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Modeling and Analysis of the Vessel Traffic in the Delaware River and Bay Area Risk Assessment and Mitigation

FINAL REPORT
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Submitted by

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16. Abstract

This is the final report of a comprehensive study focusing on the maritime traffic in Delaware River and Bay. The study started in July of 2007 in collaboration with the Area maritime Security Committee in Sector Delaware Bay of the USCG. The study was carried out at the Laboratory for Port Security (LPS) at the Center for Advanced Infrastructure and Transportation, Rutgers, State University of New Jersey. The following milestones were achieved in the study.

Simulation modeling of the maritime traffic
Model based risk analysis of the maritime traffic
Deepening impact analysis
Analysis of the resumption of trade after reopening

This report presents project description, objectives, model development and analysis carried out for each sub topic above.

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In particular, we are indebted to Capt. David Scott (USCG, Ret.), former COPT of Sector Delaware Bay, for being instrumental at the initiation of the project and putting his years of experience on maritime issues at our service, especially in the risk analysis part of the project. Capt. John Cuff of the Pilots Association for the Bay and River Delaware was available at every opportunity for information on navigational issues. Doug Dillon, USCG (Ret.), Executive Director, Tri-State Maritime Safety Assoc., Harold Neil, former Director of Transportation Security and Michael Riley, former Manager of the Office of Maritime Resources, both retired from New Jersey Department of Transportation were all instrumental at the initiation of the project. . Ken Beatty (USCG, ret.) Capt at Wilmington Tug, LCDR Soo Klein (USCG, ret.) of Sun Oil Co. and Jeffery Milstein of Moran Shipping Agency have all contributed to different parts of the project.

Mr. Joe Balzano of the South Jersey Port Corporation and Marlin Peterson showed every effort to build future projects on this particular one.

We are thankful to South Jersey Port Corporation, Philadelphia Regional Port Authority, OSG Inc., Sun Oil Co., Maritime Exchange for the Delaware River and Bay for their contributions and the Army Core of Engineers for making their information and data available to us for use in this project.

The principal investigator also thanks to Dennis Rochford and Lisa Himber of the Maritime Exchange for the Delaware River and Bay for their insightful comments and strategic feedback in the deepening impact analysis.

Finally, this project is being conducted in cooperation and under the sponsorship of the Office of Maritime Resources at the New Jersey Department of Transportation (NJDOT). The principal investigator expresses his gratitude to the NJDOT for providing the necessary funding for the research described herein. Special thanks are extended to Mr. Scott Douglas of the NJDOT for his input, support, and extending the opportunity to work in such a significant initiative.

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EXECUTIVE SUMMARY

The project, entitled "Modeling and Analysis of Maritime Traffic in Delaware River" was initiated in July of 2007 by the Maritime Resources Program in New Jersey Department of Transportation in cooperation with the Area Maritime Security Committee (AMSC) and the U.S. Coast Guard Sector Delaware Bay.

Project goals included

- Development of a simulation model of the maritime traffic in Delaware River
- Analysis of the impact of deepening on port performance
- Risk analysis of the maritime traffic
- Analysis of the resumption of trade after reopening.

The project had 4 parts, each focusing on one of the goals mentioned above. A detailed large-scale simulation model was developed in Part 1 and used for the analysis of impact of deepening on port performance in Part 2, for risk analysis in Part 3 and finally for vessel prioritization in Part 4. A 30-year planning horizon was used in the project.

The project was carried out by the Laboratory for Port Security (LPS) of the Center for Advanced Infrastructure and Transportation (CAIT) at Rutgers, the State University of New Jersey, under the direction of Dr. Tayfur Altiok, resident director of LPS and a professor in the Department of Industrial and Systems Engineering at Rutgers.

The project was referenced under Maritime Domain Awareness projects in the Strategic Risk Management Plan (Tetra Tech, 2008) of the Area Maritime Security Committee of the U.S. Coast Guard Sector Delaware Bay. It was also described in the section entitled Current Port-Wide Risk Reduction Measures (Section 4.4.6). It was recommended that its results be used to establish an Aid-to-Navigation (ATON) plan for the Sector in section entitled Systems Interdependencies and Resilience (Section 5.5.3.1). It was recommended that its results be used to establish vessel prioritization (Systems Interdependencies and Resiliency – Section 5.6.2). It was recommended that its results be used for Resiliency and Continuity Exercise Program in the section entitled Risk Reduction and Gap Analysis for Vulnerabilities (Section 6.1.15). Finally, it was recommended that its results be used for cascading economic effects in the section entitled Mitigation Measures (Section 8.2.4).

This report presents project description, objectives, and model development and analysis carried out for each part of the project in detail, conclusions and recommendations.

BACKGROUND

Delaware River is the most important waterway in the East Coast of the U.S. with incoming traffic bringing 20% of the nation's crude imports. This clearly shows that a closure for even a few days will result in devastating consequences in the region. The Delaware River Main Channel (DRMC) accommodates navigation of deep draft (up to 40 feet) vessels over 110 miles from its entrance at Cape May (NJ) and Cape Henlopen (DE) to Trenton, New Jersey. The shoreline is the home of a number of petroleum refineries processing nearly 1 million barrels of crude oil per day and other chemicals as part of the refining process, making it one of the most critical petroleum infrastructures in the U.S. The Ports of Philadelphia, South Jersey and Wilmington make one of the largest general cargo port complexes in the nation involving container, general cargo and bulk terminals with critical importance to nation's economy. Currently, the DRMC is being deepened to 45 feet to accommodate larger vessels into various port terminals in the river.

Navigation in the river is managed according to the recommendations spelled out in the Coast Pilot (the book of navigation recommendations for the entire US coast line) and overseen by the Pilots Association for the Bay and River Delaware. Depth of the main channel is 40 feet and, as a result, tide is a major factor in moving deep draft vessels into the channel. Tankers with deeper drafts need to be lightered at the Big Stone anchorage before they proceed to the channel.

The long-term demand for energy products such as petroleum and natural gas translate into significant increases in projected numbers of crude oil, LP gas and, potentially LNG carriers and corresponding port calls required to meet future demand. In particular, the DRMC is expected to have increased vessel traffic, or traffic involving larger vessels due to deepening, giving rise to concerns for port performance and risk. Also, the SAFE Port Act of 2006 (PL 109-711) requires Area Maritime Security Plans to include preparedness, response and recovery plans to ensure that commerce is rapidly restored in U.S. ports following a transportation incident. All of these motivated the need to study the Delaware River and Bay vessel traffic to better develop a post incident recovery strategy.

Part 1: SIMULATION MODELING OF THE MARITIME TRAFFIC IN DELAWARE RIVER AND BAY

A simulation model was developed to mimic the vessel traffic in the DRMC from the Cape Henlopen/Cape May entrance up to Trenton. It incorporated all of the cargo vessels as well as all the terminals using the data (2004 - 2008) from the Maritime Exchange for the Delaware River and Bay (MEX). The model maintained the navigational recommendations of the Coast Pilot as well as the thought processes used by the pilots in bringing vessels to anchorages. Vessel arrival patterns and frequencies, travel times, anchorage delays and dock holding times at terminals were meticulously analyzed and included as part of the model's logic. Finally, details of the lightering operation at the Big Stone anchorage were also included.

The model was built using the Arena simulation tool (Rockwell Software), one of the most extensively used simulation tools that exist today. It was verified, and validated using the aforementioned data, and it became an accurate representation of the traffic in the river. It produced statistical estimations for vessel port times, anchorage delays, delays at the entrance, terminal berth utilization and the overall port occupancy. It was used as part of the analysis in the remaining tasks of the project, namely the deepening impact analysis, risk analysis and vessel prioritization.

Conclusions and Recommendations Regarding the Simulation Model

The project produced an accurate representation of the main channel traffic for all vessel and cargo types and terminals. The model and its findings were already put into use in understanding the impact of the planned vessel stream for the Paulsboro terminal of the South Jersey Port Corporation on the overall maritime performance in Delaware River. With modification, it can be used as a tool of analysis for informed decision making in many critical projects regarding navigation and infrastructure planning in the DRB area.

In the years to come, the model will be updated with new data and information and will be maintained by the CAIT-LPS at Rutgers University.

Part 2: IMPACT OF DEEPENING ON PORT PERFORMANCE

Deepening of the DRMC has been debated over several years due to the current expansion of the Panama Canal. The project was to deepen the main channel from the Capes entrance to Philadelphia Harbor, PA and to Beckett Street Terminal in Camden, NJ. The plan consisted of deepening the channel to 45 feet below Mean Low Water (MLW) and provision of a two-space anchorage with a depth of 45 feet at Marcus Hook. The anticipated benefits included reduced costs of transportation due to reduced lightering and light-loading, and the use of larger vessels resulting in cost reduction per ton of cargo.

In this respect, the motivation behind this part of the study was to analyze the impact of deepening on port performance in the river based on measures such as vessel port times, anchorage delays and terminal berth occupancies. Navigational benefits were expected to include shortened port time per vessel call, lesser anchorage delays and lesser tidal delays, among others. To analyze these benefits, scenarios were generated considering three key factors; increase in vessel arrivals due to trade growth, deepen the river and dredge selected terminals by 5 feet, and change vessel configuration and bring larger vessels to the river. Data used in the analysis were taken from the

Comprehensive Economic Reanalysis Report of Delaware River Main Channel Deepening Project, prepared by the U.S. Army Corp of Engineers (USACE).

Particular scenarios considered in this part of the study included

A. Current scenario
B. Current scenario with 30-year trade growth
C. Deepen & dredge with 30-year trade growth
D. Deepen & dredge and shift to a fleet of larger vessels with 30-year trade growth

These scenarios were analyzed and compared from the port performance perspective looking at the key port performance measures. Gains and deficiencies were indicated for each scenario.

Conclusions Regarding Deepening and Port Performance

The Growth Scenario (B), considering only the growth assumption, showed slight increase in vessel port times with container vessels being the least affected due to available berth capacity in container terminals. The Deepening Scenario (C), considering growth and deepening together, verified the anticipated benefits due to lesser tidal delays and lightering activity. Tankers benefitted from deepening more in the case of increased oil trade in the port. Their port times decreased by 14% in the first year, and 21% through the end of the 30-year planning horizon. Container and bulk vessels showed weaker gains.

The Larger Vessels Scenario (D), considering growth and deepening together, focused on shifting the current vessel portfolio to a fleet of larger vessels despite the intrinsic longer vessel port times. Port time per kiloton results in this scenario indicated slight benefits for container vessels and weaker values for the remaining vessel types. This finding was sensitive to vessel holding times at terminals, and specifically to the factor used in the model to increase holding time for larger vessels. In the case of better operations management at terminals, this measure would indicate higher navigational benefits.

Lightering activity results early in the planning horizon revealed more than 40% decrease in the Deepening Scenario (C) and 28% decrease in the Larger Vessels Scenario (D), as measured in vessel calls at the Big Stone Anchorage. Furthermore, The Growth Scenario (B) exhibited almost doubled usage of major anchorages whereas Scenario D helped reduce anchorage calls for all vessel types while increasing anchorage delays per vessel call.

Note that this study focused only on port performance. It neither covered potential reduction in operating costs nor improved safety due to lesser number of vessels sailing if the DRMC were to be deepened.

Recommendations:

Future growth scenarios point to the need for more anchorage space in the Delaware River. This is especially the case if channel deepening materializes as planned. Long anchorage delays are anticipated for bulk and break bulk cargo vessels in the next 10 to 15 years. Thus, the study recommends making plans for additional anchorage space in the years to come.

Furthermore, additional dredged berth capacity in bulk terminals is recommended to reduce anchorage delays and port times in case large bulk vessels start calling the port once the channel is deepened.

It is also recommended that the model developed in Part 1 should be used to assist in the decision making for how large the newly anticipated vessels (assumed to visit the river after deepening) can be. Vessel size directly impacts port performance as well as safety risks in the river. Current study has focused on vessel sizes and tonnages as estimated from the additional 5 feet draft gain due to deepening. Within this draft specification, there will be vessels varying in beam, length and air draft, and each will have its own berth holding times and possible other requirements. Therefore, it is here recommended that a comprehensive study should be carried out to analyze how large the vessel sizes should be in view of the river's deepening.

Part 3: RISK ANALYSIS OF THE MARITIME TRAFFIC IN DELAWARE RIVER

An extensive risk analysis was carried out by incorporating a risk model into the simulation model developed in Part 1 of the project. Primarily safety risks were considered as a result of accidents such as collision, allision, grounding, fire/explosion, sinking and oil spill. The instigators, as suggested by the historical accident data obtained from the U.S. Coast Guard, included human error, propulsion failure, electrical/electronic failures, steering failures and failures of other systems such as hull structure and cargo control systems. Finally, human casualty, environmental damage and property damage were considered as potential consequences, again as suggested by the historical data. For certain information lacking in the historical data, expert opinion elicitation was carried out surveying regional experts mostly with the USCG background. This required extensive surveying using questionnaires collecting information on the influence of situations such as day/night times, tide, vessel types, number of vessels and seasons on the occurrence of instigators, accidents and consequences. Consequences were estimated as dollar values. Various accident probabilities, expert opinions and consequence values were all combined in an overall safety risk measure where the risk was expressed in dollar terms. The DRMC was divided into six zones and the overall safety risk measure was evaluated for each zone, creating a risk profile for the entire river. This made it possible to evaluate and compare risks of different zones and produced supporting evidence for various risk mitigation initiatives.

Conclusions Regarding Accident Risks in the DRMC

The risk model developed in Part 3 of the study indicated that the risks in Zone 1 (from Cape Henlopen/Cape May entrance to slightly above Bombay Hook Anchorage), Zone 3 (Wilmington to Marcus Hook Anchorage) and Zone 4 (Marcus Hook to Gloucester City) are much higher compared to the rest of the river. This is mainly due to tanker movements and crude handling operations including lightering in the Big Stone Beach Anchorage, and loading and unloading operations in terminals in the upstream part of the river. It was also observed in the model's results that over a planning horizon of 30 years, deepening and bringing larger vessels resulted in lesser risks in Zone 1 and slightly higher risks in Zone 4. This could be attributed to lesser number of vessels in the relatively larger Zone 1 and the presence of larger vessels with longer holding times in the relatively narrower Zone 4.

Recommendations:

There are several ways to mitigate risks at a marine port such as escorting dangerous cargo vessels, increasing pursuit distances, frequent cleanups of the river bed, various best practices for handling loading/unloading dangerous cargo at terminals and best practices for lightering among many other approaches such a training, communication and interoperability. In fact, all the recommendations in the Coast Pilot are there to mitigate safety risks. Many of these are already in place in Delaware River.

In this study, a rather non-traditional approach to mitigate risks was sought after especially since the risk profile of the entire river was obtained in this part of the study and it could be used to measure the effectiveness of mitigation ideas. Thus, a potential non-traditional approach is to try to shorten vessel port times resulting in a lesser number vessels in the river at any point in time. One way to achieve that is to improve terminal efficiencies resulting in shorter berth holding times which will release vessels out of terminals faster and therefore resulting in a lesser number of them at any point in time in the channel. A demonstration of this idea achieved using the model of Part 1 has shown that a 15% increase in operational efficiency produced maximum risk reductions ranging from 28% to 33%. Even though achieving such efficiencies might be quite challenging due to many reasons such as financial, physical and regulatory limitations, any concerted effort among terminals in the river towards better efficiencies would result in considerable risk reductions coupled with environmental benefits.

Thus, it is recommended to initiate a mechanism among the terminal operators to communicate with each other and the AMSC to report their monthly (e.g.) efficiency improvements as percent improvement without disclosing what their actual efficiencies are. This will encourage port partners to do better in their overall efficiency targets and will generate an indirect positive impact on risk reductions.

Part 4: VESSEL PRIORITIZATION DURING RECOVERY IN DELAWARE RIVER

In the final phase of the project, the important topic of vessel prioritization during port reopening was studied. Again using the simulation model of Part 1 and the risk model of Part 3, this part focused on vessel prioritization rules to be used for entry into and exit from the river during recovery operations following a channel-closing event and to evaluate their impact on port performance as well as risk performance.

