonstrated for two segments along the corridor.

Chapter 4 is a departure from the discussion and development of the maritime corridor trace analysis to introduce risk-based and scenario-based asset management methods. The methods are applied to the acquisition of technological solutions for improved tool control in a department of corrections setting.

Chapter 5 is the culmination of methods applied to the management of the James River corridor in Virginia. The context is in relation to Port of Virginia operations, but could apply to other enterprises involved in freight transport on inland waterway corridors. Two additional factors are introduced, related to safety and capacity expansion on the corridor. The maritime corridor trace is used in the development of initiatives for asset management of the corridor. The initiative ranking methodology and scenario-based analysis approach is applied to the baseline ranking and disruption of rankings of corridor segments as well as initiatives.

Application of maritime corridor trace analysis to three unique inland waterway corridors demonstrates the wide applicability of the methodology across geographic locations and a variety of stakeholders. The demonstrations also describe how additional risk factors are seamlessly added to the analysis and incorporated in prioritization of corridor segment and initiative rankings for asset management aims. In addition to the Central California, St. Johns River, and James River corridors presented, inland waterway corridors in Washington (Strait of Juan de Fuca and Puget Sound), Oregon (Columbia River), Georgia (St. Mary's River), and the Delaware River were also studied in preparation of this dissertation. The methodology should also be applicable to inland waterway corridors outside the United States. Some common themes are recognized over the range of corridors. In the United States, the U.S. Army Corps of Engineers (USACE), the United States Coast Guard (USG), and the National Oceanic and Atmospheric Administration (NOAA) play significant roles in the monitoring and management of maritime corridors. Obstacle types, in the form of buoys lights and other aids to navigation, are generally standard throughout. Channels maintained by USACE are a common feature of at least some portion of most all corridors studied. Theses maintained segments are characteristic of uniform channel depth and high-risk channel width assessments.

Adaptations of the maritime corridor trace methodology may be desirable depending on the specific region of interest. Orientation of segment numbering might be altered from the west to east standard presented to reflect the direction of flow of the river, inland to ocean, or to suit stakeholder preference. A motivation of the dissertation is to describe methods of asset management of inland waterway corridors to create a more resilient regional transportation network by relieving congestion among other transportation modes. This could be achieved by movement of goods between two inland ports, along tributaries of a major river system such as the Mississippi River for example. In these systems, the need to consider additional infrastructure risk factors, especially the presence of locks and dams, is likely. The maritime corridor trace methodology is applicable for such systems. It is also meaningfully applied to safety and security considerations for large vessels transiting long distances to deep-water inland ports. This is the case for corridors in the Pacific Northwest for example, where the Strait of Juan de Fuca and the Puget Sound, and the Columbia River are over one hundred nautical miles from sea to major ports in Seattle, Tacoma, Vancouver, Canada, and Portland. Similarly, Port of Jacksonville facilities are located up to twenty-four nautical miles inland from the Atlantic Ocean. In these systems, channel depth is generally not a significant risk factor along large portions of the corridor, though channels maintained by USACE remain key features of some sections. In other maritime transportation systems, ultra-large ocean-going vessels arrive to ocean-side ports and cargo is transloaded for continued shipment to inland ports in order to relieve congestion on surface-modes, among other benefits. This system type is possible in the Central California region, from Oakland to Sacramento and Stockton. The growth of barge operations along the James River corridor is a key strategic goal of the Port of Virginia.

The maritime corridor trace methodology is adaptable to the varying concerns of regional port authorities while remaining applicable to a variety of stakeholders interested in the use and management of inland waterway corridors. Selection of safety and security risk factors in this dissertation is focused on the operation of commercial vessels (cargo, tanker, tug and towed barges) and associated enterprise operations of port authorities. Each stakeholder may desire to add or delete considered risk factors or adjust risk factor thresholds as appropriate. System characteristics are likely to dictate to the prevalence of commercial vessel types transiting the various corridors. Vessel characteristics are likely to impact risk factor thresholds, especially those in the channel geometry category. A potential set of factors not addressed in this dissertation is regulatory considerations. Various regions may be impacted by local, state, and federal laws constraining operations in certain segments. Corridor segments may also have unique wildlife and habitat factors to be addressed. Additionally, regional priorities may be dictated by a prevalence of commercial or agricultural activity.

The use of maritime corridor trace analysis to inform asset management of inland waterway corridors enhances the regional adaptability of the methodology. The development of success criteria initiatives reflects stakeholder values for corridor use and management. Relative weighting of criteria for baseline and potentially disruptive scenarios reflect stakeholder preferences. These values and preferences will incorporate unique community needs. The maritime corridor trace analysis will impact the preferencing of corridor risk factors and asset management initiatives, reflecting unique corridor characteristics. Identifying the influence of emergent and future conditions on stakeholder priorities will aid in the persistence of realized benefits from the utilization of inland water corridors and help to mitigate the emergence of undesirable conditions.

References

Abramowicz-Gerigk, T., and Hejmlich, A. (2015) “Human factor modelling in risk assessment of port manoeuvers.” International Journal on Marine Navigation and Safety of Sea Transportation, 9(3) 427-433.

Abrecht, B.R. (2016). “Systems theoretic process analysis applied to an offshore supply vessel dynamic positioning system,” M.S. Thesis, Inst. For Data, Systems, and Society, MIT, City of Cambridge, MA, USA, 2016. [Online]. Available: http://sunnyday.mit.edu/Abrecht_Thesis.pdf.

Abrecht, B.R., and Leveson, N. (2016). “Systems theoretic process analysis (STPA) of an offshore supply vessel dynamic positioning system.” Massachusetts Institute of Technology, Lincoln Laboratory.

Acton, M., Byantun, C., Kirby, R., and Wessely, S. (2020). “Coronavirus: reducing the impact of quarantine.” Trends in Urology & Men’s Health, 11(2), 6-8.

ADC (AR) (2019). 2019-2020 Strategic Plan. Arkansas Department of Correction, Pine Bluff, AR.

ADC (AZ) (2018). Five-Year Strategic Plan: FY 2018 to FY 2022. Arizona Department of Corrections, Phoenix, AZ.

ADC (AZ) (2019). Department Order Manual, Chapter: 700 – Operational Security; Department Order: 712 – Tool Control. Arizona Department of Corrections, Phoenix, AZ.

ADOC (2019). Strategic Plan 2019-2022. Alabama Department of Corrections, Montgomery, AL.

Akhtar, M.J., Utne, I.B. (2014). Human fatigue's effect on the risk of maritime groundings – A Bayesian Network modeling approach. Safety Science, 62, 427-440.

Akiyama, M.J., Spaulding, A.C., and Rich, J.D. (2020). "Flattening the curve for incarcerated populations – Covid-19 in jails and prisons." The New England Journal of Medicine. doi: 10.1056/NEJMp2005687.

Al-Kaff, A., Martin, D., Garcia, F., de la Escalera, A., Armingol, J.M. (2017). Survey of computer vision algorithms and applications for unmanned aerial vehicles. *Expert Systems With Applications*, 92, 447-463

Almaz, O.A., and Altiok, T. (2012). "Simulation modeling of the vessel traffic in Delaware River: impact of deepening on port performance." Simulation Modelling Practice and Theory, 22(2012) 146-165.

Almutairi A., Thorisson, H., Wheeler, J.P., Slutzky, D.L., and Lambert, J.H. (2018). "Scenario-based preferences in development of advanced mobile grid services and a bidirectional charger network." ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A; Civil Engineering, 4(2): 04018017.

Almutairi, A., Wheeler, J.P., Slutzky, D.L, and Lambert, J.H. (2019). "Integrating stakeholder mapping and risk scenarios to improve resilience of cyber-physical-social networks." Risk Analysis, 39(9), 2093-2112.

Almutairi, A., Collier, Z. A., Hendrickson, D., Palma-Oliveira, J. M., Polmateer, T. L., and Lambert, J. H. (2019). "Stakeholder mapping and disruption scenarios with application to resilience of a container port." *Reliability Eng. Syst. Saf.*, 182, 219-232.

Alsultan, M., Jun, J., and Lambert, J.H. (2019). "Systems evaluation for access management of multiscale transportation networks," in 2019 IEEE Int. Syst. Conf., Orlando, FL, USA, doi: 10.1109/SYSCON.2019.8836850.

Álvarez López, Yuri, et al. "RFID Technology for management and tracking: e-health applications." Sensors 18.8 (2018): 2663.

Arslan, V., Kurt, R.E., Turan, O., and Wolff, L.D. (2016). "Safety culture assessment and implementation framework to enhance maritime safety." Transportation Research Procedia, 14, 3895-3904.

Asset Management Council (2009). Asset Management Council Newsletter, April-May 2009, https://www.amcouncil.com.au/files/Asset_Management_Council_0905_Newsletter0905.pdf

Batalden, B.M., and Sydnes, A.K., (2017). "What causes 'very serious' maritime accidents?" Safety and Reliability – Theory and Applications, doi: 10.1201/9781315210469-389

Becker, M.J. (2008). "FOD for thought: Boeing comes together to help eliminate debris in airplanes." Boeing Frontiers, April 2008: 22-23.

Berle, O., Asbjornslett, B. E., and Rice, J. B. (2011). “Formal vulnerability assessment of a maritime transportation system.” Reliability Eng. Syst. Saf., 96, 696-705.

Bisio, Igor, Andrea Sciarrone, and Sandro Zappatore. "A new asset tracking architecture integrating RFID, Bluetooth Low Energy tags and ad hoc smartphone applications." Pervasive and Mobile Computing 31 (2016): 79-93.

Boyce, J.M. (2018). “Alcohols as surface disinfectants in healthcare settings.” Infection Control & Hospital Epidemiology. 39(3), 323-328.

Braekers, K., Caris, A., and Janssens, G. K. (2013). “Optimal shipping routes and vessel size for intermodal barge transport with empty container repositioning.” *Computers in Industry*, 64, 155-164.

Bryan, J., Weisbrod, G., and Martland, C. D. (2007). “Rail freight as a means of reducing roadway congestion.” *Transportation Res. Rec.: J. Transportation Res. Board*, 2008(1), 75-83.

Burns, C.M., Kuo, J. and Ng, S. (2003). Ecological interface design: a new approach for visualizing network management. Computer Networks, 43(3), pp.369-388.

CALTRANS (2019). California Freight Mobility Plan 2020, California Department of Transportation, Sacramento, CA.

CALTRANS (2015). Interregional Transportation Strategic Plan, California Department of Transportation, Sacramento, CA.

Carter, B.T., Bakirtzis, G., Elks, C.R., and Fleming, C.H. (2018). “A systems approach for eliciting mission-centric security requirements,” in 2018 Annual IEEE Int. Syst. Conf., Vancouver, BC, Canada, April 23-26, 2018, doi: 10.1109?SYSCON.2018.8369539.

Cambridge Systematics. (2010). *Feasibility Plan for Maximum Truck to Rail Diversion in Virginia’s I-81 Corridor*. Cambridge Systematics, Inc., Bethesda, MD.

Camp, J., Abkowitz, M., Hornberger, G., Benneyworth, L., and Banks, J. C. (2013). “Climate change and freight-transportation infrastructure: current challenges for adaptation.” J. Infrastruct. Syst., 19(4), 363-370.

CDCR (2009). Operations Manual, Chapter 5 – Adult Custody and Security Operations. California Department of Corrections and Rehabilitation, Sacramento, CA.

CDCR (2016). An Update to the Future of California Corrections. California Department of Corrections and Rehabilitation, Sacramento, CA.

Chartered Management Institute. (2013). “Carrying out a PEST analysis checklist.” http://www.managers.org.uk/~/media/Files/Campus%20CMI/Checklists%20PDP/Carrying%20out%20a%20PEST%20analysis

Chen, L.X., Chowdhury, A.A., Loulakis, C.M., Ownes, M.A., Thorisson, H., and Connelly, E.B. (2015). “Visualization of large data sets for project planning and prioritization on transportation corridors,” in 2015 IEEE Syst. and Information Engineering Design Symposium, Charlottesville, VA, USA, Apr. 24, 2015, doi: 10.1109/SIEDS.2015.7116954.

CO DOC (2020). Administrative Regulation 300-09, Chapter: Facility Security, Subject: Tool Control. Colorado Department of Corrections, Denver, CO.

Collier, Z.A., Lambert, J.H. (2019). "Evaluating management actions to mitigate disruptive scenario impacts in an e-commerce system integration project." IEEE Systems Journal, 13(1): 593-602.

Collier, Z.A., Hendrickson, D., Polmateer, T.L., Lambert, J.H. (2018). "Scenario analysis and PERT/CPM applied to strategic investment at an automated container port." ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 4(3): 04018026.

Collier, Z.A., Lambert, J.H. (2018). "Time management of infrastructure recovery schedules by anticipation and valuation of disruptions." ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 4(2): 04018012.

Collier ZA, Linkov I, DiMase D, Walters S, Tehranipoor M, Lambert JH (2014) Cybersecurity standards: managing risk and creating resilience. IEEE Computer 47(9): 70-76.

Collier, Z. A., Walters, S., DiMase, D., Keisler, J. M., and Linkov, I. (2014) "A semi-quantitative risk assessment standard for counterfeit electronics detection." SAE Int. J. Aerosp., 7(1), 171-181.

ConnectedWorld. (2014). Tracking System for Police Moves Forward. https://connectedworld.com/tracking-system-for-police-moves-forward/

Conti, S., La Corte, A., Nicolosi, R., & Rizzo, S. A. (2016). Impact of cyber-physical system vulnerability, telecontrol system availability and islanding on distribution network reliability. Sustainable Energy, Grids and Networks, 6, 143–151.

CTDOC (2014). Administrative Directive 1.1: Mission Statement and Values. Connecticut Department of Corrections, Hartford, CT. Accessed Apr. 3, 2020. Available: https://portal.ct.gov/-/media/DOC/Pdf/Ad/ad0101pdf.pdf?la=en.

de Langhe, B., Fernback, P.M., and Lichtenstein, D.R. (2016). "Navigating by the stars: investigating the actual and perceived validity of online user ratings." Journal of Consumer Research, 42, 817-833.

Deng, R., Yang, Z., Chow, M., and Chen, J. (2015). "A survey on demand response in smart grids: mathematical models and approaches." IEEE Transactions on Industrial Informatics, 11(3), 570-582.

DOE (2012). United States Department of Energy, "Liquefied Natural Gas Safety Research: Report to Congress," Washington, D.C., USA, May 2012, Accessed: Sep. 29, 2019. Available: https://www.energy.gov/sites/prod/files/2013/03/f0/DOE_LNG_Safety_Research_Report_To_Congre.pdf.

Du, L., Wen, Y.-Q., Xiao, C.-S., and Wang, L. (2015). "Safe speed of ships passing access channel of port," in 3rd Int. Conf. Transportation Information Safety, Wuahn, China, June 25-28, 2015, pp. 623-627.

Dunović, I.B., Radujković, M., and Vukomanović, M. (2013). "Risk register development and implementation for construction projects." Gradevinar, 65(1), 23-25.

du Plessis, M. (2015). The Bowtie Risk Assessment Method. Greenice Pty Ltd, North Epping NSW, Australia.

Eddy, D.M., Hollingsworth, W., Caro, J.J., Tsevat, J., McDonald, K.M., and Wong, J.B. (2012). "Model transparency and validation: A report of the ISPOR-SMDM Modeling Good Research Practices Task Force-7." Value in Health, 15: 843-850.

El-Akruti, K. & Dwight, R. (2013). A framework for the engineering asset management system. Journal of Quality in Maintenance Engineering, 19 (4), 398-412.

Elcheikh, M., and Burrow, M. P. N. (2017). "Uncertainties in forecasting maintenance costs for asset management: application to an aging canal system." ASCE-ASME J. Risk Uncertainty Eng. Syst., Part A: Civ. Eng., 3(1), 10.1061/AJRUA6.0000890.

Elrayes, A., Hag Ali, M., Zakaria A., and Ismail, M.H. (2019). Smart airport foreign object debris detection rover using LiDAR technology. Internet of Things, 5: 1-11.

Fan, C.Y., Field, R., and Lai, F. (2003). "Sewer-sediment control: overview of an environmental protection agency wet-weather flow research program." Journal of Hydraulic Engineering, 129(4), 253-259.

Fan, S., Yan, X., Zhang, J., and Wang, J., (2017). "A review on human factors in maritime transportation using seafarers' physiological data." 4th International Conference on Transportation Information and Safety (ICTIS), August 8-10, 2017, Banff, CA, USA.

Farr, J.V., Faber, I.J., and Richards, J.E. (2016). "Assessing bias of expert solicited parameters for simulation based costing." Proceedings of the 2016 Industrial and Systems Engineering Research Conference.

FDC (2017). Inspector General Annual Report: Fiscal Year 2016-2017. Florida Department of Corrections, Tallahassee, FL.

FDC (2018). 2018-2022 Strategic Plan. Florida Department of Corrections, Tallahassee, FL.

Fitzsimmons J.D., Kritzer S.J., Muthiah V.A., Parmer J.J., Rykal T.J., Stone M.T., et al., 2016. Simulation of an electric vehicle fleet to forecast availability of grid balancing resources. IEEE Systems and Information Engineering Design Conference.

Fritelli, J. (2019). "Shipping Under the Jones Act: Legislative and Regulatory Background," Congressional Research Service, Washington, D.C., USA, R45725, May 17, 2019. Accessed: Sep. 29, 2019. [Online]. Available: https://fas.org/sgp/crs/misc/R45725.pdf.

Frolov, Vladimir, et al. "Identifying core functions of asset management." Definitions, concepts and scope of engineering asset management. Springer, London, 2010. 19-30.

Ganin, A.A., Quach, P., Panwar, M., Collier, Z.A., Keisler, J.M., Marchese, D., et al. (2020). "Multicriteria decision framework for cybersecurity risk assessment and management." Risk Analysis 40(1), 183-199.

GAO (2007). United States Government Accountability Office, “Maritime Security: Federal Efforts Needed to Address Challenges in Preventing and Responding to Terrorist Attacks on Energy Commodity Tankers,” Washington, D.C., USA, GAO-08-141, December 2007, Accessed: Sep. 29, 2019. [Online]. Available: https://www.gao.gov/new.items/d08141.pdf.

GDC (2020). Standard Operating Procedures, Policy Number 409.04.11: Risk Management. Georgia Department of Corrections, Atlanta, GA.

George, R. (2013). Ninety Percent of Everything: Inside Shipping, the Invisible Industry That Puts Clothes on Your Back, Gas in Your Car, and Food on Your Plate, Metropolitan Books, Henry Holt and Company, LLC, New York, NY, 2013.

Giordano, G., Segata M., Blanchini F., Lo Cigno, R. (2019). The joint network/control design of platooning algorithms can enforce guaranteed safety constraints. *Ad Hoc Networks*, doi:10.1016/j.adhoc.2019.101962.

Giudice, G.D., Padulano, R., Siciliano, D. (2016). “Multivariate probability distribution for sewer system vulnerability assessment under data-limited conditions.” Water Science and Technology, 73(4), 751-760.

Gladysz, B., and K. Santarek. "An approach to RTLS selection." DEStech Transactions on Engineering and Technology Research icpr (2017).

Goerlandt, F., and Montewka, J. (2014). “A probabilistic model for accidental cargo oil outflow from product tankers in a ship-ship collision.” Marine Pollution Bulletin, 79, 130-144.

Greyling, Berno & Jooste, Wyhan. (2017). The Application of Business Process Mining to Improving a Physical Asset Management Process: A Case Study. South African Journal of Industrial Engineering. 28. 10.7166/28-2-1691.

Guo, J. Y., Gong, Q., and Obernesser, A. (2010). Assessment of Multimodal Freight Bottlenecks and Alleviation Strategies for the Upper Midwest Region. National Center for Freight & Infrastructure Research & Education, University of Wisconsin-Madison, Madison, WI.

Gurriet, T., Mote, M.L., Ames, A., and Feron, E. (2016). “Establishing trust in remotely reprogrammable systems.” Proceedings of the International Conference on Human-Computer Interaction in Aerospace, 1-4. doi: 10.1145/2950112.2964573.

Hamilton, M.C., J.H. Lambert, and J. Valverde 2015. Climate and related uncertainties influencing research and development priorities. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems. Part A: Civil Engineering. 1(2): 8pp.

Hampapur, A., H. Cao, A. Davenport, W. S. Dong, D. Fenhagen, R. S. Feris, G. Goldszmidt, Z. B. Jiang, J. Kalagnanam, T. Kumar, H. Li, X. Liu, S. Mahatma, S. Pankanti, D. Pelleg, W. Sun, M. Taylor, C. H. Tian, S. Wasserkrug, L. Xie, M. Lodhi, C. Kiely, K. Butturff, L. Desjardins. (2011). Analytics-driven asset management. IBM J. RES. & DEV. VOL. 55 NO. 1&2 PAPER 13

Hassler, M.L., D.J. Andrews, T.L. Polmateer, B. Ezell, and J.H. Lambert (2020). Multi-perspective scenario-based preferences in enterprise risk analysis of public safety wireless broadband network. Reliability Engineering and System Safety. 197: 106775.

Hawks, L., Woolhandler, S., and McCormick, D. (2020). "COVID-19 in prisons and jails in the United States." Journal of the American Medical Association Internal Medicine, doi: 10.1001/jamainternmed.2020.1856.

Heaney, C., Wilson, S., Wilson, O., Cooper, J., Bumpass, N., and Snipes, M. (2011). "Use of community-owned and -managed research to assess the vulnerability of water and sewer services in marginalized and underserved environmental justice communities." Journal of Environmental Health, 74(1), 8-17.

Henderson, M.T. (2016). "Mining Manne's vein." Journal of Law, Economics, & Policy, 12(3), 339-360.

Hillson, D. and Simon, P. (2007). Practical Project Risk Management: The Atom Methodology, 2nd ed. Tysons Corner, VA, Management Concepts Press.

HI PSD (2017). Strategic Plan 2017-2020. Hawaii Department of Public Safety, Honolulu, HI.

Hoffman, R.R., Johnson, M., Bradshaw, J.M., and Underbrink, A. (2013). "Trust in automation." IEEE Intelligent Systems, 28(1), 84-88.

Holland, C.P., Shaw, D.R., Kawalek, P. (2005). BP's multi-enterprise asset management system. Information and Software Technology 47, 999–1007.

Holvik, J. (1998). Basics of dynamic positioning. *Marine Technology Society Dynamic Positioning Conference*, Houston, TX, October 13–14.

Horowitz, B.M. and J.H. Lambert 2006. Assembling off-the-shelf components: Learn as you go systems engineering. Transactions on Systems, Man, and Cybernetics Part A. 36(2):286-297.

Hossain, K.A., and Zakaria, N.M.G., (2016). "A study on global shipbuilding growth, trend and future forecast." 10th International Conference on Marine Technology, MARTEC 2016, Procedia Engineering, 194(2017), 247-253.

Hussin, R., Ismail, N., and Mustapa S. (2016). A study of foreign object damage (FOD) and prevention method at the airport and aircraft maintenance area. IOP Conference Series: Materials Science and Engineering. 152: 012038.

IDOC (IA) (2017). 2017-2021 Strategic Plan. Iowa Department of Corrections, Des Moines, IA.

IDOC (ID) (2017). Strategic Plan FY 2017-2021. Idaho Department of Correction, Boise, ID.

IDOC (IL) (2018). Fiscal Year 2018 Annual Report. Illinois Department of Corrections, Springfield, IL.

IDOC (IN) (2010). Strategic Plan 2010 through 2013. Indiana Department of Correction, Indianapolis, IN.

Imai, H. (2020). "Trust is a key factor in the willingness of health professionals to work during the COVID-19 outbreak: experience from the H1N1 pandemic in Japan 2009." Psychiatry and Clinical Neurosciences, 74, 329-330, doi: 10.1111/pcn.12995.

IMO (2008). Revised MARPOL Annex VI: Regulation 14 – Sulphur Oxides (SOx) and Particulate Matter, Resolution, MEPC.176(58), The Marine Environment Protection Committee, International Maritime Organization, Oct. 10, 2008.

Ivanov, S.H., Webster, S., Stoilova, E., and Slobodskoy, D. (2020). “Biosecurity, automation technologies and economic resilience of travel, tourism and hospitality companies.” SocArXiv, doi:10.21235/ofs.io/2hx6f.

Jian, D., Shengxiang, L., Jie, M., Xinpei, H., and Yuan, Z. (2017). “The design and development of a real-time navigation safety onitoring system for LNG-fuelled ship in inland water,” in 2017 4th Int. Conf. on Transportation Information and Safety, Banff, AB, Canada, Aug. 8-10, 2017, pp. 1170-1176, doi: 10.1109/ICTIS.2017.8047919.

Kakimoto, K., Kamiya, H., Yamagishi, T., Suzuki, M., and Wakita T., (2020). “Initial investigation of transmission of COVID-19 among crew members during quarantine of a cruise ship – Yokohama, Japan.” Morbidity and Mortality Weekly Report, 69, 312-213. doi: dx.doi.org/10.15585/mmwr.mm6911e2.

Kampf, G. (2020). “Potential role of inanimate surfaces for the spread of coronaviruses and their inactivation with disinfectant agents.” Infection Prevention in Practice. 2, 100044. doi: 10.1016/j.infpip.2020.100044.

Kara, M. (2017). A Model for Secure Data Sharing Between Different Security Level Networks. Computer Engineering & Information Technology, 06(01). https://doi.org/10.4172/2324-9307.1000163

Kaplan, S., and Garrick, B.J. (1981). “On the quantitative definition of risk.” Risk Analysis, 1(1), 11-27.

Karvetski, C.W. and J.H. Lambert (2012). Evaluating deep uncertainties in strategic priority-setting with an application to facility energy investments. Systems Engineering, 15(4), 483-493.

Karvetski, C.W., J.H. Lambert, and I. Linkov 2009. Emergent conditions and multicriteria analysis in infrastructure prioritization for developing countries. Journal of Multiple Criteria Decision Analysis. 16(5): 125-137.

Kaur, K., and Rampersad, G. (2018). “Trust in driverless cars: investigating key factors influencing the adoption of driverless cars.” Journal of Engineering and Technology Management, 48, 87-96.

KDOC (2019). Fiscal Year 2019 Annual Report. Kansas Department of Corrections, Topeka, KS.

Kenger, P., and Karlsson A. (2007). Human error driving the development of a checklist for foreign material exclusion in the nuclear industry. Human Factors and Ergonomics in Manufacturing. 17(3): 283-298.

Khan T., Alam, M., Kadir K., Shahid, Z., Mazliham M.S., Khan S., and Miqdad M. (2017). Foreign objects debris (FOD) identification: a cost effective investigation of FOD with less alarm rate. Proceedings of the 4th IEEE Conference on Smart Instrumentation, Measurement and Applications (ICSIMA). November 28-20, 2017. Putrajaya, Malaysia.

Kim, H., Ahn, H. (2016). Realization of swarm formation flying and optimal trajectory generation for multi-drone performance show. *Proceedings of IEEE/SICE International Symposium on System Integration*, December 13-15, 2016.

Kimura, S., Morikawa, T., and Singh, S. (2016). "Sea Lane Security of Oil and Liquefied Natural Gas in the East Asia Summit Region," Economic Research Institute for ASEAN and East Asia, Jakarta, Indonesia, ERIA research project FY2015 No.14, November 2016. https://think-asia.org/handle/11540/10893.

Kirchner, A., (2019). "Rise of the machines – a legal analysis of seaworthiness in the context of autonomous shipping," M.L. Thesis, Dept. of Law, Lund Univ., City of Lund, Sweden, 2019. [Online]. Available: https://lup.lub.lu.se/student-papers/search/publication/8977227.

Kruse, C. J., Warner, J. E., and Olson, L. E. (2017). A Modal Comparison of Domestic Freight Transportation Effects on the General Public: 2001-2014. Texas A&M Transportation Institute, Center for Ports and Waterways, Houston, TX.

LaDPS&C (2017). Strategic Plan FY 2017-2018 to 2021-2022. Louisiana Department of Public Safety and Corrections, Baton Rouge, LA.

Lalla-Ruiz, E., Shi, X., Vols, S. (2018). "The waterway ship scheduling problem." Transportation Res. Part D, 60, 191-209.

Lambert, J.H., R.A. Jennings, and N.N. Joshi 2006. Integration of risk identification to business process models. Systems Engineering. 9(3):187-198.

Lambert, J.H. and T. Turley 2005. Priority setting for the distribution of localized hazard protection. Risk Analysis. 25(3): 745-752.

Lambert, James H., et al. "Identification, ranking, and management of risks in a major system acquisition." Reliability Engineering & System Safety 72.3 (2001): 315-325.

Larsson, M., Jonsson, M., Warg, F., Karlsson, K. (2016). A data age dependent broadcast forwarding algorithm for reliable platooning applications. *Mobile Information Systems*, 7489873.

Laue, M., Brown, K., Scherrer, P., Keast, R. (2012). Integrated Strategic Asset Management: Frameworks and Dimensions. Third International Engineering Systems Symposium, Delft University of Technology, 18-20 June 2012.

Leveson, N.G., (2004). A new accident model for engineering safer systems. *Safety Science,* 42 (4), 237–270.

Li, Y.-L., Yang, Q., and Chin, K.-S. (2019). "A decision support model for risk management of hazardous materials road transportation based on quality function deployment," Transp. Res. Part D, pp.154-173 vol. 74, Aug. 2019, doi:10.1016/j.trd.2019.07.026.

Lin, S., Gao, J., Koronios, A., Chanana, V. (2007). Developing a data quality framework for asset management in engineering organisations. Int. J. Information Quality, Vol. 1, No. 1, pp. 100-126.

Lin, S., Gao, J., Koronios, A. (2006). Key data quality issues for enterprise asset management in engineering organizations. International Journal of Electronic Business Management, Vol. 96 4, No. 1, pp. 96-110.

Liu, C., Liu, Y., Liu J., and Liu, Z. (2017). "Vulnearability assessment of water transportation system based on entropy theory," in 4th Int. Conf. Transportation Information and Safety, Banff, AB, Canada, August 8-10, 2017, pp. 496-502, doi: 10.1109/ICTIS.2017.8047811.

Liu, P., Yang, R., and Xu, Z. (2019). "Public acceptance of fully automated driving: effects of social trust and risk/benefit perceptions." Risk Analysis, 39(2), 326-341.

MADOC (2015). Strategic Plan 2015-2020. Massachusetts Department of Correction, Boston, MA.

Mair, M., Sitzenfrei, R., Kleidorfer, M., Moderl, M., and Rauch, W. (2012). "GIS-based applications of sensitivity analysis for sewer models." Water Science and Technology, 65(7), 1215-1222.

MARAD (2011). United States Department of Transportation, Maritime Administration, America's Marine Highway: Report to Congress, April 2011. Available: https://maritime.dot.gov/sites/marad.dot.gov/files/docs/intermodal-systems/marine-highways/3051/maradamhreporttocongress.pdf

Marshall, C.S., Sherry, J., Raffa, G., Anderson, G.J., Panneer, S., Pohl D. (2019). Systems, methods and apparatus for self-coordinated drone based digital signage. U.S. Patent Application Publication, US 2019/0051224 A1, February 14, 2019.

Maruschak, L.M., Berzofsky, M., and Unangst, J. (2015) "Medical problems of state and federal prisoners and jail inmates, 2011-2012. U.S. Department of Justice: Bureau of Justice Statistics. Available: https://www.bjs.gov/content/pub/pdf/mpsfpji1112.pdf.

MCE (2019). Business Plan for FY 2019-2021. Maryland Correctional Enterprises, Jessup, MD.

MDOC (MI) (2018). Policy Directive 04.04.120: Tool Control. Michigan Department of Corrections, Lansing, MI.

MDOC (MI) (2019). Strategic Plan January 1, 2019 – December 31, 2022. Michigan Department of Corrections, Lansing, MI.