In November of 2004, a major oil spill occurred when the 750-foot tanker M/V Athos I struck a submerged anchor in Paulsboro. The resulting breach in the ship's hull spilled approximately 265,000 gallons of crude oil into the river. The entire channel was closed to traffic for three days. This was one of the most significant incidents in the history of Delaware River having a major impact on its operation. Thus, an incident similar to Athos I oil spill was considered in this study. Three cases were considered regarding channel closure resulting in varying degrees of impact on traffic as well as the environment. Cases A and B had a major oil spill and cleanup effort and Case C had a medium level environmental consequence. The river was closed to vessel traffic for 3 days in Cases A and B and 2 days in Case C.

In Case A, the oil spill had a potential of spreading to other parts of the channel and it prohibited vessel entry into the river. In Case B, the spill was similar but only the outbound traffic was allowed to operate after cleanup was over. The inbound traffic was allowed only after a threshold number of vessels departed from the river. The spill in Case C was not as significant and thus it made it possible to let vessels enter the channel and move among terminals on either side of the incident.

Extensive numerical investigation was carried out focusing on river opening scenarios prioritizing tankers and refrigerated vessels in entrance queues and varying vessel pursuit distances.

Conclusions Regarding Vessel Prioritization during Recovery

It was observed that vessel prioritization and pursuit distance had a direct impact on vessel waiting times, port times and accident risks in the channel. In all three cases considered, extensive investigation was carried out prioritizing tankers and refrigerated vessels in entrance/closure queues and varying vessel pursuit distances. Model's results indicated that placing tankers into closure queues with higher priorities moved them into the channel physically closer to each other and thereby increased the risks in Zone 1 and impacted the risks in Zone 4. Larger pursuit distances increased average risks but reduced maximum risks in Cases A and C. Case B on the other hand was special in the sense that it emptied the system out until some number of vessels remained and then opened the system to new vessels. Larger pursuit distance scenarios produced smaller average as well as maximum risks in Case B. It was further observed in this case that priority scenarios better performed when higher pursuit distances were employed.

Performance implications of vessel prioritization in Case A indicated that tankers and refrigerated vessels experienced shorter waiting times in the entrance queues as expected. No doubt, this was achieved at the expense of delaying other vessels. Furthermore, a vessel pursuit distance of 45 minutes generated an entrance-queue clearance time of roughly 30 hours. Case B on the other hand built up a longer entrance queue than Case A due to the time until a threshold number of vessels departed from the river. Still, tankers and refrigerated vessels had shorter waiting times than other vessels in Case B. Finally, Case C accumulated very few vessels such that prioritization did not make any difference in queue performance.

Recommendations

While recovering from a river closure, prioritizing oil and refrigerated vessels is unavoidable even though everyone’s cargo is important. Thus, decisions regarding priorities as well as vessel pursuit distances need to be made for a safe and rapid resumption of trade. Among the three cases discussed, Case B (that allowed a certain number of vessels depart from the system and then started moving the waiting vessels in) turned out to be a recommended approach. It reduced both the average as well as the maximum risks in the river. While moving the vessels in, it is recommended that priority is given to vessels carrying national response materials, heating oil and food products, and the pursuit distance should be plausible based on pilot availability and closure-queue clearance time. Numerical investigation suggests 45-minute intervals due to reasonable queue clearance times provided that sufficient number of pilots is available. Clearly, the risk gains of this approach are at the expense of delaying vessels in the entrance queue. This is acceptable since it has not created unreasonable waiting times even in the growth scenario.

1. INTRODUCTION

1.1. Project Description

The Delaware River Main Channel (DRMC) affords deep draft (40 foot) navigation for nearly 110 miles, from the mouth of Delaware Bay to Trenton, NJ (Figure 1.1). The Delaware River shoreline has a number of major petroleum refineries that process nearly 1 million barrels of crude oil per day, as well as other chemicals associated with the refining process, making it one of the most critical petroleum infrastructures in the U.S. Collectively, the Ports of Philadelphia, South Jersey and Wilmington, DE combine to be one of the largest general cargo port complexes in the nation. With one third of the entire U.S. population living within 5 hours of the Port of Philadelphia, the Delaware River and its surrounding facilities are of critical importance to the nation's economy. Consequently, major security vulnerabilities exist in view of the vessel traffic in the channel carrying potentially combustible cargo (oil and LP gas), dry cargo (bulk and container), as well as passenger ships, among others. Thus, the magnitude and nature of the traffic render the area a tempting potential target for terrorist activity.

As traffic intensity is expected to increase during this decade and beyond, the risk of a major vessel collision can be expected to rise concomitantly. Indeed, the U.S. Office of Energy Information Administration expects a 0.9% increase in the consumption of petroleum products in the U.S. in 2012 (Short-Term Energy Outlook, August 2011.) Furthermore, the world LNG trade sector is in a period of large-scale expansion with a 22% jump in trade volume in 2010 compared to 2009. The world fleet of LNG carriers has expanded from 195 vessels in 2005 to the current total of 360. (World LNG Report, 2010). These facts translate into significant increases in projected numbers of crude oil, LP gas and, potentially LNG carriers and corresponding port calls required to meet future demand. In particular, the DRMC is expected to experience increased vessel traffic in all categories with oil, chemical, LP gas and LNG carriers giving rise to concerns for high risk incidents.

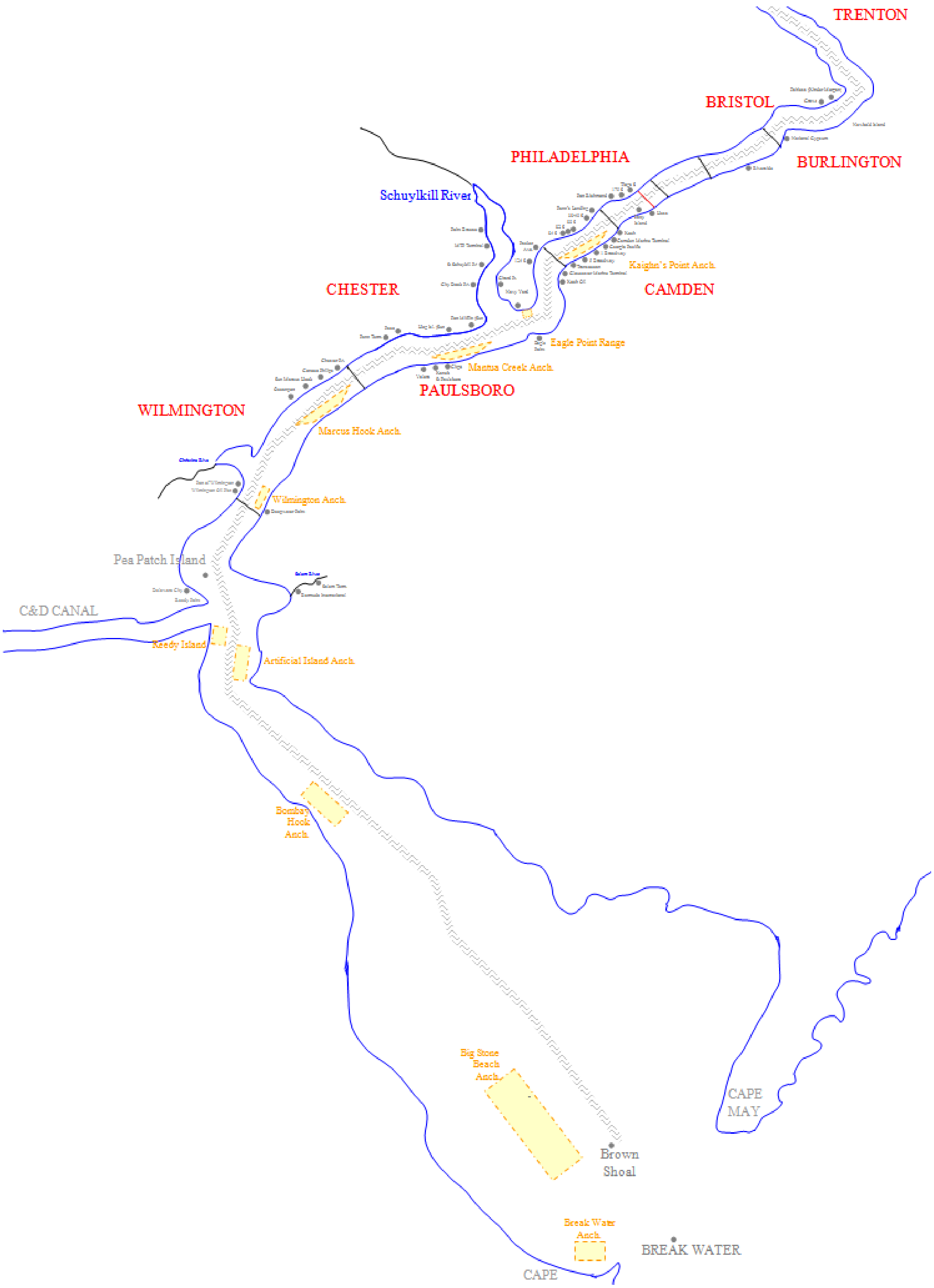

Figure 1.1. Delaware River and Bay (DRB)

The SAFE Port Act of 2006 (PL 109-711) requires Area Maritime Security Plans to include a salvage response plan intended, inter alia, to ensure that commerce is quickly restored to US ports following a transportation security incident. Accordingly, this motivates the need to study and analyze the risks inherent in Delaware River and Bay (DRB) vessel traffic, to be better able to develop a post incident recovery strategy. Accordingly, the CAIT Laboratory for Port Security (LPS) at Rutgers University was charged to study the following issues in this project:

1. Vessel traffic logistics in the DRMC, including current practices in handling dangerous cargo vessels and vessel delays at Delaware Bay.
2. Impact of channel deepening on the navigational issues in the DRMC.
3. Risk analysis for safe and efficient traffic management and port operations.
4. Prioritization analysis of Delaware River vessel traffic in the course of recovery from a channel-closing incident (collision, ramming, grounding, fire, or explosion, stemming from an accident or a terrorist activity).

A number of reports and papers are written and conference presentations made about the project by the LPS team. A list of these academic activities of the project is given in Appendix C.

Below, we describe each phase of the project in more detail:

1.1.1. <u>Phase 1: Analysis of Vessel Traffic in the Delaware River Main Channel</u>

In this phase a detailed high-fidelity simulation model of the vessel traffic in the DRMC was constructed consisting of all the vessel classes, and including pilot and tugboat activities. The model incorporated current vessel handling practices (by the USCG, Ports of Philadelphia, Pilots Assoc., and others), such as entrance scheduling, inter-vessel displacements and other considerations. Past accident data was used to model navigation incidents and closures. The simulation model produced a number of performance metrics including vessel delays, transit times, channel sojourn times, resource utilization, channel vessel density (number of vessels in a given section over time) and others. More importantly, the model's fidelity allowed us to predict these measures for any future scenarios of interest (e.g., deepening or new port terminals, among others), and to answer various other “what-if” questions.

1.1.2. Phase 2: Deepening Impact on Navigation

Using the model developed in Phase 1, an economic impact analysis was carried out for a given volume of traffic, operational practices, and a scenario of anticipated incidents and vessel delays. In particular, the project focused on the impact of channel deepening on the navigational issues as well as the maritime traffic performance in the channel. A detailed report describing the impact of deepening on navigational efficiency circulated among the port partners is provided in Appendix A.

1.1.3. Phase 3: Risk Analysis and Mitigation Strategies

A risk analysis was carried out by incorporating a risk model into the simulation model developed in Phase 1. The model was instrumental in estimating key parameters essential to risk computations. A particular risk measure that is the sum of the expected consequences of various potential incidents was used in the analysis to quantify the risks in the DRMC. Such risk measures were computed separately for each critical zone of the DRMC. Risk factors that were considered include incident types (collision, ramming, grounding, fire/explosion, etc.), instigators (human error, mechanical failures, communication problems, etc.), situational variables affecting incident occurrence (vessel attributes such as class, reliability, pilotage, etc), situational attributes (e.g., vessel proximity, visibility, current, time of the day, etc.) and other variables affecting impact severity (vessel attributes such as cargo type, vessel length and shore attributes such as population, property and infrastructure).

1.1.4. Phase 4: Vessel Prioritization during Incident Recovery

Again using the simulation model of Phase 1 and the risk model of Phase 3, this phase focused on vessel prioritization schemes for entry/exit of the DRMC during recovery operations following a channel-closing event.

1.2. Why is Delaware River Vessel Traffic Important?

The Delaware River and Bay area maritime traffic is a major activity feeding not only the region's economy, but the Nation's and the world economy as clearly depicted in Figure 1.2 and Figure 1.3 shown below. Import as well as export cargo containers extend their routes all the way to the west coast as shown in Figure 1.2.

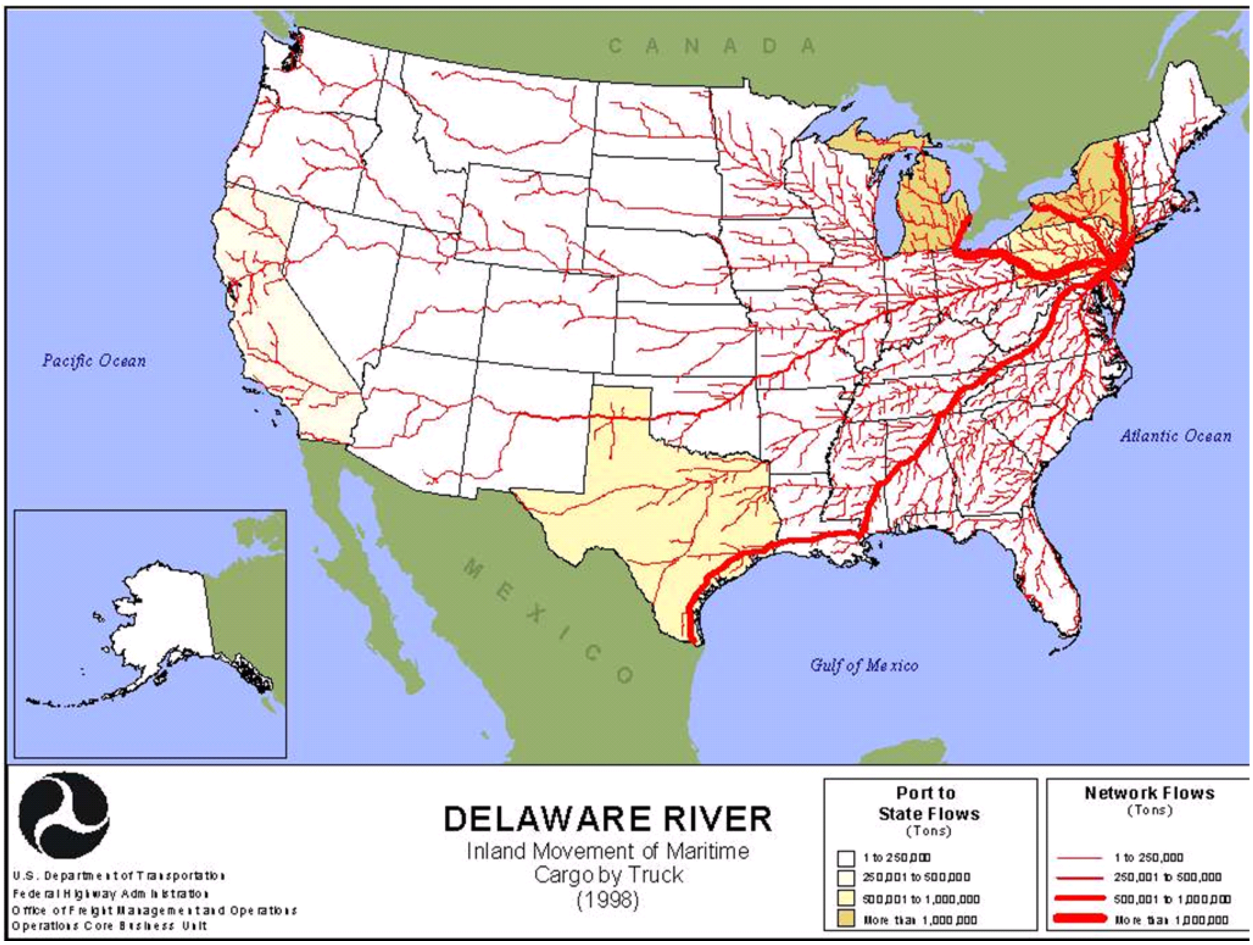

Figure 1.2. Cargo flows coming out of the Delaware River and Bay area

As shown in Figure 1.3, the oil traffic in DRB is significant. More than 90% of the incoming traffic brings crude oil to the port amounting to around 21MST (million ST) and amounting to around 20% of the nation's crude imports. This clearly shows that a closure for even a few days will result in devastating consequences in the region quickly depleting oil reserves for uses in cars, heating and other industrial and household use.

Figure 1.3. Major crude oil routes to the US Ports in the East Coast

The Delaware River is both geographically and operationally one of the most significant waterways on the East Coast of the U.S. Port operations and maritime activity on the River extends from Breakwater entrance all the way to Trenton, NJ. There are two entrance points to the Delaware River port system. Around 93% of vessel arrivals are through Breakwater (BW) and the rest are through the Chesapeake and Delaware Canal (CD). Vessel profiles are in line with the cargo types being carried to the terminals and are mostly tankers (30%), cargo containers (15%), bulk vessels (14%), refrigerated vessels (11%), vehicle vessels (10%) and general cargo vessels (8%). Aside from the regular cargo vessel traffic there is also tug/barge traffic carrying cargo in and out of the port district.

Navigation in the river is restricted by draft limitations such as the maximum fresh water draft for river transit from BW to Delair, NJ is 40 feet and from Delair to Trenton, NJ is 38 feet. The maximum draft limitation is 33 feet for vessels using the CD.

Along with the recommendations and regulations, oceanic tidal activity significantly influences the entrance of large vessels from BW. Tides recurring in almost 12-hour periods cause changes in the water level up to 6 feet above mean lower low water (MLLW) and restrict the sailing of the deep draft vessels through the River. Thus, vessels with more than 35 feet draft are especially affected by tide and experience extra delays in port operations.

There are a number of privately operated oil and chemical terminals in all three states comprising most of the operations in the river. They handle crude, refined oil and chemicals. Other major terminals include those operated by the Philadelphia Regional Port Authority such as Packer Avenue Terminal (container), Tioga Terminal (container); those operated by the South Jersey Port Corp. such as Beckett Street Terminal, Broadway Terminal (bulk); those by the Port of Wilmington (auto, general cargo) and many other terminals run by private industries.

Also there are several anchorage areas throughout the river for vessels to wait between terminal visits due to berth unavailability, tidal activity, maintenance or emergency reasons. These include Breakwater (BWA), Big Stone Beach (BSB), Marcus Hook (MHA), Mantua Creek (MCA) and Kaighns Point (KPA). Each anchorage has its own capacity and draft limitations. Thus, logistics of navigation in the DRMC is a critical issue for safe goods movement.

Finally, lightering, the process of transferring cargo between vessels to reduce a vessel's draft, is another significant activity that takes place at the BSB anchorage in the river. The maximum salt-water draft in the entrance of Delaware Bay is 55 feet and the main channel only allows travel of vessels less than 40 feet fresh water draft. Based on this constraint, deep draft tankers carrying petroleum products can do lightering depending on the water depth at the first terminal they will be visiting in the port. There are four privately operated barges serving vessels in need of lightering, and navigating between terminals and the BSB.

Next, we discuss the simulation model in detail.

2. SIMULATION MODEL OF THE VESSEL TRAFFIC IN DRMC

Given the complexities of the vessel traffic, large number of terminal operations of practically all types, rules of navigation, as well as tidal activity, a model is needed to study economic impact, risks and vessel prioritization during recovery in the DRMC. This chapter introduces a high fidelity simulation model of the vessel traffic in the channel. The model incorporates all critical components, key issues and parameters to represent the maritime traffic in a realistic manner. It has been successfully verified and validated. This chapter also summarizes the relevant literature, operational procedures and key components of the work flow.

2.1. Literature on Models for Waterway and Port Traffic

Simulation modeling has been used in various fields where analytical models cannot be used due to complex nature of problems. Simulation in the maritime transportation domain have been used in port/terminal operations and logistics, modeling of vessel traffic in waterways, as a tool to evaluate accident probabilities, risks and various economic issues.

On the other hand, literature on simulation modeling of vessel traffic on waterways is not large but growing. A SLAM[1] model of the Suez Canal traffic flow is reported by Clark et al. (1983). The authors propose an experimental traffic control scheme and present the results and discussion of the test performed. A method for analysis of systems with multiple response variables is discussed and illustrated. Rosselli et al. (1994) and Bronzini (1995) consider an existing simulation model developed originally by the US Army Corps of Engineers for use on the US inland waterway system, and its extensions to study the Panama Canal. The objective is to predict the transit capacities of the various Panama Canal alternatives in the future.

In another study, Golkar et al. (1998) present the Panama Canal Simulation Model (PCSM) developed by the SABRE group for the Panama Canal Authority. The model is

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[1] Simulation Language for Alternative Modeling

built as a tool for scenario and policy analyses, specifically to measure Canal's capacity under different operating conditions. Another simulation model of the Panama Canal is presented by Franzese et al. (2004). The objective is to help the Panama Canal Authority design a strategic planning tool. The authors incorporate vessel arrivals, traffic rules and vessel sequencing components into the model created using the Arena simulation software. Performance analysis of current and future alternatives of the system is carried out using several measures such as waiting times, transit times, queue lengths and resulting lock utilization.

Thiers and Janssens (1998) developed a detailed maritime traffic simulation model for the port of Antwerp, Belgium including navigation rules, tides and lock operations in order to investigate effects of a container quay to be built outside the port on the vessel traffic and especially on the waiting time of the vessels.

Merrick et al. (2003) performed traffic density analysis which would lead later to the risk analysis for the ferry service expansion in San Francisco Bay area. They tried to estimate the frequency of vessel interactions and their increases caused by three alternative expansion plans using a simulation model they developed, in which vessel movements, visibility conditions and geographical features were included. The simulation output is in the form of geographic profiles showing the frequency of vessel interactions across the study area, thus representing the level of congestion for each alternative and the current ferry system. The increase in the number of situations where ferries are exposed to adverse conditions is evaluated by comparing the outputs.

Biles et al. (2004) describe the integration of geographic information systems (GIS) with simulation modeling of traffic flow on inland waterways. They present two special cases: the AutoMod modeling of barge traffic on the Ohio River, and the Arena modeling of the transit vessels through the Panama Canal.

Smith et al. (2009) worked on congestion in Upper Mississippi River through building a traffic simulation model representing lock operations and vessel movements and performed tests under different operating conditions.

Cortes et al. (2007) simulated both the freight traffic and terminal logistics for Port of Seville, Spain using Arena software focusing on port utilization (and dredging is recommended to accommodate bigger vessels for potential growth).

For the Strait of Istanbul there is considerable literature bringing different perspectives in which simulation modeling was used for scenario and policy analyses. Köse et al. (2003) developed an elementary model of the Strait of Istanbul and tested the effect of arrival intensity on waiting times. Ozbas and Or (2007) and Almaz et al. (2006) developed extensive simulation models including vessel types, cargo characteristics, pilot and tugboat services, traffic rules, and environmental conditions and investigated effects of numerous factors on different performance measures such as transit times, waiting times, vessel density in the Strait and service utilizations.

In addition to these, in various studies vessel traffic simulation was used as an environment for further analysis of accident probabilities, risks and various economic and technical issues. Ince and Topuz (2004) used traffic simulation environment as a test bed for development of navigational rules and to estimate potential system improvements in the Strait of Istanbul. Traffic simulations including traffic rules, weather and relevant environmental conditions were also developed by van Dorp et al. (2001) for Washington State Ferries in Puget Sound area and Merrick et al. (2002) for the Prince William Sound in order to perform risk assessment through integrating accident probability models. In similar studies Uluscu et al. (2009a) used a traffic simulator to test and deploy a scheduling algorithm for transit vessels in the Strait of Istanbul and Uluscu et al. (2009b) developed a dynamic risk analysis map based on an extensive vessel traffic simulation for the Strait of Istanbul. Goerlandt and Kujala (2011) also used vessel traffic simulation to evaluate ship collision probability in the open sea where environmental conditions are negligible. Somanathan et al. (2009) investigated economic viability of the Northwest Passage compared to the Panama Canal using simulation for vessel movements and environmental conditions. Martagan et al. (2009) built a simulation model to evaluate the performance of re-routing strategies of vessels in the U.S. ports under crisis conditions. Quy et al. (2008) used traffic simulation which includes tide and wave conditions in order to find optimal channel depths for vessel navigation by minimizing the grounding risk based on a wave-induced ship motion model.

There are also studies which are relevant and can guide analyses of several components in the development of a traffic simulation model. Asperen et al. (2003) investigated different vessel arrival methods which can be used in simulation studies and compares their effects on port efficiency. Jagerman and Altiok (2003) studied modeling of negatively correlated vessel arrivals and developed approximations for the queuing behavior. Pachakis and Kiremidjian (2003) proposed a ship traffic modeling methodology for ports in which functional relationships are used among ship length, draft and cargo capacity.

Maritime transportation studies on Delaware River and Bay are limited in number. However, the work of Andrews et al. (1996) is closely related to the scope and some components of our study. In this work the authors used simulation for modeling of oil lightering in Delaware Bay and investigated effects of alternative policies on service levels. Lightering operations were modeled in detail and calibrated to match historical data statistics. Number of lightering barges, their capacities, loading and discharge rates, heating features, weather sensitivities and priorities that are used in the assignment procedure and tidal issues were all taken into account. Moreover, a representative scheduling algorithm for lightering barge assignments were tried to be built. As a contrast to the work of Andrews et al., our study has further simplifying assumptions to model the lightering operations such as neglecting heating features, weather sensitivities and priorities. However, the general modeling perspective, scheduling algorithm, service times being dependent on the volume of oil to be lightered and the barge in use and possibility of two barges working a vessel at the same time are all analogous to our study.

2.2. Modeling Maritime Traffic

In our modeling approach, vessel arrivals are modeled using vessel inter-arrival times for various different rig types. Upon a vessel's arrival, its cargo type, length, beam, draft and a trip itinerary are determined and the vessel proceeds to the river entrance. Depending on the tide conditions, vessels either proceed to the main channel or they anchor at either the Big Stone Anchorage or Break Water Anchorage. Tankers, depending on their drafts, may do lightering at an off shore location or at the Big Stone Anchorage. They may also arrive from the Chesapeake and Delaware (C&D) Canal. Once they enter the main channel, vessels move to their destinations for loading or unloading. A vessel may move among a number of terminals depending on their itineraries. Eventually, vessels leave either from the C&D Canal or most of the time from the main entrance.

Note that all this movement is illustrated by the data obtained from various sources for years 2004 through 2008. We will next summarize the vessel movement data.

2.3. Vessel Traffic Data

Data for detailed vessel movements for the last five years (2004 to 2008) have been provided by the Maritime Exchange, USCG – Sector Delaware and OSG Inc (formerly Maritrans Inc.) who all have been very cooperative from the start of the project. Below, Figure 2.1 shows the rig types and the number vessels of a particular rig that have arrived per year. Table 2.1 shows the total arrivals over five years emphasizing the crude oil activity in DRB. Note that tug and barge activity is not included in these numbers.

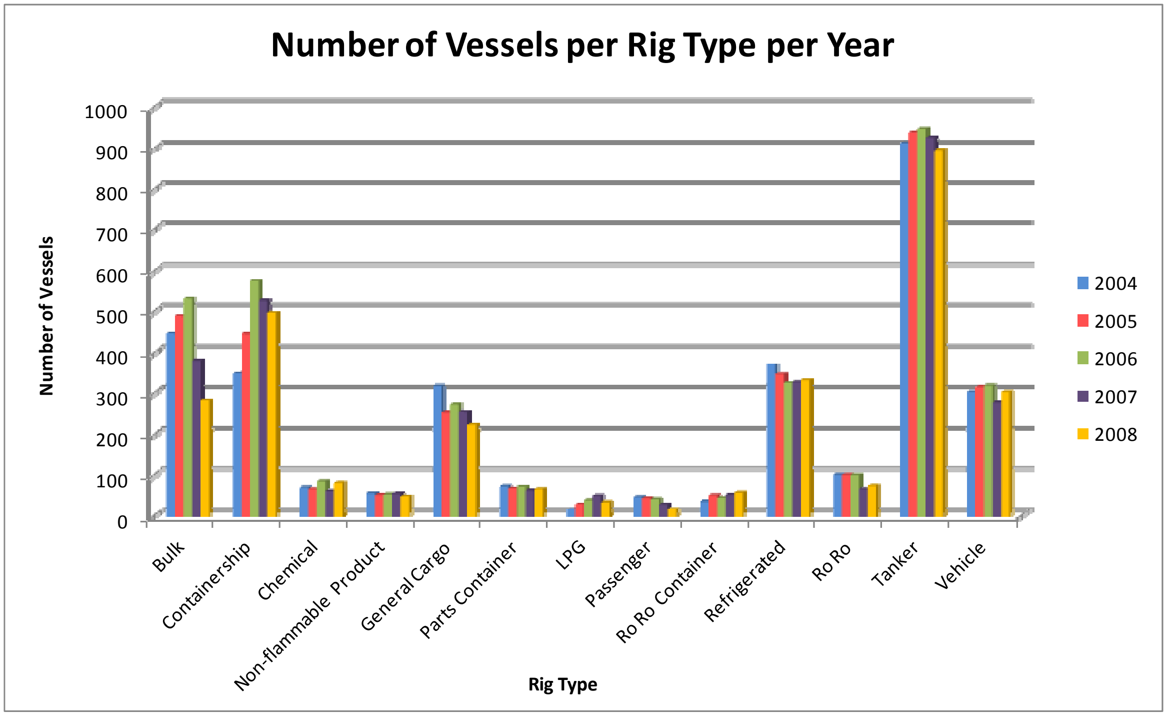

Figure 2.1. Annual vessel counts per rig type for the years 2004 to 2008

Table 2.1 - Annual vessel counts per rig type for the years 2004 to 2008

Rig Description	2004	2005	2006	2007	2008	Total
Bulk	444	486	528	379	280	2117
Containership	345	443	574	523	494	2379
Chemical	68	64	83	59	79	353
Non-flammable Product	54	50	51	53	47	255
General Cargo	315	252	271	253	222	1313
Parts Container	71	66	70	61	64	332
LPG	13	28	37	48	32	158
Passenger	45	42	40	27	14	168
Ro Ro Container	34	49	43	50	55	231
Refrigerated	368	343	322	324	329	1686
Ro Ro	98	98	97	64	72	429
Tanker	910	937	945	924	890	4606
Vehicle	300	313	316	275	300	1504
Total	**3065**	**3171**	**3377**	**3040**	**2878**	**15531**

Figure 2.2 provides the total number of vessels counts in Delaware River and Bay through 5 year horizon of 2004 to 2008. Tug and barge activity is not included in these figures.