MDOC (MS) (2019). FY 2019 Annual Report. Mississippi Department of Corrections, Jackson, MS.

MetalCraft. (2019). Motorola RFID Tool Tracking Case Study. https://www.idplate.com/case-studies/motorola-rfid-tool-tracking-case-study.

Mihic, S., Golusin, M., and Mihajovic, M. (2011). "Policy and promotion of sustainable inland waterway transport in Europe – Danube River." Renew. Sustain. Energy Rev., 15, 1801-1809.

Mitchell, G. (2005). "Mapping hazard from urban non-point pollution: a screening model to support sustainable urban drainage planning." Journal of Environmental Management, 74, 1-9.

MN DOC (2014). Policy 201.040: Tool Control. Minnesota Department of Corrections, St. Paul, MN.

MN DOC (2020). Strategic Plan 2020 – 2022. Minnesota Department of Corrections, St. Paul, MN.

MO DOC (2020). Strategic Plan & Initiatives: February 2020 Updates. Missouri Department of Corrections, Jefferson City, MO. Accessed: April 3, 2020, Available: https://doc.mo.gov/about/strategic-plan.

Montewka, J., Ehlers, S., Goerlandt, F., Hinz, T., Tabri, K., Kujala, P. (2014). A framework for risk assessment for maritime transportation systems — A case study for open sea collisions involving RoPax vessels. Reliability Engineering and System Safety, 124, 142-157.

MSC (2017). “Charting the course for success.” Military Sealift Command: Voyage Plan, 2017.

MT DOC (2019a). 2019 Biennial Report. Montana Department of Corrections, Helena, MT.

MT DOC (2019b). Operational Procedure 3.1.14: Tool Control. Montana Department of Corrections, Helena, MT.

Nalepka, J.P., Hinchman, J.L. (2005). Automated aerial refueling: extending the effectiveness of unmanned air vehicles. *AIAA Modeling and Simulation Technologies Conference and Exhibit*, August 15-18, 2005.

NC DPS (2018a). Policy and Procedure, Chapter F, Section .2700: Tool Control. North Carolina Department of Public Safety, Raleigh, NC.

NC DPS (2018b). Strategic Plan 2019-2021. North Carolina Department of Public Safety, Raleigh, NC.

NDCS (2019). 2019-2023 Strategic Plan. Nebraska Department of Correctional Services, Lincoln, NE.

NDOC (2016). Fiscal Years 2014 and 2015 Annual Statistical Report. Nevada Department of Corrections, Carson City, NV.

Nel, C.B.H., Jooste, J.L. (2016). A technologically-driven asset management approach to managing physical assets – a literature review and research agenda for ‘smart’ asset management. South African Journal of Industrial Engineering December 2016 Vol 27(4), pp 50-65.

NFAS (2017). “Definitions for autonomous merchant ships.” Norwegian Forum for Autonomous Ships.

Nguyen, C.T., Saputra, M.Y., Nguyen, V.H., Nguyen, N., Khoa, T.V., Tuan, B.M. (2020). “Enabling and emerging technologies for social distancing: a comprehensive survey.” Cornell University, arXiv:2005.02816.

NHDOC (2018). 2018 Annual Report. New Hampshire Department of Corrections, Concord, NH.

Ni, P., Miao, C., Tang, H., Jiang, M., and Wu, W. (2020). Small foreign object debris detection for millimeter-wave radar based on power spectrum features. Sensors, 20: 2316.

NIST (2018). Internet of Things (IoT) Trust Concerns, National Institute of Standards and Technology, U.S. Department of Commerce, Washington, D.C.

NJDOC (2019). Year in Review 2018. New Jersey Department of Corrections, Trenton, NJ.

NMCD (2013). Strategic Plan for Fiscal Years 2015 through 2018. New Mexico Corrections Department, Santa Fe, NM.

NOAA (2019). United States Coast Pilot 7, Pacific Coast: California, Oregon, Washington, Hawaii and Pacific Islands, United States Department of Commerce, National Oceanic and Atmospheric Administration, 51st ed.

NY State Assembly (2018). 2018 Annual Report: Standing Committee on Correction. New York State Assembly, Albany, NY.

ODOC (2018). Operations Memorandum OP-040107: Tool Control Standards. Oklahoma Department of Corrections, Oklahoma City, OK.

OFR (2013). United States Code of Federal Regulations, Title 33, Chapter I, Subchapter P, Part 168, Escort Requirements for Certain Tankers. Available: https://www.ecfr.gov/cgi-bin/text-idx?SID=b4737cd71c613add8ff8eec36b6f776b&mc=true&node=pt33.2.168&rgn=div5

Okello, D.R.O., and Gilson, L. (2015). "Exploring the influence of trust relationships on motivation in the health sector: a systemic review." Human Resources for Health, 13, doi: 10.11886/s12960-015-0007-5.

Oliveira, T., Alhinho, M., Rita, P., and Dhillon, G. (2017). "Modelling and testing consumer trust dimensions in e-commerce." Computers in Human Behavior, 71, 153-164.

OR DOC (2016). Policy: 40.1.19, Tool Control. Oregon Department of Corrections, Salem, OR.

OR DOC (2019). Agency Summary, Agency Request Budget: 2019-2021. Oregon Department of Corrections, Salem, OR. Accessed: April 3, 2020. Available: https://www.oregon.gov/doc/divisions-and-units/Documents/agency-summary-ARB-19-2021.pdf.

Paaske, Stephanie, et al. "The benefits and barriers to RFID technology in healthcare." On-Line Journal of Nursing Informatics 21.2 (2017).

PA DOC (2017). Pennsylvania Department of Corrections: Overview. Pennsylvania Department of Corrections, Harrisburg, PA. Accessed: April 3, 2020. Available: https://www.cor.pa.gov/About%20Us/Documents/Overview.pdf.

Patterson Jr., J. (2008). "Foreign object debris (FOD) detection research." International Airport Review, 2008(2): 22-27.

Pavitra, J., Clarke, J. (2019). Landing a fixed-wing UAV on a moving platform: a pseudospectral optimal control approach. *AIAA Aviation Forum*, June 17-21, 2019.

Port of Jacksonville (2019). Port of Jacksonville Annual Report 2018/2019. Available at: https://www.jaxport.com/wp-content/uploads/2020/04/Annual-report-2019_web_comp.pdf

Port of Jacksonville (2018). Port of Jacksonville Liquefied Natural Gas Fact Sheet. Available at: https://www.jaxport.com/sites/default/files/images/JAXPORT%20LNG%20Booklet.pdf

Port of Stockton (2018). Port of Stockton 2018 Annual Report. Available at: http://online.anyflip.com/vzeli/wklm/mobile/index.html.

Port of Virginia (2020). Statistics provided by Daniel C. Hendrickson, Vice President for Asset Management and Special Projects, April 21, 2020.

Port of Virginia (2017). The Port of Virginia 2065 Master Plan Executive Summary, Norfolk, VA.

Port of Virginia (2016). The Port of Virginia, Port of Richmond Master Plan, January 2016, Norfolk, VA.

Quenum, A., H. Thorisson, D. Wu, and J.H. Lambert. 2019. Resilience of business strategy to emergent and future conditions. Journal of Risk Research. 19pp.

RAND (2006). Maritime Terrorism, Risk and Liability. The RAND Corporation, Center for Terrorism Risk Management Policy, Santa Monica, CA.

Rasmussen, J. (1997). Risk management in a dynamic society: a modelling problem. *Safety Science*, 27 (2/3), 183–213.

Reason, J. (1998). "Achieving a safe culture: theory and practice." Work & Stress, 12(3), 293-306.

Reason, J., (1990). *Human Error*. New York: Cambridge University Press.

Rodseth, O.J., Nordahl, H., and Hoem, A. (2018). "Characterization of autonomy in merchant ships," in 2018 Oceans – MTS/IEEE Kobe Techno-Oceans (OTO), Kobe, Japan, doi: 10.1109/OCEANSKOBE.2018.8559061.

Roeleven, D., Kok, M., Stipdonk, H. L., and de Vries, W. A. (1995). "Inland waterway transport: modelling the probability of accidents." Safety Sci., 19, 191-202.

Rogerson, E.C. and J.H. Lambert 2012. Prioritizing risk via several expert perspectives with application to airport runway safety. Reliability Engineering and System Safety. 103: 22-34.

Saberi, A.K., Vissers, J., and Benders, F.P.A. (2019). "On the impact of early design decisions on quality attributes of automated driving systems," in 2019 IEEE Int. Syst. Conf., Orlando, FL, USA, doi: 10.1109/SYSCON.8836917.

Sadatsafavi, H., Kim, A. A., Anderson, S. D., and Bishop, P. (2019). "Scenario planning application in U.S. highway transportation industry." J. Infrastruct. Syst., 25(2), 10.1061/(ASCE)IS.1943-555X.0000474.

SCDC (2018). Agency Accountability Report: Fiscal Year 201-2018. South Carolina Department of Corrections, Columbia, SC.

SD DOC (2018). FY2018 Annual Report. South Dakota Department of Corrections, Pierre, SD.

Seal, A., Bhattacharya, S., and Mukherjee, A. (2019). "Fog computing for real-time accident identification and relaed congestion control," in 2019 IEEE Int. Syst. Conf., Orlando, FL, USA, doi: 10.1109/SYSCON.2019.8836965.

Sherpa, A.M., Koottatep, T., Zurbrugg, C., and Cisse, G., (2014). “Vulnerability and adaptability of sanitation systems to climate change.” Journal of Water and Climate Change, 5(4), 487-495.

Siau, K., and Wang, W. (2018). “Building trust in artificial intelligence, machine learning, and robotics.” Cutter Business Technology Journal, (31)2, 47-53.

Siegel, R.S., Welch S.C., Barfield, J.R. Jr. (2016). Method and system for drone deliveries to vehicles in route. U.S. Patent Application Publication, US 9,494,937 B2, November 15, 2016.

Siegrist, M. (2019). “Trust and risk perception: a critical review of the literature.” Risk Analysis, doi: 10.1111/risa.13325.

Sippl, C., Bock, F., Lauer, C., Heinz, A., Neumayer, T., and German, R. (2019). “Scenario-based systems engineering: an approach towards automated driving function development,” in 2019 IEEE Int. Syst. Conf., Orlando, FL, USA, doi: 10.1109/SYSCON.2019.8836763.

Sørensen, A.J., (2014). Dynamic Positioning Control Systems for Ships and Underwater Vehicles. *Encyclopedia of Systems and Control*, London: Springer-Verlag

St. Johns Bar Pilot Association (2016). https://jaxpilots.com/facts/

Steward D., 2017. Critical elements of vehicle-to-grid (V2G) economics. National Renewable Energy Laboratory. Denver, CO.

Su, L., Qin, X-J., Liu, Z.-L., and Zhang, Z. (2019). “Intelligent collision avoidance decision for single ship considering ship maneuverability,” in 2019 9th Int. Conf. Information Science and Technology, Hulunbuir, China, pp. 164-168, doi: 10.1109/ICIST.2019.8836732.

Swedberg, C. (2008). Holt Cat Markets RFID for Tool Tracking. RFID Journal. https://www.rfidjournal.com/articles/view?4475

Teng, K., S.A. Thekdi, and J.H. Lambert 2013. Risk and safety program performance evaluation and business process modeling. IEEE Transactions on Systems, Man, and Cybernetics: Part A. 42(6): 1504-1513.

Teng, K., S.A. Thekdi, and J.H. Lambert 2012. Identification and evaluation of priorities in the business process of a risk or safety organization. Reliability Engineering and System Safety. 99: 74-86.

TDCJ (2019). Agency Strategic Plan for Fiscal Years 2019-2023. Texas Department of Criminal Justice, Austin, TX.

TDOC (2019). Annual Report FY 2019. Tennessee Department of Correction, Nashville, TN.

Thekdi, S.A., and Lambert, J.H. (2015). “Integrated risk management of safety and development on transportation corridors,” Reliab. Eng. Syst. Saf., vol. 138, pp. 1-12, Jan. 2015, doi: 10.1016/j.ress.2014.11.015.

Thigpen, E.B., Stewart, M.A., Boyer, R.L., Fougere, P. (2017). Dynamic positioning system (DPS) risk analysis using probabilistic risk assessment (PRA). *Marine Technology Society Dynamic Positioning Conference*, Houston, TX, October 10–11.

ThingMagic. (2009). Greenville Hospital Deploys Integrated RFID Solution for Operating Room Asset Tracking. http://jamisondoor.com/product-families/deleted-products/about/case-studies/ThingMagic_GreenvilleHospital_CaseStudy_3.2009.pdf

Thorisson, H., and Lambert, J.H., (2017). "Multiscale identification of emergent and future conditions along corridors of transportation networks," Reliab. Eng. Syst. Saf., vol. 167, pp. 255-263, Jun. 2017, doi: 10.1016/j.ress.2017.06.005.

Thorisson, H., Hendrickson, D.C., Polmateer, T.L, and Lambert, J.H., (2019). "Disaggregating uncertainties in operations analysis of intermodal logistics systems." ASCE Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering, 5, 011007-1-10.

Thorisson, H., Pennetti, C.A., Andrews, D.J., Hendrickson, D.A., Polmateer, T.L., and Lambert, J.H. (2019). "Systems modeling and optimization of container ship berthing with various enterprise risks." 2019 IEEE International Systems Conference, Orlando, FL.

Torres-Matallana, J.A., Leopold, U., Klepiszewski, K., and Heuvelink, G.B.M. (2018). "EmiStatR: a simplified and scalable urban water quality model for simulation of combined sewer overflows." Water, 10, 782.

Tran, N. K. and Haasis, H. D. (2015). "An empirical study of fleet expansion and growth of ship size in container liner shipping." Int. J. Production Economics, 159, 241-253.

Trucco, P., Cagno, E., Ruggeri, F., Grande, O. (2008). A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation. Reliability Engineering and System Safety, 93, 823-834.

Tsukerman, A., Weiss, M., Shima, T. (2018). Optimal rendezvous guidance laws with application to civil autonomous aerial refueling. *Journal of Guidance, Control, and Dynamics*, 41(5), 1167-1174.

Ugurlu, O., Yildirim, U., and Basar, E. (2015). "Analysis of grounding accidents caused by human error." Journal of Marine Science and Technology, 23(5), 748-760.

UNCTAD. (2019). *Handbook of Statistics 2019*. United Nations Conference on Trade and Development, United Nations publication, Geneva, Switzerland.

USDOD (2019). United States Department of Defense, Army Doctrine Publication 4-0: Sustainment, July 2019.

USDOD (2019). United States Department of Defense, Joint Publication 4-0: Joint Logistics, February 4, 2019.

USDOT (2019). United States Department of Transportation, Bureau of Transportation Statistics, "Number of vessel calls by type at U.S. ports," https://www.bts.gov/number-vessel-calls-type-us-ports-0, accessed: 2019-09-15.

USDOT. (2019). *Pocket Guide to Transportation 2019*. U. S. Department of Transportation, Bureau of Transportation Statistics, Washington, D.C.

USDOT (2019). United States Department of Transportation, Bureau of Transportation Statistics, "Hazardous materials transportation incidents and property damage," https://www.bts.gov/hazardous-materials-transportation-incidents-and-property-damage, accessed: 2019-09-15.

USDOT. (2018). *Port Performance Freight Statistics Program: Annual Report to Congress, 2018*. U. S. Department of Transportation, Bureau of Transportation Statistics, Washington, D.C.

VADOC (2018). Strategic Plan: FY2018-2022. Virginia Department of Corrections, Richmond, VA.

Valasek, J., Famularo, D., Marwaha, M. (2017). Fault-tolerant adaptive model inversion control for vision-based autonomous air refueling. Journal of Guidance, Control, and Dynamics, 40(6), 1336-1347.

Vidan, P., Grzadzieal, A., and Bosnjak, R. (2012). “Proposal of measures for increasing the safety level of inland navigation.” Trans. Marit. Sci., 2, 85-88. 10.7225/toms.v01.n02.003.

Vidmar, P, and Perkovic, M. (2018). “Safety assessment of crude oil tankers,” Safety Science, vol. 105, pp. 178-191, Feb. 2018, doi: 10.1016/j.ssci.2018.02.009.

WA DOC (2019). 2019-2023 Strategic Plan: Achieving Results. Washington State Department of Corrections, Olympia, WA.

Walton I.A., Diduch K.W., Kim A.H., Lockett S.B., O’Rourke J.M., Sinha T., 2018. Statistical analysis of building energy load profiles to assess site-specific feasibility of demand charge management. IEEE Systems and Information Engineering Design Conference.

Wan, Y., Liu, C., and Qiao, W. (2019). “An safety assessment model of ship collision based on Bayesian network,” in European Navigation Conf., Warsaw, Poland, April 9-12, 2019, doi: 10.1109/EURONAV.2019.8714177.

Wang, C., Chen, Y., and Ray Liu, K.J. (2018). “Game-theoretic cross social media analytic: how Yelp ratings affect deal selection on Groupon.” IEEE Transactions on Knowledge and Data Engineering, 30(5), 908-921.

Wang, Jun, et al. "A coordinated approach for supply-chain tracking in the liquefied natural gas industry." Sustainability 10.12 (2018): 4822.

Wang, Y., Zhang J., Chen X., Chu X., and Yan, X., (2013). “A spatial-temporal forensic analysis for inland-water ship collisions using AIS data.” *Safety Sci*., 57, 187-202.

WDOC (2019). FY 2019-2023 Strategic Plan. Wyoming Department of Corrections, Cheyenne, WY.

Weber, D.J., Anderson, D.J., and Sickbert-Bennett, E.E., (2016). “Effectiveness of ultraviolet devices and hydrogen peroxide systems for terminal room decontamination: focus on clinical trials.” American Journal of Infection Control, 44, e77-e84.

Weber, D.J., Otter, J.A., and Rutala, W.A., (2017). “Can copper-coated surfaces prevent healthcare-associated infections?” Infection Control & Hospital Epidemiology, 38(7), 772-776.

Webler, T. and Tuler, S. (2018). “Four decades of public participation in risk decision making.” Risk Analysis, doi: 10.1111/risa.13250.

White, M.P. and Eiser, J.R. (2006). "Marginal trust in risk managers: building and losing trust following decisions under uncertainty." Risk Analysis, 26(5), 1187-1203.

Wiegmann, D.A., Shappell, S.A. (2003). *A Human Error Approach to Aviation Accident Analysis*: *The Human Factors Analysis and Classification System*. Burlington, VT: Ashgate Publishing Ltd.

Wilson, D.B., Goktogan, A.H., Sukkarieh, S. (2015). Experimental validation of a drogue estimation algorithm for autonomous aerial refueling. *IEEE International Conference on Robotics and Aviation*, May 26-30, 2015.

Wissler, J.E. (2018). "Logistics: the lifeblood of military power." The Heritage Foundation: 2019 Essays, Available: https://www.heritage.org/military-strength-topical-essays/2019-essays/logistics-the-lifeblood-military-power.

Wood, M. D., Collier, Z. A., Bridges, T. S., and Russo Jr., E. J. (2018). "Mental models of navigation safety to inform risk management decisions: case study on the Houston ship channel." ASCE-ASME J. Risk Uncertainty Eng. Syst., Part A: Civ. Eng., 4(3), 10.1061/AJRUA6.0000963.

WTO. (2019). World Trade Statistical Review 2019. World Trade Organization, Geneva, Switzerland.

Wu, D., Wu, J., Wang, R. (2019). An energy -efficient and trust-based formation algorithm for cooperative vehicle platooning. *IEEE International Conference on Computing, Networking and Communications (ICNC): Green Computing, Networking, and Communications.*

WVDOC (2018). Annual Report: FY2018. West Virginia Division of Corrections, Charleston, WV.

Yara (2017). "Yara West Sacramento is newest addition." Yara North America. Available: https://www.yara.us/news-and-events/news/west-sacramento-ribbon-cutting/

Zhang, D., Yan, X., Yang, Z., and Wang, J. (2014). "An accident data-based approach for congestion risk assessment of inland waterways: a Yangtze River case." Journal of Risk and Reliability, 228(2), 176-188.

Zhao, X., Grimes, K.L., Colosi, L.M., and Lung, W. (2019). "Attenuation, transport, and management of estrogens: a review." Chemosphere, 230, 462-478.

Zhou, Q., Wong, Y.D., Xu, H., Thai, V.V., Loh, H.S., and Yuen, K.F. (2017) "An enhanced CREAM with stakeholder-graded protocols for tanker shipping safety application," Safety Science, pp. 140-147, Feb. 2017, doi: 10.1016/j.ssci.2017.02.014.

Zhou, Q. (2014) "A review of sustainable urban drainage systems considering the climate change and urbanization impacts." Water, 6, 976-992.

Zhou, X.-Y., Liu, Z.-J., Wang, F.-W., and Ni, S.-K.(2018). "Collision risk identification of autonomous ships based on the synergy ship domain," in 2018 Chinese Control and Decision Conf., Shenyang, China, pp. 6746-6752, doi: 10.1109/CCDC.2018.8408320.

Appendix A. Raw Data for Demonstrated Corridor Segments

Table A-1. Safety risk factor raw data for Central California - section 1.

	Safety Risk Factors																			
	Channel Width	Channel Depth	Shore-to-Shore Distance	Turning Angle	Vessel Traffic Tug/Tow	Vessel Traffic Cargo	Vessel Traffic Tanker	Vessel Traffic Passenger	Vessel Traffic Fishing	Vessel Traffic Pleasure	Bridges	Commercial Piers	Bouys and Lights	Obstructions	Inflows	Wind Max	Wind Avg	Precip Max	Precip Avg	Fog
Segment	meters	meters	meters	degrees	threshold	threshold	threshold	threshold	threshold	threshold	presence	shore count	count	count	count	knots	knots	cm	cm	% of days
1	220	15.2	1850	0	3	3	3	3	3	3	0	1	5	0	0	33.02	7.49	4.1	0.14	25.5
2	300	14.6	1850	14	3	3	3	3	3	3	1	0	3	0	0	33.02	7.49	4.1	0.14	25.5
3	700	21.6	1850	55	2	3	3	3	3	3	2	1	1	0	0	33.02	7.49	4.1	0.14	25.5
4	1000	22.3	1850	0	2	3	3	3	2	3	1	1	2	0	0	33.02	7.49	4.1	0.14	25.5
5	1000	14.9	1850	59	2	3	3	3	2	2	0	0	0	0	0	33.02	7.49	4.1	0.14	25.5
6	1000	19.5	1850	6	3	3	3	3	2	2	0	0	0	0	0	33.02	7.49	4.1	0.14	25.5
7	640	20.1	1850	16	2	3	3	3	3	3	0	0	1	0	0	33.02	7.49	4.1	0.14	25.5
8	1000	12.8	1850	0	1	3	3	3	3	3	0	0	1	0	0	33.02	7.49	4.1	0.14	25.5
9	170	13.4	1850	0	1	3	3	3	2	2	0	0	1	0	0	33.02	7.49	4.1	0.14	25.5
10	180	11.6	1850	37	2	3	3	3	2	1	1	0	3	0	0	33.02	7.49	4.1	0.14	25.5
11	180	12.5	1850	0	2	3	3	2	2	1	2	0	1	0	0	33.02	7.49	4.1	0.14	25.5
12	170	13.7	1850	0	3	3	3	2	2	2	1	0	1	0	0	33.02	7.49	4.1	0.14	25.5
13	590	19.2	1850	16	2	3	3	2	2	1	0	1	2	0	0	33.02	7.49	4.1	0.14	25.5
14	790	22.9	1850	13	1	3	3	2	3	1	0	0	0	0	0	33.02	7.49	4.1	0.14	25.5
15	1000	14.9	1850	0	2	3	3	2	1	1	0	0	0	0	0	33.02	7.49	4.1	0.14	25.5
16	170	10.7	1850	5	2	3	3	2	1	1	0	0	0	0	0	33.02	7.49	4.1	0.14	25.5
17	170	10.7	1850	11	2	3	3	2	1	1	0	0	1	0	0	33.02	7.49	4.1	0.14	25.5
18	170	10.7	1850	10	2	3	3	2	2	1	0	0	0	0	0	33.02	7.49	4.1	0.14	25.5
19	170	10.7	1850	0	2	3	3	2	2	1	0	0	2	0	0	33.02	7.49	4.1	0.14	25.5
20	170	10.7	1850	0	2	3	3	2	2	1	0	0	2	0	0	33.02	7.49	4.1	0.14	25.5
21	170	10.7	1850	21	2	3	3	2	2	1	0	0	3	0	0	33.02	7.49	4.1	0.14	25.5
22	170	10.7	1850	0	2	3	3	2	2	1	0	0	3	1	0	33.02	7.49	4.1	0.14	25.5
23	170	10.7	1850	8	2	3	3	2	2	1	0	0	1	0	0	33.02	7.49	4.1	0.14	25.5
24	280	10.7	1100	0	2	3	3	2	2	2	0	1	0	1	0	33.02	7.49	4.1	0.14	25.5
25	170	10.7	1800	0	2	3	3	2	2	2	1	2	0	0	1	33.02	7.49	4.1	0.14	25.5
26	230	14.9	750	6	2	3	3	1	3	2	2	2	1	0	0	33.02	7.49	4.1	0.14	25.5
27	440	16.8	780	17	2	3	3	1	3	2	1	1	0	0	0	33.02	7.49	4.1	0.14	25.5
28	480	15.2	1270	22	2	3	3	1	3	2	0	0	1	0	0	33.02	7.49	4.1	0.14	25.5
29	330	18.3	1100	0	2	3	3	1	1	1	0	0	0	0	0	33.02	7.49	4.1	0.14	25.5
30	310	14.3	1850	54	2	3	3	1	1	1	0	2	1	0	0	33.02	7.49	4.1	0.14	25.5
31	80	10.7	1700	28	2	3	3	1	1	1	1	2	1	1	0	33.02	7.49	4.1	0.14	25.5
32	80	10.7	1300	0	2	2	3	1	2	1	2	2	5	0	0	33.02	7.49	4.1	0.14	25.5
33	80	10.7	1800	6	2	2	3	1	1	2	1	1	1	0	0	33.02	7.49	4.1	0.14	25.5
34	100	10.7	1800	8	2	2	3	1	1	2	0	1	1	0	0	33.02	7.49	4.1	0.14	25.5
35	100	10.7	1800	15	2	2	3	1	1	2	0	0	4	2	1	33.02	7.49	4.1	0.14	25.5
36	100	10.7	1500	32	2	2	3	1	1	2	0	0	5	2	1	33.02	7.49	4.1	0.14	25.5
37	100	10.7	1100	8	1	2	3	1	1	2	0	1	2	6	0	33.02	7.49	4.1	0.14	25.5
38	100	10.7	1850	7	1	2	3	1	1	2	0	1	2	4	0	33.02	7.49	4.1	0.14	25.5
39	100	10.7	1850	9	1	2	3	1	1	2	0	0	2	5	0	33.02	7.49	4.1	0.14	25.5
40	100	10.7	1850	14	1	2	3	1	1	2	0	0	3	0	0	33.02	7.49	4.1	0.14	25.5
41	150	13.1	750	5	1	2	3	1	1	2	0	0	0	1	0	33.02	7.49	4.1	0.14	25.5
42	280	13.7	720	16	1	2	3	1	1	2	0	0	0	0	0	33.02	7.49	4.1	0.14	25.5
43	300	14.3	1100	39	1	2	3	1	1	2	0	1	1	1	1	33.02	7.49	4.1	0.14	25.5

Table A-2. Safety risk factor raw data for Central California - section 2.

	Safety Risk Factors																			
	Channel Width	Channel Depth	Shore-to-Shore Distance	Turning Angle	Vessel Traffic Tug/Tow	Vessel Traffic Cargo	Vessel Traffic Tanker	Vessel Traffic Passenger	Vessel Traffic Fishing	Vessel Traffic Pleasure	Bridges	Commercial Piers	Bouys and Lights	Obstructions	Inflows	Wind Max	Wind Avg	Precip Max	Precip Avg	Fog
Segment	meters	meters	meters	degrees	threshold	threshold	threshold	threshold	threshold	threshold	presence	shore count	count	count	count	knots	knots	cm	cm	% of days
44	115	10.7	250	50	2	2	3	1	1	2	1	0	3	0	0	31.2	6.9	2.97	0.11	27.1
45	115	10.7	220	26	2	2	3	1	1	2	1	1	3	0	0	31.2	6.9	2.97	0.11	27.1
46	115	10.7	260	53	2	2	3	1	1	2	1	1	2	0	0	31.2	6.9	2.97	0.11	27.1
47	115	10.7	450	64	2	2	3	1	1	2	1	0	1	0	0	31.2	6.9	2.97	0.11	27.1
48	115	10.7	530	25	1	2	3	1	2	2	1	1	2	0	0	31.2	6.9	2.97	0.11	27.1
49	110	10.7	290	0	1	2	3	1	2	2	1	0	1	0	0	31.2	6.9	2.97	0.11	27.1
50	100	10.7	280	23	1	2	3	1	2	2	2	0	4	0	0	31.2	6.9	2.97	0.11	27.1
51	100	10.7	1240	16	1	2	3	2	2	2	3	0	4	0	1	31.2	6.9	2.97	0.11	27.1
52	150	7.3	900	44	1	2	3	1	2	2	2	0	1	0	1	31.2	6.9	2.97	0.11	27.1
53	150	6.7	880	58	1	2	3	1	2	2	1	0	2	0	0	31.2	6.9	2.97	0.11	27.1
54	150	9.8	480	35	1	2	3	1	2	2	1	0	1	0	0	31.2	6.9	2.97	0.11	27.1
55	150	7.0	700	55	1	2	3	1	3	3	1	0	1	1	1	31.2	6.9	2.97	0.11	27.1
56	150	6.1	590	26	1	2	3	1	3	3	1	0	2	0	1	31.2	6.9	2.97	0.11	27.1
57	150	7.9	510	95	1	2	3	1	3	3	1	0	2	0	0	31.2	6.9	2.97	0.11	27.1
58	150	6.1	570	36	1	2	3	1	1	3	1	0	2	0	0	31.2	6.9	2.97	0.11	27.1
59	200	11.9	480	113	1	2	3	1	1	3	1	0	2	0	1	31.2	6.9	2.97	0.11	27.1
60	200	7.3	530	80	1	2	3	1	3	3	1	0	3	0	0	31.2	6.9	2.97	0.11	27.1
61	230	8.8	620	15	1	2	3	1	2	3	1	0	1	0	0	31.2	6.9	2.97	0.11	27.1
62	170	10.7	680	33	1	2	3	1	1	3	1	0	5	0	2	31.2	6.9	2.97	0.11	27.1
63	150	10.7	670	53	1	2	3	1	1	3	1	0	4	0	0	31.2	6.9	2.97	0.11	27.1
64	200	10.4	720	54	1	2	3	1	1	3	1	0	4	0	0	31.2	6.9	2.97	0.11	27.1
65	60	10.7	170	70	1	2	3	1	1	3	1	0	3	0	0	31.2	6.9	2.97	0.11	27.1
66	60	10.7	150	0	1	2	3	1	1	2	1	0	1	0	1	31.2	6.9	2.97	0.11	27.1
67	60	10.7	170	57	1	2	3	1	1	2	1	0	2	0	0	31.2	6.9	2.97	0.11	27.1
68	60	10.7	160	22	1	2	3	1	3	2	1	0	5	0	0	31.2	6.9	2.97	0.11	27.1
69	60	10.7	150	0	1	2	3	1	3	1	1	0	1	0	0	31.2	6.9	2.97	0.11	27.1
70	60	10.7	230	23	1	2	3	1	1	1	1	0	4	0	0	31.2	6.9	2.97	0.11	27.1
71	60	10.7	180	7	1	2	3	1	1	1	1	0	2	0	0	31.2	6.9	2.97	0.11	27.1
72	60	10.7	210	62	1	2	3	1	1	1	1	0	4	0	0	31.2	6.9	2.97	0.11	27.1
73	60	10.7	190	48	1	2	3	1	1	1	1	0	3	0	0	31.2	6.9	2.97	0.11	27.1
74	60	10.7	130	22	1	2	3	1	1	1	1	0	1	0	0	31.2	6.9	2.97	0.11	27.1
75	60	10.7	120	0	1	2	3	1	1	1	1	0	3	0	0	31.2	6.9	2.97	0.11	27.1
76	60	10.7	130	0	1	2	3	1	3	1	1	0	1	2	1	31.2	6.9	2.97	0.11	27.1
77	60	10.7	130	22	1	2	3	1	3	1	1	0	1	0	0	31.2	6.9	2.97	0.11	27.1
78	60	10.7	110	22	1	2	3	1	3	1	1	1	1	0	1	31.2	6.9	2.97	0.11	27.1

Table A-3. Safety risk factor raw data for Central California - section 3.