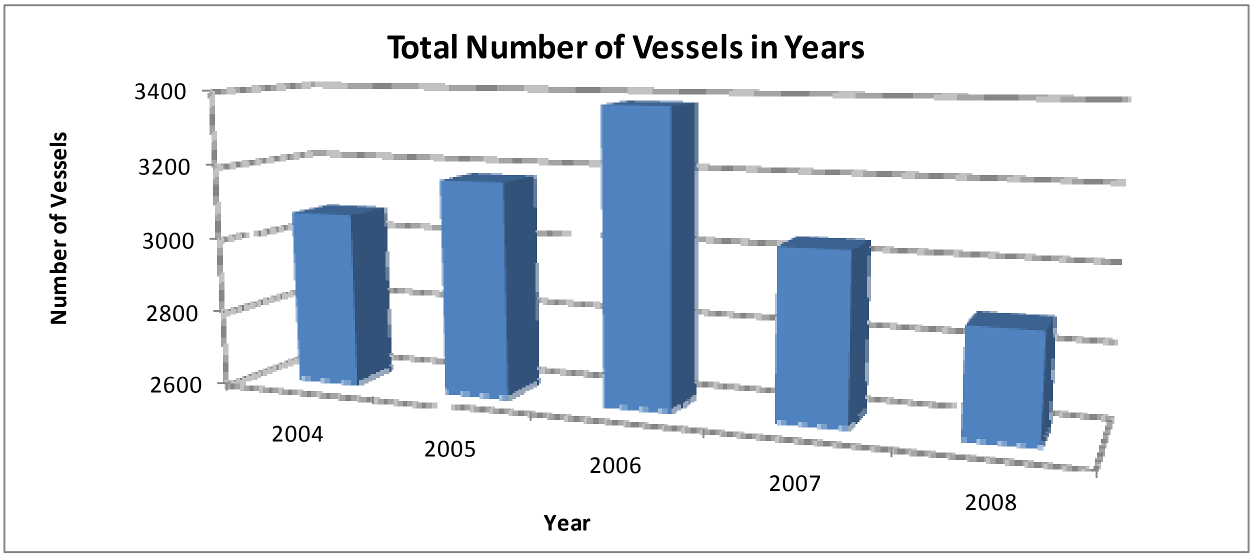

Figure 2.2. Total number of vessels per year

Vessel calls are averaged over the same five years in Figure 2.3 for all of the major terminals.

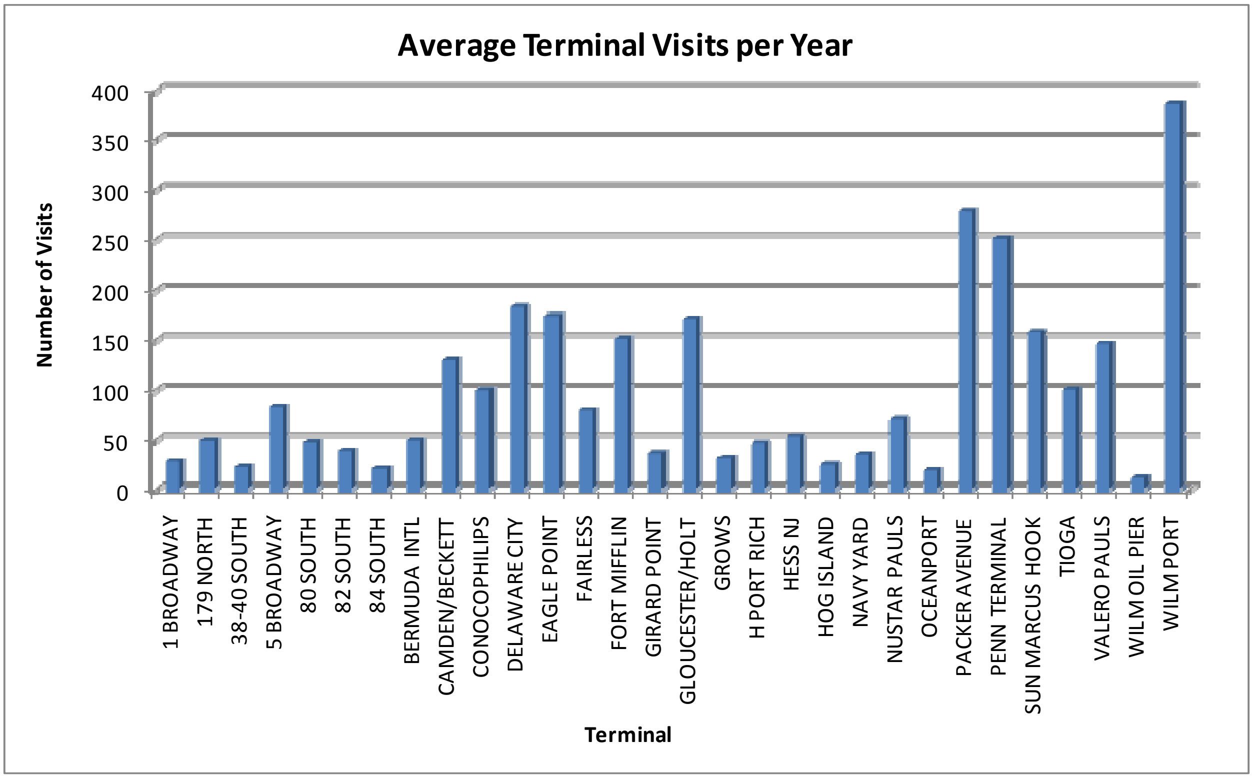

Figure 2.3. Average annual vessel calls in major terminals in DRB for years 2004 to 2008

Figure 2.4 also provides the number of vessel calls to major ports annually.

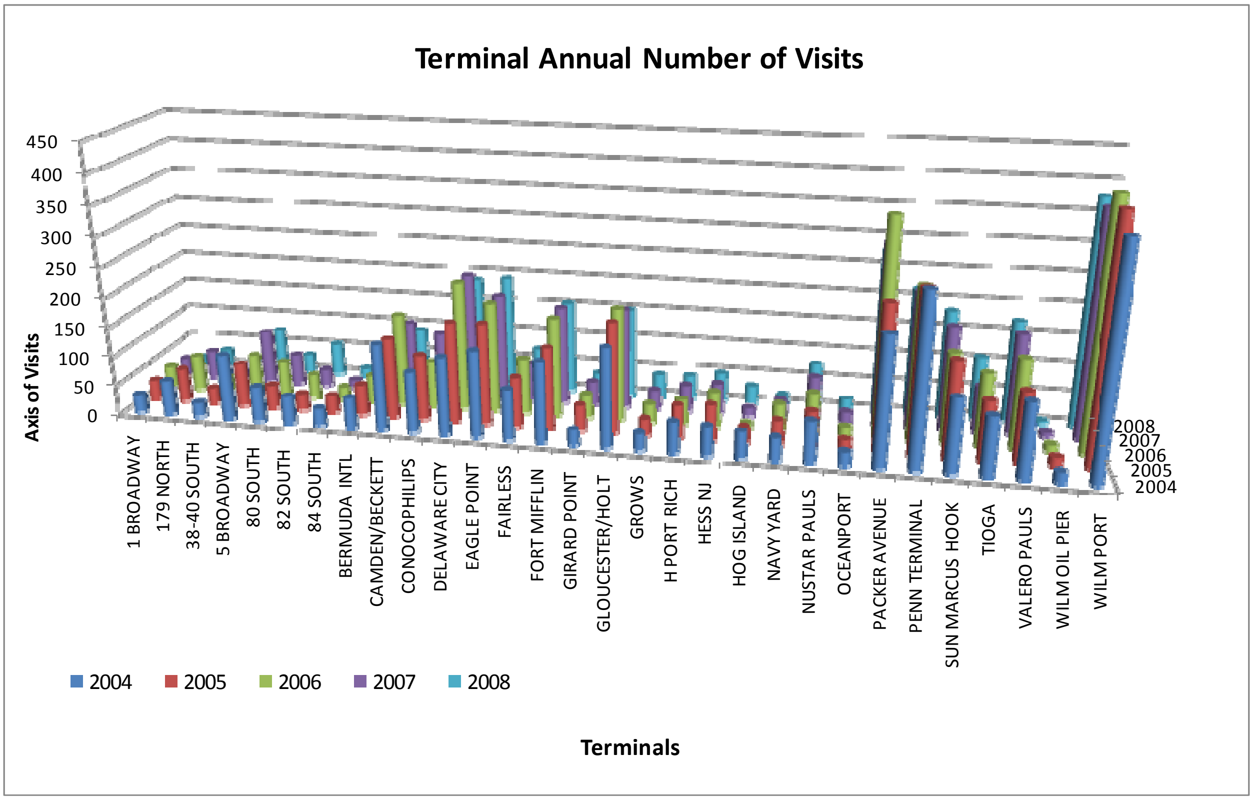

Figure 2.4. Annual vessel calls in major terminals in DRB for years 2004 to 2008

Vessel visits to major anchorages is given in Figure 2.5. Tug and barge activity is not included in these figures.

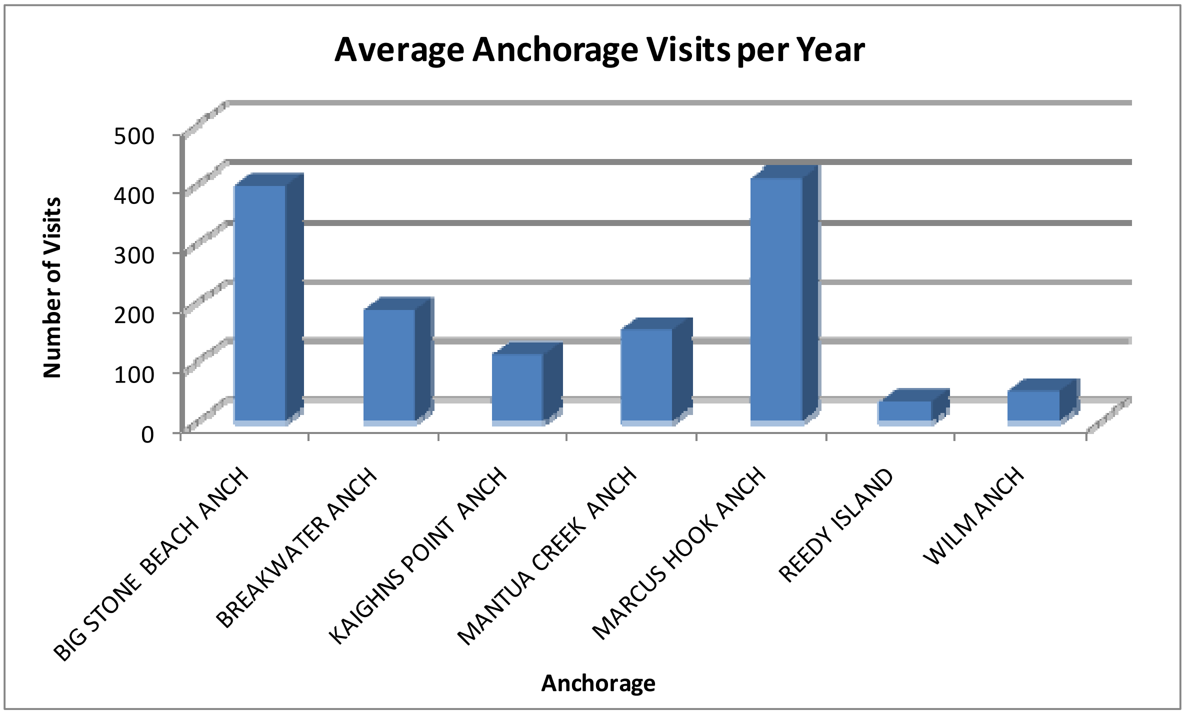

Figure 2.5. Number of vessel calls at major anchorages averaged over the years 2004 to 2008

2.4. Coast Pilot Recommendations for Navigation in DRB

As explained in the Coast Pilot (2008) for the North East Region, the Delaware River and Bay area has a number of recommendations for inbound and outbound vessels. Below we will summarize the more critical ones using graphical representations and using the words recommendations and regulations, interchangeably. The main channel is divided into 6 zones to better express these rules as shown in Figure 2.6. Division of the channel into zones is a concept that was facilitated the model building process. Note that the max fresh water depth (FWD) in the channel is 40 ft. as explained in the Coast Pilot.

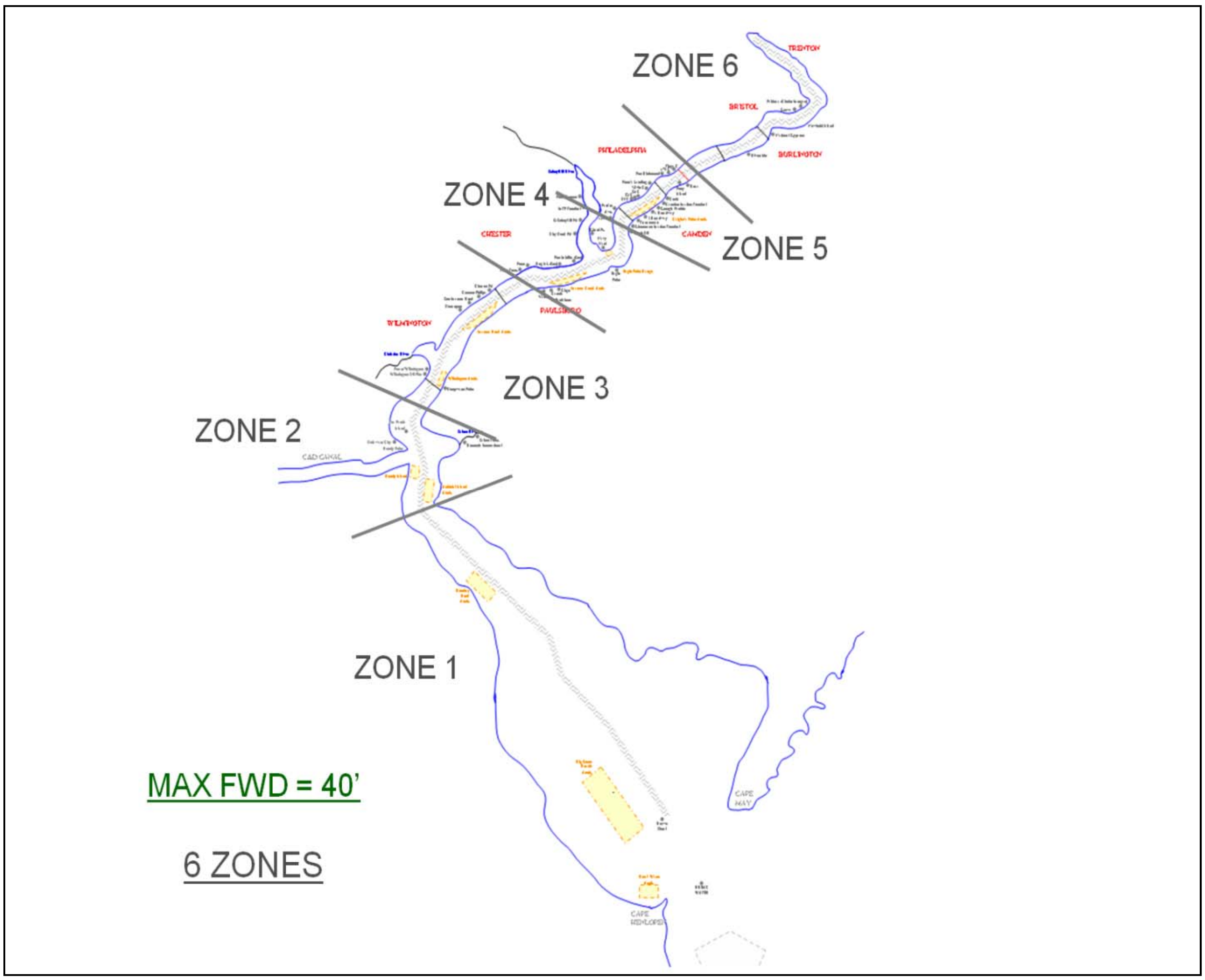

Figure 2.6. Zones of DRB

Regulation 1: Inbound Traffic

Critical components of Regulation 1 are given in Figure 2.7 and summarized below:

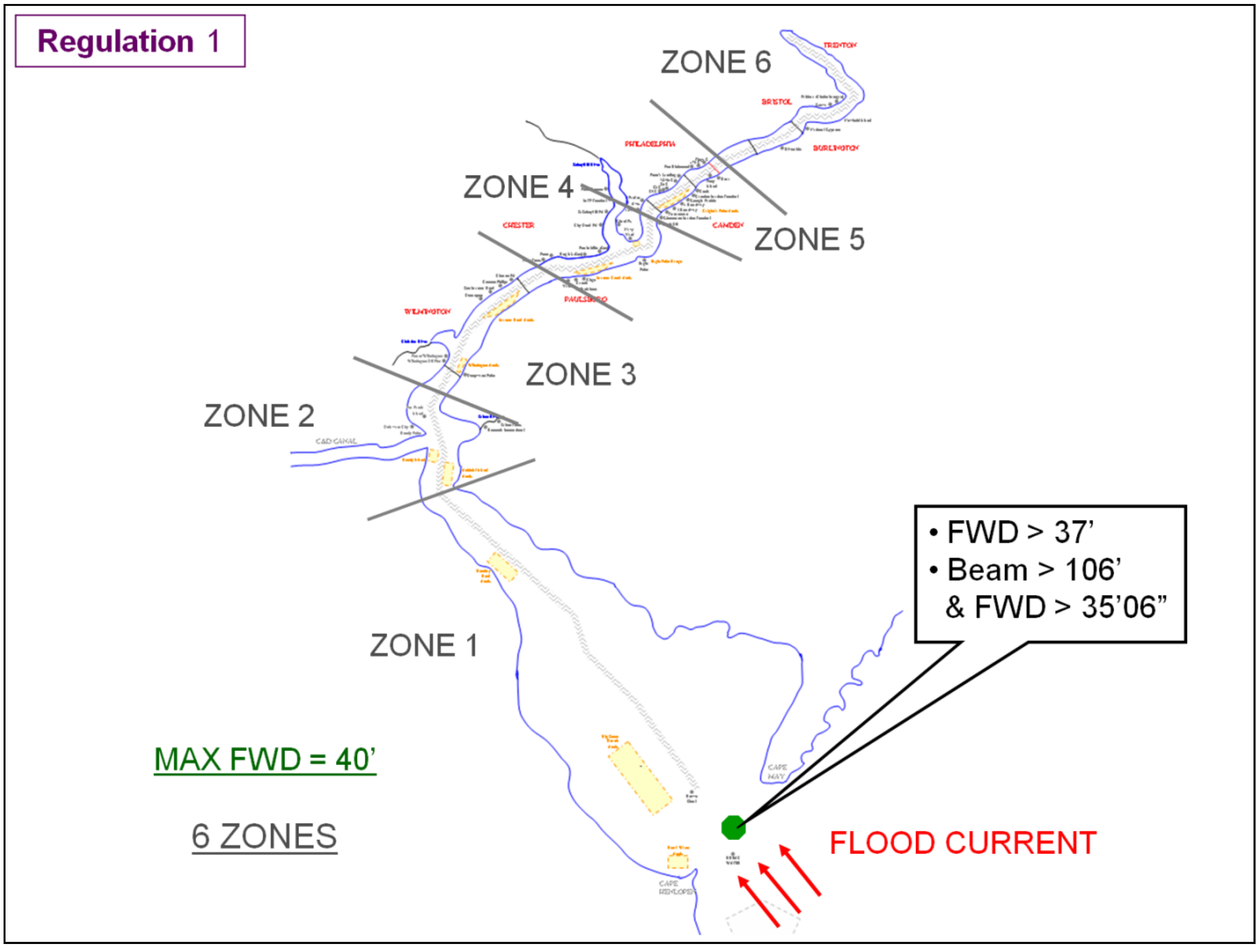

Figure 2.7. Components of Regulation 1

- The maximum fresh water draft for river transit from sea to Delair, NJ is 40 feet.
- All vessels arriving with a fresh water draft in excess of 37 feet are to transit during flood current only.
- All vessels over Panamax size beam (106 ft) having a fresh water draft in excess of 35'–06" shall only transit during flood current.
- The maximum salt-water draft for entrance into Delaware Bay and Big Stone Beach anchorage is 55 feet, as per federal regulation.

Regulation 2:

Critical components of Regulation 2 are given in Figure 2.8 and summarized below:

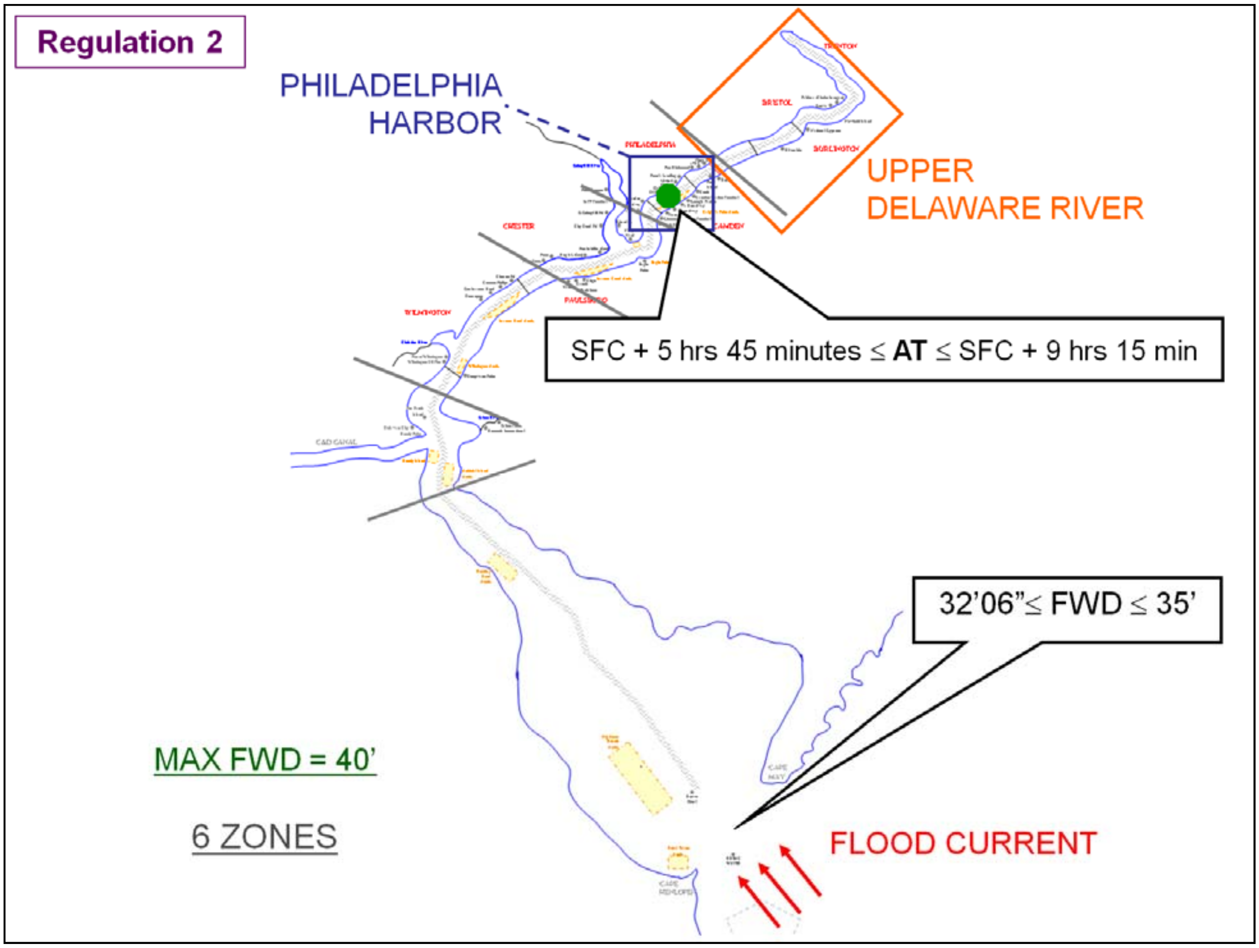

Figure 2.8. Components of Regulation 2

- Vessels less than 32'–06" FW may transit on any stage of the tide or current.
- Vessels 32'–06" FW or greater up to 35'–00"FW in draft should arrive in Philadelphia harbor no later than 9 hours and 15 minutes, or earlier than 5 hours and 45 minutes from slack flood current at Cape Henlopen.

Regulation 3:

Critical components of Regulation 3 are given in Figure 2.9 and summarized below:

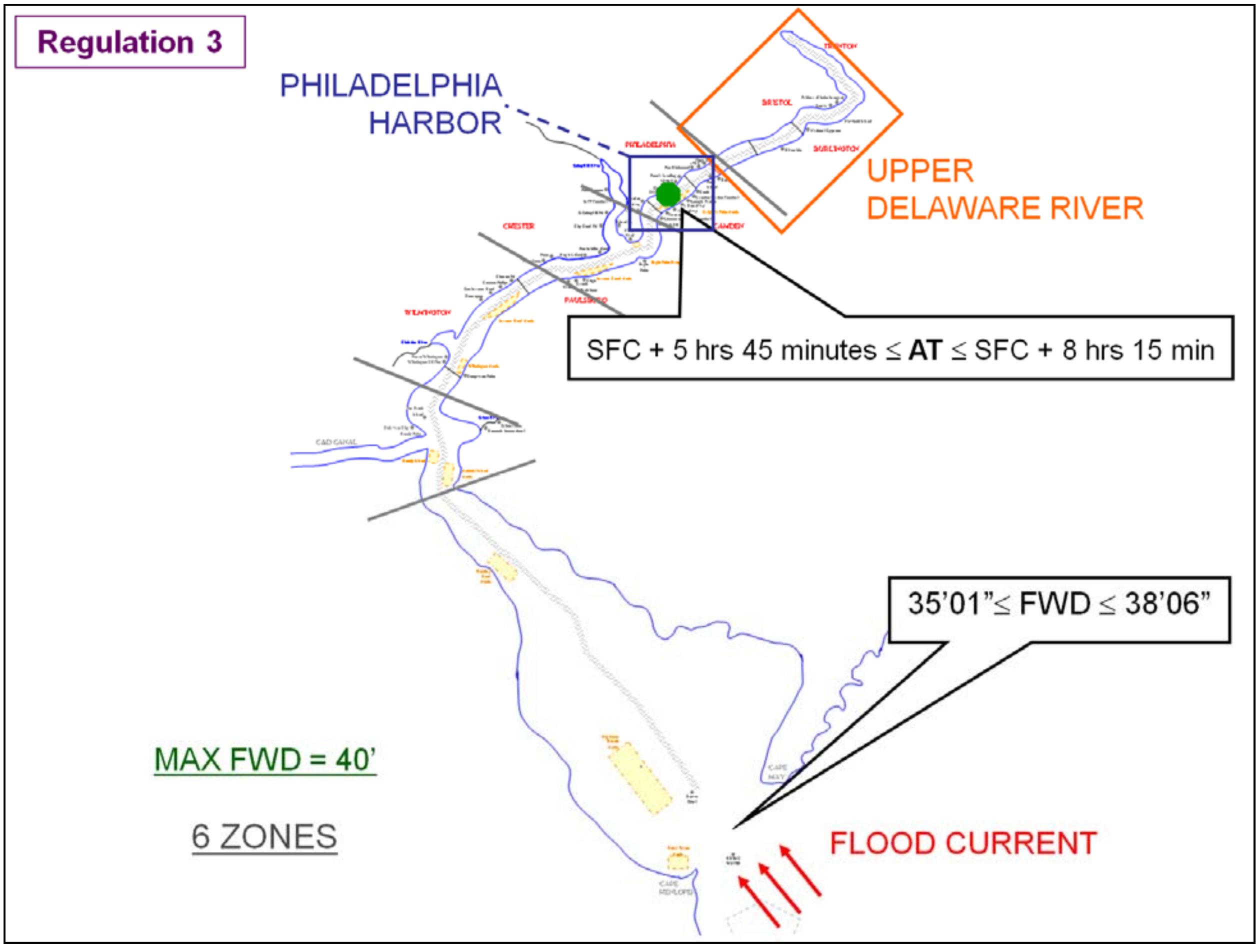

Figure 2.9. Components of Regulation 3

- Vessels 35'–01" FW or greater up to 38'–06" FW in draft should arrive in Philadelphia harbor no later than 8 hours and 15 minutes, or earlier than 5 hours and 45 minutes from slack flood current at Cape Henlopen.

Regulation 4:

Critical components of Regulation 4 are given in Figure 2.10 and summarized below:

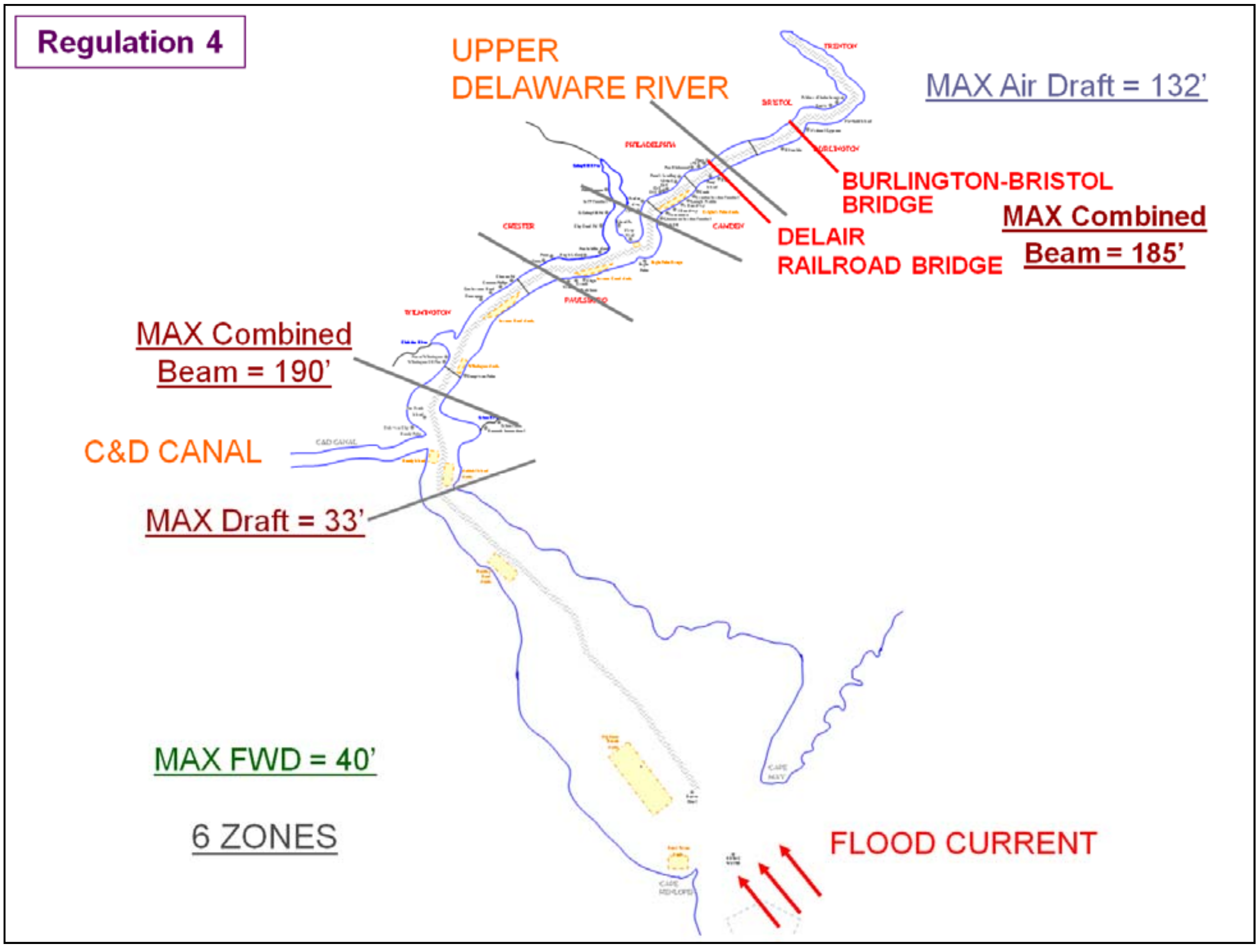

Figure 2.10. Components of Regulation 4

- Maximum air draft should not exceed 132 feet.
- Vessels of combined beam greater than 185 feet should not meet between the Delair Railroad Bridge and the Burlington Bristol Bridge.
- There is no recommended length limitation for vessels using the C&D Canal, however the maximum draft limitation is 33 feet.
- The maximum combined beam of vessels transiting the C&D Canal at the same time is 190 feet.