	Safety Risk Factors																			
	Channel Width	Channel Depth	Shore-to-Shore Distance	Turning Angle	Vessel Traffic Tug/Tow	Vessel Traffic Cargo	Vessel Traffic Tanker	Vessel Traffic Passenger	Vessel Traffic Fishing	Vessel Traffic Pleasure	Bridges	Commercial Piers	Bouys and Lights	Obstructions	Inflows	Wind Max	Wind Avg	Precip Max	Precip Avg	Fog
Segment	meters	meters	meters	degrees	threshold	threshold	threshold	threshold	threshold	threshold	presence	shore count	count	count	count	knots	knots	cm	cm	% of days
44	225	11.6	1500	9	2	2	1	1	1	1	1	0	1	0	1	33.02	6.76	6.1	0.17	35.3
45	230	11.0	1250	22	2	2	1	1	1	1	1	0	1	0	1	33.02	6.76	6.1	0.17	35.3
46	100	10.7	1050	20	2	2	1	1	1	1	1	0	5	0	2	33.02	6.76	6.1	0.17	35.3
47	100	10.7	880	0	2	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
48	100	10.7	950	40	2	2	1	1	1	1	1	0	5	0	0	33.02	6.76	6.1	0.17	35.3
49	100	10.7	810	0	2	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
50	100	10.7	780	0	2	2	1	1	1	1	1	0	2	1	0	33.02	6.76	6.1	0.17	35.3
51	60	10.7	840	0	2	2	1	1	1	1	1	0	2	0	1	33.02	6.76	6.1	0.17	35.3
52	60	10.7	830	6	2	2	1	1	1	1	1	0	2	0	0	33.02	6.76	6.1	0.17	35.3
53	60	10.7	850	0	1	2	1	1	1	1	1	0	2	0	0	33.02	6.76	6.1	0.17	35.3
54	60	10.7	910	17	1	2	1	1	1	1	1	0	4	1	0	33.02	6.76	6.1	0.17	35.3
55	60	10.7	880	13	1	2	1	1	1	1	1	0	2	0	0	33.02	6.76	6.1	0.17	35.3
56	60	10.7	690	22	1	2	1	1	1	1	2	0	6	0	0	33.02	6.76	6.1	0.17	35.3
57	60	10.7	450	0	1	2	1	1	1	1	3	0	1	0	0	33.02	6.76	6.1	0.17	35.3
58	60	10.7	440	0	1	2	1	1	1	1	2	0	4	0	2	33.02	6.76	6.1	0.17	35.3
59	60	10.7	220	44	1	2	1	1	1	1	1	0	1	0	0	33.02	6.76	6.1	0.17	35.3
60	60	10.7	280	37	1	2	1	1	1	1	1	0	1	0	0	33.02	6.76	6.1	0.17	35.3
61	60	10.7	170	34	1	2	1	1	1	1	1	0	4	0	0	33.02	6.76	6.1	0.17	35.3
62	60	10.7	200	5	1	2	1	1	1	1	1	0	1	0	2	33.02	6.76	6.1	0.17	35.3
63	60	10.7	250	0	1	2	1	1	1	1	1	0	2	1	0	33.02	6.76	6.1	0.17	35.3
64	60	10.7	150	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
65	60	10.7	120	0	1	2	1	1	1	1	1	0	0	2	0	33.02	6.76	6.1	0.17	35.3
66	60	10.7	150	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
67	60	10.7	140	0	1	2	1	1	1	1	1	0	0	1	0	33.02	6.76	6.1	0.17	35.3
68	60	10.7	130	9	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
69	60	10.7	140	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
70	60	10.7	150	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
71	60	10.7	150	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
72	60	10.7	160	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
73	60	10.7	170	0	1	2	1	1	1	1	1	0	0	1	0	33.02	6.76	6.1	0.17	35.3
74	60	10.7	140	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
75	60	10.7	140	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
76	60	10.7	140	0	1	2	1	1	1	1	1	0	0	2	0	33.02	6.76	6.1	0.17	35.3
77	60	10.7	130	18	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
78	60	10.7	120	0	1	2	1	1	1	1	1	0	0	2	0	33.02	6.76	6.1	0.17	35.3
79	60	10.7	140	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
80	60	10.7	140	0	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
81	60	10.7	140	42	1	2	1	1	1	1	1	0	0	0	0	33.02	6.76	6.1	0.17	35.3
82	60	10.7	130	45	1	2	1	1	1	1	1	1	0	0	0	33.02	6.76	6.1	0.17	35.3
83	60	10.7	130	0	1	2	1	1	1	1	1	1	0	0	0	33.02	6.76	6.1	0.17	35.3

Table A-4. Safety risk factor raw data for St. Johns River corridor.

	Safety Risk Factors																			
	Channel Width	Channel Depth	Shore-to-Shore Distance	Turning Angle	Vessel Traffic Tug/Tow	Vessel Traffic Cargo	Vessel Traffic Tanker	Vessel Traffic Passenger	Vessel Traffic Fishing	Vessel Traffic Pleasure	Bridges	Commercial Piers	Bouys and Lights	Obstructions	Inflows	Wind Max	Wind Avg	Precip Max	Precip Avg	Fog
segment	meters	meters	meters	degrees	threshold	threshold	threshold	threshold	threshold	threshold	presence	shore count	count	count	count	knots	knots	cm	cm	% of days
1	170	12	700	8	3	3	2	1	3	3	0	1	1	0	0	38	8.45	3.4	0.2	47.0
2	225	12	820	62	3	3	3	1	3	3	0	1	0	1	0	38	8.45	3.4	0.2	47.0
3	115	12	940	42	3	3	3	1	3	3	0	1	6	3	0	38	8.45	3.4	0.2	47.0
4	120	12	1070	41	3	3	3	1	3	3	0	1	3	1	1	38	8.45	3.4	0.2	47.0
5	120	12	690	0	3	3	3	1	3	3	0	1	2	0	0	38	8.45	3.4	0.2	47.0
6	120	12	660	34	3	3	3	1	3	3	0	1	3	0	1	38	8.45	3.4	0.2	47.0
7	125	12	540	47	3	3	3	2	3	3	0	1	2	0	1	38	8.45	3.4	0.2	47.0
8	125	12	650	10	3	3	3	2	3	3	2	1	2	0	0	38	8.45	3.4	0.2	47.0
9	125	12	510	68	3	3	3	2	3	3	3	1	0	0	0	38	8.45	3.4	0.2	47.0
10	200	12	450	0	3	3	3	2	3	3	2	1	1	1	1	38	8.45	3.4	0.2	47.0
11	140	12	350	0	3	3	3	2	3	3	0	1	2	0	0	38	8.45	3.4	0.2	47.0
12	140	12	350	25	3	3	3	2	3	3	0	0	2	1	1	38	8.45	3.4	0.2	47.0
13	175	12	550	35	3	3	3	2	3	3	0	0	1	0	1	38	8.45	3.4	0.2	47.0
14	175	12	600	53	3	3	3	2	3	3	0	0	1	2	1	35	9.48	3.4	0.2	47.0
15	145	12	770	12	3	3	3	2	3	3	0	0	1	0	1	35	9.48	15	0.3	41.0
16	185	12	580	65	3	3	3	2	3	3	0	1	7	1	1	35	9.48	15	0.3	41.0
17	185	12	470	42	3	3	3	2	3	3	0	1	3	1	0	35	9.48	15	0.3	41.0
18	270	12	430	45	3	3	3	3	3	3	0	1	0	2	0	35	9.48	15	0.3	41.0
19	230	12	670	29	3	3	3	3	3	3	0	0	1	1	0	35	9.48	15	0.3	41.0
20	230	12	530	0	3	3	3	3	3	3	0	1	2	0	0	35	9.48	15	0.3	41.0
21	240	13	470	0	3	3	3	3	3	3	0	1	4	5	0	35	9.48	15	0.3	41.0
22	240	13	1850	0	3	3	3	3	2	3	0	0	2	6	0	35	9.48	15	0.3	41.0
23	240	13	1850	0	2	3	3	3	2	3	0	0	0	0	0	35	9.48	15	0.3	41.0
24	240	13	1850	0	1	3	2	1	2	1	0	0	0	0	0	35	9.48	15	0.3	41.0

Table A-5. Security risk factor raw data for St. Johns River corridor.

	Security Risk Factors						
	Inlets	Civilian Docks	Vessel Traffic Pleasure	Bridges	Shore Cover Type	Shore-to-Shore Distance	Fog
segment	count	shore count	threshold	degrees		meters	% of days
1	0	12	3	0	3	700	47
2	0	12	3	0	3	820	47
3	1	12	3	0	3	940	47
4	2	12	3	0	3	1070	47
5	2	12	3	0	4	690	47
6	2	12	3	0	4	660	47
7	1	12	3	0	4	540	47
8	0	12	3	1	4	650	47
9	1	12	3	2	4	510	47
10	2	12	3	1	4	450	47
11	1	12	3	0	4	350	47
12	3	12	3	0	3	350	47
13	2	12	3	0	3	550	47
14	1	12	3	0	4	600	47
15	3	12	3	0	4	770	41
16	1	12	3	0	4	580	41
17	0	12	3	0	4	470	41
18	1	12	3	0	3	430	41
19	0	12	3	0	4	670	41
20	1	12	3	0	1	530	41
21	0	13	3	0	0	470	41
22	0	13	3	0	0	1850	41
23	0	13	3	0	0	1850	41
24	0	13	1	0	0	1850	41

Table A-6. Safety risk factor raw data for the James River corridor, segments 1-41.

	Safety Risk Factors																			
	Channel Width	Channel Depth	Shore-to-Shore Distance	Turning Angle	Vessel Traffic Tug/Tow	Vessel Traffic Cargo	Vessel Traffic Tanker	Vessel Traffic Passenger	Vessel Traffic Fishing	Vessel Traffic Pleasure	Bridges	Commercial Piers	Bouys and Lights	Obstructions	Inflows	Wind Max	Wind Avg	Precip Max	Precip Avg	Fog
segment	meters	meters	meters	degrees	threshold	threshold	threshold	threshold	threshold	threshold	presence	shore count	count	count	count	knots	knots	cm	cm	% of days
1	55	8	170	30	1	1	1	1	1	1	3	1	1	1	0	38	7.53	5.6	0.31	35
2	55	8	170	60	1	1	1	1	1	1	2	0	0	0	0	38	7.53	5.6	0.31	35
3	55	8	170	66	1	1	1	1	1	1	1	1	1	0	0	38	7.53	5.6	0.31	35
4	55	8	170	85	1	1	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
5	55	8	190	51	1	1	1	1	1	1	1	1	1	2	0	38	7.53	5.6	0.31	35
6	55	8	170	147	1	1	1	1	1	1	1	1	1	1	0	38	7.53	5.6	0.31	35
7	55	8	140	7	1	1	1	1	1	1	2	0	0	0	0	38	7.53	5.6	0.31	35
8	55	8	190	67	1	1	1	1	1	1	3	0	1	1	2	38	7.53	5.6	0.31	35
9	55	8	220	14	1	1	1	1	1	1	2	0	2	0	0	38	7.53	5.6	0.31	35
10	55	8	120	92	1	1	1	1	1	1	1	0	2	0	1	38	7.53	5.6	0.31	35
11	55	8	240	48	1	1	1	1	1	1	1	0	1	1	0	38	7.53	5.6	0.31	35
12	70	8	220	46	1	1	1	1	1	1	1	0	0	0	1	38	7.53	5.6	0.31	35
13	70	8	130	111	1	1	1	1	1	1	1	0	3	1	1	38	7.53	5.6	0.31	35
14	60	8	690	36	2	1	1	1	1	1	1	0	3	0	0	38	7.53	5.6	0.31	35
15	90	8	350	44	2	1	1	1	1	1	1	0	2	2	1	38	7.53	5.6	0.31	35
16	90	8	450	60	2	2	1	1	1	1	1	1	3	0	1	38	7.53	5.6	0.31	35
17	90	8	1160	14	2	2	1	1	1	1	2	1	2	1	0	38	7.53	5.6	0.31	35
18	90	8	1270	35	2	2	1	1	1	1	3	0	1	0	0	38	7.53	5.6	0.31	35
19	90	8	1850	30	2	2	1	1	1	1	2	0	4	0	0	38	7.53	5.6	0.31	35
20	90	8	830	17	2	2	1	1	1	1	1	0	4	0	1	38	7.53	5.6	0.31	35
21	90	8	790	0	2	2	1	1	1	1	1	0	2	0	0	38	7.53	5.6	0.31	35
22	90	8	1070	5	2	2	1	1	1	1	1	0	0	0	2	38	7.53	5.6	0.31	35
23	90	8	1300	37	2	2	1	1	1	1	1	0	4	0	0	38	7.53	5.6	0.31	35
24	90	8	1170	48	2	2	1	1	1	1	1	0	3	0	0	38	7.53	5.6	0.31	35
25	90	7.6	1700	77	2	2	1	1	1	1	1	0	5	0	1	38	7.53	5.6	0.31	35
26	370	6.1	920	19	2	2	1	1	1	1	1	0	1	0	0	38	7.53	5.6	0.31	35
27	260	9.4	460	75	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
28	90	7.6	480	52	2	2	1	1	1	1	1	0	1	0	0	38	7.53	5.6	0.31	35
29	90	7.3	1150	19	2	2	1	1	1	1	1	0	3	0	0	38	7.53	5.6	0.31	35
30	610	6.4	1000	12	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
31	370	10.7	910	57	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
32	330	9.8	490	38	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
33	400	9.1	520	43	2	2	1	1	1	1	1	0	0	1	0	38	7.53	5.6	0.31	35
34	330	7.6	840	27	2	2	1	1	1	1	1	0	1	0	0	38	7.53	5.6	0.31	35
35	700	6.7	1600	15	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
36	240	6.1	1640	25	2	2	1	1	1	1	1	0	2	1	1	38	7.53	5.6	0.31	35
37	810	7.6	1180	3	2	2	1	1	1	1	1	0	0	1	0	38	7.53	5.6	0.31	35
38	90	7.6	1120	0	2	2	1	1	1	1	1	0	0	0	1	38	7.53	5.6	0.31	35
39	90	7.6	1850	0	2	2	1	1	1	1	1	0	2	0	1	38	7.53	5.6	0.31	35
40	90	7.6	1850	36	2	2	1	1	1	1	1	0	3	0	1	38	7.53	5.6	0.31	35
41	90	7.6	1850	0	2	2	1	1	1	1	1	0	2	0	1	38	7.53	5.6	0.31	35

Table A-7. Safety risk factor raw data for the James River corridor, segments 42-82.

	Safety Risk Factors																			
	Channel Width	Channel Depth	Shore-to-Shore Distance	Turning Angle	Vessel Traffic Tug/Tow	Vessel Traffic Cargo	Vessel Traffic Tanker	Vessel Traffic Passenger	Vessel Traffic Fishing	Vessel Traffic Pleasure	Bridges	Commercial Piers	Bouys and Lights	Obstructions	Inflows	Wind Max	Wind Avg	Precip Max	Precip Avg	Fog
segment	meters	meters	meters	degrees	threshold	threshold	threshold	threshold	threshold	threshold	presence	shore count	count	count	count	knots	knots	cm	cm	% of days
42	90	7.6	1850	0	2	2	1	1	1	1	1	0	0	0	1	38	7.53	5.6	0.31	35
43	90	7.6	1850	0	2	2	1	1	1	1	1	0	2	0	1	38	7.47	10.7	0.37	35
44	90	7.62	1850	0	2	2	1	1	1	1	1	0	2	0	0	38	7.47	10.7	0.37	35
45	90	7.62	1650	56	2	2	1	3	1	2	1	1	2	0	0	38	7.47	10.7	0.37	35
46	500	7.62	1850	12	2	2	1	3	1	2	1	0	1	0	1	38	7.47	10.7	0.37	35
47	500	7.0104	1850	36	2	2	1	1	1	2	1	1	0	0	0	38	7.47	10.7	0.37	35
48	90	7.62	1850	31	2	2	1	1	1	2	1	0	3	0	0	38	7.47	10.7	0.37	35
49	90	7.62	1850	28	2	2	1	1	1	2	1	0	3	0	0	38	7.47	10.7	0.37	35
50	90	7.62	1850	0	2	2	1	1	1	2	1	0	4	0	0	38	7.47	10.7	0.37	35
51	90	7.62	1850	29	2	2	1	1	1	2	1	0	1	0	1	38	7.47	10.7	0.37	35
52	90	7.62	1850	0	1	2	1	1	1	1	1	0	1	0	0	38	7.47	10.7	0.37	35
53	90	7.62	1850	48	1	2	1	1	1	1	1	0	4	0	0	38	7.47	10.7	0.37	35
54	90	7.62	1850	7	1	2	1	1	1	1	1	0	4	0	0	38	7.47	10.7	0.37	35
55	90	7.62	1850	25	1	2	1	1	1	1	1	0	2	0	0	38	7.47	10.7	0.37	35
56	90	7.62	1850	23	1	2	1	1	1	1	1	0	4	0	1	38	7.47	10.7	0.37	35
57	90	7.62	1850	21	1	2	1	1	1	1	1	1	4	2	0	38	7.47	10.7	0.37	35
58	590	8.8392	1850	0	2	2	1	1	1	2	1	1	0	0	0	38	7.47	10.7	0.37	35
59	590	9.7536	1850	30	2	2	1	1	1	2	1	1	0	1	0	38	7.47	10.7	0.37	35
60	90	7.62	1850	0	2	2	1	1	1	2	1	1	3	0	0	38	7.47	10.7	0.37	35
61	90	7.62	1850	0	2	2	1	1	1	2	1	0	2	1	0	38	7.47	10.7	0.37	35
62	90	7.62	1850	0	2	2	1	1	1	2	1	0	2	1	0	38	7.47	10.7	0.37	35
63	90	7.62	1850	0	2	2	1	1	1	2	1	0	2	0	0	38	7.47	10.7	0.37	35
64	90	7.62	1850	60	2	2	1	1	1	2	1	0	4	1	1	38	7.47	10.7	0.37	35
65	90	7.62	1850	40	1	2	1	1	1	1	1	0	4	0	1	38	7.47	10.7	0.37	35
66	480	6.4008	1850	0	1	2	1	1	1	1	1	0	0	0	1	38	7.47	10.7	0.37	35
67	480	8.2296	1850	4	2	2	1	1	1	1	1	0	1	1	1	38	7.47	10.7	0.37	35
68	420	9.4488	1850	0	2	2	1	1	1	2	1	0	1	0	0	38	7.47	10.7	0.37	35
69	400	9.144	1850	4	2	2	1	1	1	2	1	0	2	2	0	38	7.47	10.7	0.37	35
70	590	10.0584	1850	2	2	2	1	1	1	2	2	0	0	1	0	38	7.47	10.7	0.37	35
71	110	7.9248	1850	26	2	2	1	1	1	2	3	0	0	1	0	38	7.47	10.7	0.37	35
72	830	10.0584	1850	0	2	1	1	1	1	2	2	1	0	1	0	38	7.47	10.7	0.37	35
73	240	15.24	1850	0	2	1	2	1	2	2	1	1	0	5	0	36	8.89	5.5	0.31	28
74	240	15.24	1850	12	3	3	2	1	2	2	1	1	1	0	0	36	8.89	5.5	0.31	28
75	240	15.24	1850	36	2	3	2	1	3	1	1	1	4	1	0	36	8.89	5.5	0.31	28
76	185	6.096	1850	25	1	1	2	1	2	1	1	1	2	0	0	36	8.89	5.5	0.31	28
77	185	6.096	1850	18	1	1	2	1	2	1	1	0	0	0	0	36	8.89	5.5	0.31	28
78	185	6.4008	1850	0	1	1	2	1	2	1	1	0	0	0	0	36	8.89	5.5	0.31	28
79	370	15.24	1850	94	3	3	3	3	3	3	1	1	4	0	0	36	8.89	5.5	0.31	28
80	370	15.24	1850	8	3	3	3	3	3	3	1	1	2	0	0	36	8.89	5.5	0.31	28
81	240	15.24	1710	0	3	3	3	3	3	3	1	0	4	0	1	36	8.89	5.5	0.31	28
82	240	15.24	1710	0	3	3	3	3	3	3	1	1	4	0	0	36	8.89	5.5	0.31	28

Table A-8. Security risk factor raw data for the James River corridor, segments 1-41.

	Security Risk Factors						
	Inlets	Civilian Docks	Vessel Traffic Pleasure	Bridges	Shore Cover Type	Shore-to-Shore Distance	Fog
segment	count	shore count	threshold	degrees		meters	% of days
1	0	0	1	3	4	170	35
2	1	0	1	2	4	170	35
3	1	0	1	1	4	170	35
4	0	1	1	1	4	170	35
5	0	1	1	1	4	190	35
6	1	1	1	1	3	170	35
7	2	0	1	2	4	140	35
8	2	0	1	3	4	190	35
9	2	1	1	2	4	220	35
10	2	1	1	1	4	120	35
11	1	1	1	1	4	240	35
12	1	0	1	1	4	220	35
13	2	0	1	1	4	130	35
14	1	0	1	1	4	690	35
15	1	1	1	1	4	350	35
16	1	0	1	1	4	450	35
17	0	1	1	2	4	1160	35
18	1	2	1	3	3	1270	35
19	1	2	1	2	4	1850	35
20	0	1	1	1	3	830	35
21	1	1	1	1	4	790	35
22	0	0	1	1	4	1070	35
23	0	0	1	1	4	1300	35
24	0	1	1	1	4	1170	35
25	1	2	1	1	4	1700	35
26	0	1	1	1	4	920	35
27	1	0	1	1	4	460	35
28	1	0	1	1	4	480	35
29	0	1	1	1	4	1150	35
30	1	1	1	1	4	1000	35
31	0	1	1	1	4	910	35
32	1	1	1	1	4	490	35
33	0	1	1	1	4	520	35
34	0	1	1	1	3	840	35
35	0	0	1	1	2	1600	35
36	1	2	1	1	3	1640	35
37	0	2	1	1	3	1180	35
38	0	1	1	1	3	1120	35
39	1	1	1	1	3	1850	35
40	1	1	1	1	4	1850	35
41	1	0	1	1	4	1850	35

Table A-9. Security risk factor raw data for the James River corridor, segments 42-82.

	Security Risk Factors						
	Inlets	Civilian Docks	Vessel Traffic Pleasure	Bridges	Shore Cover Type	Shore-to-Shore Distance	Fog
segment	count	shore count	threshold	degrees		meters	% of days
42	1	2	1	1	4	1850	35
43	0	1	1	1	4	1850	35
44	0	2	1	1	4	1850	35
45	0	1	2	1	3	1650	35
46	1	0	2	1	3	1850	35
47	0	1	2	1	3	1850	35
48	0	1	2	1	4	1850	35
49	1	0	2	1	4	1850	35
50	1	0	2	1	4	1850	35
51	0	0	2	1	4	1850	35
52	1	1	1	1	3	1850	35
53	0	1	1	1	3	1850	35
54	0	0	1	1	3	1850	35
55	0	0	1	1	1	1850	35
56	1	0	1	1	1	1850	35
57	1	0	1	1	1	1850	35
58	1	0	2	1	1	1850	35
59	0	1	2	1	4	1850	35
60	1	1	2	1	3	1850	35
61	0	1	2	1	3	1850	35
62	0	1	2	1	3	1850	35
63	1	1	2	1	3	1850	35
64	1	2	2	1	3	1850	35
65	1	2	1	1	3	1850	35
66	1	1	1	1	3	1850	35
67	2	2	1	1	3	1850	35
68	0	2	2	1	3	1850	35
69	0	2	2	1	3	1850	35
70	0	1	2	2	3	1850	35
71	0	1	2	3	3	1850	35
72	0	0	2	2	1	1850	35
73	0	0	2	1	1	1850	28
74	2	0	2	1	3	1850	28
75	0	0	1	1	1	1850	28
76	0	0	1	1	1	1850	28
77	0	0	1	1	1	1850	28
78	0	0	1	1	1	1850	28
79	0	0	3	1	1	1850	28
80	0	0	3	1	1	1850	28
81	1	1	3	1	3	1710	28
82	0	1	3	1	3	1710	28

Table A-10. Assessment of segments s.01 – s.30 against factors f.01 – f.15: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.01 - s.30 Factors: f.01 - f.15 Safety Factors	seg.01 - Richmond - RMT/VVM Bridge	seg.02 - CC/HC - Bellwood	seg.03 - CC/HC - Carbonic Ind	seg.04 - CC/HC - Chaffin Bluff	seg.05 - CC/HC - Canaday Logistics	seg.06 - CC/HC - Chesterfield Power	seg.07 - CC/HC - Hatcher Island	seg.08 - CC/HC - Varina-Enon Bridge	seg.09 - CC/HC - Varina Farm	seg.10 - CC/HC - Jones Neck Cutoff	seg.11 - CC/HC - Amazon FC	seg.12 - CC/HC - Dupont Teijin Films	seg.13 - CC/CCC - Turkey Island	seg.14 - CC/CCC - Bermuda Hundred	seg.15 - Hope/CCC - West	seg.16 - Hope/CCC - East	seg.17 - PGC/CCC - Eppes Island	seg.18 - PGC/CCC - BHM Bridge	seg.19 - PGC/CCC - Indian Point	seg.20 - PGC/CCC - Tar Bay	seg.21 - PGC/CCC - Coggins Point	seg.22 - PGC/CCC - Maycocks Point	seg.23 - PGC/CCC - Bucklers Point	seg.24 - PGC/CCC - Wilcox Wharf	seg.25 - PGC/CCC - Windmill Point	seg.26 - PGC/CCC - Threemile Reach	seg.27 - PGC/CCC - Weyanoke Pt West	seg.28 - PGC/CCC - Weyanoke Pt East	seg.29 - PGC/CCC - Weyanoke Shoal	seg.30 - PGC/CCC - Sevenmile Reach
the factor f.xx is addressed by this segment																														
f.01 - Channel width	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	◐	●	●	○
f.02 - Channel depth	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.03 - Shore-to-shore distance (safety)	●	●	●	●	●	●	●	●	●	●	●	●	●	◐	●	●	○	○	○	◐	◐	○	○	○	○	◐	●	●	○	○
f.04 - Turning angle	○	◐	●	●	◐	●	○	●	○	●	◐	◐	●	◐	◐	◐	○	◐	○	○	○	○	◐	◐	●	○	●	◐	○	○
f.05 - Vessel traffic tug/tow	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.06 - Vessel traffic cargo	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.07 - Vessel traffic tanker	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.08 - Vessel traffic passenger	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.09 - Vessel traffic fishing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.10 - Vessel traffic pleasure (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.11 - Bridges (safety)	●	◐	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	○	○	○	○
f.12 - Commercial pier	◐	○	◐	○	◐	◐	○	○	○	○	○	○	○	○	○	◐	◐	○	○	○	○	○	○	○	○	○	○	○	○	○
f.13 - Buoys and Lights	○	○	○	○	○	○	○	○	◐	◐	○	○	●	●	◐	●	◐	○	●	●	◐	○	●	●	●	○	○	○	●	○
f.14 - Obstructions	○	○	○	○	◐	○	○	○	○	○	○	○	○	○	◐	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.15 - Inflows	○	○	○	○	○	○	○	●	○	◐	○	◐	◐	○	◐	◐	○	○	○	◐	○	●	○	○	◐	○	○	○	○	○

Table A-11. Assessment of segments s.31 – s.60 against factors f.01 – f.15: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.31 - s.60 Factors: f.01 - f.15 Safety Factors	seg.31 - PGC/CCC - Milton	seg.32 - PGC/CCC - Sturgeon Point	seg.33 - PGC/CCC - Bachelor Point	seg.34 - PGC/CCC - Brandon Point	seg.35 - PGC/CCC - Brandon	seg.36 - SC/CCC - Chippokes Creek	seg.37 - SC/CCC - Claremont	seg.38 - SC/CCC - Sandy Point	seg.39 - SC/CCC - Chickahominy West	seg.40 - SC/CCC - Chickahominy Center	seg.41 - SC/JCC - Chickahominy East	seg.42 - SC/JCC - Two Rivers CC	seg.43 - SC/JCC - Segment 43	seg.44 - SC/JCC - Segment 44	seg.45 - SC/JCC - JS Ferry Settlement	seg.46 - SC/JCC - JS Ferry	seg.47 - SC/JCC - JS Ferry Scotland	seg.48 - SC/JCC - Cobham Wharf	seg.49 - SC/JCC - Cobham Bay	seg.50 - SC/JCC - Surry Nuclear Power	seg.51 - SC/JCC - Hog Island 1	seg.52 - SC/JCC - Hog Island 2	seg.53 - SC/JCC - Hog Island 3	seg.54 - SC/JCC - Hog Island 4	seg.55 - SC/JCC - Hog Island 5	seg.56 - SC/JCC - Hog Island 6	seg.57 - SC/NN - Fort Eustis	seg.58 - SC/NN - Felker Army Airfield	seg.59 - IWC/NN - Reserve Fleet	seg.60 - IWC/NN - Mulberry Island 1
the factor f.xx is addressed by this segment																														
f.01 - Channel width	○	○	○	○	○	◐	○	●	●	●	●	●	●	●	●	○	○	●	●	●	●	●	●	●	●	●	●	○	○	●
f.02 - Channel depth	○	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.03 - Shore-to-shore distance (safety)	◐	●	◐	◐	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.04 - Turning angle	◐	◐	◐	○	○	○	○	○	○	◐	○	○	○	○	◐	○	◐	◐	○	○	○	○	◐	○	○	○	○	○	○	○
f.05 - Vessel traffic tug/tow	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	○	○	○	○	○	○	◐	◐	◐
f.06 - Vessel traffic cargo	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.07 - Vessel traffic tanker	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.08 - Vessel traffic passenger	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.09 - Vessel traffic fishing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.10 - Vessel traffic pleasure (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	◐	◐	○	○	○	○	○	○	◐	◐	◐
f.11 - Bridges (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.12 - Commercial pier	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	○	◐	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐
f.13 - Buoys and Lights	○	○	○	○	○	○	○	○	◐	●	◐	○	◐	◐	◐	○	○	●	●	●	○	○	●	●	◐	●	●	○	○	●
f.14 - Obstructions	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	○	○	○
f.15 - Inflows	○	○	○	○	○	◐	○	◐	◐	◐	◐	◐	◐	○	○	◐	○	○	○	○	◐	○	○	○	○	◐	○	○	○	○