Regulation 5:

Critical components of Regulation 5 are given in Figure 2.11 and summarized below:

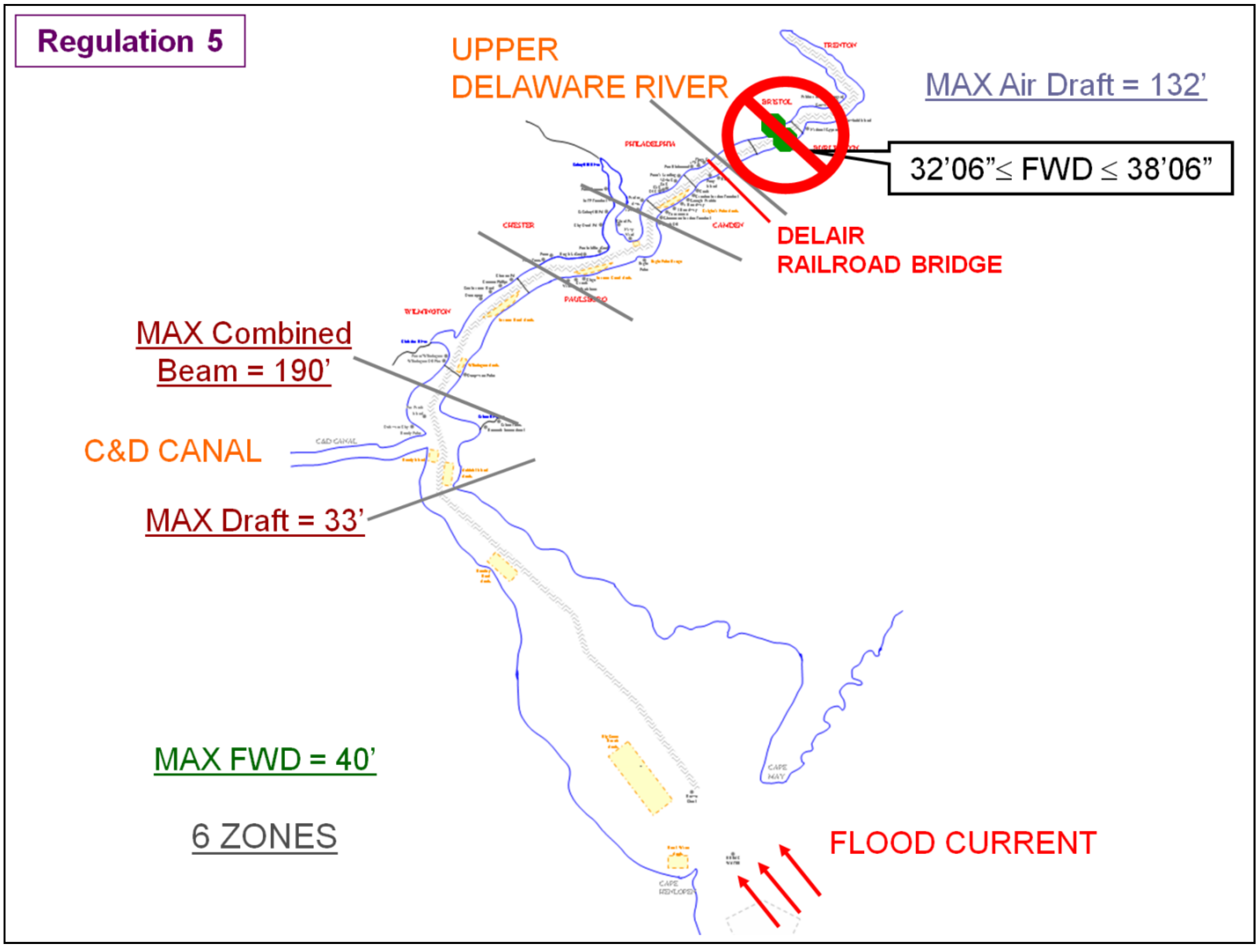

Figure 2.11. Components of Regulation 5

- Vessels 32'–06" FW or greater up to 38'–06" FW in draft shall avoid meeting outbound shipping traffic above the Delair Railroad Bridge.

Regulation 6:

Critical components of Regulation 6 are given in Figure 2.12 and summarized below:

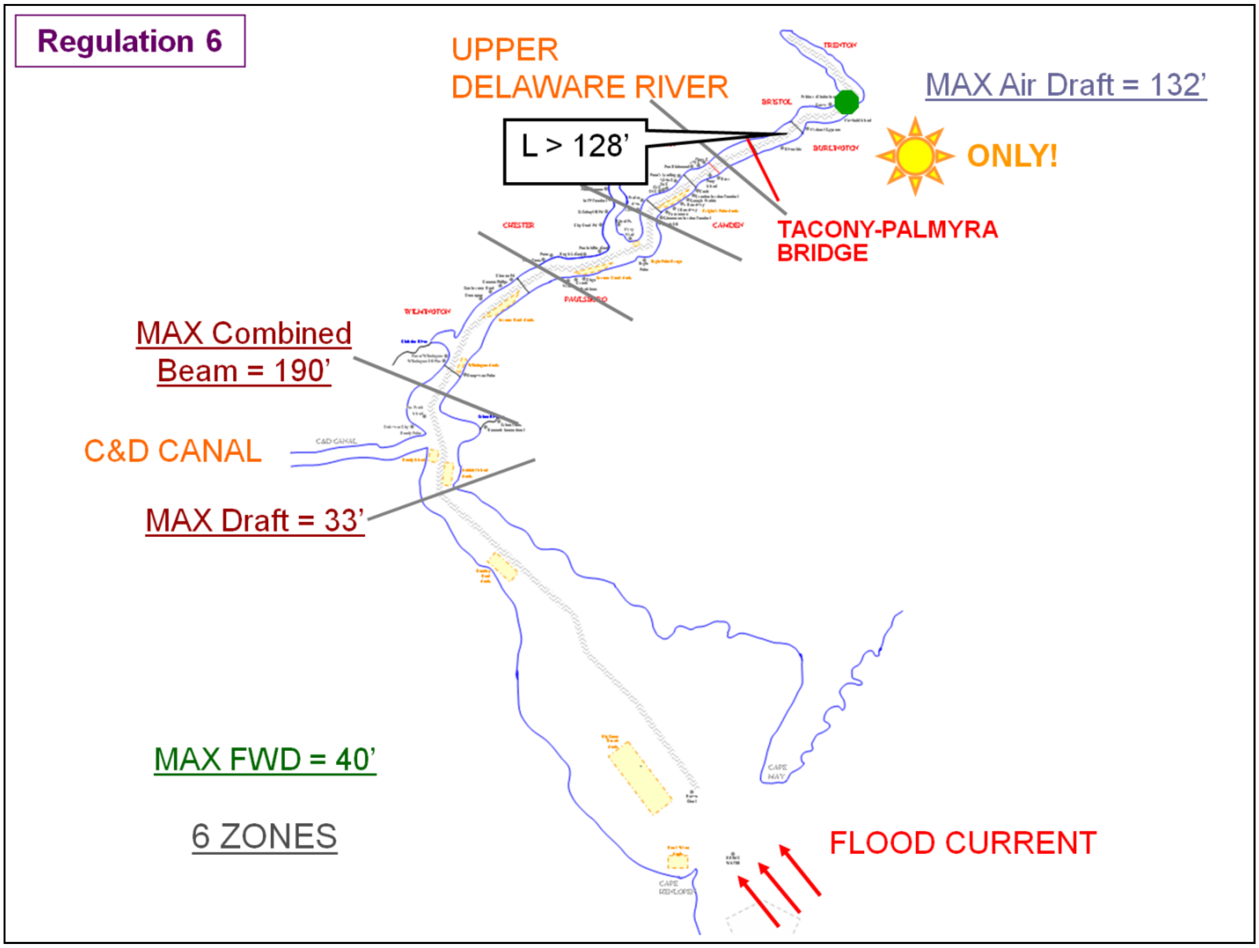

Figure 2.12. Components of Regulation 6

- Any vessel whose beam exceeds 128 feet should transit through the Tacony–Palmyra Bridge during daylight only.
- Vessels of greater beam and vessels known to be difficult to maneuver should be scheduled on a case by case basis after consultation between the pilots and the operators prior to arrival and departure.

Regulation 7:

Major component of Regulation 7 is given in Figure 2.13 and summarized below:

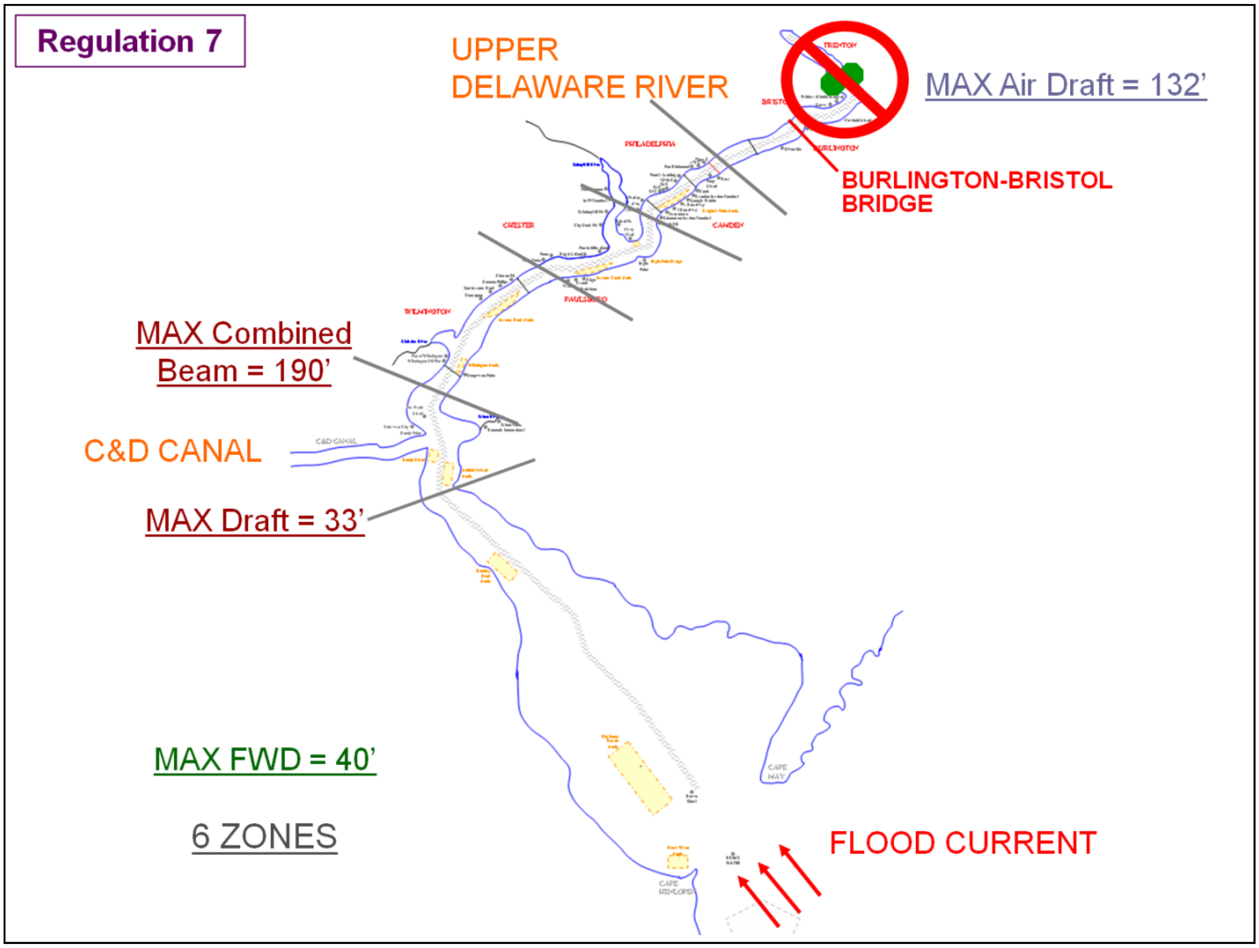

Figure 2.13. Components of Regulation 7

- Shipping traffic should avoid meeting above the Burlington Bristol Bridge.

Regulation 8: Outbound Traffic

Critical components of Regulation 8 are given in Figure 2.14 and summarized below:

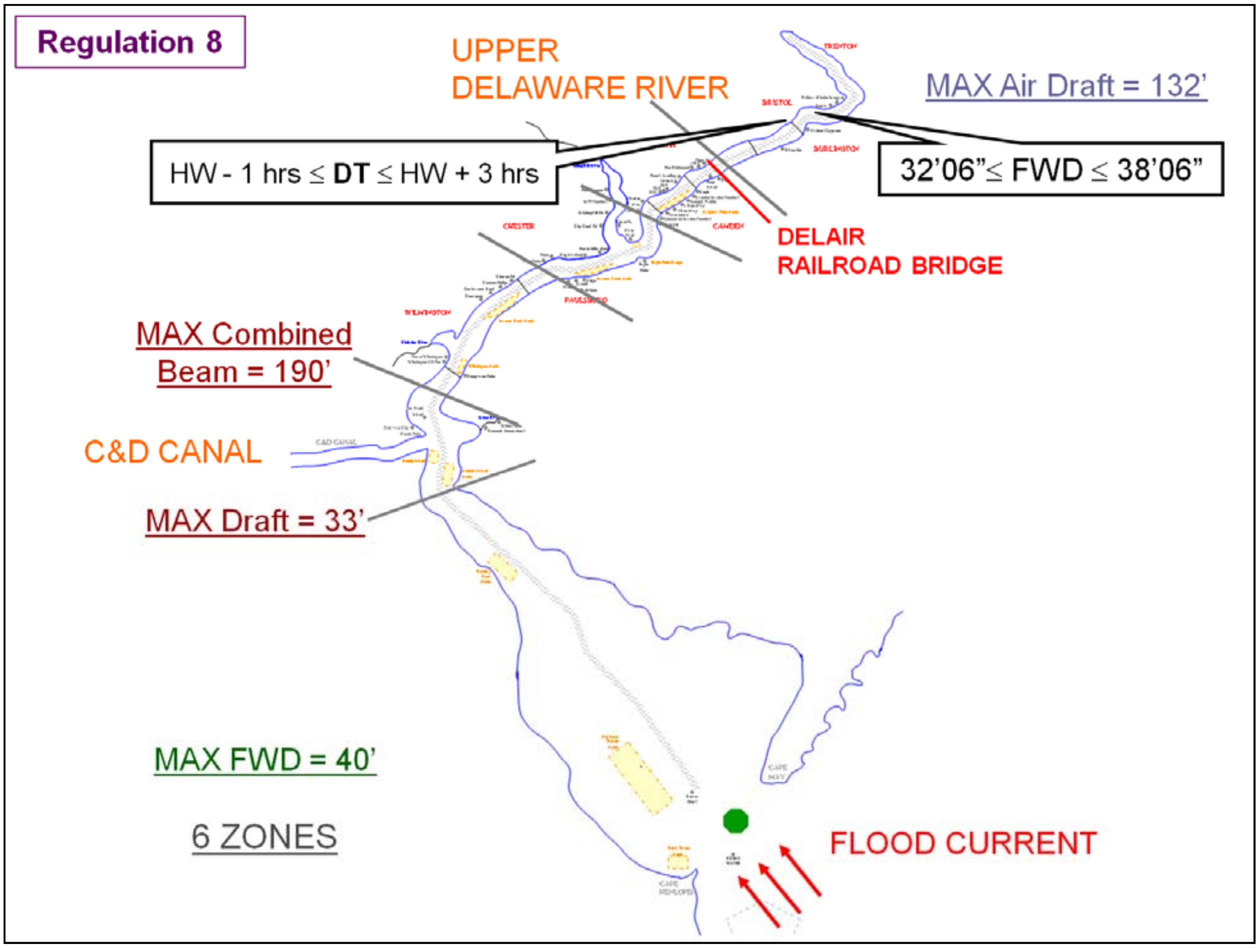

Figure 2.14. Components of Regulation 8

- Vessel less than 32'–06" FW may transit on any stage of the tide or current.
- Vessels 32'–06" FW or greater up to 38'–06" FW in draft, should sail from terminals above the Delair Railroad Bridge between 1 hour before high water and 3 hours after high water at the dock at which it is sailing.