Table A-12. Assessment of segments s.61 – s.82 against factors f.01 – f.15: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.61 - s.82 Factors: f.01 - f.15 Safety Factors	seg.61 - IWC/NN - Mulberry Island 2	seg.62 - IWC/NN - Mulberry Island 3	seg.63 - IWC/NN - Mulberry Island 4	seg.64 - IWC/NN - Warwick River East	seg.65 - IWC/NN - Warwick River West	seg.66 - IWC/NN - Segment 66	seg.67 - IWC/NN - Pagan River	seg.68 - IWC/NN - Segment 68	seg.69 - IWC/NN - Segment 69	seg.70 - IWC/NN - Segment 70	seg.71 - IWC/NN - James River Bridge	seg.72 - IWC/NN - NN Shipbuilding 1	seg.73 - IWC/NN - NN Shipbuilding 2	seg.74 - Suff/NN - NN Marine Terminal	seg.75 - Suff/NN - MM Bridge Tunnel	seg.76 - Port/NN - Craney Island West	seg.77 - Port/NN - Craney Island North	seg.78 - Port/Norf - Harbor Reach Ent	seg.79 - Port/Norf - Norfolk Naval Sta	seg.80 - Port/Norf - NIT North	seg.81 - Port/Norf - NIT South	seg.82 - Port/Norf - VIG
the factor f.xx is addressed by this segment																						
f.01 - Channel width	●	●	●	●	●	○	○	○	○	○	◐	○	◐	◐	◐	◐	◐	◐	○	○	◐	◐
f.02 - Channel depth	◐	◐	◐	◐	◐	◐	◐	◐	◐	○	◐	○	○	○	○	◐	◐	◐	○	○	○	○
f.03 - Shore-to-shore distance (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.04 - Turning angle	○	○	○	◐	◐	○	○	○	○	○	○	○	○	○	◐	○	○	○	●	○	○	○
f.05 - Vessel traffic tug/tow	◐	◐	◐	◐	○	○	◐	◐	◐	◐	◐	◐	◐	●	◐	○	○	○	●	●	●	●
f.06 - Vessel traffic cargo	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	○	○	●	●	○	○	○	●	●	●	●
f.07 - Vessel traffic tanker	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	◐	●	●	●	●
f.08 - Vessel traffic passenger	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●
f.09 - Vessel traffic fishing	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	●	◐	◐	◐	●	●	●	●
f.10 - Vessel traffic pleasure (safety)	◐	◐	◐	◐	○	○	○	◐	◐	◐	◐	◐	◐	◐	○	○	○	○	●	●	●	●
f.11 - Bridges (safety)	○	○	○	○	○	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	○	○	○
f.12 - Commercial pier	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	○	○	◐	◐	○	◐
f.13 - Buoys and Lights	◐	◐	◐	●	●	○	○	○	○	○	○	○	○	○	◐	○	○	○	◐	○	◐	◐
f.14 - Obstructions	○	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
f.15 - Inflows	○	○	○	◐	◐	◐	◐	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	○

Table A-13. Assessment of segments s.01 – s.30 against factors f.16 – f.29: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.01 - s.30 Factors: f.16 - f.29 Security Factors Sea-State Factors	seg.01 - Richmond - RMT/VVM Bridge	seg.02 - CC/HC - Bellwood	seg.03 - CC/HC - Carbonic Ind	seg.04 - CC/HC - Chaffin Bluff	seg.05 - CC/HC - Canaday Logistics	seg.06 - CC/HC - Chesterfield Power	seg.07 - CC/HC - Hatcher Island	seg.08 - CC/HC - Varina-Enon Bridge	seg.09 - CC/HC - Varina Farm	seg.10 - CC/HC - Jones Neck Cutoff	seg.11 - CC/HC - Amazon FC	seg.12 - CC/HC - Dupont Teijin Films	seg.13 - CC/CCC - Turkey Island	seg.14 - CC/CCC - Bermuda Hundred	seg.15 - Hope/CCC - West	seg.16 - Hope/CCC - East	seg.17 - PGC/CCC - Eppes Island	seg.18 - PGC/CCC - BHM Bridge	seg.19 - PGC/CCC - Indian Point	seg.20 - PGC/CCC - Tar Bay	seg.21 - PGC/CCC - Coggins Point	seg.22 - PGC/CCC - Maycocks Point	seg.23 - PGC/CCC - Bucklers Point	seg.24 - PGC/CCC - Wilcox Wharf	seg.25 - PGC/CCC - Windmill Point	seg.26 - PGC/CCC - Threemile Reach	seg.27 - PGC/CCC - Weyanoke Pt West	seg.28 - PGC/CCC - Weyanoke Pt East	seg.29 - PGC/CCC - Weyanoke Shoal	seg.30 - PGC/CCC - Sevenmile Reach
the factor f.xx is addressed by this segment																														
f.16 - Inlets	○	◐	◐	○	○	◐	●	●	●	●	◐	◐	●	◐	◐	◐	○	◐	◐	○	◐	○	○	○	◐	○	◐	◐	○	◐
f.17 - Civilian docks and piers	○	○	○	◐	◐	◐	○	○	◐	◐	◐	○	○	○	◐	○	◐	●	●	◐	◐	○	○	◐	●	◐	○	○	◐	◐
f.18 - Vessel traffic pleasure (security)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.19 - Bridges (security)	●	◐	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	○	○	○	○
f.20 - Shore cover type	●	●	●	●	●	◐	●	●	●	●	●	●	●	●	●	●	●	◐	●	◐	●	●	●	●	●	●	●	●	●	●
f.21 - Shore-to-shore distance (security)	●	●	●	●	●	●	●	●	●	●	●	●	●	◐	●	●	○	○	○	◐	◐	○	○	○	○	◐	●	●	○	○
f.22 - Industrial zoned shores	◐	○	●	●	●	●	◐	○	○	●	○	●	●	●	○	◐	○	○	●	●	●	●	●	○	○	○	○	○	○	○
f.23 - Maintained channels	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	○	◐	◐	○	○	○	○	○	○	○	●	●	●	●	●
f.24 - Wind (maximum)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
f.25 - Wind (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.26 - Precipitation (maximum)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.27 - Precipitation (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.28 - Fog (safety)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.29 - Fog (security)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐

Table A-14. Assessment of segments s.31 – s.60 against factors f.16 – f.29: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.31 - s.60 Factors: f.16 - f.29 Security Factors Sea-State Factors	seg.31 - PGC/CCC - Milton	seg.32 - PGC/CCC - Sturgeon Point	seg.33 - PGC/CCC - Bachelor Point	seg.34 - PGC/CCC - Brandon Point	seg.35 - PGC/CCC - Brandon	seg.36 - SC/CCC - Chippokes Creek	seg.37 - SC/CCC - Claremont	seg.38 - SC/CCC - Sandy Point	seg.39 - SC/CCC - Chickahominy West	seg.40 - SC/CCC - Chickahominy Center	seg.41 - SC/JCC - Chickahominy East	seg.42 - SC/JCC - Two Rivers CC	seg.43 - SC/JCC - Segment 43	seg.44 - SC/JCC - Segment 44	seg.45 - SC/JCC - JS Ferry Settlement	seg.46 - SC/JCC - JS Ferry	seg.47 - SC/JCC - JS Ferry Scotland	seg.48 - SC/JCC - Cobham Wharf	seg.49 - SC/JCC - Cobham Bay	seg.50 - SC/JCC - Surry Nuclear Power	seg.51 - SC/JCC - Hog Island 1	seg.52 - SC/JCC - Hog Island 2	seg.53 - SC/JCC - Hog Island 3	seg.54 - SC/JCC - Hog Island 4	seg.55 - SC/JCC - Hog Island 5	seg.56 - SC/JCC - Hog Island 6	seg.57 - SC/NN - Fort Eustis	seg.58 - SC/NN - Felker Army Airfield	seg.59 - IWC/NN - Reserve Fleet	seg.60 - IWC/NN - Mulberry Island 1
the factor f.xx is addressed by this segment																														
f.16 - Inlets	○	◐	○	○	○	◐	○	○	◐	◐	◐	◐	○	○	○	◐	○	○	◐	◐	○	◐	○	○	○	◐	◐	◐	○	◐
f.17 - Civilian docks and piers	◐	◐	◐	◐	○	●	●	◐	◐	◐	○	●	◐	●	◐	○	◐	◐	○	○	○	◐	◐	○	○	○	○	○	◐	◐
f.18 - Vessel traffic pleasure (security)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	◐	◐	○	○	○	○	○	○	◐	◐	◐
f.19 - Bridges (security)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.20 - Shore cover type	●	●	●	◐	◐	◐	◐	◐	◐	●	●	●	●	●	◐	◐	◐	●	●	●	●	◐	◐	◐	○	○	○	○	●	◐
f.21 - Shore-to-shore distance (security)	◐	●	◐	◐	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.22 - Industrial zoned shores	○	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.23 - Maintained channels	●	●	●	●	●	●	●	◐	○	○	○	○	○	○	◐	●	●	○	○	○	○	○	○	○	○	○	◐	●	●	○
f.24 - Wind (maximum)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
f.25 - Wind (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.26 - Precipitation (maximum)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
f.27 - Precipitation (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.28 - Fog (safety)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.29 - Fog (security)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐

Table A-15. Assessment of segments s.61 – s.82 against factors f.16 – f.29: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.61 - s.82 Factors: f.16 - f.29 Security Factors Sea-State Factors	seg.61 - IWC/NN - Mulberry Island 2	seg.62 - IWC/NN - Mulberry Island 3	seg.63 - IWC/NN - Mulberry Island 4	seg.64 - IWC/NN - Warwick River East	seg.65 - IWC/NN - Warwick River West	seg.66 - IWC/NN - Segment 66	seg.67 - IWC/NN - Pagan River	seg.68 - IWC/NN - Segment 68	seg.69 - IWC/NN - Segment 69	seg.70 - IWC/NN - Segment 70	seg.71 - IWC/NN - James River Bridge	seg.72 - IWC/NN - NN Shipbuilding 1	seg.73 - IWC/NN - NN Shipbuilding 2	seg.74 - Suff/NN - NN Marine Terminal	seg.75 - Suff/NN - MM Bridge Tunnel	seg.76 - Port/NN - Craney Island West	seg.77 - Port/NN - Craney Island North	seg.78 - Port/Norf - Harbor Reach Ent	seg.79 - Port/Norf - Norfolk Naval Sta	seg.80 - Port/Norf - NIT North	seg.81 - Port/Norf - NIT South	seg.82 - Port/Norf - VIG
the factor f.xx is addressed by this segment																						
f.16 - Inlets	○	○	◐	◐	◐	◐	●	○	○	○	○	○	○	●	○	○	○	○	○	○	◐	○
f.17 - Civilian docks and piers	◐	◐	◐	●	●	◐	●	●	●	◐	◐	○	○	○	○	○	○	○	○	○	◐	◐
f.18 - Vessel traffic pleasure (security)	◐	◐	◐	◐	○	○	○	◐	◐	◐	◐	◐	◐	◐	○	○	○	○	●	●	●	●
f.19 - Bridges (security)	○	○	○	○	○	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	○	○	○
f.20 - Shore cover type	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	○	○	◐	○	○	○	○	○	○	◐	◐
f.21 - Shore-to-shore distance (security)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.22 - Industrial zoned shores	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	○	○	○	○	◐	◐	◐
f.23 - Maintained channels	○	○	○	○	○	●	●	●	●	●	●	●	◐	○	○	○	○	○	○	○	○	○
f.24 - Wind (maximum)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
f.25 - Wind (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.26 - Precipitation (maximum)	●	●	●	●	●	●	●	●	●	●	●	●	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.27 - Precipitation (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.28 - Fog (safety)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.29 - Fog (security)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐

Appendix B. Sensitivity Analysis

This appendix documents the results of sensitivity analysis conducted on the James River corridor to investigate resulting changes in prioritizations of segments and initiatives and scenario disruptiveness. Impact is assessed for two types of changes. Both types are applied to the pairing of corridor factor weights and corridor segments and to the pairing of success criteria and initiatives.

Change Type 1 is the reweighting of baseline corridor factor and success criteria relevance to determine the impact on baseline ranking and resilience of corridor segments and initiatives, and to assess the impact on the disruptiveness of scenarios applicable to the pairing of corridor factor weights and corridor segments and to the pairing of success criteria and initiatives. Different stakeholder preference perspectives are imagined. For corridor factor weights, they are associated with prioritizing the different categories of safety and security factors. The prioritization is realized by leaving all other factors' baseline rankings the same as determined by the stakeholders for the demonstration in Chapter 5 and by setting the factors in the preferred category to a relevance of "highest." For example, in the preference perspective "geometry factors highest" all safety risk factors from the geometry category are set to highest, while the other factors retain their baseline ranking from the demonstration in Chapter 5. There are six explored preference perspectives for the pairing of corridor factors and corridor segments. The results are divided among two sets of figures for display purposes. Figure B-1 and Figure B-4 describe set 1 and set 2 respectively of the preference perspective settings for the pairing of corridor factors and corridor segments. Figure B-2 and Figure B-5 depict the impact of these perspective preferences on the baseline ranking and resiliency of corridor segments. Figure B-3 and Figure B-6 depict the changes in scenario disruptiveness under each set of preference perspectives. For tractability, only the top twenty ranked segments under each preference perspective are shown in the figures.

One set of three preference perspectives is evaluated for the pairing of success criteria and initiatives. Table B-1 provides the description of the preference perspectives for the pairing of criteria and initiatives. These perspectives are also demonstrated in Figure B-8.

Table B-1. Preference perspectives for sensitivity analysis of criteria/initiatives pairing.

Preference Perspective	Criteria Set to "highest" Relevance
Barge Water Highest	c.03 - Barge service reliability c.04 - Barge turn times c.08 - Improve navigation waters
Security Highest	c.19 - Security of goods and commodities c.20 - Security of employees and community
Business Partners	c.01 - Address customer needs c.09 - Public/private/port integration c.10 - Stewardship of grants and investments c.11 - Diversify business relationships c.12 - Facilitate job growth

Figure B-9 depicts the impact of these perspective preferences on the baseline ranking and resiliency of initiatives. Figure B-10 depicts the changes in scenario disruptiveness under each of the three of preference perspectives. For tractability only the top fifteen ranked initiatives under each preference perspective are shown in the figure.

For the pairing of corridor factors and corridor segments, the baseline segments rankings appear to be robust to the preference perspectives. There are changes to rankings of the corridor segments, but many of the segments that appear in the top twenty ranked segments in the original baseline remain ranked in the top twenty segments under the different preference perspectives. Scenario disruptive scores do change in magnitude among the perspectives, there is very little change in the relative disruptiveness among the scenarios. The distribution of the histogram figures for scenario disruptive scores is quite stable over all preference perspectives.

For the pairing of criteria and initiatives, there appears to be a similar lack in movement of initiatives in and out of the top fifteen as with the corridor factors and corridor segments pairing. The impact on disruptive scores of scenarios is significantly greater however.

Change Type 2 is the rescaling of relative importance weighting scale for both corridor factors and criteria. In the scale presented to stakeholders, linguistic response options are highest, high, medium, low, and lowest. For Change Type 2, the response options are changed to highest, medium, and lowest.

Figure B-7 depicts the changes in segment rankings and scenario disruptive scores for Change Type 2. Concerning corridor factors and corridor segments, there is only a slight shuffling of rankings among the corridor segments. Many of the segments appear to have a higher resilience to disruption though. The length of the blue and red bars associated with many of the segments appears to be shorter. This seems reasonable given that there is less distinction among the relative weights of the corridor factors in the baseline scenario.

Figure B-11 depicts the changes in initiative rankings and scenario disruptive scores for Change Type 2. Concerning criteria and initiatives, there is only a slight shuffling of initiatives among the top fifteen. One initiative moves into the top fifteen under Change Type 2, *i.30 – increase barge frequency*, at the expense of *i.08 – improve vessel traffic data access*. The relative disruptive scores of scenarios experiences little change as well.

Baseline

the criterion c.xx has	-	relevance among the other criteria
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	high	relevance
f.03 - Shore-to-shore distance (safety) has	medium	relevance
f.04 - Turning angle has	high	relevance
f.05 - Vessel traffic tug/tow has	medium	relevance
f.06 - Vessel traffic cargo has	high	relevance
f.07 - Vessel traffic tanker has	high	relevance
f.08 - Vessel traffic passenger has	medium	relevance
f.09 - Vessel traffic fishing has	low	relevance
f.10 - Vessel traffic pleasure (safety) has	low	relevance
f.11 - Bridges (safety) has	high	relevance
f.12 - Commercial pier has	medium	relevance
f.13 - Buoys and Lights has	high	relevance
f.14 - Obstructions has	lowest	relevance
f.15 - Inflows has	medium	relevance
f.16 - Inlets has	high	relevance
f.17 - Civilian docks and piers has	low	relevance
f.18 - Vessel traffic pleasure (security) has	high	relevance
f.19 - Bridges (security) has	medium	relevance
f.20 - Shore cover type has	low	relevance
f.21 - Shore-to-shore distance (security) has	medium	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

Geometry Factors Highest

the criterion c.xx has	-	relevance among the other criteria
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	highest	relevance
f.03 - Shore-to-shore distance (safety) has	highest	relevance
f.04 - Turning angle has	highest	relevance
f.05 - Vessel traffic tug/tow has	medium	relevance
f.06 - Vessel traffic cargo has	high	relevance
f.07 - Vessel traffic tanker has	high	relevance
f.08 - Vessel traffic passenger has	medium	relevance
f.09 - Vessel traffic fishing has	low	relevance
f.10 - Vessel traffic pleasure (safety) has	low	relevance
f.11 - Bridges (safety) has	high	relevance
f.12 - Commercial pier has	medium	relevance
f.13 - Buoys and Lights has	high	relevance
f.14 - Obstructions has	lowest	relevance
f.15 - Inflows has	medium	relevance
f.16 - Inlets has	high	relevance
f.17 - Civilian docks and piers has	low	relevance
f.18 - Vessel traffic pleasure (security) has	high	relevance
f.19 - Bridges (security) has	medium	relevance
f.20 - Shore cover type has	low	relevance
f.21 - Shore-to-shore distance (security) has	medium	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

Traffic Factors Highest

the criterion c.xx has	-	relevance among the other criteria
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	high	relevance
f.03 - Shore-to-shore distance (safety) has	medium	relevance
f.04 - Turning angle has	high	relevance
f.05 - Vessel traffic tug/tow has	highest	relevance
f.06 - Vessel traffic cargo has	highest	relevance
f.07 - Vessel traffic tanker has	highest	relevance
f.08 - Vessel traffic passenger has	highest	relevance
f.09 - Vessel traffic fishing has	highest	relevance
f.10 - Vessel traffic pleasure (safety) has	highest	relevance
f.11 - Bridges (safety) has	high	relevance
f.12 - Commercial pier has	medium	relevance
f.13 - Buoys and Lights has	high	relevance
f.14 - Obstructions has	lowest	relevance
f.15 - Inflows has	medium	relevance
f.16 - Inlets has	high	relevance
f.17 - Civilian docks and piers has	low	relevance
f.18 - Vessel traffic pleasure (security) has	high	relevance
f.19 - Bridges (security) has	medium	relevance
f.20 - Shore cover type has	low	relevance
f.21 - Shore-to-shore distance (security) has	medium	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

Infrastructure and Obstacle Factors Highest

the criterion c.xx has	-	relevance among the other criteria
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	high	relevance
f.03 - Shore-to-shore distance (safety) has	medium	relevance
f.04 - Turning angle has	high	relevance
f.05 - Vessel traffic tug/tow has	medium	relevance
f.06 - Vessel traffic cargo has	high	relevance
f.07 - Vessel traffic tanker has	high	relevance
f.08 - Vessel traffic passenger has	medium	relevance
f.09 - Vessel traffic fishing has	low	relevance
f.10 - Vessel traffic pleasure (safety) has	low	relevance
f.11 - Bridges (safety) has	highest	relevance
f.12 - Commercial pier has	highest	relevance
f.13 - Buoys and Lights has	highest	relevance
f.14 - Obstructions has	highest	relevance
f.15 - Inflows has	medium	relevance
f.16 - Inlets has	high	relevance
f.17 - Civilian docks and piers has	low	relevance
f.18 - Vessel traffic pleasure (security) has	high	relevance
f.19 - Bridges (security) has	medium	relevance
f.20 - Shore cover type has	low	relevance
f.21 - Shore-to-shore distance (security) has	medium	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

Figure B-1. Reweighting of baseline corridor factor relevance for segment rankings and scenario disruptiveness, set 1 of 2.

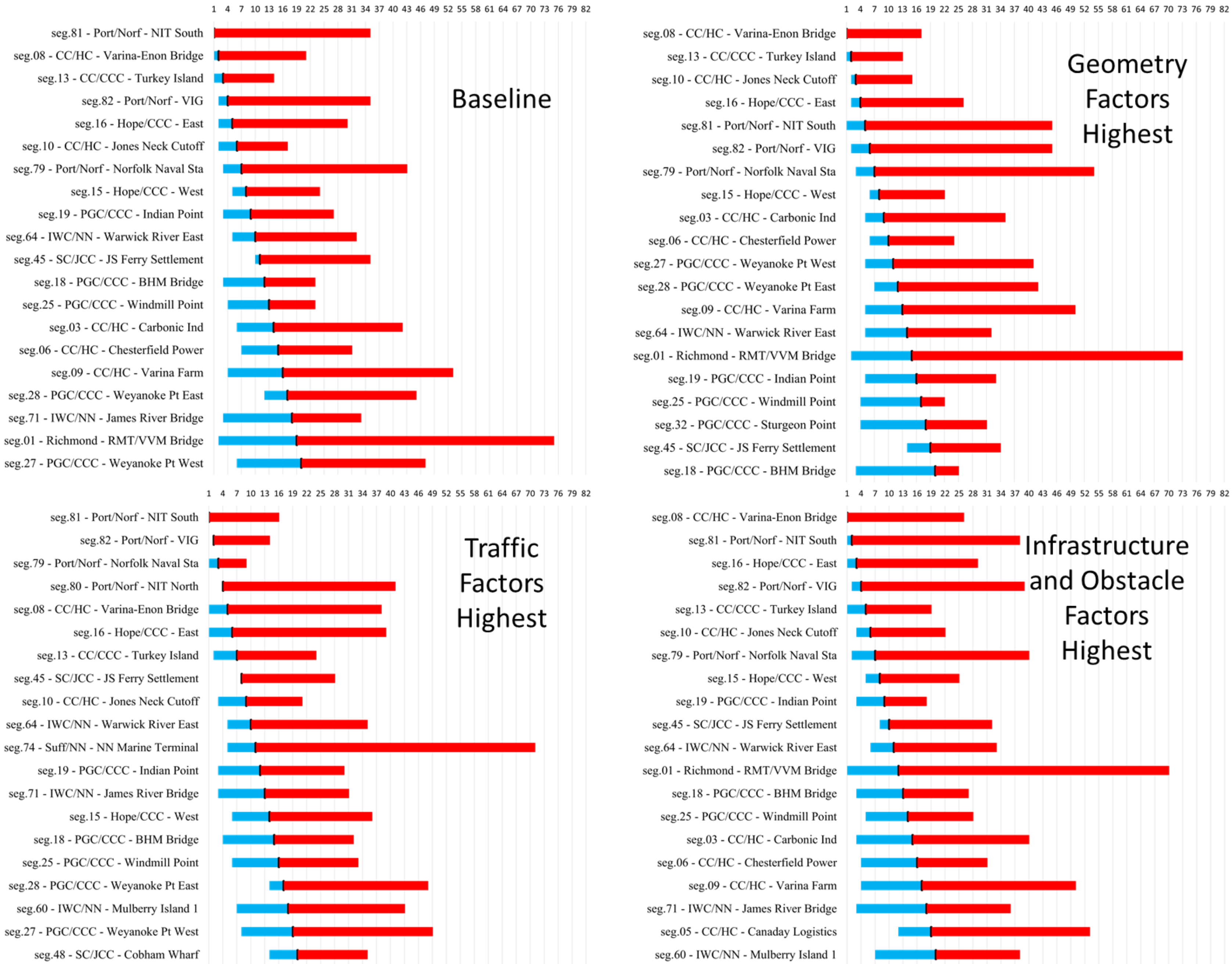


Figure B-2. Changes in rankings and resiliency of segments from reweighting of baseline corridor factor relevance, set 1 of 2.

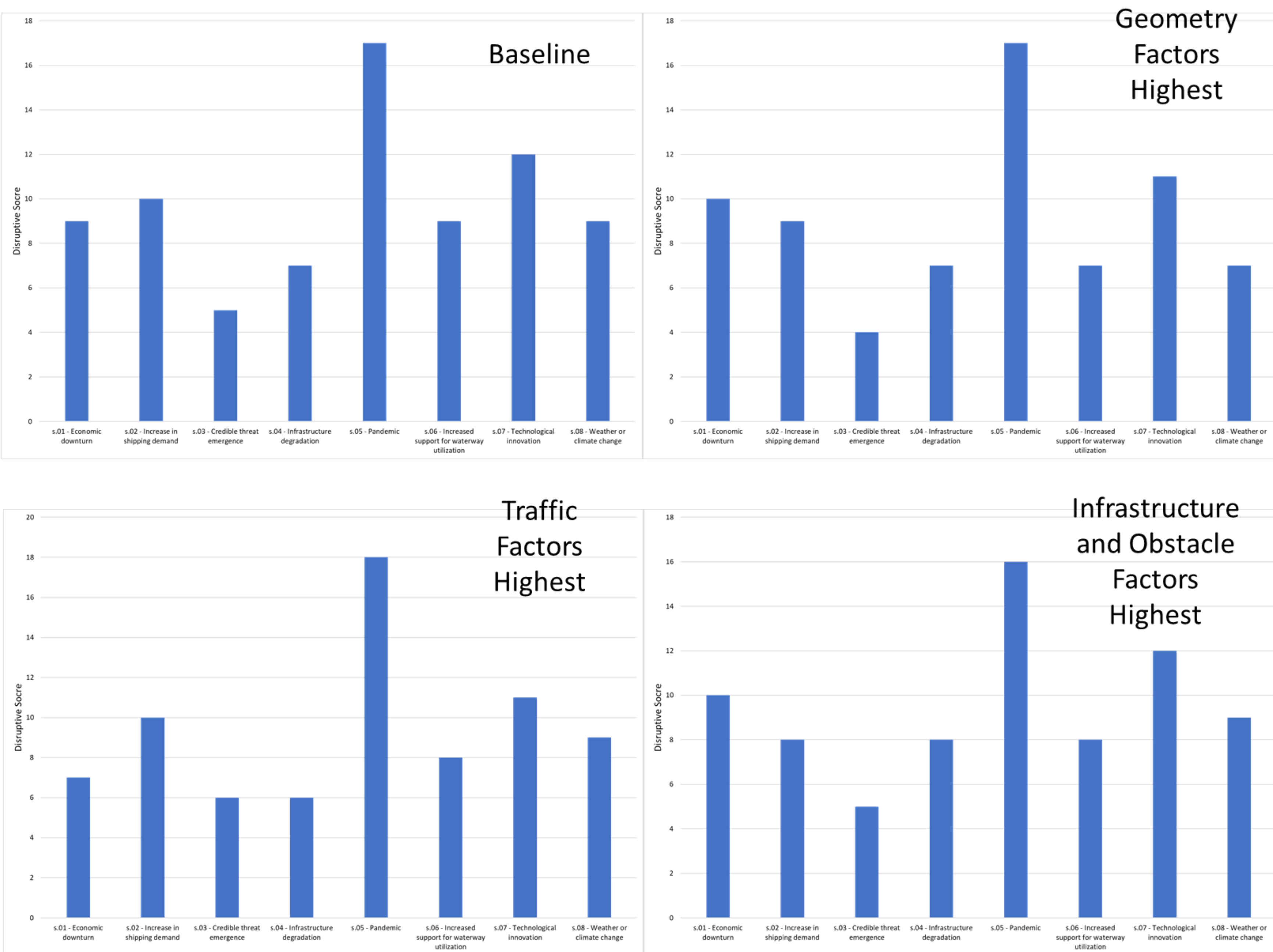


Figure B-3. Changes in scenario disruptiveness to corridor factors from reweighting of baseline corridor factor relevance, set 1 of 2.

Baseline

the criterion c.xx has	-	relevance among the other criteria
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	high	relevance
f.03 - Shore-to-shore distance (safety) has	medium	relevance
f.04 - Turning angle has	high	relevance
f.05 - Vessel traffic tug/tow has	medium	relevance
f.06 - Vessel traffic cargo has	high	relevance
f.07 - Vessel traffic tanker has	high	relevance
f.08 - Vessel traffic passenger has	medium	relevance
f.09 - Vessel traffic fishing has	low	relevance
f.10 - Vessel traffic pleasure (safety) has	low	relevance
f.11 - Bridges (safety) has	high	relevance
f.12 - Commercial pier has	medium	relevance
f.13 - Buoys and Lights has	high	relevance
f.14 - Obstructions has	lowest	relevance
f.15 - Inflows has	medium	relevance
f.16 - Inlets has	high	relevance
f.17 - Civilian docks and piers has	low	relevance
f.18 - Vessel traffic pleasure (security) has	high	relevance
f.19 - Bridges (security) has	medium	relevance
f.20 - Shore cover type has	low	relevance
f.21 - Shore-to-shore distance (security) has	medium	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

VBA Security Highest

the criterion c.xx has	-	relevance among the other criteria
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	high	relevance
f.03 - Shore-to-shore distance (safety) has	medium	relevance
f.04 - Turning angle has	high	relevance
f.05 - Vessel traffic tug/tow has	medium	relevance
f.06 - Vessel traffic cargo has	high	relevance
f.07 - Vessel traffic tanker has	high	relevance
f.08 - Vessel traffic passenger has	medium	relevance
f.09 - Vessel traffic fishing has	low	relevance
f.10 - Vessel traffic pleasure (safety) has	low	relevance
f.11 - Bridges (safety) has	high	relevance
f.12 - Commercial pier has	medium	relevance
f.13 - Buoys and Lights has	high	relevance
f.14 - Obstructions has	lowest	relevance
f.15 - Inflows has	medium	relevance
f.16 - Inlets has	highest	relevance
f.17 - Civilian docks and piers has	highest	relevance
f.18 - Vessel traffic pleasure (security) has	highest	relevance
f.19 - Bridges (security) has	medium	relevance
f.20 - Shore cover type has	low	relevance
f.21 - Shore-to-shore distance (security) has	medium	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

Bridges Inflows Highest

the criterion c.xx has	-	relevance among the other criteria
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	high	relevance
f.03 - Shore-to-shore distance (safety) has	medium	relevance
f.04 - Turning angle has	high	relevance
f.05 - Vessel traffic tug/tow has	medium	relevance
f.06 - Vessel traffic cargo has	high	relevance
f.07 - Vessel traffic tanker has	high	relevance
f.08 - Vessel traffic passenger has	medium	relevance
f.09 - Vessel traffic fishing has	low	relevance
f.10 - Vessel traffic pleasure (safety) has	low	relevance
f.11 - Bridges (safety) has	highest	relevance
f.12 - Commercial pier has	medium	relevance
f.13 - Buoys and Lights has	high	relevance
f.14 - Obstructions has	lowest	relevance
f.15 - Inflows has	highest	relevance
f.16 - Inlets has	high	relevance
f.17 - Civilian docks and piers has	low	relevance
f.18 - Vessel traffic pleasure (security) has	high	relevance
f.19 - Bridges (security) has	highest	relevance
f.20 - Shore cover type has	low	relevance
f.21 - Shore-to-shore distance (security) has	medium	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

LBA Security Highest

the criterion c.xx has	-	relevance among the other criteria
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	high	relevance
f.03 - Shore-to-shore distance (safety) has	medium	relevance
f.04 - Turning angle has	high	relevance
f.05 - Vessel traffic tug/tow has	medium	relevance
f.06 - Vessel traffic cargo has	high	relevance
f.07 - Vessel traffic tanker has	high	relevance
f.08 - Vessel traffic passenger has	medium	relevance
f.09 - Vessel traffic fishing has	low	relevance
f.10 - Vessel traffic pleasure (safety) has	low	relevance
f.11 - Bridges (safety) has	high	relevance
f.12 - Commercial pier has	medium	relevance
f.13 - Buoys and Lights has	high	relevance
f.14 - Obstructions has	lowest	relevance
f.15 - Inflows has	medium	relevance
f.16 - Inlets has	high	relevance
f.17 - Civilian docks and piers has	low	relevance
f.18 - Vessel traffic pleasure (security) has	high	relevance
f.19 - Bridges (security) has	highest	relevance
f.20 - Shore cover type has	highest	relevance
f.21 - Shore-to-shore distance (security) has	highest	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

Figure B-4. Reweighting of baseline corridor factor relevance for segment rankings and scenario disruptiveness, set 2 of 2.

Figure B-5. Changes in rankings and resiliency of segments from reweighting of baseline corridor factor relevance, set 2 of 2.

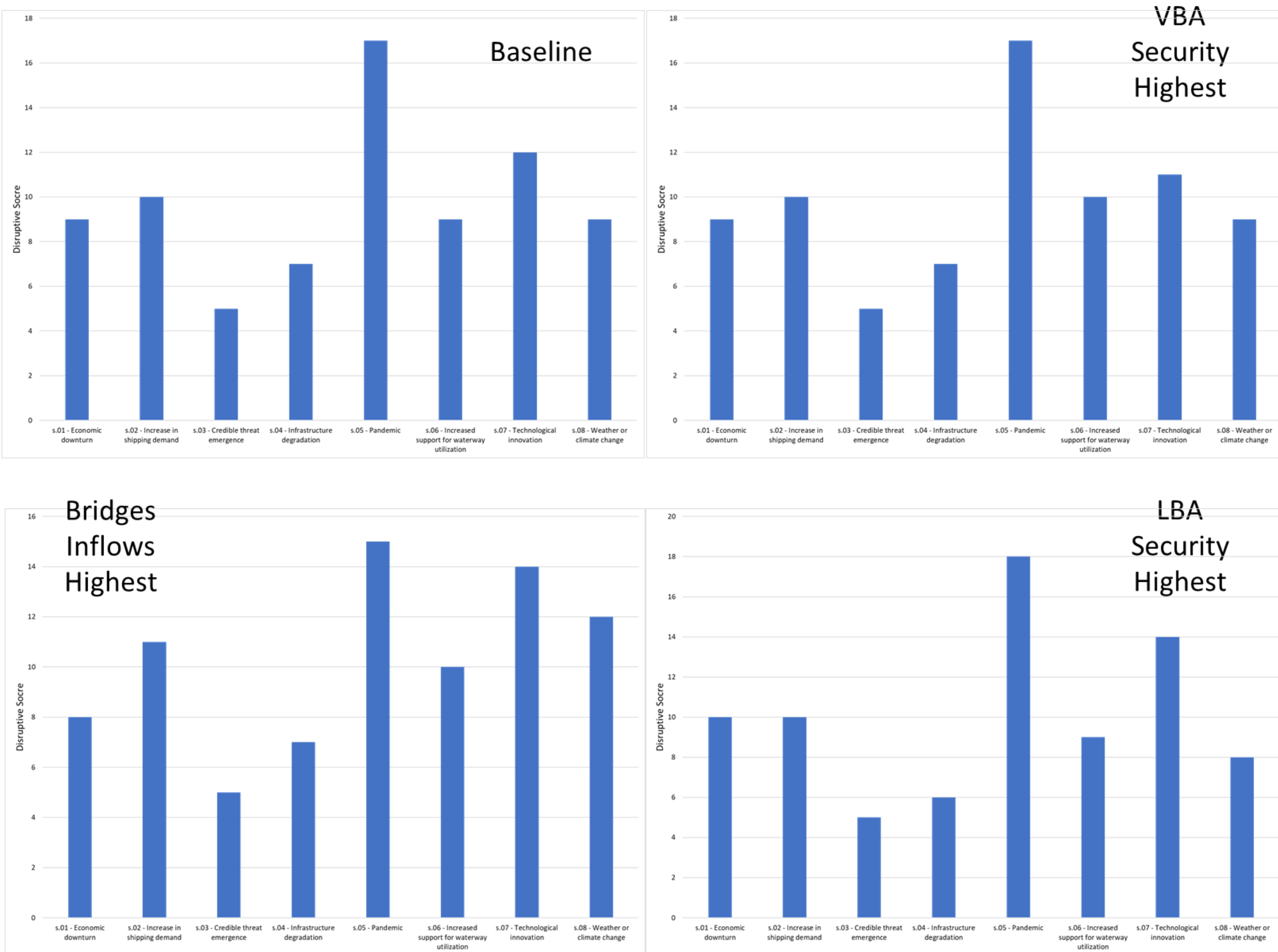


Figure B-6. Changes in scenario disruptiveness to corridor factors from reweighting of baseline corridor factor relevance, set 2 of 2.

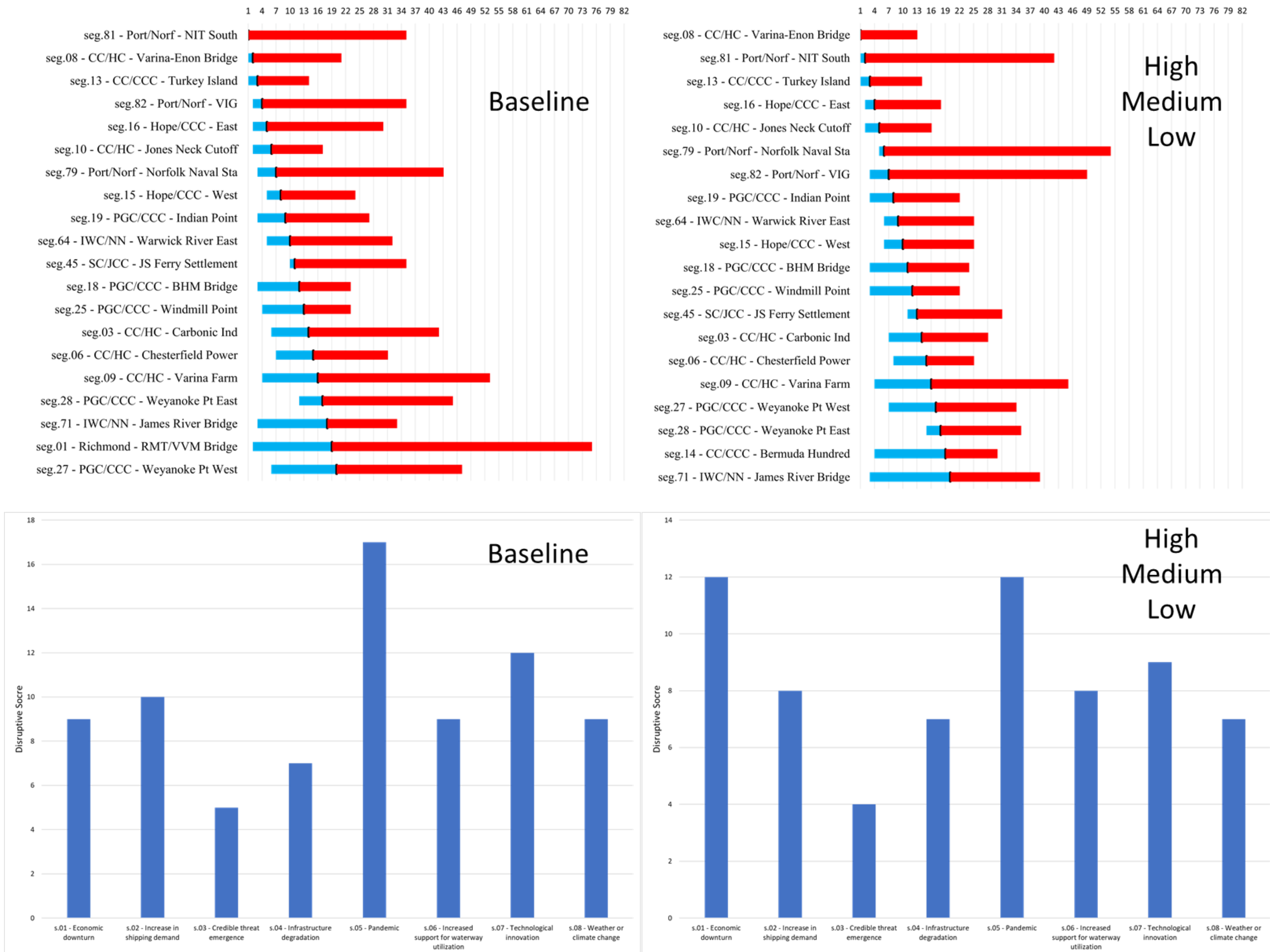


Figure B-7. Changes in segment rankings and scenario disruptiveness from changing the corridor factor relative importance weight scale.

Baseline

the criterion c.xx has	-	relevance among the other criteria
c.01 - Address customer needs has	high	relevance
c.02 - Improve operational efficiencies has	highest	relevance
c.03 - Barge service reliability has	high	relevance
c.04 - Barge turn times has	medium	relevance
c.05 - Sustainable growth operations has	medium	relevance
c.06 - Support innovation in operations has	low	relevance
c.07 - Fiscal responsibility has	highest	relevance
c.08 - Improve navigation waters has	medium	relevance
c.09 - Public/private/port integration has	medium	relevance
c.10 - Stewardship of grants and investments has	high	relevance
c.11 - Diversify business relationships has	medium	relevance
c.12 - Facilitate job growth has	high	relevance
c.13 - Human health conscious has	high	relevance
c.14 - Protect the environment has	high	relevance
c.15 - Unrestricted waterway access for all has	low	relevance
c.16 - Support natural disaster response has	lowest	relevance
c.17 - Address needs of communities has	high	relevance
c.18 - Vessel accident prevention has	medium	relevance
c.19 - Security of goods and commodities has	lowest	relevance
c.20 - Security of employees and community has	low	relevance

Barge Water Highest

the criterion c.xx has	-	relevance among the other criteria
c.01 - Address customer needs has	high	relevance
c.02 - Improve operational efficiencies has	highest	relevance
c.03 - Barge service reliability has	highest	relevance
c.04 - Barge turn times has	highest	relevance
c.05 - Sustainable growth operations has	medium	relevance
c.06 - Support innovation in operations has	low	relevance
c.07 - Fiscal responsibility has	highest	relevance
c.08 - Improve navigation waters has	highest	relevance
c.09 - Public/private/port integration has	medium	relevance
c.10 - Stewardship of grants and investments has	high	relevance
c.11 - Diversify business relationships has	medium	relevance
c.12 - Facilitate job growth has	high	relevance
c.13 - Human health conscious has	high	relevance
c.14 - Protect the environment has	high	relevance
c.15 - Unrestricted waterway access for all has	low	relevance
c.16 - Support natural disaster response has	lowest	relevance
c.17 - Address needs of communities has	high	relevance
c.18 - Vessel accident prevention has	medium	relevance
c.19 - Security of goods and commodities has	lowest	relevance
c.20 - Security of employees and community has	low	relevance

Business Partners

the criterion c.xx has	-	relevance among the other criteria
c.01 - Address customer needs has	highest	relevance
c.02 - Improve operational efficiencies has	highest	relevance
c.03 - Barge service reliability has	high	relevance
c.04 - Barge turn times has	medium	relevance
c.05 - Sustainable growth operations has	medium	relevance
c.06 - Support innovation in operations has	low	relevance
c.07 - Fiscal responsibility has	highest	relevance
c.08 - Improve navigation waters has	medium	relevance
c.09 - Public/private/port integration has	highest	relevance
c.10 - Stewardship of grants and investments has	highest	relevance
c.11 - Diversify business relationships has	highest	relevance
c.12 - Facilitate job growth has	highest	relevance
c.13 - Human health conscious has	high	relevance
c.14 - Protect the environment has	high	relevance
c.15 - Unrestricted waterway access for all has	low	relevance
c.16 - Support natural disaster response has	lowest	relevance
c.17 - Address needs of communities has	high	relevance
c.18 - Vessel accident prevention has	medium	relevance
c.19 - Security of goods and commodities has	lowest	relevance
c.20 - Security of employees and community has	low	relevance

Security Highest

the criterion c.xx has	-	relevance among the other criteria
c.01 - Address customer needs has	high	relevance
c.02 - Improve operational efficiencies has	highest	relevance
c.03 - Barge service reliability has	high	relevance
c.04 - Barge turn times has	medium	relevance
c.05 - Sustainable growth operations has	medium	relevance
c.06 - Support innovation in operations has	low	relevance
c.07 - Fiscal responsibility has	highest	relevance
c.08 - Improve navigation waters has	medium	relevance
c.09 - Public/private/port integration has	medium	relevance
c.10 - Stewardship of grants and investments has	high	relevance
c.11 - Diversify business relationships has	medium	relevance
c.12 - Facilitate job growth has	high	relevance
c.13 - Human health conscious has	high	relevance
c.14 - Protect the environment has	high	relevance
c.15 - Unrestricted waterway access for all has	low	relevance
c.16 - Support natural disaster response has	lowest	relevance
c.17 - Address needs of communities has	high	relevance
c.18 - Vessel accident prevention has	medium	relevance
c.19 - Security of goods and commodities has	highest	relevance
c.20 - Security of employees and community has	highest	relevance

Figure B-8. Reweighting of baseline criteria relevance for initiative rankings and scenario disruptiveness.

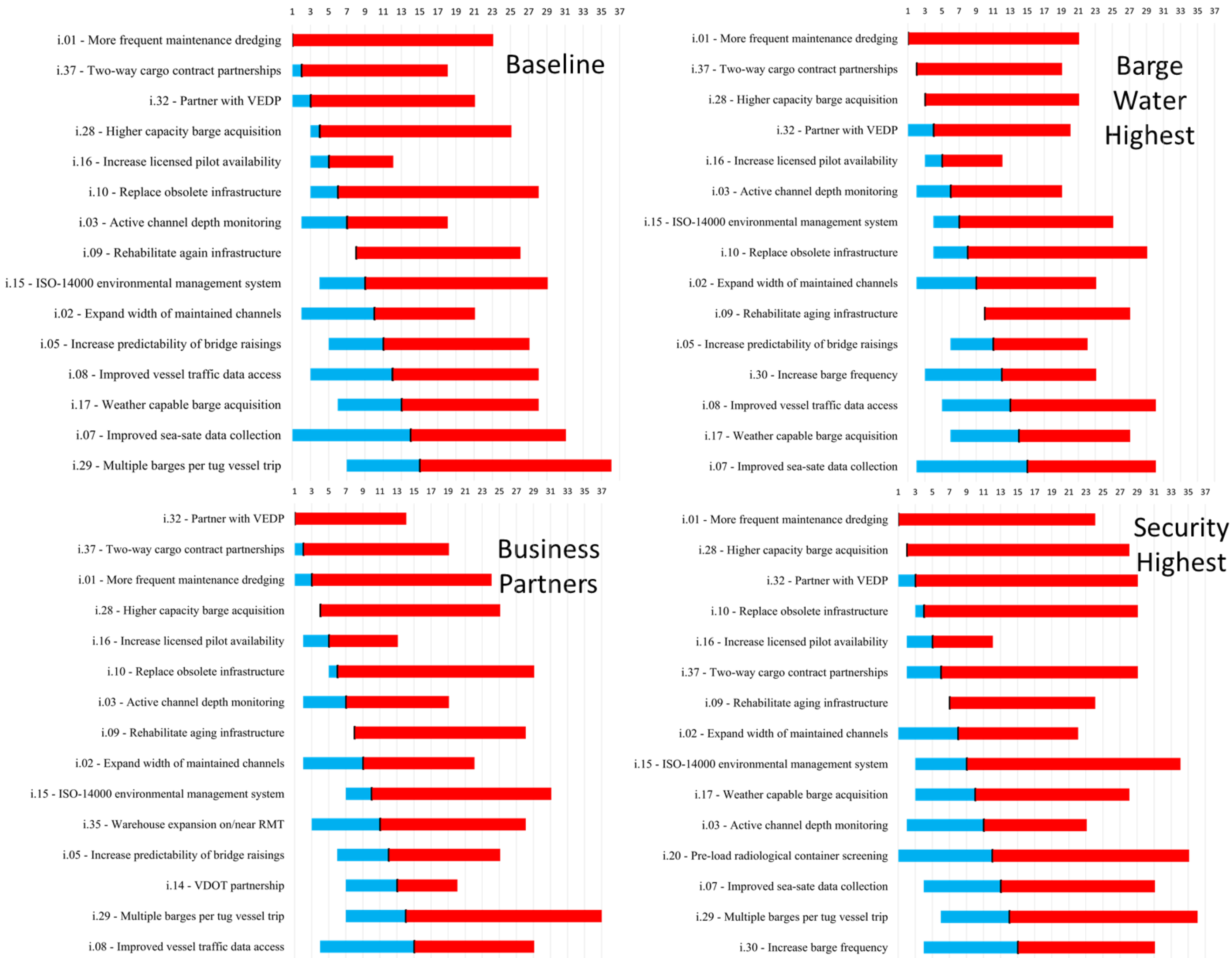


Figure B-9. Changes in rankings and resiliency of initiatives from reweighting of baseline criteria relevance.

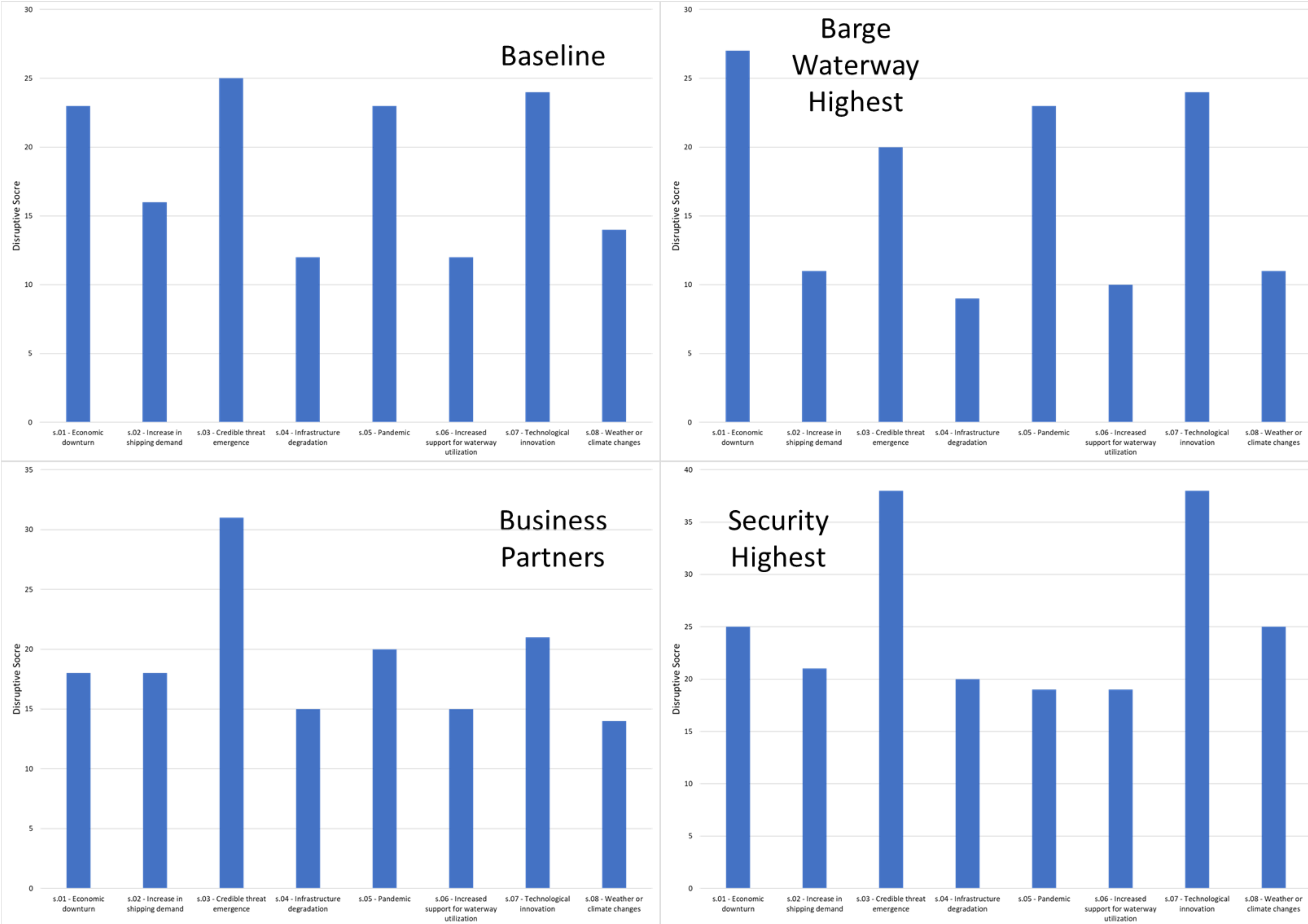


Figure B-10. Changes in scenario disruptiveness to initiatives from reweighting of baseline criteria relevance.

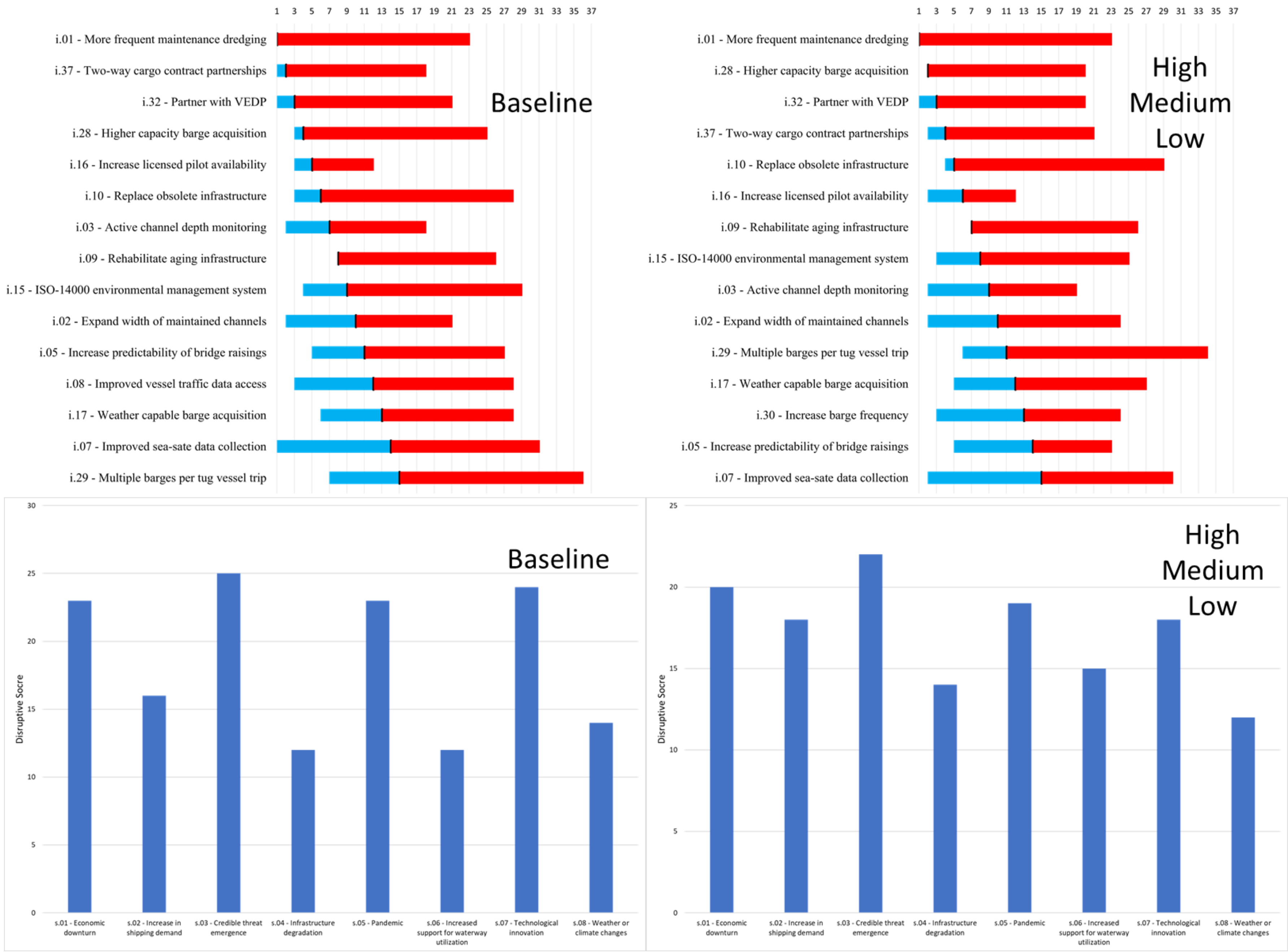


Figure B-11. Changes in initiative rankings and scenario disruptiveness from changing the criteria relative importance weight scale.

Appendix C. Risk Register

This appendix describes the consolidation and application of products developed in this dissertation for use by stakeholders in the analysis and asset management of inland waterway corridors. The risk register represents the portfolio of system-related, risk-relevant data to be viewed, tracked, and updated by the stakeholder. The flow of information and the cascading impacts of updates generally follow the stepwise processes of the maritime corridor trace methodology and the scenario-based asset management of inland waterway corridors described in this dissertation. Figure C-1 describes the process flow for maritime corridor trace analysis. Figure C-2 describes the process flow for asset management of inland waterway corridors. The products presented in this appendix are relevant to the James River corridor.

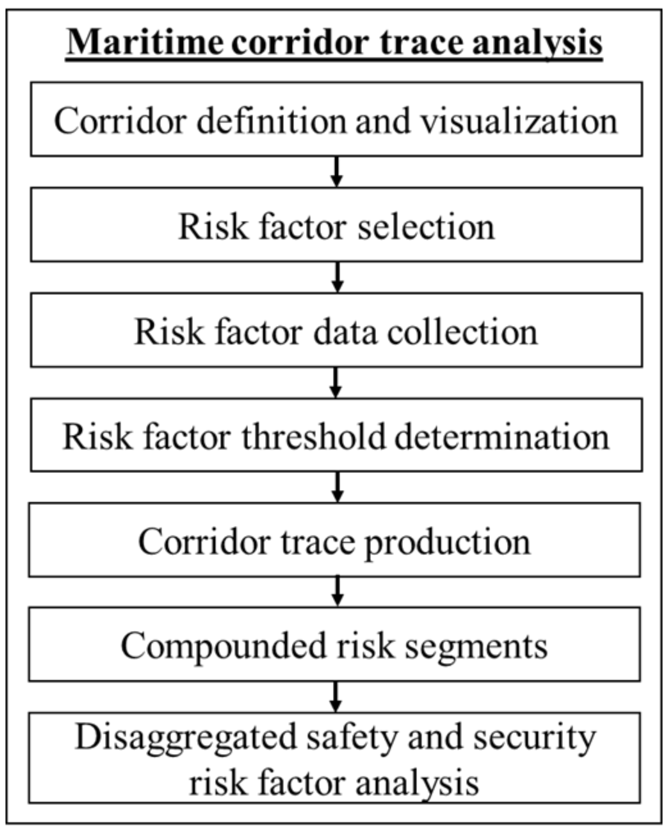


Figure C-1. Process flow for maritime corridor trace analysis.

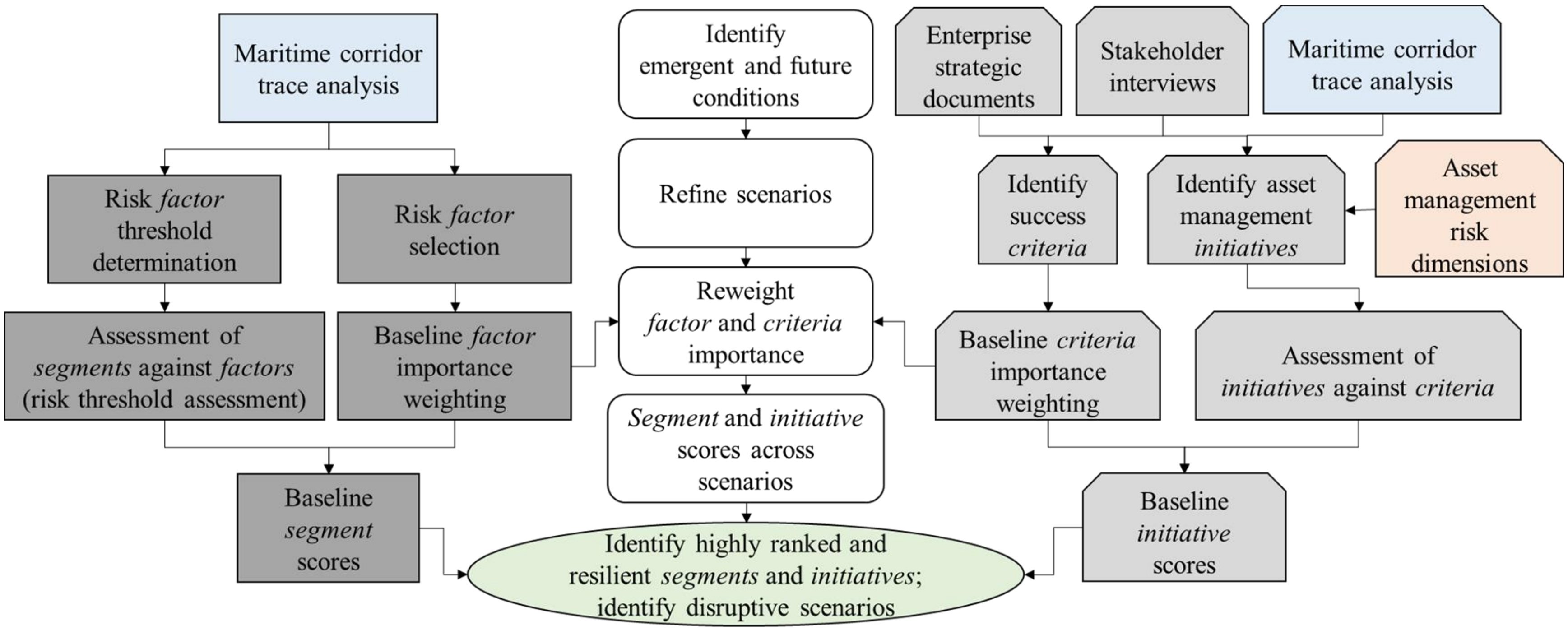


Figure C-2. Process flow for asset management of inland waterway corridors.

Table C-1. Corridor safety risk factors determined by risk factor selection process.

Safety Risk Factor	Category	Source(s)
Channel width	Geometry	Lalla-Ruiz et al. (2018); Vidan et al. (2012); Wood et al. (2018); NOAA (2019); MOC (2019); POV (2020)
Channel depth	Geometry	Lalla-Ruiz et al. (2018); Vidan et al. (2012); NOAA (2019); POV (2020)
Shore-to-shore distance	Geometry	Vidan et al. (2012); Wood et al. (2018);
Turning angle	Geometry	Montewka et al. (2014); Roeleven et al. (1995); MOC (2019);
Vessel traffic tug/tow	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic cargo	Traffic	Akhtar and Utne (2014); Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic tanker	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic passenger	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic fishing	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Vessel traffic pleasure	Traffic	Lalla-Ruiz et al. (2018); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);
Bridges	Infrastructure	Akhtar and Utne (2014); Elcheick et al. (2017); Roeleven et al. (1995); Vidan et al. (2012); NOAA (2019); MOC (2019); POV (2020)
Commercial pier	Infrastructure	POV (2020)
Buoys and lights	Obstacle	NOAA (2019); MOC (2019);
Obstructions	Obstacle	Vidan et al. (2012); NOAA (2019);
Inflows	Sea-State	Akhtar and Utne (2014); Roeleven et al. (1995); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); POV (2020)
Wind	Sea-State	Akhtar and Utne (2014); Roeleven et al. (1995); Trucco et al. (2008); Wood et al. (2018); MOC (2019); POV (2020)
Precipitation	Sea-State	Montewka et al. (2014); Trucco et al. (2008); NOAA (2019); POV (2020)
Fog	Sea-State	Akthar and Utne (2014); Roeleven et al. (1995); Trucco et al. (2008); Vidan et al. (2012); Wood et al. (2018); Zhang et al. (2014); MOC (2019);

Table C-2. Corridor safety risk factor thresholds.