Regulation 9:

Major component of Regulation 9 is given in Figure 2.15 and summarized below:

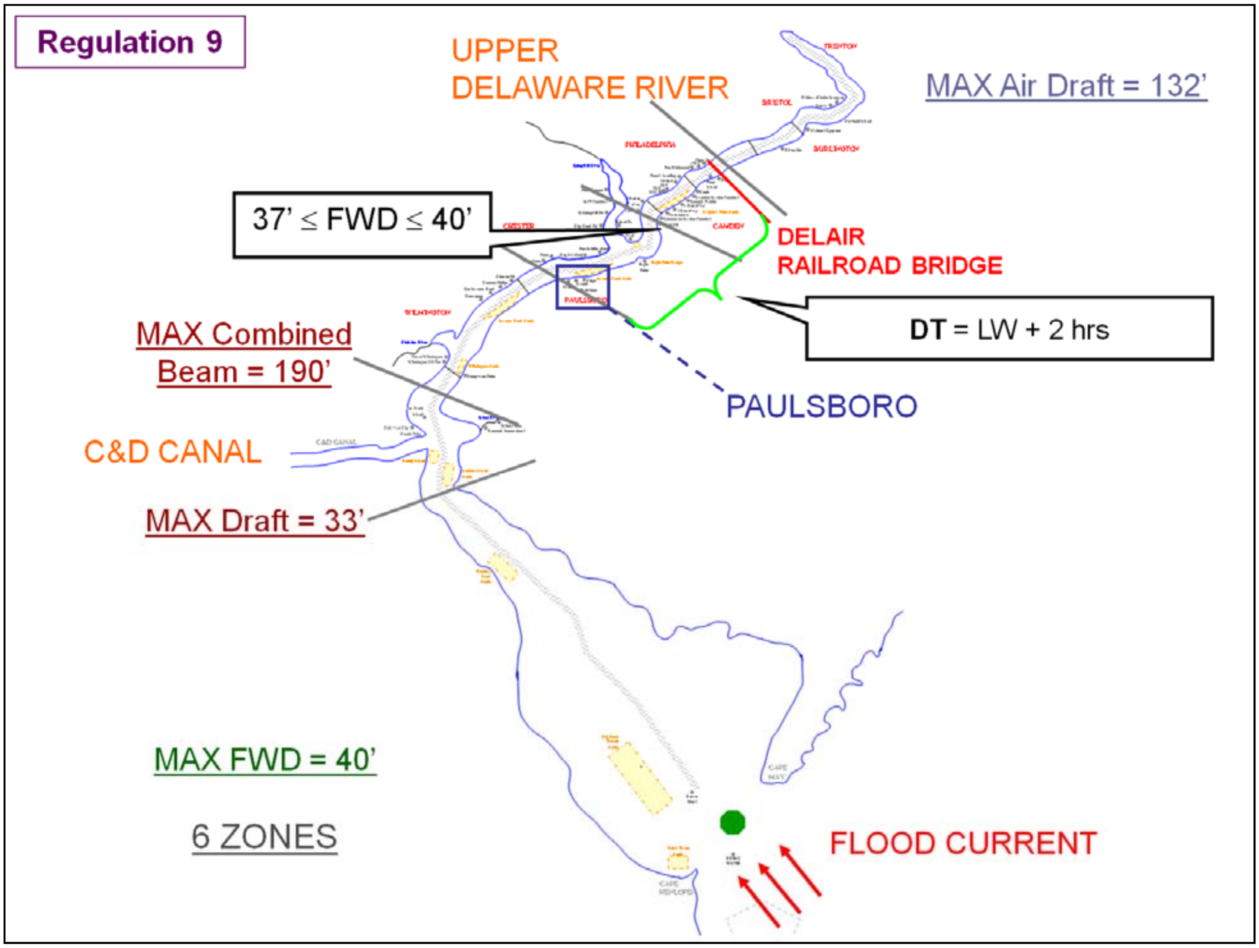

Figure 2.15. Components of Regulation 9

- Vessels 37 or above '–06" FW in draft, should sail from terminals between Paulsboro and the Delair Railroad Bridge should sail 2 hours after low tide at the dock at which it is sailing.

Regulation 10:

Critical components of Regulation 10 are given in Figure 2.16 and summarized below:

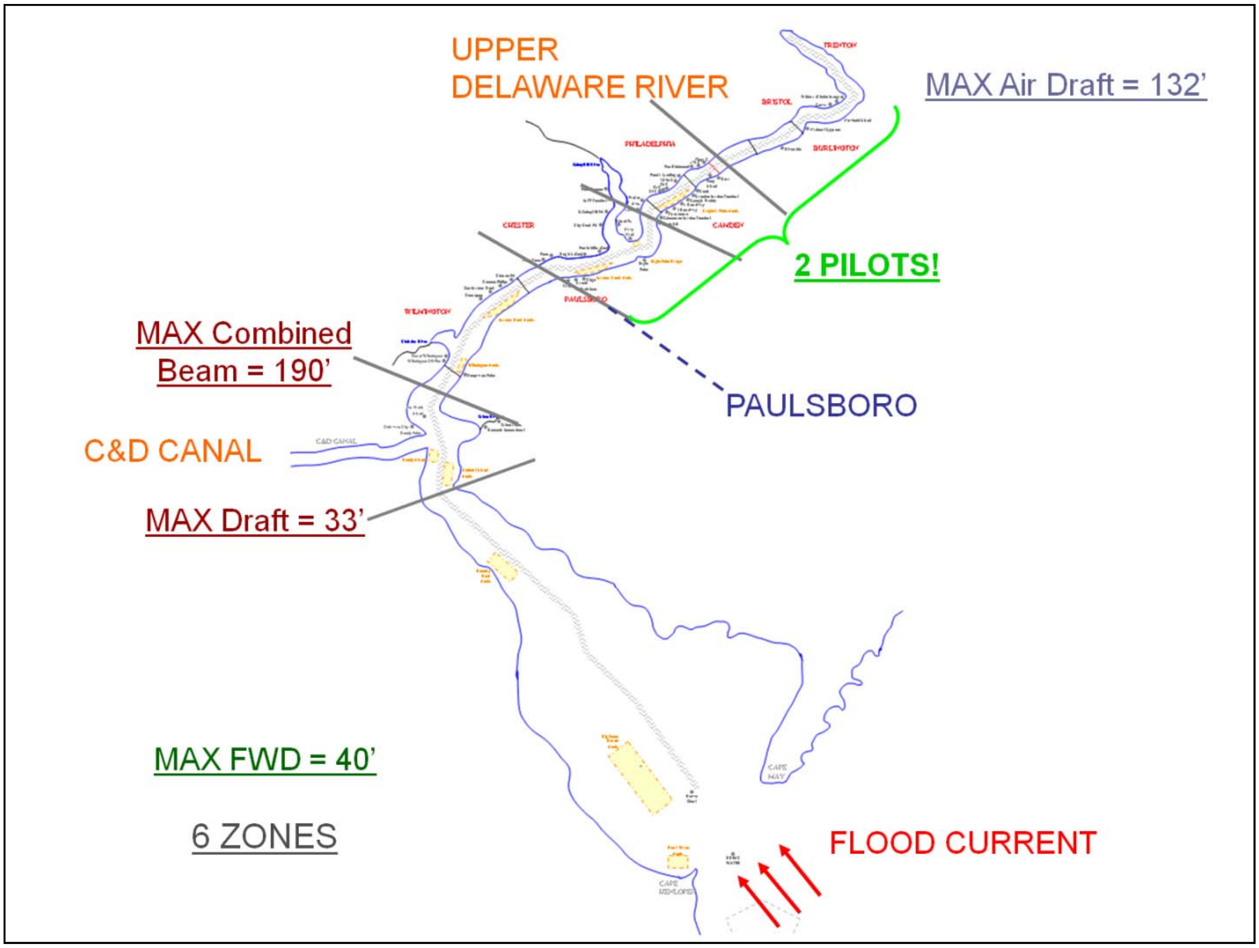

Figure 2.16. Components of Regulation 10

- Vessels outbound from Paulsboro, NJ and above, having a fresh water draft of 37 feet and up to 40 feet should arrange to sail 2 hours after low water. Due to the extended time of transit for these particular deep draft vessels, two (2) river pilots will be arranged for transit to sea.

These recommendations / regulations govern navigation in the DRMC and are included in the simulation model which is explained in detail in the following sections.

2.5. Simulation Model Structure

The main goal behind the model development is to constitute an accurate means to study key issues regarding the Delaware River's operation via scenario analysis such as increase in vessel arrivals, deepening the river and changes in the operational/navigational policies. A detailed model is needed to answer questions regarding these key issues. For this purpose, a detailed, large-scale simulation model of vessel traffic in DRMC was developed involving all vessel types and all of the port terminal facilities along the river from Cape May to Trenton. Arena[2] 11.0 simulation tool was used in the development of the model.

The model includes all cargo vessel types, their particulars, arrival patterns, their trips in the river, and incorporates all the navigational rules as explained in the Coast Pilot (2008), tidal activity, lightering activity and anchorage holding activity along with terminal operations to the extent of vessel berth holding excluding internal terminal logistics.

Detailed historical data were obtained from the Maritime Exchange for the Delaware River and Bay on vessel arrivals and vessel movements for the years between 2004 and 2008. The input data include arrival times, vessel characteristics of length, beam, underway draft, max draft and gross tonnage, travel times, terminal holding times, and terminal transition probabilities of vessels' moving from one terminal to another. Data for random components were analyzed and distributions were fitted. In addition to these, tidal activity was generated by reading historical data obtained from the National Oceanic and Atmospheric Administration (NOAA) through text files into the model.

The simulation model was developed by paying attention to technical issues regarding the random events occurring in the river. In line with the objectives of the study, the simulation model was developed with the major components listed below that are necessary for a realistic representation of the current traffic system in the DRMC. Note

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[2] Arena is a discrete-event simulation software of Rockwell Automation, Wexford, PA.

that weather conditions are not considered in the model due to their marginal impact on operations.

Components of the simulation model are:

- Randomized vessel arrivals at BW and CD,
- Randomized vessel characteristics of length, beam, underway draft, max draft and gross tonnage,
- Terminal calls based on a randomized itinerary generation,
- Randomized vessel holding times at the terminals,
- Vessel navigation with randomized vessel travel times to terminals and anchorages,
- Tidal and navigational rules in the River,
- Lightering rules and procedure,
- Anchorage selection procedure.

Below, the model components mentioned above are described in some detail.

2.5.1. Vessel Generation

Vessel types considered in this study were selected based on their frequency observed in the historical data provided by the MEX, utilizing vessel categories based on vessel characteristics and cargo being carried. This categorization was adopted in this study with few vessel categories combined in order to minimize loss of information and enhance simplicity. Major vessel types visiting Delaware River and Bay area can be classified into 14 categories. These are: Bulk (BU), Containership (CC), Chemical Tanker (CH), Non-flammable Product Tanker (NP), General Cargo (GC), Part Container (PC), Liquid Petroleum Gas (PG), Passenger (PR), RO-RO Container (RC), Refrigerated (RF), RO-RO (RR), Tanker (TA), Vehicle (VE) and Tug Boat (TG).

Each vessel type may have entries from both BW and/or CD. Based on the interarrival time analysis performed for each vessel type, probability distributions are fitted and modeled for each stream. Note that we have also taken seasonality into consideration with some vessels (e.g., PR vessels). Vessel characteristics of length, beam, underway draft, maximum draft and gross tonnage have all been assigned based on statistical analysis of the historical data.

Arrival streams were analyzed for each vessel type at BW and CD independently. As an example, the histogram and inter-arrival time distribution results of the BU vessels at BW obtained from the Arena's Input Analyzer are presented in Table 2.2.

Table 2.2 - The Input Analyzer distribution fit summary for interarrival times of the BU vessels at BW

Distribution Summary

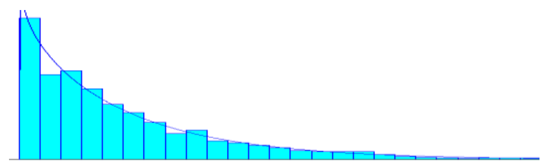
Distribution	Gamma
Expression	GAMM(1560, 0.909)
Square Error	0.00094

Chi Square Test

Number of intervals	23
Degrees of freedom	20
Test Statistic	27.2
Corresponding p-value	0.14

Kolmogorov-Smirnov Test

Test Statistic	0.0273
Corresponding p-value	0.126



Data Summary

Number of Data Points	1848
Min Data Value	0
Max Data Value	11100
Sample Mean	1420
Sample Std Dev	1470

Histogram Summary

Histogram Range	0 to 11,100
Number of Intervals	40

For a realistic characterization of vessels and cargo loading profiles of different terminals, underway drafts of vessels were analyzed and modeled using empirical distributions for each terminal, vessel type and entrance point information, independently. Thus, based on the first terminal to be visited, an underway draft is assigned to each vessel generated in the model.

Since vessels are not fully loaded when visiting terminals, their underway drafts are expected to be less than their maximum drafts. Based on this relation, a regression model was produced with the data on hand for each vessel type. Thus, using the underway draft produced in the model, the maximum draft of a vessel can be estimated.

Vessel particulars such as maximum draft, length, beam and gross tonnage are expected to be closely related to each other since they are defining the size of the vessel. Therefore, once any of these size-related elements is known, other vessel particulars can be estimated. First, maximum draft was estimated using the underway draft. Then, regression models were built using the data on hand to estimate the other vessel particulars based on the maximum draft (Figure 2.17).

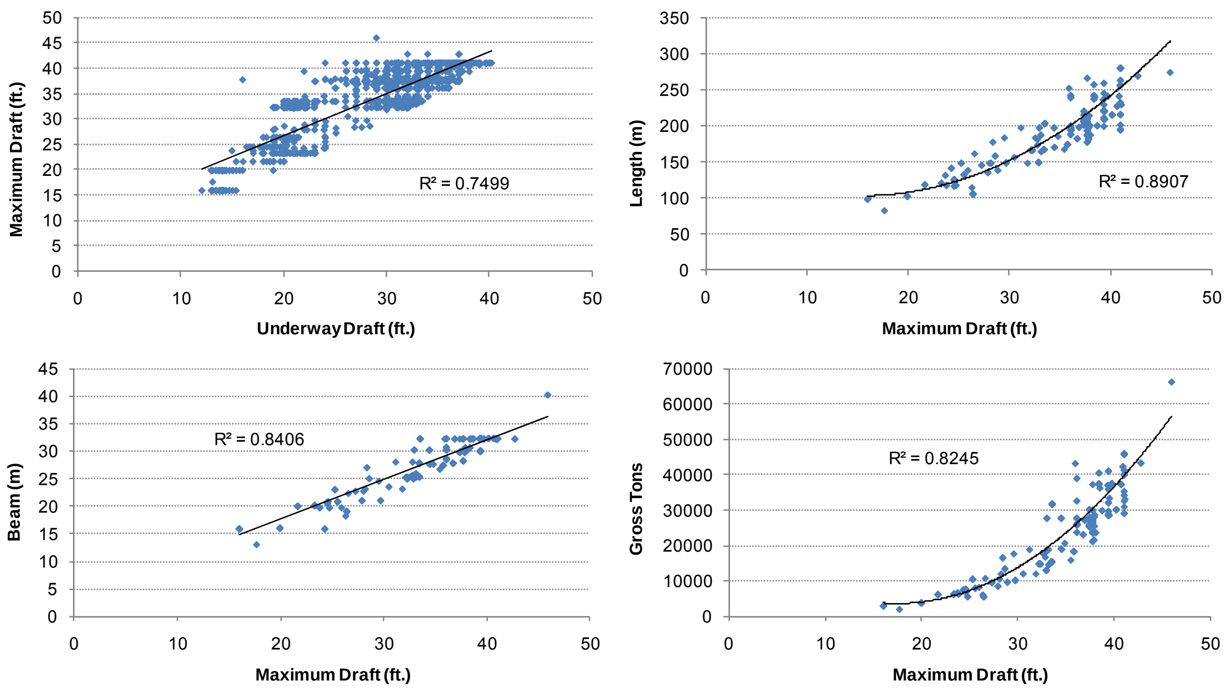


Figure 2.17. Regression models for vessel particulars of maximum draft, length, beam and gross tonnage for the CC vessels

Figure 2.18 shows a snapshot of a part of the model where vessels are generated as described. In this figure it is illustrated how bulk vessels are created. The same logic is duplicated for generation of other vessel types.