Factor	Unit of measure	Threshold values		
		High	**Moderate**	**Low**
Channel width (cw)	meters	< 100	100 - 300	> 300
Channel depth	meters	< 6	6 - 10	> 10
Shore-to-shore distance	meters	< 500	500 - 1000	> 1000
Turning angle	degrees	> 60	30 - 60	< 30
Vessel traffic tug/tow	color-scale estimate of AIS vessel counts	> 46,000	23,000 - 46,000	< 23,000
Vessel traffic cargo	color-scale estimate of AIS vessel counts	> 4,000	2,000 - 4,000	< 2,000
Vessel traffic tanker	color-scale estimate of AIS vessel counts	> 6,000	3,000 - 6,000	< 3,000
Vessel traffic passenger	color-scale estimate of AIS vessel counts	> 50,000	25,000 - 50,000	< 25,000
Vessel traffic fishing	color-scale estimate of AIS vessel counts	> 10,000	5,000 - 10,000	< 5,000
Vessel traffic pleasure	color-scale estimate of AIS vessel counts	> 40,000	20,000 - 40,000	< 20,000
Bridges		bridge in segment	bridge in adjacent segment	no bridge
Commercial pier		present on both shores	present on one shore	none
Buoys and lights	number of buoys	> 2 if cw < 100 > 5 otherwise	2 if cw < 100 3 - 4 otherwise	< 2 if cw < 100 < 3 otherwise
Obstructions	number of obstructions	> 4	2 - 4 if cw < 100 3 - 4 otherwise	< 2 if cw < 100 < 3 otherwise
Inflows	number of inflows	> 1	1	0
Wind	knots	> 30	10 - 30	< 10
Precipitation	centimeters	> 10	4 - 10	< 4
Fog	% days / year	> 40	20 - 40	< 20

Table C-3. Corridor security risk factors determined by risk factor selection process.

Security Risk Factor	Category	Hazard
Inlets	Terrain	VBA
Civilian docks and piers	Enemy, civil considerations	VBA
Vessel traffic pleasure	Enemy, civil considerations	VBA
Bridges	Terrain	LBA
Shore cover type	Terrain	LBA
Shore-to-shore distance	Terrain	LBA
Fog	Sea-state (weather)	VBA

Table C-4. Corridor security risk factor thresholds.

Factor	Unit of measure	Threshold values		
		High	**Moderate**	**Low**
Inlets	# of inlets	> 1	1	0
Civilian docks and piers		present on both shores	present on one shore	none
Vessel traffic pleasure	color-scale estimate of AIS vessel counts	> 40,000	20,000 - 40,000	< 20,000
Bridges		bridge in segment	bridge in adjacent segment	no bridge
Shore cover type	factor value	4 or 5	2 or 3	0 or 1
Shore-to-shore distance	meters	< 500	500 - 1000	> 1000
Fog	% days / year	> 40	20 - 40	< 20

Table C-5. Safety risk factor raw data for the James River corridor, segments 1-41.

	Safety Risk Factors																			
	Channel Width	Channel Depth	Shore-to-Shore Distance	Turning Angle	Vessel Traffic Tug/Tow	Vessel Traffic Cargo	Vessel Traffic Tanker	Vessel Traffic Passenger	Vessel Traffic Fishing	Vessel Traffic Pleasure	Bridges	Commercial Piers	Bouys and Lights	Obstructions	Inflows	Wind Max	Wind Avg	Precip Max	Precip Avg	Fog
segment	meters	meters	meters	degrees	threshold	threshold	threshold	threshold	threshold	threshold	presence	shore count	count	count	count	knots	knots	cm	cm	% of days
1	55	8	170	30	1	1	1	1	1	1	3	1	1	1	0	38	7.53	5.6	0.31	35
2	55	8	170	60	1	1	1	1	1	1	2	0	0	0	0	38	7.53	5.6	0.31	35
3	55	8	170	66	1	1	1	1	1	1	1	1	1	0	0	38	7.53	5.6	0.31	35
4	55	8	170	85	1	1	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
5	55	8	190	51	1	1	1	1	1	1	1	1	1	2	0	38	7.53	5.6	0.31	35
6	55	8	170	147	1	1	1	1	1	1	1	1	1	1	0	38	7.53	5.6	0.31	35
7	55	8	140	7	1	1	1	1	1	1	2	0	0	0	0	38	7.53	5.6	0.31	35
8	55	8	190	67	1	1	1	1	1	1	3	0	1	1	2	38	7.53	5.6	0.31	35
9	55	8	220	14	1	1	1	1	1	1	2	0	2	0	0	38	7.53	5.6	0.31	35
10	55	8	120	92	1	1	1	1	1	1	1	0	2	0	1	38	7.53	5.6	0.31	35
11	55	8	240	48	1	1	1	1	1	1	1	0	1	1	0	38	7.53	5.6	0.31	35
12	70	8	220	46	1	1	1	1	1	1	1	0	0	0	1	38	7.53	5.6	0.31	35
13	70	8	130	111	1	1	1	1	1	1	1	0	3	1	1	38	7.53	5.6	0.31	35
14	60	8	690	36	2	1	1	1	1	1	1	0	3	0	0	38	7.53	5.6	0.31	35
15	90	8	350	44	2	1	1	1	1	1	1	0	2	2	1	38	7.53	5.6	0.31	35
16	90	8	450	60	2	2	1	1	1	1	1	1	3	0	1	38	7.53	5.6	0.31	35
17	90	8	1160	14	2	2	1	1	1	1	2	1	2	1	0	38	7.53	5.6	0.31	35
18	90	8	1270	35	2	2	1	1	1	1	3	0	1	0	0	38	7.53	5.6	0.31	35
19	90	8	1850	30	2	2	1	1	1	1	2	0	4	0	0	38	7.53	5.6	0.31	35
20	90	8	830	17	2	2	1	1	1	1	1	0	4	0	1	38	7.53	5.6	0.31	35
21	90	8	790	0	2	2	1	1	1	1	1	0	2	0	0	38	7.53	5.6	0.31	35
22	90	8	1070	5	2	2	1	1	1	1	1	0	0	0	2	38	7.53	5.6	0.31	35
23	90	8	1300	37	2	2	1	1	1	1	1	0	4	0	0	38	7.53	5.6	0.31	35
24	90	8	1170	48	2	2	1	1	1	1	1	0	3	0	0	38	7.53	5.6	0.31	35
25	90	7.6	1700	77	2	2	1	1	1	1	1	0	5	0	1	38	7.53	5.6	0.31	35
26	370	6.1	920	19	2	2	1	1	1	1	1	0	1	0	0	38	7.53	5.6	0.31	35
27	260	9.4	460	75	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
28	90	7.6	480	52	2	2	1	1	1	1	1	0	1	0	0	38	7.53	5.6	0.31	35
29	90	7.3	1150	19	2	2	1	1	1	1	1	0	3	0	0	38	7.53	5.6	0.31	35
30	610	6.4	1000	12	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
31	370	10.7	910	57	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
32	330	9.8	490	38	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
33	400	9.1	520	43	2	2	1	1	1	1	1	0	0	1	0	38	7.53	5.6	0.31	35
34	330	7.6	840	27	2	2	1	1	1	1	1	0	1	0	0	38	7.53	5.6	0.31	35
35	700	6.7	1600	15	2	2	1	1	1	1	1	0	0	0	0	38	7.53	5.6	0.31	35
36	240	6.1	1640	25	2	2	1	1	1	1	1	0	2	1	1	38	7.53	5.6	0.31	35
37	810	7.6	1180	3	2	2	1	1	1	1	1	0	0	1	0	38	7.53	5.6	0.31	35
38	90	7.6	1120	0	2	2	1	1	1	1	1	0	0	0	1	38	7.53	5.6	0.31	35
39	90	7.6	1850	0	2	2	1	1	1	1	1	0	2	0	1	38	7.53	5.6	0.31	35
40	90	7.6	1850	36	2	2	1	1	1	1	1	0	3	0	1	38	7.53	5.6	0.31	35
41	90	7.6	1850	0	2	2	1	1	1	1	1	0	2	0	1	38	7.53	5.6	0.31	35

Table C-6. Safety risk factor raw data for the James River corridor, segments 42-82.

	Safety Risk Factors																			
	Channel Width	Channel Depth	Shore-to-Shore Distance	Turning Angle	Vessel Traffic Tug/Tow	Vessel Traffic Cargo	Vessel Traffic Tanker	Vessel Traffic Passenger	Vessel Traffic Fishing	Vessel Traffic Pleasure	Bridges	Commercial Piers	Bouys and Lights	Obstructions	Inflows	Wind Max	Wind Avg	Precip Max	Precip Avg	Fog
segment	meters	meters	meters	degrees	threshold	threshold	threshold	threshold	threshold	threshold	presence	shore count	count	count	count	knots	knots	cm	cm	% of days
42	90	7.6	1850	0	2	2	1	1	1	1	1	0	0	0	1	38	7.53	5.6	0.31	35
43	90	7.6	1850	0	2	2	1	1	1	1	1	0	2	0	1	38	7.47	10.7	0.37	35
44	90	7.62	1850	0	2	2	1	1	1	1	1	0	2	0	0	38	7.47	10.7	0.37	35
45	90	7.62	1650	56	2	2	1	3	1	2	1	1	2	0	0	38	7.47	10.7	0.37	35
46	500	7.62	1850	12	2	2	1	3	1	2	1	0	1	0	1	38	7.47	10.7	0.37	35
47	500	7.0104	1850	36	2	2	1	1	1	2	1	1	0	0	0	38	7.47	10.7	0.37	35
48	90	7.62	1850	31	2	2	1	1	1	2	1	0	3	0	0	38	7.47	10.7	0.37	35
49	90	7.62	1850	28	2	2	1	1	1	2	1	0	3	0	0	38	7.47	10.7	0.37	35
50	90	7.62	1850	0	2	2	1	1	1	2	1	0	4	0	0	38	7.47	10.7	0.37	35
51	90	7.62	1850	29	2	2	1	1	1	2	1	0	1	0	1	38	7.47	10.7	0.37	35
52	90	7.62	1850	0	1	2	1	1	1	1	1	0	1	0	0	38	7.47	10.7	0.37	35
53	90	7.62	1850	48	1	2	1	1	1	1	1	0	4	0	0	38	7.47	10.7	0.37	35
54	90	7.62	1850	7	1	2	1	1	1	1	1	0	4	0	0	38	7.47	10.7	0.37	35
55	90	7.62	1850	25	1	2	1	1	1	1	1	0	2	0	0	38	7.47	10.7	0.37	35
56	90	7.62	1850	23	1	2	1	1	1	1	1	0	4	0	1	38	7.47	10.7	0.37	35
57	90	7.62	1850	21	1	2	1	1	1	1	1	1	4	2	0	38	7.47	10.7	0.37	35
58	590	8.8392	1850	0	2	2	1	1	1	2	1	1	0	0	0	38	7.47	10.7	0.37	35
59	590	9.7536	1850	30	2	2	1	1	1	2	1	1	0	1	0	38	7.47	10.7	0.37	35
60	90	7.62	1850	0	2	2	1	1	1	2	1	1	3	0	0	38	7.47	10.7	0.37	35
61	90	7.62	1850	0	2	2	1	1	1	2	1	0	2	1	0	38	7.47	10.7	0.37	35
62	90	7.62	1850	0	2	2	1	1	1	2	1	0	2	1	0	38	7.47	10.7	0.37	35
63	90	7.62	1850	0	2	2	1	1	1	2	1	0	2	0	0	38	7.47	10.7	0.37	35
64	90	7.62	1850	60	2	2	1	1	1	2	1	0	4	1	1	38	7.47	10.7	0.37	35
65	90	7.62	1850	40	1	2	1	1	1	1	1	0	4	0	1	38	7.47	10.7	0.37	35
66	480	6.4008	1850	0	1	2	1	1	1	1	1	0	0	0	1	38	7.47	10.7	0.37	35
67	480	8.2296	1850	4	2	2	1	1	1	1	1	0	1	1	1	38	7.47	10.7	0.37	35
68	420	9.4488	1850	0	2	2	1	1	1	2	1	0	1	0	0	38	7.47	10.7	0.37	35
69	400	9.144	1850	4	2	2	1	1	1	2	1	0	2	2	0	38	7.47	10.7	0.37	35
70	590	10.0584	1850	2	2	2	1	1	1	2	2	0	0	1	0	38	7.47	10.7	0.37	35
71	110	7.9248	1850	26	2	2	1	1	1	2	3	0	0	1	0	38	7.47	10.7	0.37	35
72	830	10.0584	1850	0	2	1	1	1	1	2	2	1	0	1	0	38	7.47	10.7	0.37	35
73	240	15.24	1850	0	2	1	2	1	2	2	1	1	0	5	0	36	8.89	5.5	0.31	28
74	240	15.24	1850	12	3	3	2	1	2	2	1	1	1	0	0	36	8.89	5.5	0.31	28
75	240	15.24	1850	36	2	3	2	1	3	1	1	1	4	1	0	36	8.89	5.5	0.31	28
76	185	6.096	1850	25	1	1	2	1	2	1	1	1	2	0	0	36	8.89	5.5	0.31	28
77	185	6.096	1850	18	1	1	2	1	2	1	1	0	0	0	0	36	8.89	5.5	0.31	28
78	185	6.4008	1850	0	1	1	2	1	2	1	1	0	0	0	0	36	8.89	5.5	0.31	28
79	370	15.24	1850	94	3	3	3	3	3	3	1	1	4	0	0	36	8.89	5.5	0.31	28
80	370	15.24	1850	8	3	3	3	3	3	3	1	1	2	0	0	36	8.89	5.5	0.31	28
81	240	15.24	1710	0	3	3	3	3	3	3	1	0	4	0	1	36	8.89	5.5	0.31	28
82	240	15.24	1710	0	3	3	3	3	3	3	1	1	4	0	0	36	8.89	5.5	0.31	28

Table C-7. Security risk factor raw data for the James River corridor, segments 1-41.

	Security Risk Factors						
	Inlets	Civilian Docks	Vessel Traffic Pleasure	Bridges	Shore Cover Type	Shore-to-Shore Distance	Fog
segment	count	shore count	threshold	degrees		meters	% of days
1	0	0	1	3	4	170	35
2	1	0	1	2	4	170	35
3	1	0	1	1	4	170	35
4	0	1	1	1	4	170	35
5	0	1	1	1	4	190	35
6	1	1	1	1	3	170	35
7	2	0	1	2	4	140	35
8	2	0	1	3	4	190	35
9	2	1	1	2	4	220	35
10	2	1	1	1	4	120	35
11	1	1	1	1	4	240	35
12	1	0	1	1	4	220	35
13	2	0	1	1	4	130	35
14	1	0	1	1	4	690	35
15	1	1	1	1	4	350	35
16	1	0	1	1	4	450	35
17	0	1	1	2	4	1160	35
18	1	2	1	3	3	1270	35
19	1	2	1	2	4	1850	35
20	0	1	1	1	3	830	35
21	1	1	1	1	4	790	35
22	0	0	1	1	4	1070	35
23	0	0	1	1	4	1300	35
24	0	1	1	1	4	1170	35
25	1	2	1	1	4	1700	35
26	0	1	1	1	4	920	35
27	1	0	1	1	4	460	35
28	1	0	1	1	4	480	35
29	0	1	1	1	4	1150	35
30	1	1	1	1	4	1000	35
31	0	1	1	1	4	910	35
32	1	1	1	1	4	490	35
33	0	1	1	1	4	520	35
34	0	1	1	1	3	840	35
35	0	0	1	1	2	1600	35
36	1	2	1	1	3	1640	35
37	0	2	1	1	3	1180	35
38	0	1	1	1	3	1120	35
39	1	1	1	1	3	1850	35
40	1	1	1	1	4	1850	35
41	1	0	1	1	4	1850	35

Table C-8. Security risk factor raw data for the James River corridor, segments 42-82.

	Security Risk Factors						
	Inlets	Civilian Docks	Vessel Traffic Pleasure	Bridges	Shore Cover Type	Shore-to-Shore Distance	Fog
segment	count	shore count	threshold	degrees		meters	% of days
42	1	2	1	1	4	1850	35
43	0	1	1	1	4	1850	35
44	0	2	1	1	4	1850	35
45	0	1	2	1	3	1650	35
46	1	0	2	1	3	1850	35
47	0	1	2	1	3	1850	35
48	0	1	2	1	4	1850	35
49	1	0	2	1	4	1850	35
50	1	0	2	1	4	1850	35
51	0	0	2	1	4	1850	35
52	1	1	1	1	3	1850	35
53	0	1	1	1	3	1850	35
54	0	0	1	1	3	1850	35
55	0	0	1	1	1	1850	35
56	1	0	1	1	1	1850	35
57	1	0	1	1	1	1850	35
58	1	0	2	1	1	1850	35
59	0	1	2	1	4	1850	35
60	1	1	2	1	3	1850	35
61	0	1	2	1	3	1850	35
62	0	1	2	1	3	1850	35
63	1	1	2	1	3	1850	35
64	1	2	2	1	3	1850	35
65	1	2	1	1	3	1850	35
66	1	1	1	1	3	1850	35
67	2	2	1	1	3	1850	35
68	0	2	2	1	3	1850	35
69	0	2	2	1	3	1850	35
70	0	1	2	2	3	1850	35
71	0	1	2	3	3	1850	35
72	0	0	2	2	1	1850	35
73	0	0	2	1	1	1850	28
74	2	0	2	1	3	1850	28
75	0	0	1	1	1	1850	28
76	0	0	1	1	1	1850	28
77	0	0	1	1	1	1850	28
78	0	0	1	1	1	1850	28
79	0	0	3	1	1	1850	28
80	0	0	3	1	1	1850	28
81	1	1	3	1	3	1710	28
82	0	1	3	1	3	1710	28

Table C-9. Distribution of safety risk factors in each segment for the James River corridor.

Segment	High	Moderate	Low	Segment	High	Moderate	Low
	Number of Factors Within Threshold				Number of Factors Within Threshold		
1	4	4	12	42	2	6	12
2	3	5	12	43	3	6	11
3	4	4	12	44	3	5	12
4	4	3	13	45	4	8	8
5	3	6	11	46	3	6	11
6	4	4	12	47	2	7	11
7	3	4	13	48	4	6	10
8	6	3	11	49	4	5	11
9	3	5	12	50	4	5	11
10	4	5	11	51	3	6	11
11	3	4	13	52	3	3	14
12	3	5	12	53	4	4	12
13	5	4	11	54	4	3	13
14	3	6	11	55	3	4	13
15	3	8	9	56	4	4	12
16	4	8	8	57	4	5	11
17	2	8	10	58	2	6	12
18	3	6	11	59	2	6	12
19	3	6	11	60	4	6	10
20	3	7	10	61	3	6	11
21	2	7	11	62	3	6	11
22	3	5	12	63	3	6	11
23	3	6	11	64	4	7	9
24	3	6	11	65	4	5	11
25	4	6	10	66	2	4	14
26	1	6	13	67	2	5	13
27	3	6	11	68	2	5	13
28	3	6	11	69	2	5	13
29	3	5	12	70	2	5	13
30	1	5	14	71	3	6	11
31	1	6	13	72	2	5	13
32	2	6	12	73	2	8	10
33	1	7	12	74	3	7	10
34	1	6	13	75	3	8	9
35	1	5	14	76	1	7	12
36	1	7	12	77	1	6	13
37	1	5	14	78	1	6	13
38	2	6	12	79	8	4	8
39	2	7	11	80	7	3	10
40	3	7	10	81	7	5	8
41	2	7	11	82	7	5	8

Table C-10. Distribution of segments by risk level within safety factors for the James River corridor.

Factor	Hazards	Number of Segments Within Threshold		
		High	Moderate	Low
Channel width	Collision	51	11	20
Channel depth	Grounding	0	72	10
Shore-to-shore distance	Grounding	18	7	57
Turn angle	Collision, allision, grounding	9	22	51
Vessel traffic tug/tow	Collision	5	53	24
Vessel traffic cargo	Collision	6	56	20
Vessel traffic tanker	Collision	4	6	72
Vessel traffic passenger	Collision	6	0	76
Vessel traffic fishing	Collision	5	5	72
Vessel traffic pleasure	Collision	4	21	57
Bridges	Allision, collision	4	7	71
Commercial pier	Collision, allision	0	20	62
Buoys and lights	Allision	20	18	44
Obstructions	Allision	1	3	78
Inflows	Collision, allision, grounding	2	22	58
Wind (average)	Collision, allision, grounding	0	0	82
Wind (maximum)	Collision, allision, grounding	82	0	0
Precipitation (average)	Collision, allision, grounding	0	0	82
Precipitation (maximum)	Collision, allision, grounding	30	52	0
Fog	Collision, allision, grounding	0	82	0

Table C-11. Distribution of security risk factor levels in each segment for the James River corridor.

Segment	High	Moderate	Low	Segment	High	Moderate	Low
	Number of Factors Within Threshold				Number of Factors Within Threshold		
1	3	1	3	42	2	2	3
2	2	3	2	43	1	2	4
3	2	2	3	44	2	1	4
4	2	2	3	45	0	4	3
5	2	2	3	46	0	4	3
6	1	4	2	47	0	4	3
7	3	2	2	48	1	3	3
8	4	1	2	49	1	3	3
9	3	3	1	50	1	3	3
10	3	2	2	51	1	2	4
11	2	3	2	52	0	4	3
12	2	2	3	53	0	3	4
13	3	1	3	54	0	2	5
14	1	3	3	55	0	1	6
15	2	3	2	56	0	2	5
16	2	2	3	57	0	2	5
17	1	3	3	58	0	3	4
18	2	3	2	59	1	3	3
19	2	3	2	60	0	5	2
20	0	4	3	61	0	4	3
21	1	4	2	62	0	4	3
22	1	1	5	63	0	5	2
23	1	1	5	64	1	4	2
24	1	2	4	65	1	3	3
25	2	2	3	66	0	4	3
26	1	3	3	67	2	2	3
27	2	2	3	68	1	3	3
28	2	2	3	69	1	3	3
29	1	2	4	70	0	5	2
30	1	3	3	71	1	4	2
31	1	3	3	72	0	3	4
32	2	3	2	73	0	2	5
33	1	3	3	74	1	3	3
34	0	4	3	75	0	1	6
35	0	2	5	76	0	1	6
36	1	3	3	77	0	1	6
37	1	2	4	78	0	1	6
38	0	3	4	79	1	1	5
39	0	4	3	80	1	1	5
40	1	3	3	81	1	4	2
41	1	2	4	82	1	3	3

Table C-12. Distribution of segments by risk level within security factors for the James River corridor.

Factor	Hazards	Number of Segments Within Threshold		
		High	Moderate	Low
Inlets	VBIED	7	34	41
Shore cover type	LBA	40	30	12
Cilivilan docks and piers	VBIED	12	37	33
Shore-to-shore distance	LBA	18	7	57
Vessel traffic pleasure	VBIED	4	21	57
Bridges	LBA	4	7	71
Fog	VBIED	0	82	0

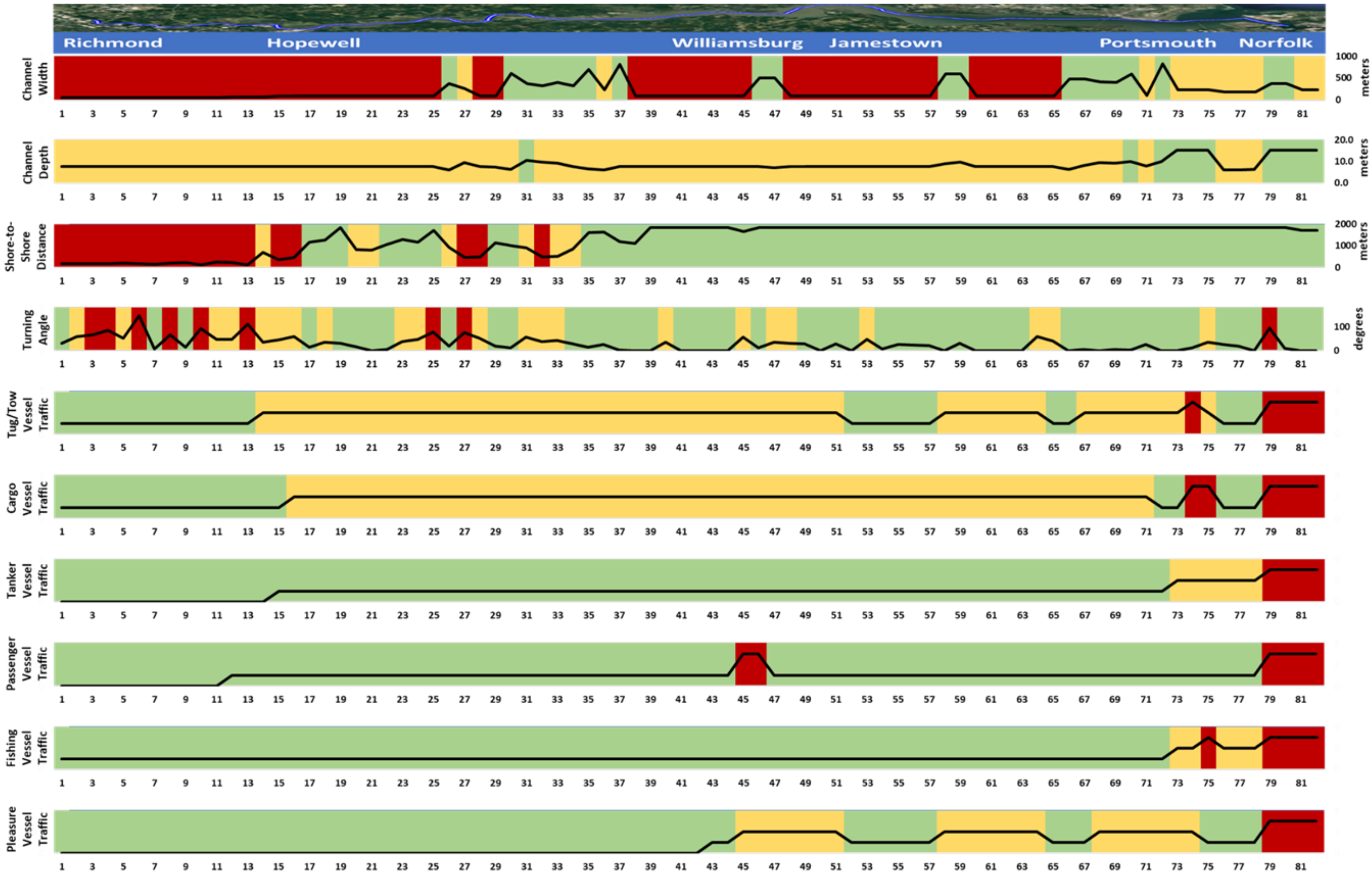


Figure C-3. Maritime corridor trace of the James River corrido for geometry and traffic safety risk factor categories.

Figure C-4. Maritime corridor trace of the James River corridor for infrastructure, obstacle, and sea-state safety risk factor categories.

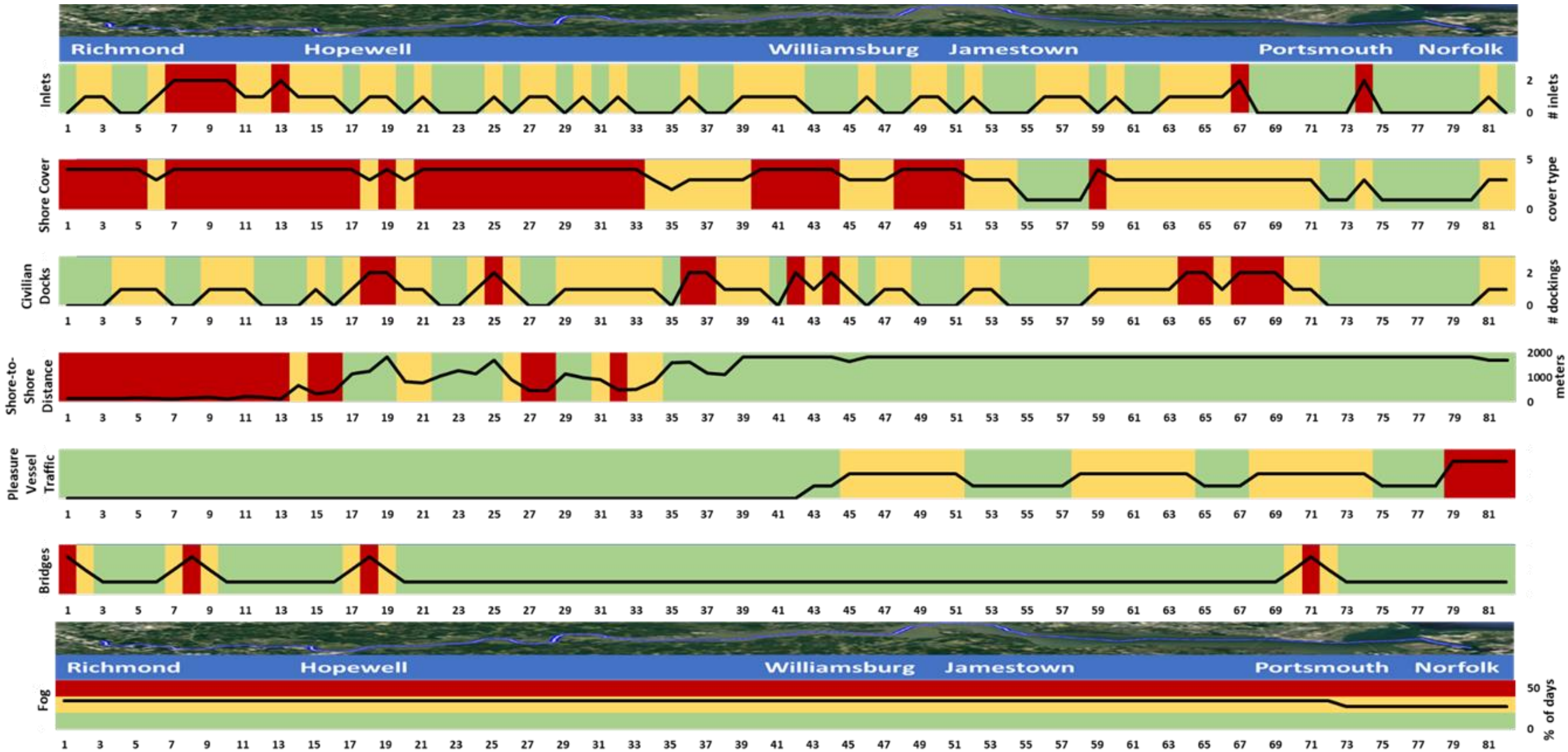


Figure C-5. Maritime corridor trace of the James River corridor for security risk factors.

Table C-13. Assessment of segments s.01 – s.30 against factors f.01 – f.15 for the James River corridor: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.01 - s.30 Factors: f.01 - f.15 Safety Factors	seg.01 - Richmond - RMT/VVM Bridge	seg.02 - CC/HC - Bellwood	seg.03 - CC/HC - Carbonic Ind	seg.04 - CC/HC - Chaffin Bluff	seg.05 - CC/HC - Canaday Logistics	seg.06 - CC/HC - Chesterfield Power	seg.07 - CC/HC - Hatcher Island	seg.08 - CC/HC - Varina-Enon Bridge	seg.09 - CC/HC - Varina Farm	seg.10 - CC/HC - Jones Neck Cutoff	seg.11 - CC/HC - Amazon FC	seg.12 - CC/HC - Dupont Teijin Films	seg.13 - CC/CCC - Turkey Island	seg.14 - CC/CCC - Bermuda Hundred	seg.15 - Hope/CCC - West	seg.16 - Hope/CCC - East	seg.17 - PGC/CCC - Eppes Island	seg.18 - PGC/CCC - BHM Bridge	seg.19 - PGC/CCC - Indian Point	seg.20 - PGC/CCC - Tar Bay	seg.21 - PGC/CCC - Coggins Point	seg.22 - PGC/CCC - Maycocks Point	seg.23 - PGC/CCC - Bucklers Point	seg.24 - PGC/CCC - Wilcox Wharf	seg.25 - PGC/CCC - Windmill Point	seg.26 - PGC/CCC - Threemile Reach	seg.27 - PGC/CCC - Weyanoke Pt West	seg.28 - PGC/CCC - Weyanoke Pt East	seg.29 - PGC/CCC - Weyanoke Shoal	seg.30 - PGC/CCC - Sevenmile Reach
the factor f.xx is addressed by this segment																														
f.01 - Channel width	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	◐	●	●	○
f.02 - Channel depth	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.03 - Shore-to-shore distance (safety)	●	●	●	●	●	●	●	●	●	●	●	●	●	◐	●	●	○	○	○	◐	◐	○	○	○	○	◐	●	●	○	○
f.04 - Turning angle	○	◐	●	●	◐	●	○	●	○	●	◐	◐	●	◐	◐	◐	○	◐	○	○	○	○	◐	◐	●	○	●	◐	○	○
f.05 - Vessel traffic tug/tow	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.06 - Vessel traffic cargo	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.07 - Vessel traffic tanker	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.08 - Vessel traffic passenger	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.09 - Vessel traffic fishing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.10 - Vessel traffic pleasure (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.11 - Bridges (safety)	●	◐	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	○	○	○	○
f.12 - Commercial pier	◐	○	◐	○	◐	◐	○	○	○	○	○	○	○	○	○	◐	◐	○	○	○	○	○	○	○	○	○	○	○	○	○
f.13 - Buoys and Lights	○	○	○	○	○	○	○	○	◐	◐	○	○	●	●	◐	●	◐	○	●	●	◐	○	●	●	●	○	○	○	●	○
f.14 - Obstructions	○	○	○	○	◐	○	○	○	○	○	○	○	○	○	◐	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.15 - Inflows	○	○	○	○	○	○	○	●	○	◐	○	◐	◐	○	◐	◐	○	○	○	◐	○	●	○	○	◐	○	○	○	○	○

Table C-14. Assessment of segments s.31 – s.60 against factors f.01 – f.15 for the James River corridor: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.31 - s.60 Factors: f.01 - f.15 Safety Factors	seg.31 - PGC/CCC - Milton	seg.32 - PGC/CCC - Sturgeon Point	seg.33 - PGC/CCC - Bachelor Point	seg.34 - PGC/CCC - Brandon Point	seg.35 - PGC/CCC - Brandon	seg.36 - SC/CCC - Chippokes Creek	seg.37 - SC/CCC - Claremont	seg.38 - SC/CCC - Sandy Point	seg.39 - SC/CCC - Chickahominy West	seg.40 - SC/CCC - Chickahominy Center	seg.41 - SC/JCC - Chickahominy East	seg.42 - SC/JCC - Two Rivers CC	seg.43 - SC/JCC - Segment 43	seg.44 - SC/JCC - Segment 44	seg.45 - SC/JCC - JS Ferry Settlement
the factor f.xx is addressed by this segment															
f.01 - Channel width	○	○	○	○	○	◐	○	●	●	●	●	●	●	●	●
f.02 - Channel depth	○	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.03 - Shore-to-shore distance (safety)	◐	●	◐	◐	○	○	○	○	○	○	○	○	○	○	○
f.04 - Turning angle	◐	◐	◐	○	○	○	○	○	○	◐	○	○	○	○	◐
f.05 - Vessel traffic tug/tow	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.06 - Vessel traffic cargo	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.07 - Vessel traffic tanker	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.08 - Vessel traffic passenger	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
f.09 - Vessel traffic fishing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.10 - Vessel traffic pleasure (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐
f.11 - Bridges (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.12 - Commercial pier	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐
f.13 - Buoys and Lights	○	○	○	○	○	○	○	○	◐	●	◐	○	◐	◐	◐
f.14 - Obstructions	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.15 - Inflows	○	○	○	○	○	◐	○	◐	◐	◐	◐	◐	◐	○	○

Segments: s.31 - s.60 Factors: f.01 - f.15 Safety Factors	seg.46 - SC/JCC - JS Ferry	seg.47 - SC/JCC - JS Ferry Scotland	seg.48 - SC/JCC - Cobham Wharf	seg.49 - SC/JCC - Cobham Bay	seg.50 - SC/JCC - Surry Nuclear Power	seg.51 - SC/JCC - Hog Island 1	seg.52 - SC/JCC - Hog Island 2	seg.53 - SC/JCC - Hog Island 3	seg.54 - SC/JCC - Hog Island 4	seg.55 - SC/JCC - Hog Island 5	seg.56 - SC/JCC - Hog Island 6	seg.57 - SC/NN - Fort Eustis	seg.58 - SC/NN - Felker Army Airfield	seg.59 - IWC/NN - Reserve Fleet	seg.60 - IWC/NN - Mulberry Island 1
the factor f.xx is addressed by this segment															
f.01 - Channel width	○	○	●	●	●	●	●	●	●	●	●	●	○	○	●
f.02 - Channel depth	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.03 - Shore-to-shore distance (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.04 - Turning angle	○	◐	◐	○	○	○	○	◐	○	○	○	○	○	○	○
f.05 - Vessel traffic tug/tow	◐	◐	◐	◐	◐	◐	○	○	○	○	○	○	◐	◐	◐
f.06 - Vessel traffic cargo	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.07 - Vessel traffic tanker	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.08 - Vessel traffic passenger	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.09 - Vessel traffic fishing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.10 - Vessel traffic pleasure (safety)	◐	◐	◐	◐	◐	◐	○	○	○	○	○	○	◐	◐	◐
f.11 - Bridges (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.12 - Commercial pier	○	◐	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐
f.13 - Buoys and Lights	○	○	●	●	●	○	○	●	●	◐	●	●	○	○	●
f.14 - Obstructions	○	○	○	○	○	○	○	○	○	○	○	◐	○	○	○
f.15 - Inflows	◐	○	○	○	○	◐	○	○	○	○	◐	○	○	○	○

Table C-15. Assessment of segments s.61 – s.82 against factors f.01 – f.15 for the James River corridor: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.61 - s.82 Factors: f.01 - f.15 Safety Factors	seg.61 - IWC/NN - Mulberry Island 2	seg.62 - IWC/NN - Mulberry Island 3	seg.63 - IWC/NN - Mulberry Island 4	seg.64 - IWC/NN - Warwick River East	seg.65 - IWC/NN - Warwick River West	seg.66 - IWC/NN - Segment 66	seg.67 - IWC/NN - Pagan River	seg.68 - IWC/NN - Segment 68	seg.69 - IWC/NN - Segment 69	seg.70 - IWC/NN - Segment 70	seg.71 - IWC/NN - James River Bridge	seg.72 - IWC/NN - NN Shipbuilding 1	seg.73 - IWC/NN - NN Shipbuilding 2	seg.74 - Suff/NN - NN Marine Terminal	seg.75 - Suff/NN - MM Bridge Tunnel	seg.76 - Port/NN - Craney Island West	seg.77 - Port/NN - Craney Island North	seg.78 - Port/Norf - Harbor Reach Ent	seg.79 - Port/Norf - Norfolk Naval Sta	seg.80 - Port/Norf - NIT North	seg.81 - Port/Norf - NIT South	seg.82 - Port/Norf - VIG
the factor f.xx is addressed by this segment																						
f.01 - Channel width	●	●	●	●	●	○	○	○	○	○	◐	○	◐	◐	◐	◐	◐	◐	○	○	◐	◐
f.02 - Channel depth	◐	◐	◐	◐	◐	◐	◐	◐	◐	○	◐	○	○	○	○	◐	◐	◐	○	○	○	○
f.03 - Shore-to-shore distance (safety)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.04 - Turning angle	○	○	○	◐	◐	○	○	○	○	○	○	○	○	○	◐	○	○	○	●	○	○	○
f.05 - Vessel traffic tug/tow	◐	◐	◐	◐	○	○	◐	◐	◐	◐	◐	◐	◐	●	◐	○	○	○	●	●	●	●
f.06 - Vessel traffic cargo	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	○	○	●	●	○	○	○	●	●	●	●
f.07 - Vessel traffic tanker	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	◐	●	●	●	●
f.08 - Vessel traffic passenger	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	●	●	●
f.09 - Vessel traffic fishing	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	●	◐	◐	◐	●	●	●	●
f.10 - Vessel traffic pleasure (safety)	◐	◐	◐	◐	○	○	○	◐	◐	◐	◐	◐	◐	◐	○	○	○	○	●	●	●	●
f.11 - Bridges (safety)	○	○	○	○	○	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	○	○	○
f.12 - Commercial pier	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	○	○	◐	◐	○	◐
f.13 - Buoys and Lights	◐	◐	◐	●	●	○	○	○	○	○	○	○	○	○	◐	○	○	○	◐	○	◐	◐
f.14 - Obstructions	○	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
f.15 - Inflows	○	○	○	◐	◐	◐	◐	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	○

Table C-16. Assessment of segments s.01 – s.30 against factors f.16 – f.29 for the James River corridor: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.01 - s.30 Factors: f.16 - f.29 Security Factors Sea-State Factors	seg.01 - Richmond - RMT/VVM Bridge	seg.02 - CC/HC - Bellwood	seg.03 - CC/HC - Carbonic Ind	seg.04 - CC/HC - Chaffin Bluff	seg.05 - CC/HC - Canaday Logistics	seg.06 - CC/HC - Chesterfield Power	seg.07 - CC/HC - Hatcher Island	seg.08 - CC/HC - Varina-Enon Bridge	seg.09 - CC/HC - Varina Farm	seg.10 - CC/HC - Jones Neck Cutoff	seg.11 - CC/HC - Amazon FC	seg.12 - CC/HC - Dupont Teijin Films	seg.13 - CC/CCC - Turkey Island	seg.14 - CC/CCC - Bermuda Hundred	seg.15 - Hope/CCC - West	seg.16 - Hope/CCC - East	seg.17 - PGC/CCC - Eppes Island	seg.18 - PGC/CCC - BHM Bridge	seg.19 - PGC/CCC - Indian Point	seg.20 - PGC/CCC - Tar Bay	seg.21 - PGC/CCC - Coggins Point	seg.22 - PGC/CCC - Maycocks Point	seg.23 - PGC/CCC - Bucklers Point	seg.24 - PGC/CCC - Wilcox Wharf	seg.25 - PGC/CCC - Windmill Point	seg.26 - PGC/CCC - Threemile Reach	seg.27 - PGC/CCC - Weyanoke Pt West	seg.28 - PGC/CCC - Weyanoke Pt East	seg.29 - PGC/CCC - Weyanoke Shoal	seg.30 - PGC/CCC - Sevenmile Reach
the factor f.xx is addressed by this segment																														
f.16 - Inlets	○	◐	◐	○	○	◐	●	●	●	●	◐	◐	●	◐	◐	◐	○	◐	◐	○	◐	○	○	○	◐	○	◐	◐	○	◐
f.17 - Civilian docks and piers	○	○	○	◐	◐	◐	○	○	◐	◐	◐	○	○	○	◐	○	◐	●	●	◐	◐	○	○	◐	●	◐	○	○	◐	◐
f.18 - Vessel traffic pleasure (security)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.19 - Bridges (security)	●	◐	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	○	○	○	○
f.20 - Shore cover type	●	●	●	●	●	◐	●	●	●	●	●	●	●	●	●	●	●	◐	●	◐	●	●	●	●	●	●	●	●	●	●
f.21 - Shore-to-shore distance (security)	●	●	●	●	●	●	●	●	●	●	●	●	●	◐	●	●	○	○	○	◐	◐	○	○	○	○	◐	●	●	○	○
f.22 - Industrial zoned shores	◐	○	●	●	●	●	◐	○	○	●	○	●	●	●	○	◐	○	○	●	●	●	●	●	○	○	○	○	○	○	○
f.23 - Maintained channels	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	○	◐	◐	○	○	○	○	○	○	○	●	●	●	●	●
f.24 - Wind (maximum)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
f.25 - Wind (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.26 - Precipitation (maximum)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.27 - Precipitation (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.28 - Fog (safety)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.29 - Fog (security)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐

Table C-17. Assessment of segments s.31 – s.60 against factors f.16 – f.29 for the James River corridor: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.31 - s.60 Factors: f.16 - f.29 Security Factors Sea-State Factors	seg.31 - PGC/CCC - Milton	seg.32 - PGC/CCC - Sturgeon Point	seg.33 - PGC/CCC - Bachelor Point	seg.34 - PGC/CCC - Brandon Point	seg.35 - PGC/CCC - Brandon	seg.36 - SC/CCC - Chippokes Creek	seg.37 - SC/CCC - Claremont	seg.38 - SC/CCC - Sandy Point	seg.39 - SC/CCC - Chickahominy West	seg.40 - SC/CCC - Chickahominy Center	seg.41 - SC/JCC - Chickahominy East	seg.42 - SC/JCC - Two Rivers CC	seg.43 - SC/JCC - Segment 43	seg.44 - SC/JCC - Segment 44	seg.45 - SC/JCC - JS Ferry Settlement	seg.46 - SC/JCC - JS Ferry	seg.47 - SC/JCC - JS Ferry Scotland	seg.48 - SC/JCC - Cobham Wharf	seg.49 - SC/JCC - Cobham Bay	seg.50 - SC/JCC - Surry Nuclear Power	seg.51 - SC/JCC - Hog Island 1	seg.52 - SC/JCC - Hog Island 2	seg.53 - SC/JCC - Hog Island 3	seg.54 - SC/JCC - Hog Island 4	seg.55 - SC/JCC - Hog Island 5	seg.56 - SC/JCC - Hog Island 6	seg.57 - SC/NN - Fort Eustis	seg.58 - SC/NN - Felker Army Airfield	seg.59 - IWC/NN - Reserve Fleet	seg.60 - IWC/NN - Mulberry Island 1
the factor f.xx is addressed by this segment																														
f.16 - Inlets	○	◐	○	○	○	◐	○	○	◐	◐	◐	◐	○	○	○	◐	○	○	◐	◐	○	◐	○	○	○	◐	◐	◐	○	◐
f.17 - Civilian docks and piers	◐	◐	◐	◐	○	●	●	◐	◐	◐	○	●	◐	●	◐	○	◐	◐	○	○	○	◐	◐	○	○	○	○	○	◐	◐
f.18 - Vessel traffic pleasure (security)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	◐	◐	○	○	○	○	○	○	◐	◐	◐
f.19 - Bridges (security)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.20 - Shore cover type	●	●	●	◐	◐	◐	◐	◐	◐	●	●	●	●	●	◐	◐	◐	●	●	●	●	◐	◐	◐	○	○	○	○	●	◐
f.21 - Shore-to-shore distance (security)	◐	●	◐	◐	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.22 - Industrial zoned shores	○	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.23 - Maintained channels	●	●	●	●	●	●	●	◐	○	○	○	○	○	○	◐	●	●	○	○	○	○	○	○	○	○	○	◐	●	●	○
f.24 - Wind (maximum)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
f.25 - Wind (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.26 - Precipitation (maximum)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
f.27 - Precipitation (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.28 - Fog (safety)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.29 - Fog (security)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐

Table C-18. Assessment of segments s.61 – s.82 against factors f.16 – f.29 for the James River corridor: high-risk (●), moderate-risk (◐), low-risk (○).

Segments: s.61 - s.82 Factors: f.16 - f.29 Security Factors Sea-State Factors	seg.61 - IWC/NN - Mulberry Island 2	seg.62 - IWC/NN - Mulberry Island 3	seg.63 - IWC/NN - Mulberry Island 4	seg.64 - IWC/NN - Warwick River East	seg.65 - IWC/NN - Warwick River West	seg.66 - IWC/NN - Segment 66	seg.67 - IWC/NN - Pagan River	seg.68 - IWC/NN - Segment 68	seg.69 - IWC/NN - Segment 69	seg.70 - IWC/NN - Segment 70	seg.71 - IWC/NN - James River Bridge	seg.72 - IWC/NN - NN Shipbuilding 1	seg.73 - IWC/NN - NN Shipbuilding 2	seg.74 - Suff/NN - NN Marine Terminal	seg.75 - Suff/NN - MM Bridge Tunnel	seg.76 - Port/NN - Craney Island West	seg.77 - Port/NN - Craney Island North	seg.78 - Port/Norf - Harbor Reach Ent	seg.79 - Port/Norf - Norfolk Naval Sta	seg.80 - Port/Norf - NIT North	seg.81 - Port/Norf - NIT South	seg.82 - Port/Norf - VIG
the factor f.xx is addressed by this segment																						
f.16 - Inlets	○	○	◐	◐	◐	◐	●	○	○	○	○	○	○	●	○	○	○	○	○	○	◐	○
f.17 - Civilian docks and piers	◐	◐	◐	●	●	◐	●	●	●	◐	◐	○	○	○	○	○	○	○	○	○	◐	◐
f.18 - Vessel traffic pleasure (security)	◐	◐	◐	◐	○	○	○	◐	◐	◐	◐	◐	◐	◐	○	○	○	○	●	●	●	●
f.19 - Bridges (security)	○	○	○	○	○	○	○	○	○	◐	●	◐	○	○	○	○	○	○	○	○	○	○
f.20 - Shore cover type	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	○	○	◐	○	○	○	○	○	○	◐	◐
f.21 - Shore-to-shore distance (security)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.22 - Industrial zoned shores	○	○	○	○	○	○	○	○	○	○	◐	◐	◐	◐	◐	○	○	○	○	◐	◐	◐
f.23 - Maintained channels	○	○	○	○	○	●	●	●	●	●	●	●	◐	○	○	○	○	○	○	○	○	○
f.24 - Wind (maximum)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
f.25 - Wind (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.26 - Precipitation (maximum)	●	●	●	●	●	●	●	●	●	●	●	●	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.27 - Precipitation (average)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
f.28 - Fog (safety)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
f.29 - Fog (security)	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐

Table C-19. Success criteria for asset management of the James River corridor.

Index	Criterion
c.01	Address customer needs
c.02	Improve operational efficiencies
c.03	Barge service reliability
c.04	Barge turn times
c.05	Sustainable growth operations
c.06	Support innovation in operations
c.07	Fiscal responsibility
c.08	Improve navigation waters
c.09	Public/private/port integration
c.10	Stewardship of grants and investments
c.11	Diversify business relationships
c.12	Facilitate job growth
c.13	Human health conscious
c.14	Protect the environment
c.15	Unrestricted waterway access for all
c.16	Support natural disaster response
c.17	Address needs of communities
c.18	Vessel accident prevention
c.19	Security of goods and commodities
c.20	Security of employees and community

Table C-20. Initiatives for asset management of the James River corridor.

Index	Initiative	Source	Risk Dimension
i.01	More frequent maintenance dredging	CTA	Control *vulnerability* *safety and security*
i.02	Expand width of maintained channels	CTA	
i.03	Active channel depth monitoring	CTA; POV	
i.04	Coordinate barge departures and vessel schedule	POV	
i.05	Increase predictability of bridge raisings	POV	
i.06	Barge escort services	CTA; GAO	
i.07	Improved sea-sate data collection	CTA	Management *life cycle* *reliable availability*
i.08	Improved vessel traffic data access	CTA	
i.09	Rehabilitate aging infrastructure	POV	
i.10	Replace obsolete infrastructure	POV	
i.11	RMT wharf repairs/improvements	POV	
i.12	RMT fender repairs/improvements	POV	
i.13	USCG liaison with port	GAO; POV	System Integrity *incident management* *audit management* *policy integration*
i.14	VDOT partnership	CTA; POV	
i.15	ISO-14000 environmental management system	POV	
i.16	Increase licensed pilot availability	CTA	
i.17	Weather capable barge acquisition	CTA; POV	
i.18	Dedicated barge wharf at HR terminals	POV	
i.19	Port terminal as civilian evacuation point	MARAD	
i.20	Pre-load radiological container screening	POV; RAND	
i.21	Stakeholder barge service ride-alongs	POV	
i.22	Provide barge tracking data to customers	POV	Protection *cyber security* *information security*
i.23	Balance routine and off-schedule shipments	ARDP	
i.24	Maintain pilots on autonomously capable vessels	CTA	
i.25	Refrigerated container tamper proofing	RAND	
i.26	Use container loading to limit access	RAND	
i.27	Create additional turning basins on James River	POV	Capacity *future* *system requirements*
i.28	Higher capacity barge acquisition	POV	
i.29	Multiple barges per tug vessel trip	POV	
i.30	Increase barge frequency	POV	
i.31	Increase length of maintained channels	CTA	
i.32	Partner with VEDP	POV	
i.33	RMT on-terminal rail expansion	POV	Other / Enterprise
i.34	Establish additional inland ports	POV	
i.35	Warehouse expansion on/near RMT	POV	
i.36	Increase barge service marketing	POV	
i.37	Two-way cargo contract partnerships	POV	

Table C-21. Assessment of initiatives i.01 – i.20 against criteria c.01 – c.20 for asset management of the James River corridor: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Initiatives: i.1 - i.20 Criteria: c.01 - c.20	i.01 - Maintenance dredging	i.02 - Expand channel width	i.03 - Channel depth monitor	i.04 - Barge/vessel scheduling	i.05 - Bridge predictability	i.06 - Barge escort services	i.07 - Sea-state data collection	i.08 - Vessel traffic data access	i.09 - Rehab old infrastructure	i.10 - Replace infrastructure	i.11 - RMT wharf improvement	i.12 - RMT fender improvement	i.13 - USCG liaison	i.14 - VDOT partnership	i.15 - ISO-14000 EMS	i.16 - Increase # of pilots	i.17 - Weather hardened barge	i.18 - Dedicated barge wharf	i.19 - Civilian evacuation	i.20 - Radiological screening
the criterion c.xx is address by this initiative																				
c.01 - Address customer needs				○					◐	●	○			◐	○	◐	◐	○		
c.02 - Improve operational efficiencies			◐	◐	●		◐	○	◐	●	○	○	○	◐		◐	◐	○		
c.03 - Barge service reliability	●	◐	●	●	●		●	◐	◐	◐	◐	◐				◐	●	◐		
c.04 - Barge turn times	●	◐	◐	●	●		◐	●								●	○	●		
c.05 - Sustainable growth operations	●	◐	◐		○			◐	○	○	◐	◐		○	◐	◐	○	◐		
c.06 - Support innovation in operations						◐	○	○		◐			○	○						
c.07 - Fiscal responsibility	◐								●	○	○	○			○					
c.08 - Improve navigation waters	●	●	●		○			◐							◐					
c.09 - Public/private/port integration	◐	◐	◐	○	◐	◐	◐	◐	○	○			●	●		◐			●	◐
c.10 - Stewardship of grants and investments	◐								◐	○	○	○			○					
c.11 - Diversify business relationships			○											◐						
c.12 - Facilitate job growth		○				○				◐						◐		◐		○
c.13 - Human health conscious									○	○					●				◐	◐
c.14 - Protect the environment	◐	◐	○				◐		○		○	◐		○	●	○	◐			●
c.15 - Unrestricted waterway access for all	●	●	◐		○			●					◐		◐	○				
c.16 - Support natural disaster response		◐	○				●	○			○	○	◐	○	○		◐		●	◐
c.17 - Address needs of communities					○									◐	◐				●	
c.18 - Vessel accident prevention	●	●	●	◐	◐	◐	●	●	○	○	◐	●			◐	●	●	◐		
c.19 - Security of goods and commodities		○				●	○	○	○	○	○	○	◐			○	○	○		●
c.20 - Security of employees and community		○				●			○	○	○	○	●			○	○	○		●

Table C-22. Assessment of initiatives i.21 – i.37 against criteria c.01 – c.20 for asset management of the James River corridor: strongly agree (●), agree (◐), somewhat agree (○), and neutral ( ).

Initiatives: i.21 - i.37 Criteria: c.01 - c.20	i.21 - Barge ride-alongs	i.22 - Barge tracking data	i.23 - Randomize barge moves	i.24 - Pilots on automated ships	i.25 - Refer tamper proofing	i.26 - Container access security	i.27 - Additional turning basin	i.28 - Higher capacity barge	i.29 - Multiple barges per trip	i.30 - Increase barge frequency	i.31 - Increase channel lengths	i.32 - VEDP partnership	i.33 - RMT rail expansion	i.34 - New inland ports	i.35 - RMT warehouse expansion	i.36 - Barge service marketing	i.37 - Two-way cargo partners
the criterion c.xx is address by this initiative																	
c.01 - Address customer needs	◐	●			●	◐		●	●	●		●	◐	◐	◐		
c.02 - Improve operational efficiencies		○				◐	○	●	●			◐	◐		◐		●
c.03 - Barge service reliability	○	○			○		○			●	●						◐
c.04 - Barge turn times		○					◐			●	●			◐			○
c.05 - Sustainable growth operations							○	◐	◐	◐		◐	●	○	◐	●	●
c.06 - Support innovation in operations	○	○	○	●	○	○				○		○				○	◐
c.07 - Fiscal responsibility								○				○				○	●
c.08 - Improve navigation waters							●				●						
c.09 - Public/private/port integration	●	◐					◐	○			○	●	◐	○	◐	●	○
c.10 - Stewardship of grants and investments								◐			○	◐	◐	○	○		○
c.11 - Diversify business relationships	◐	○			◐			○	○	○		◐		◐	◐	●	●
c.12 - Facilitate job growth				○				◐	◐	◐		●	○	●	●	○	◐
c.13 - Human health conscious					●			○	○								
c.14 - Protect the environment			○				◐	◐	○								○
c.15 - Unrestricted waterway access for all	○			○			○										
c.16 - Support natural disaster response							○										
c.17 - Address needs of communities	○				○			○	○	○		◐		○			
c.18 - Vessel accident prevention				●			◐				●						
c.19 - Security of goods and commodities		◐	●	◐	●	●	○								○		
c.20 - Security of employees and community	○		●	○		◐											

Table C-23. Baseline relevance of risk factors for asset management of the James River corridor.

the factor f.xx has	-	relevance among the other factors
f.01 - Channel width has	highest	relevance
f.02 - Channel depth has	high	relevance
f.03 - Shore-to-shore distance (safety) has	medium	relevance
f.04 - Turning angle has	high	relevance
f.05 - Vessel traffic tug/tow has	medium	relevance
f.06 - Vessel traffic cargo has	high	relevance
f.07 - Vessel traffic tanker has	high	relevance
f.08 - Vessel traffic passenger has	medium	relevance
f.09 - Vessel traffic fishing has	low	relevance
f.10 - Vessel traffic pleasure (safety) has	low	relevance
f.11 - Bridges (safety) has	high	relevance
f.12 - Commercial pier has	medium	relevance
f.13 - Buoys and Lights has	high	relevance
f.14 - Obstructions has	lowest	relevance
f.15 - Inflows has	medium	relevance
f.16 - Inlets has	high	relevance
f.17 - Civilian docks and piers has	low	relevance
f.18 - Vessel traffic pleasure (security) has	high	relevance
f.19 - Bridges (security) has	medium	relevance
f.20 - Shore cover type has	low	relevance
f.21 - Shore-to-shore distance (security) has	medium	relevance
f.22 - Industrial zoned shores has	medium	relevance
f.23 - Maintained channels has	medium	relevance
f.24 - Wind (maximum) has	low	relevance
f.25 - Wind (average) has	lowest	relevance
f.26 - Precipitation (maximum) has	low	relevance
f.27 - Precipitation (average) has	lowest	relevance
f.28 - Fog (safety) has	low	relevance
f.29 - Fog (security) has	lowest	relevance

Table C-24. Baseline relevance of criteria for asset management of the James River corridor.

the criterion c.xx has	-	relevance among the other criteria
c.01 - Address customer needs has	high	relevance
c.02 - Improve operational efficiencies has	highest	relevance
c.03 - Barge service reliability has	high	relevance
c.04 - Barge turn times has	medium	relevance
c.05 - Sustainable growth operations has	medium	relevance
c.06 - Support innovation in operations has	low	relevance
c.07 - Fiscal responsibility has	highest	relevance
c.08 - Improve navigation waters has	medium	relevance
c.09 - Public/private/port integration has	medium	relevance
c.10 - Stewardship of grants and investments has	high	relevance
c.11 - Diversify business relationships has	medium	relevance
c.12 - Facilitate job growth has	high	relevance
c.13 - Human health conscious has	high	relevance
c.14 - Protect the environment has	high	relevance
c.15 - Unrestricted waterway access for all has	low	relevance
c.16 - Support natural disaster response has	lowest	relevance
c.17 - Address needs of communities has	high	relevance
c.18 - Vessel accident prevention has	medium	relevance
c.19 - Security of goods and commodities has	lowest	relevance
c.20 - Security of employees and community has	low	relevance

Table C-25. Emergent and future conditions impacting the James River corridor.

Index	Emergent and Future Condition
e.01	Sea-level rise
e.02	Active hurricane seasons
e.03	Heavy rain events near Richmond
e.04	Frequent flooding in Norfolk area
e.05	Increasing average temperatures
e.06	Low visibility events
e.07	Water level rise near RMT
e.08	Increased capacity on I-64
e.09	Decreased capacity on I-64
e.10	Toll requirements added to road networks
e.11	Increase ferry traffic Jamestown-Scotland
e.12	Required bridge repair: JRB, BHMB, VEB, VVMB
e.13	Vertical-lift bridge failure: JRB, BHMB
e.14	Vehicular accident requiring aquatic search and rescue
e.15	Reduction in fuel prices
e.16	Aggressive truck transportation pricing
e.17	Economic downturn affecting port customers
e.18	Train derailment
e.19	Redirecting of container volume to POV
e.20	Completion of deepwater channel dredging project
e.21	Commercial enterprise expansion in Richmond
e.22	Increased activity at Kinder Morgan facility north of RMT
e.23	Commercial development at Bachelor Point (north shore)
e.24	Commerical development at Mayocks Point (south shore)
e.25	Supply chain disruptions
e.26	Lack of federal funding contributions
e.27	Lack of state funding contributions
e.28	Lack of funding for USACE maintenance dredging
e.29	New grant sources for barge service
e.30	Private investment in barge service
e.31	Lack of public awareness of barge service
e.32	Lack of public awareness of barge benefits
e.33	Increased public support for barge operations
e.34	Autonomous vessels begin operating on James River
e.35	Improved container tracking capabilities
e.36	Container handling technology
e.37	Vessel accident on James River
e.38	Vessel accident on out-of-region corridor
e.39	Credible threat intelligence
e.40	U.S. domestic VBA hijacking of vessel
e.41	U.S. domestic VBA suicide attack on vessel
e.42	U.S. domestic LBA against vessel

Table C-26. Scenario definitions for asset management of the James River corridor.

Index	Scenario	Associated Emergent and Future Conditions
s.00	Baseline	--
s.01	Economic downturn	e.17 - Economic downturn affecting port customers
		e.26 - Lack of federal funding contributions
		e.27 - Lack of state funding contributions
s.02	Increase in shipping demand	e.20 - Completion of deepwater channel dredging project
		e.21 - Commercial enterprise expansion in Richmond
		e.29 - New grant sources for barge service
s.03	Credible threat emergence	e.39 - Credible threat intelligence
		e.40 - U.S. domestic VBA hijacking of vessel
		e.41 - U.S. domestic VBA suicide attack on vessel
		e.42 - U.S. domestic LBA against vessel
s.04	Infrastructure degradation	e.09 - Decreased capacity on I-64
		e.12 - Required bridge repair: JRB, BHMB, VEB, VVMB
		e.13 - Vertical-lift bridge failure: JRB, BHMB
s.05	Pandemic	e.15 - Reduction in fuel prices
		e.16 - Aggressive truck transportation pricing
		e.17 - Economic downturn affecting port customers
		e.25 - Supply chain disruptions
s.06	Increased support for waterway utilization	e.09 - Decreased capacity on I-64
		e.33 - Increased public support for barge operations
s.07	Technological innovation	e.30 - Private investment in barge service
		e.34 - Autonomous vessels begin operating on James River
		e.35 - Improved container tracking capabilities
		e.36 - Container handling technology
s.08	Weather or climate changes	e.01 - Sea-level rise
		e.02 - Active hurricane seasons
		e.03 - Heavy rain events near Richmond
		e.05 - Increasing average temperatures
		e.06 - Low visibility events

Table C-27. Reweighting of risk factors under scenarios s.01 - s.03 for asset management of the James River corridor.

Scenarios: s.01 - s.03 Factors: f.01 - f.29	s.01 - Economic downturn	s.02 - Increase in shipping demand	s.03 - Credible threat emergence	s.00 - Baseline
f.01 - Channel width	Decreases Somewhat	-	-	highest
f.02 - Channel depth	Increases Somewhat	Increases Somewhat	-	high
f.03 - Shore-to-shore distance (safety)	-	-	-	medium
f.04 - Turning angle	-	Increases Somewhat	Increases Somewhat	high
f.05 - Vessel traffic tug/tow	-	Increases	-	medium
f.06 - Vessel traffic cargo	Decreases Somewhat	-	-	high
f.07 - Vessel traffic tanker	Decreases Somewhat	-	-	high
f.08 - Vessel traffic passenger	-	-	-	medium
f.09 - Vessel traffic fishing	Increases Somewhat	-	-	low
f.10 - Vessel traffic pleasure (safety)	-	-	-	low
f.11 - Bridges (safety)	Increases Somewhat	Increases Somewhat	Increases Somewhat	high
f.12 - Commercial pier	-	Increases Somewhat	-	medium
f.13 - Buoys and Lights	-	Increases Somewhat	Increases Somewhat	high
f.14 - Obstructions	-	-	-	lowest
f.15 - Inflows	-	-	-	medium
f.16 - Inlets	-	-	Increases	high
f.17 - Civilian docks and piers	-	-	Increases Somewhat	low
f.18 - Vessel traffic pleasure (security)	-	-	Increases Somewhat	high
f.19 - Bridges (security)	-	-	-	medium
f.20 - Shore cover type	Increases Somewhat	-	-	low
f.21 - Shore-to-shore distance (security)	-	-	Increases Somewhat	medium
f.22 - Industrial zoned shores	-	Increases	-	medium
f.23 - Maintained channels	-	Increases Somewhat	-	medium
f.24 - Wind (maximum)	-	-	-	low
f.25 - Wind (average)	-	-	-	lowest
f.26 - Precipitation (maximum)	-	-	-	low
f.27 - Precipitation (average)	-	-	-	lowest
f.28 - Fog (safety)	-	-	-	low
f.29 - Fog (security)	-	-	-	lowest

Table C-28. Reweighting of corridor risk factors under scenarios s.04 - s.06 for asset management of the James River corridor.

Scenarios: s.04 - s.06 Factors: f.01 - f.29	s.04 - Infrastructure degradation	s.05 - Pandemic	s.06 - Increased support for waterway	s.00 - Baseline
f.01 - Channel width	-	-	-	highest
f.02 - Channel depth	Increases Somewhat	-	Increases Somewhat	high
f.03 - Shore-to-shore distance (safety)	-	-	Increases Somewhat	medium
f.04 - Turning angle	-	-	Increases Somewhat	high
f.05 - Vessel traffic tug/tow	-	-	Increases	medium
f.06 - Vessel traffic cargo	-	Decreases Somewhat	-	high
f.07 - Vessel traffic tanker	-	Decreases Somewhat	-	high
f.08 - Vessel traffic passenger	-	Decreases	-	medium
f.09 - Vessel traffic fishing	-	Increases	-	low
f.10 - Vessel traffic pleasure (safety)	-	Increases	-	low
f.11 - Bridges (safety)	Increases Somewhat	-	Increases Somewhat	high
f.12 - Commercial pier	Increases Somewhat	-	Increases	medium
f.13 - Buoys and Lights	-	-	Increases Somewhat	high
f.14 - Obstructions	-	-	-	lowest
f.15 - Inflows	-	-	-	medium
f.16 - Inlets	-	Increases Somewhat	-	high
f.17 - Civilian docks and piers	-	Increases Somewhat	-	low
f.18 - Vessel traffic pleasure (security)	-	Increases Somewhat	-	high
f.19 - Bridges (security)	-	-	-	medium
f.20 - Shore cover type	-	-	-	low
f.21 - Shore-to-shore distance (security)	-	-	-	medium
f.22 - Industrial zoned shores	-	-	Increases	medium
f.23 - Maintained channels	-	-	Increases Somewhat	medium
f.24 - Wind (maximum)	-	-	-	low
f.25 - Wind (average)	-	-	-	lowest
f.26 - Precipitation (maximum)	-	-	-	low
f.27 - Precipitation (average)	-	-	-	lowest
f.28 - Fog (safety)	-	-	-	low
f.29 - Fog (security)	-	-	-	lowest

Table C-29. Reweighting of corridor risk factors under scenarios s.07 - s.08 for asset management of the James River corridor.

Scenarios: s.07 - s.08 Factors: f.01 - f.29	s.07 - Technological innovation	s.08 - Weather or climate change	s.00 - Baseline
f.01 - Channel width	-	-	highest
f.02 - Channel depth	-	Increases Somewhat	high
f.03 - Shore-to-shore distance (safety)	-	Increases Somewhat	medium
f.04 - Turning angle	Increases	Increases Somewhat	high
f.05 - Vessel traffic tug/tow	Increases	-	medium
f.06 - Vessel traffic cargo	-	-	high
f.07 - Vessel traffic tanker	-	Increases Somewhat	high
f.08 - Vessel traffic passenger	-	-	medium
f.09 - Vessel traffic fishing	-	-	low
f.10 - Vessel traffic pleasure (safety)	Increases Somewhat	-	low
f.11 - Bridges (safety)	-	Increases Somewhat	high
f.12 - Commercial pier	Increases Somewhat	-	medium
f.13 - Buoys and Lights	Increases Somewhat	Increases Somewhat	high
f.14 - Obstructions	-	-	lowest
f.15 - Inflows	-	Increases Somewhat	medium
f.16 - Inlets	Increases Somewhat	-	high
f.17 - Civilian docks and piers	Increases Somewhat	-	low
f.18 - Vessel traffic pleasure (security)	-	-	high
f.19 - Bridges (security)	-	-	medium
f.20 - Shore cover type	-	-	low
f.21 - Shore-to-shore distance (security)	-	-	medium
f.22 - Industrial zoned shores	Increases Somewhat	-	medium
f.23 - Maintained channels	Increases	Increases Somewhat	medium
f.24 - Wind (maximum)	-	Increases Somewhat	low
f.25 - Wind (average)	-	Increases Somewhat	lowest
f.26 - Precipitation (maximum)	-	Increases	low
f.27 - Precipitation (average)	-	Increases Somewhat	lowest
f.28 - Fog (safety)	Increases Somewhat	Increases	low
f.29 - Fog (security)	-	-	lowest

Table C-30. Reweighting of criteria under scenarios s.01 - s.03 for asset management of the James River corridor.

Scenarios: s.01 - s.03 Criteria: c.01 - c.20	s.01 - Economic downturn	s.02 – Increase in shipping demand	s.03 – Credible threat emergence	s.00 - Baseline
c.01 - Address customer needs	Decreases Somewhat	Increases Somewhat	-	high
c.02 - Improve operational efficiencies	-	-	-	highest
c.03 - Barge service reliability	-	Increases Somewhat	Increases Somewhat	high
c.04 - Barge turn times	Decreases Somewhat	Increases	-	medium
c.05 - Sustainable growth operations	Increases Somewhat	-	-	medium
c.06 - Support innovation in operations	Increases Somewhat	Increases Somewhat	Increases Somewhat	low
c.07 - Fiscal responsibility	-	-	-	highest
c.08 - Improve navigation waters	Decreases Somewhat	Increases Somewhat	-	medium
c.09 - Public/private/port integration	Decreases Somewhat	Increases Somewhat	Increases	medium
c.10 - Stewardship of grants and investments	-	-	-	high
c.11 - Diversify business relationships	Increases	-	-	medium
c.12 - Facilitate job growth	Increases Somewhat	-	-	high
c.13 - Human health conscious	-	-	-	high
c.14 - Protect the environment	-	-	Increases Somewhat	high
c.15 - Unrestricted waterway access for all	-	Increases Somewhat	-	low
c.16 - Support natural disaster response	-	-	Increases Somewhat	lowest
c.17 - Address needs of communities	Increases Somewhat	-	-	high
c.18 - Vessel accident prevention	Decreases Somewhat	Increases Somewhat	Increases Somewhat	medium
c.19 - Security of goods and commodities	-	-	Increases	lowest
c.20 - Security of employees and community	-	-	Increases	low

Table C-31. Reweighting of criteria under scenarios s.04 - s.06 for asset management of the James River corridor.

Scenarios: s.04 - s.06 Criteria: c.01 - c.20	s.04 - Infrastructure degradation	s.05 - Pandemic	s.06 - Increased support for waterway	s.00 - Baseline
c.01 - Address customer needs	-	Increases Somewhat	-	high
c.02 - Improve operational efficiencies	-	-	-	highest
c.03 - Barge service reliability	Increases	Increases Somewhat	-	high
c.04 - Barge turn times	-	Decreases Somewhat	Increases	medium
c.05 - Sustainable growth operations	Increases Somewhat	Decreases Somewhat	Increases	medium
c.06 - Support innovation in operations	Increases	Increases	-	low
c.07 - Fiscal responsibility	-	-	-	highest
c.08 - Improve navigation waters	Increases Somewhat	-	Increases	medium
c.09 - Public/private/port integration	Increases	-	Increases Somewhat	medium
c.10 - Stewardship of grants and investments	Increases Somewhat	-	-	high
c.11 - Diversify business relationships	-	Increases	-	medium
c.12 - Facilitate job growth	-	Increases Somewhat	-	high
c.13 - Human health conscious	-	Increases	-	high
c.14 - Protect the environment	-	-	Increases Somewhat	high
c.15 - Unrestricted waterway access for all	Increases	-	-	low
c.16 - Support natural disaster response	-	Increases	-	lowest
c.17 - Address needs of communities	Increases Somewhat	Increases Somewhat	Increases Somewhat	high
c.18 - Vessel accident prevention	Increases	-	-	medium
c.19 - Security of goods and commodities	-	-	-	lowest
c.20 - Security of employees and community	-	-	-	low

Table C-32. Reweighting of criteria under scenarios s.07 - s.08 for asset management of the James River corridor.

Scenarios: s.07 - s.08 Criteria: c.01 - c.20	s.07 - Technological Innovation	s.08 - Weather or climate change	s.00 - Baseline
c.01 - Address customer needs	-	Increases Somewhat	high
c.02 - Improve operational efficiencies	-	-	highest
c.03 - Barge service reliability	-	Increases Somewhat	high
c.04 - Barge turn times	-	-	medium
c.05 - Sustainable growth operations	Increases Somewhat	-	medium
c.06 - Support innovation in operations	Increases	Increases Somewhat	low
c.07 - Fiscal responsibility	-	-	highest
c.08 - Improve navigation waters	-	Increases	medium
c.09 - Public/private/port integration	Increases Somewhat	Increases Somewhat	medium
c.10 - Stewardship of grants and investments	-	-	high
c.11 - Diversify business relationships	Increases	Increases Somewhat	medium
c.12 - Facilitate job growth	Increases Somewhat	-	high
c.13 - Human health conscious	-	-	high
c.14 - Protect the environment	-	Increases Somewhat	high
c.15 - Unrestricted waterway access for all	-	Increases	low
c.16 - Support natural disaster response	-	Increases	lowest
c.17 - Address needs of communities	-	Increases Somewhat	high
c.18 - Vessel accident prevention	Increases Somewhat	Increases	medium
c.19 - Security of goods and commodities	Increases	Increases	lowest
c.20 - Security of employees and community	Increases	Increases	low

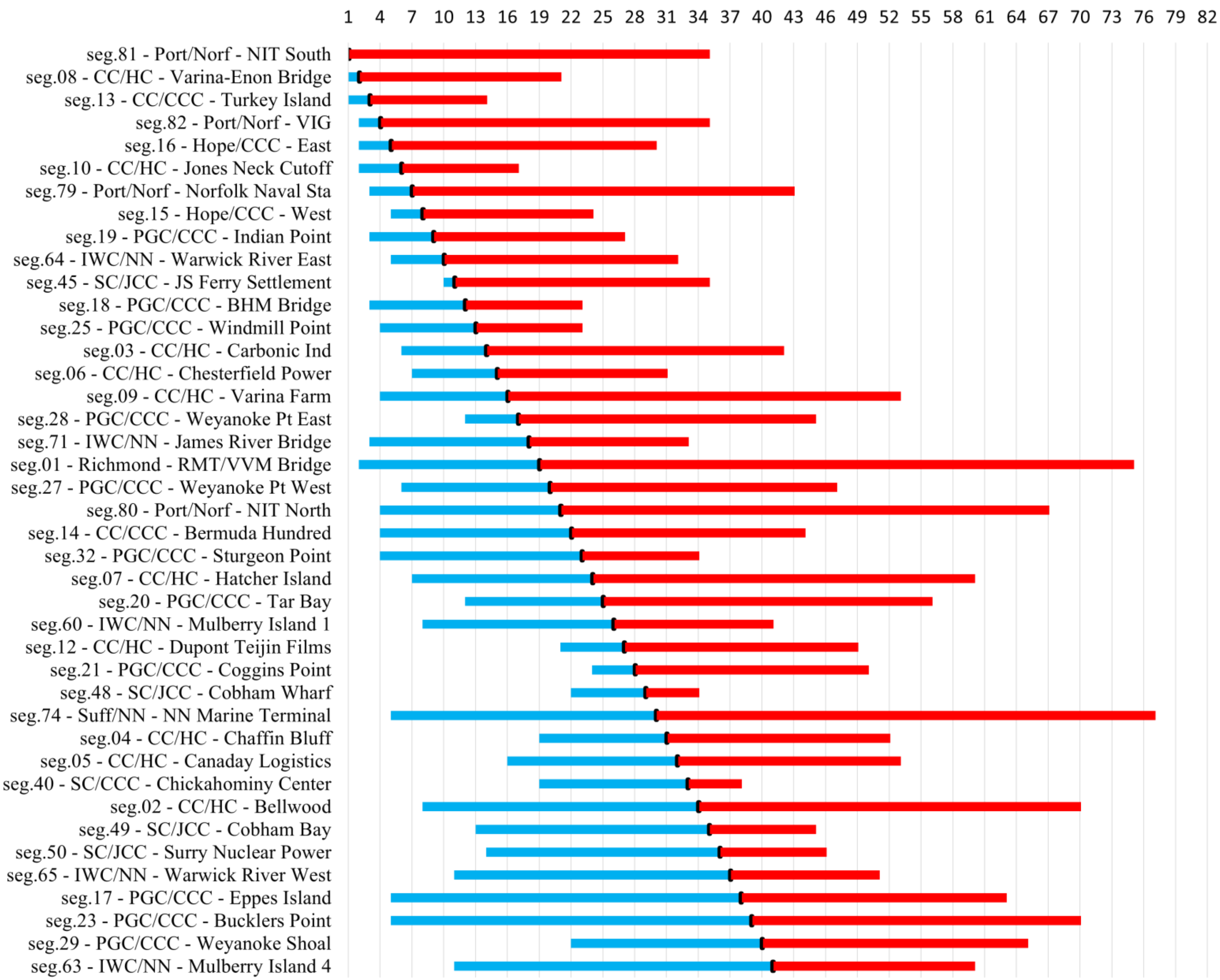


Figure C-6. Corridor segments ranked across 8 scenarios, part 1 of 2, for asset management of the James River corridor.

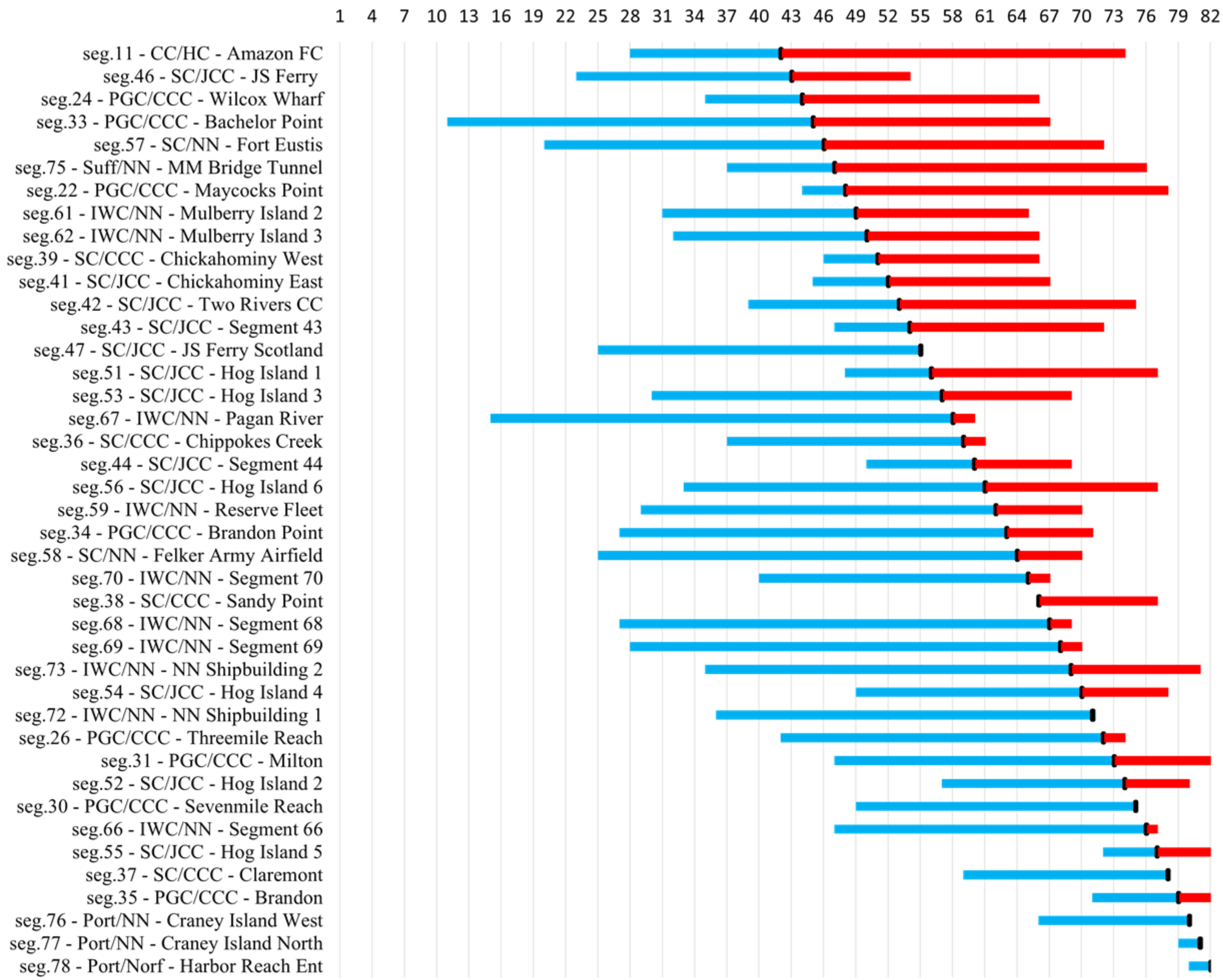


Figure C-7. Corridor segments ranked across 8 scenarios, part 2 of 2, for asset management of the James River corridor.

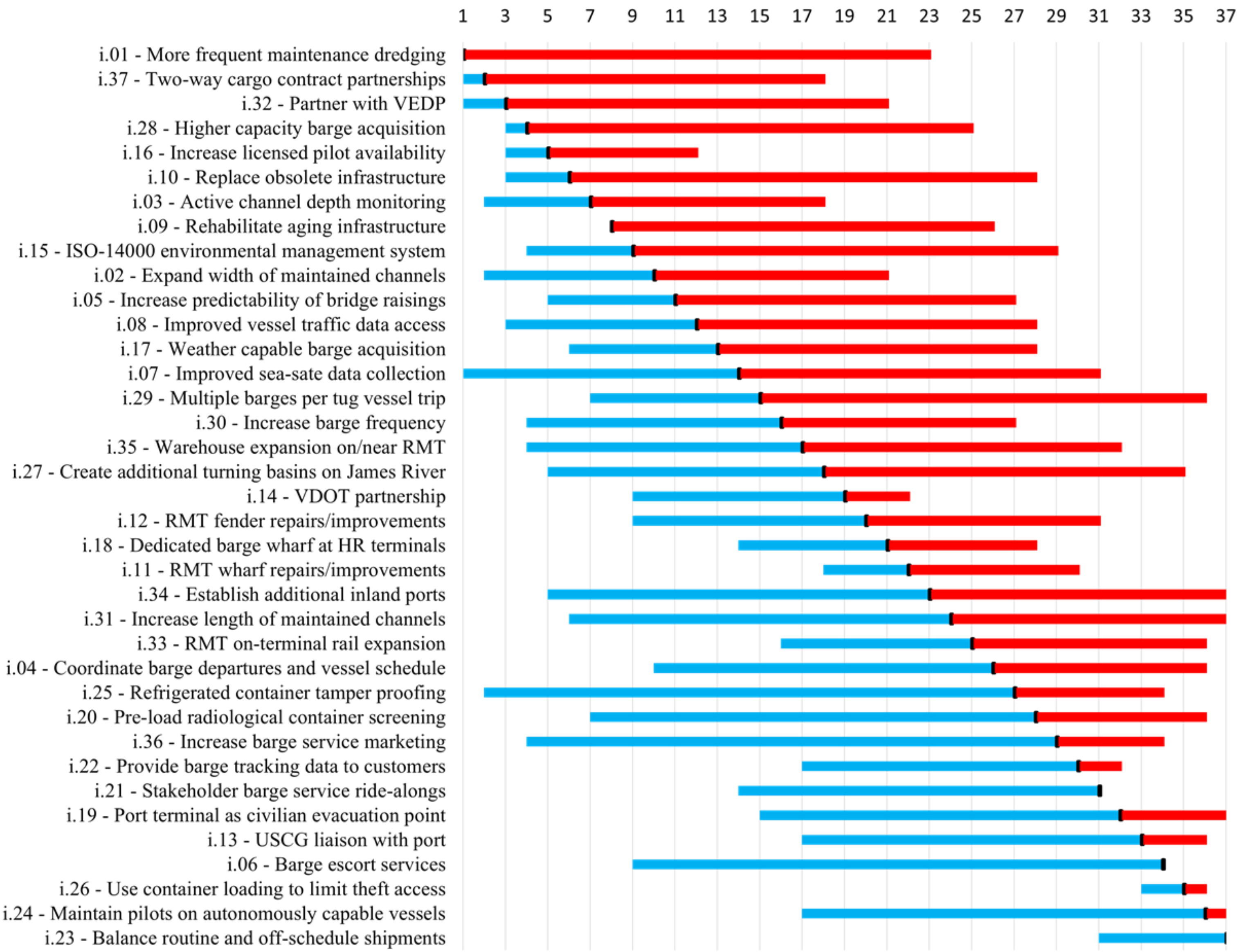


Figure C-8. Initiatives ranked across 8 scenarios for asset management of the James River corridor.

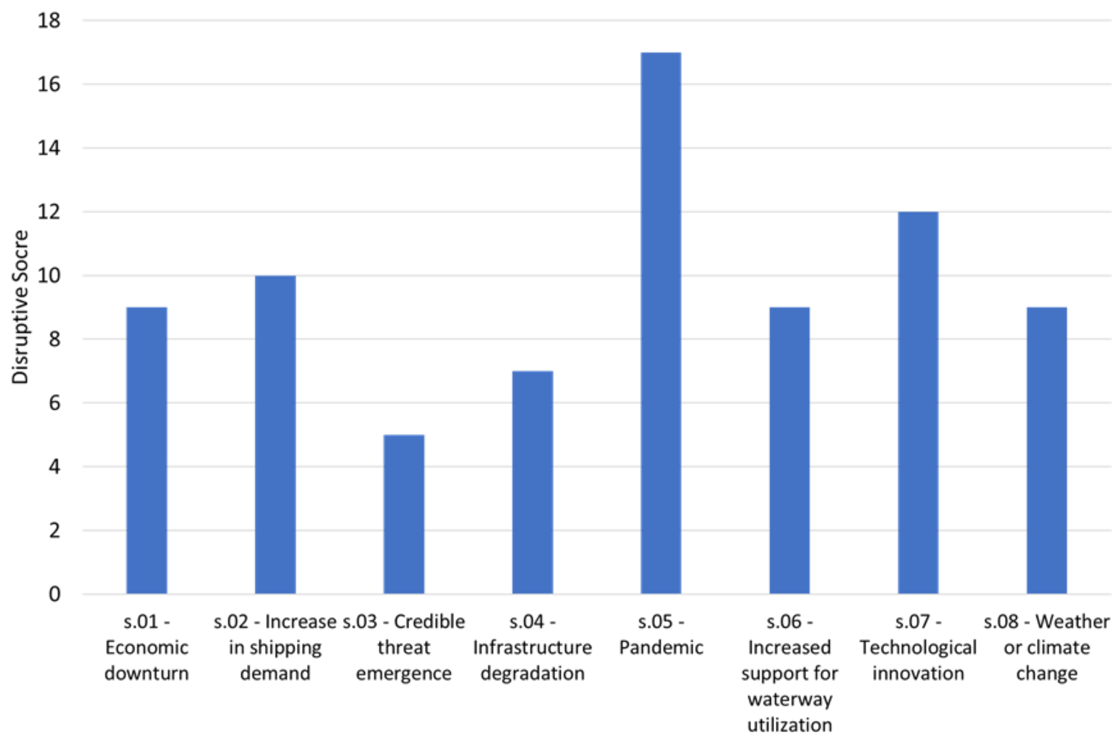


Figure C-9. Scenario disruptive scores related to corridor segment rankings.

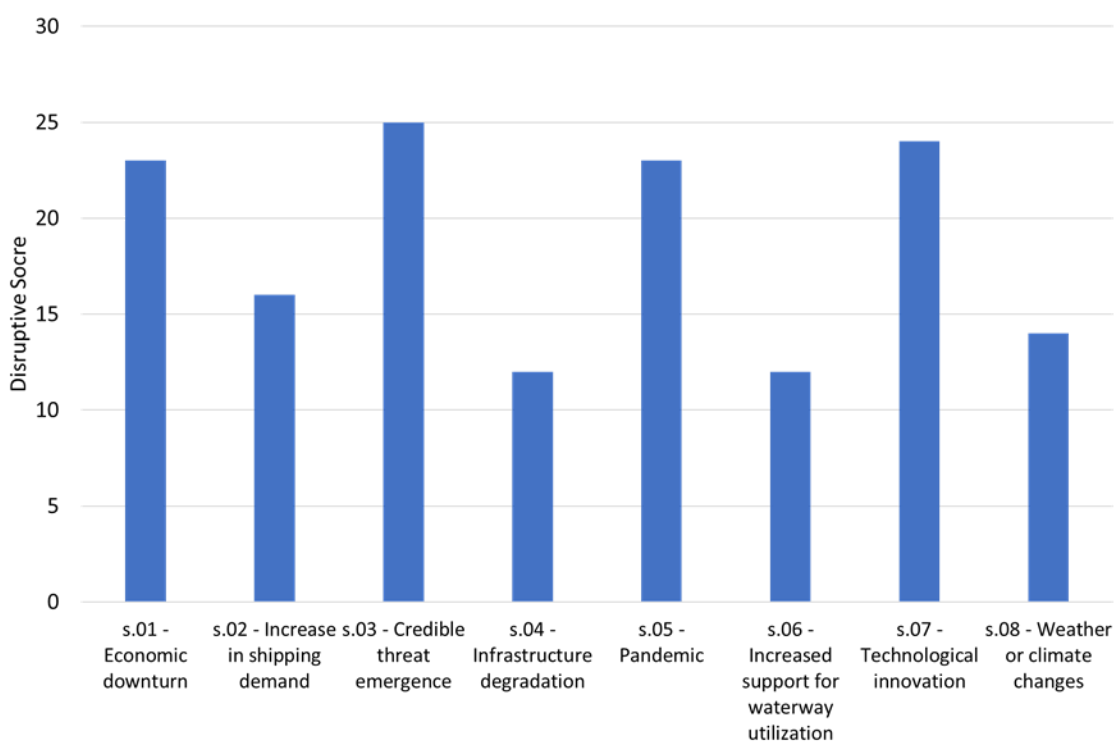


Figure C-10. Scenario disruptive scores related to initiative rankings.

Table C-33. Key results from asset management analysis of the James River corridor.

Scenarios Considered		
s.01 - Economic downturn		
s.02 - Increase in shipping demand		
s.03 - Credible threat emergence		
s.04 - Infrastructure degradation		
s.05 - Pandemic		
s.06 - Increased support for waterway utilization		
s.07 - Technological innovation		
s.08 - Weather or climate change		
Category	**Result**	**Description**
Corridor Segments	Most resilient segment	The most resilient of the highly ranked segments is *seg.13 - CC/CCC - Turkey Island*. This segment is never ranked lower than rank 14 and is ranked as the highest risk segment under at least one scenario. The most resilient segments overall are *seg.77 - Port/NN - Craney Island North* and *seg.78 - Port/Norf - Harbor Reach Entrance*. Both of these segments are always ranked among the bottom three of all segments.
	Highly ranked and resilient segments	Highly ranked and resilient segments include *seg.08 - CC/HC - Varina-Enon Bridge*, *seg.10 - CC/HC - Jones Neck Cutoff*, *seg.13 - CC/CCC - Turkey Island*, *seg.15 - Hope/CCC - West*, *seg.18 - PGC/CCC - BHM Bridge*, and *seg.25 - PGC/CCC Windmill Point*. All of these highly ranked and resilient segments are within 25 nautical miles of Richmond Marine Terminal.
	Most disruptive scenarios	The most disruptive scenario is *s.05 - Pandemic*.
	Least disruptive scenarios	The least disruptive scenario is *s.03 - Credible threat emergence*.
Initiatives	Most resilient initiative	The most resilient initiative of the higher ranked initiatives is *i.16 - Increase licensed pilot availability*. This initiative is ranked in the top third of all intitiatives under consideration of all eight scenarios and is ranked as highly as rank 3. The most resilient of all initiatives is *i.26 - Use container loading to limit theft access*. This initiative changes only three positions in ranking under the influence of eight scenarios. All of these rankings are in the among the 4 lowest ranked initiatives however.
	Highly ranked and resilient initiatives	Under the inlfuence of eight scenarios *i.16 - Increase liscense pilot availability* could be considered as the only highly ranked and resilient initiative. Two other initiatives are always ranked in the top half of initiatives. They are *i.37 - Two-way cargo contract partnerships* and *i.03 - Active channel depth monitoring*. Four others of note are *i.01 - More frequent maintenance dredging*, *i.32 - Partner with VEDP*, *i.02 - Expand width of maintained channels*, and *i.14 - VDOT partnershp*.
	Most disruptive scenarios	The most disruptive scenario is *s.03 - Credible threat emergence*. Scenarios *s.07 - Technological innovation*, *s.01 - Economic downturn*, and *s.05 - Pandemic* also have disruptive scores nearly as high.
	Least disruptive scenarios	The least disruptive scenarios are *s.04 - Infrastructure degradation* and *s.06 - Increased support for waterway utilization*.