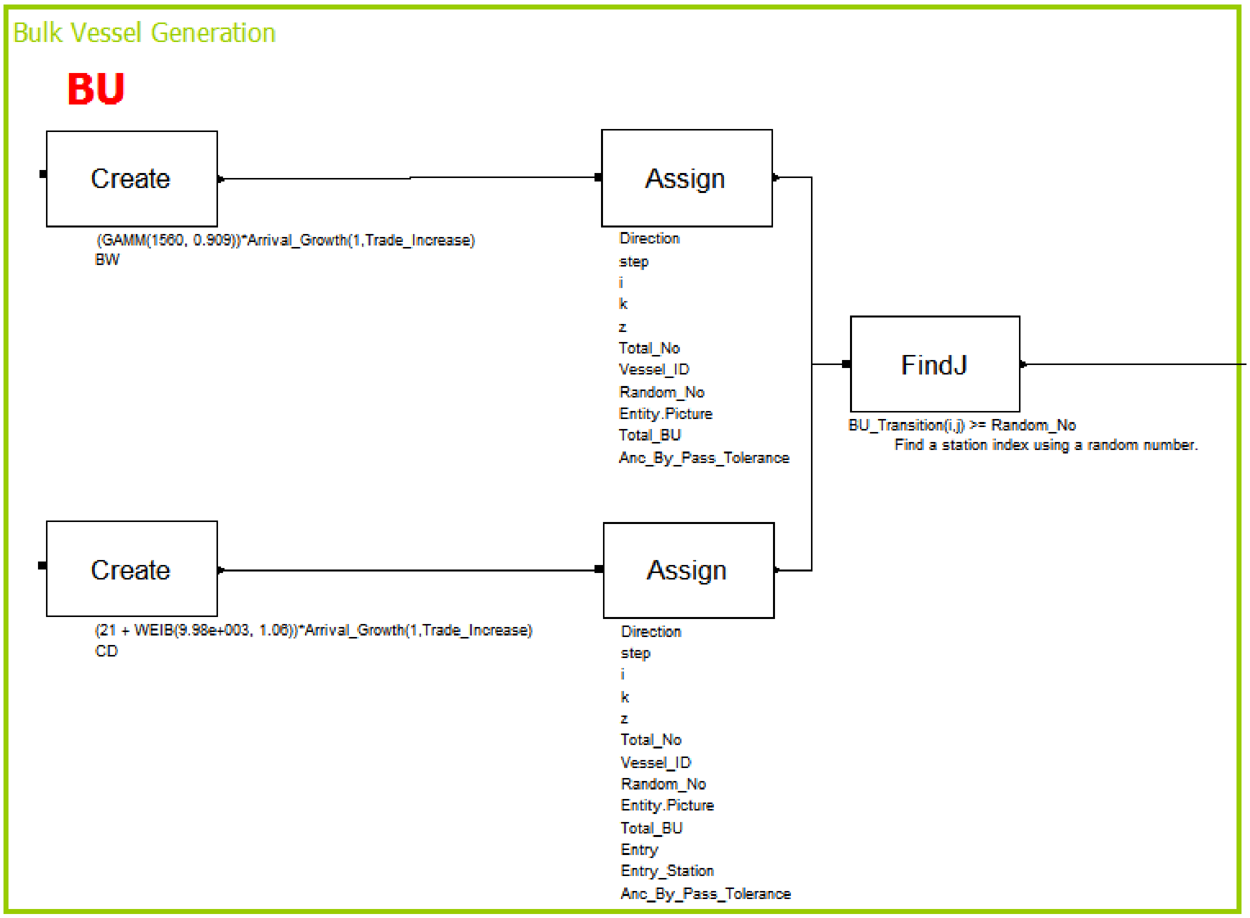


Figure 2.18. Snapshot of a sub layer from the simulation model logic for vessel generation

2.5.2. Itinerary Generation

Vessels coming to DRB may visit more than one terminal and thus itinerary generation is needed for arriving vessels to determine the sequence of ports they visit. A high level view of the itinerary generation logic is shown in Figure 2.19 below.

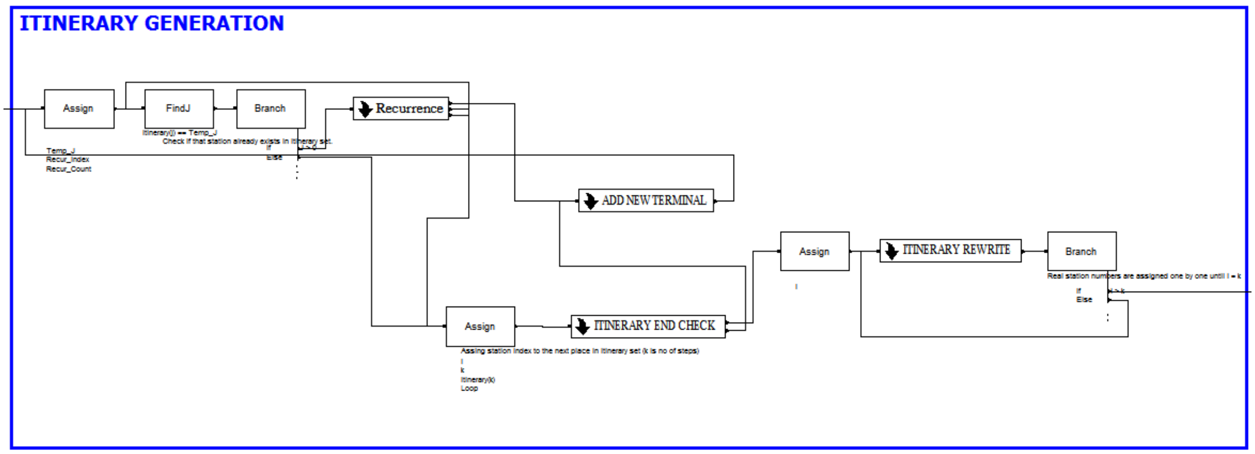


Figure 2.19. High level view of the model logic for itinerary generation

In the data analysis phase, for each vessel type investigated, an itinerary generation matrix was produced. This matrix is comprised of probabilities of vessels departing from one terminal and ending up in another. As shown in Table 2.3, each row in this matrix represents all possible transitions from one terminal to another, and thus adds up to 1.

Table 2.3 - Itinerary matrix for PG vessels

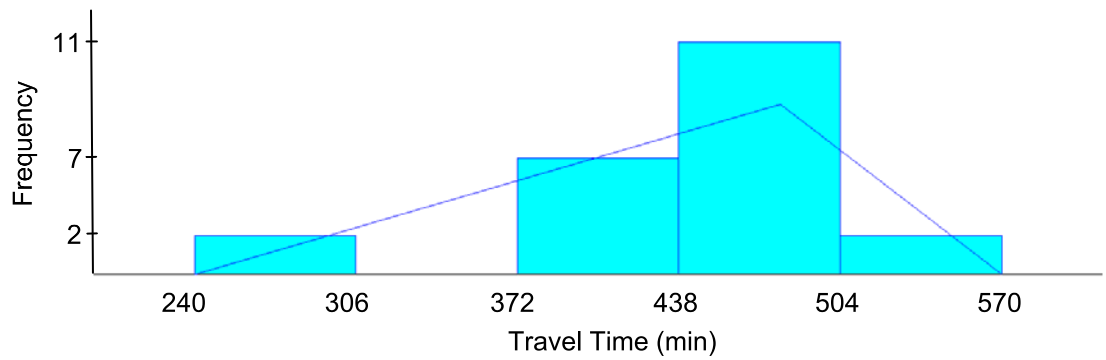
Starting Terminals	**Destination Terminals**				
	BW	*Girard Point*	*Hess*	*Sun Marcus Hook*	*Wilm Oil Pier*
BW	0	0.240	0.007	0.753	0
Girard Point	0.861	0	0	0.139	0
Hess	1	0	0	0	0
Sun Marcus Hook	0.683	0.308	0	0	0.008
Wilm Oil Pier	1	0	0	0	0

2.5.3. Modeling Navigation in the River

Based on geographical importance, terminal and anchorage locations, and considering recommendations and regulations to facilitate decisions to be made during movement of vessels, the River is separated into 6 zones in the model whose entrance and exit points are defined by virtual reference stations in the model. Reference stations constitute the keystones of navigation in the model. Each terminal and anchorage location is defined by its zone number in order to facilitate handling of navigational rules and vessel movements. A numbering scheme is also established covering terminals, anchorages and virtual reference stations in order to navigate a vessel from one point to another. Before a vessel starts moving from a station, a target station is determined in the reservation procedure that is described in Terminal Reservation Mechanism section. This target can be either an anchorage or a terminal based on berth availability and navigational rules. If the target station is in the same zone, the vessel is sent directly to the target station. Otherwise, it is sent to the closest reference point to its current location first and to the next reference station in the same direction until it reaches the entrance of the zone of the target station. The same procedure is used each time a vessel is moved in the River.

Distance and travel time matrices are important components of the navigation logic in the model. The distance matrix includes distances for all possible inter-terminal travel supported by the data. The travel time matrix, similar to the itinerary matrix, includes a probability distribution representing travel time from a terminal to other possible terminals. Thus, travel times of the vessels are calculated based on predefined probability distributions specific to vessel type, and source and destination terminal combinations. Before a trip starts, a travel time is generated and the vessel’s speed is determined based on the source and destination pair. Until the trip is completed, the vessel uses the calculated speed to move from one station to another in the model.

For instance the distribution function (and the density function - histogram) of the travel times for LPG's between BW and Girard Point is given in Figure 2.20.



Distribution:	Triangular
Expression:	TRIA(260, 484, 569)
Square Error:	0.066763

Figure 2.20. Distribution of travel times for LPG's between BW and Girard Point

Same procedure is followed for all random variables in the model.

2.5.4. Lightering Operations

Lightering operations in the Delaware River concern tankers. Due to economies of scale, tankers traveling from the open sea may arrive at the entrance with a higher underway draft and cannot enter the River. As mentioned earlier, a majority of the vessels navigating in the channel are tankers and about 75% of the tankers entering from BW have a maximum draft greater than 40 feet. However, 43% of the tankers have underway draft greater than 40 feet and need lightering.

Following tankers' arrivals, the model checks the maximum berth depth in their destination terminal and if their underway draft exceeds the berth depth, they are directed to the BSB anchorage to lighter. There, they transfer some of their cargo to lightering barges to reduce their draft down to 40 feet so that they can proceed into the River. This operation is significant in DRB and it is emphasized in the model for the purpose of establishing a basis for scenario analyses.

In addition to characterization of the 14 vessel types, four lightering barges (LB) that have been active during the time span in the historical data are also generated and maintained in the model. These barges are specified by their original size and approximate loading and discharging capacities.

The lightering procedure is modeled as follows. Once tankers enter from the BW entrance, those having drafts greater than their first terminal limits are required to do lightering before sailing into the main channel. Tankers to be lightered go to BSB and call for an available lightering barge. Depending on lightering needs of the tanker, more than one lightering barge may serve the vessel. Once a lightering barge arrives, lightering starts and continues depending on the barge loading rate and some preparation time. After lightering ends, tankers may spend some extra time in the anchorage area due to various reasons or may directly set out for their first destination terminal.

Lightering barges are also assigned a specific itinerary based on their individual itinerary matrix. Holding times per terminal are determined depending on the number of terminals to visit in each trip based on particular lightering barge's cargo discharge rate and the amount of cargo it is carrying.

Lightering needs of tankers are calculated using a regression model. According to data on hand, lightering needs of tankers are highly correlated with their gross tonnage and the amount of draft to be lifted for the tanker to safely visit its first destination terminal in the River. The lightering regression equation used in the model is given below:

$$\boldsymbol{L = 1.63163 * 10^{-5} * GT^2 + 0.4544 * GT + 421.771 * D^2 + 11551.983 * D} \qquad 2.1$$

where L is the lightering demand in barrels, GT is the gross tonnage and D is the draft to be lifted in feet in the lightering operation (R^2 = 0.965). The intercept in the equation is assumed to be zero in order to prevent negative values for the lightering demand. L is plotted in Figure 2.21.

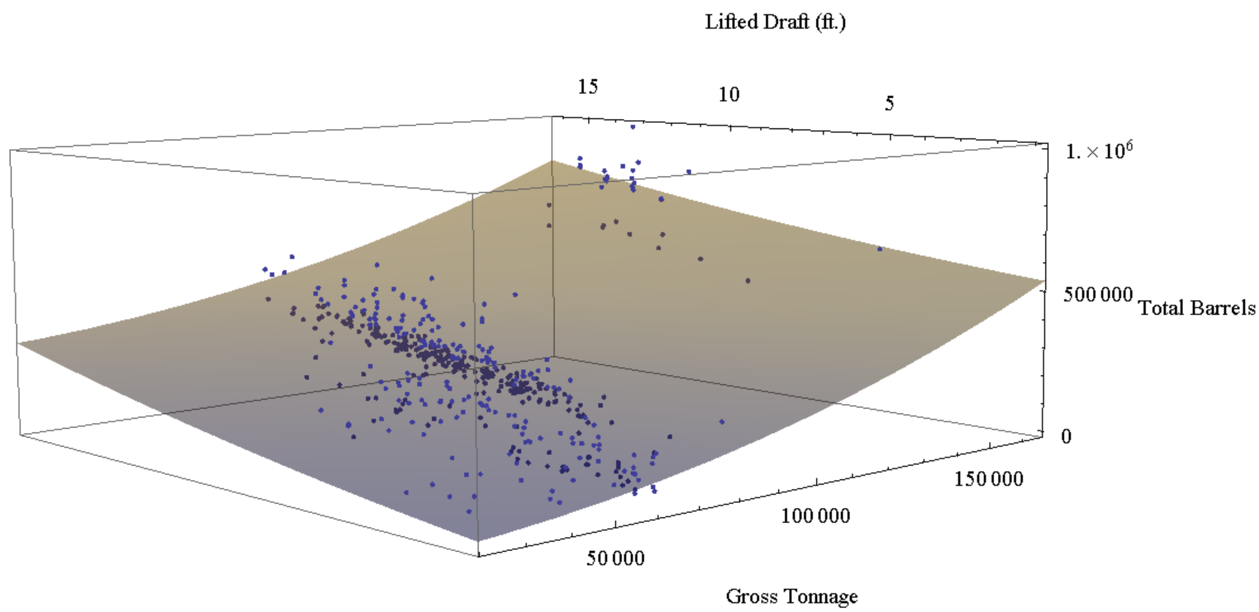


Figure 2.21. Lightering regression plot

2.5.5. <u>Terminal Reservation Mechanism</u>

In the model, a reservation system was developed to manage vessel-terminal berth pairings. Arriving vessels make reservations for berth availability in their target terminals before they start navigating in the river. Reservations are necessary in order to plan anchorage usage in case there is no berth availability. Hence, using the reservation system, efficient and orderly movement of vessels in the DRMC is achieved in the model.

A reservation for a terminal is the selection of a suitable berth considering draft/cargo limitations and berth availability. Each and every berth in the River has an availability record in the system. Besides, if terminals have size limitations among their berths or have specific cargo handling assignments, these details are also incorporated in the model. Thus, a reservation is made by updating the availability record for the next vessel arrival at a particular berth.

Reservations for the first terminal visits of the vessels are done at the entrances (BW and CD) of the River. Succeeding terminal reservations are performed at the terminals when vessels are ready to depart. For vessels using Breakwater Anchorage (BWA) or BSB right after entering the system, reservations are done when they are ready to leave the anchorage. An overview of the logic that handles the terminal reservation process is shown in Figure 2.22.

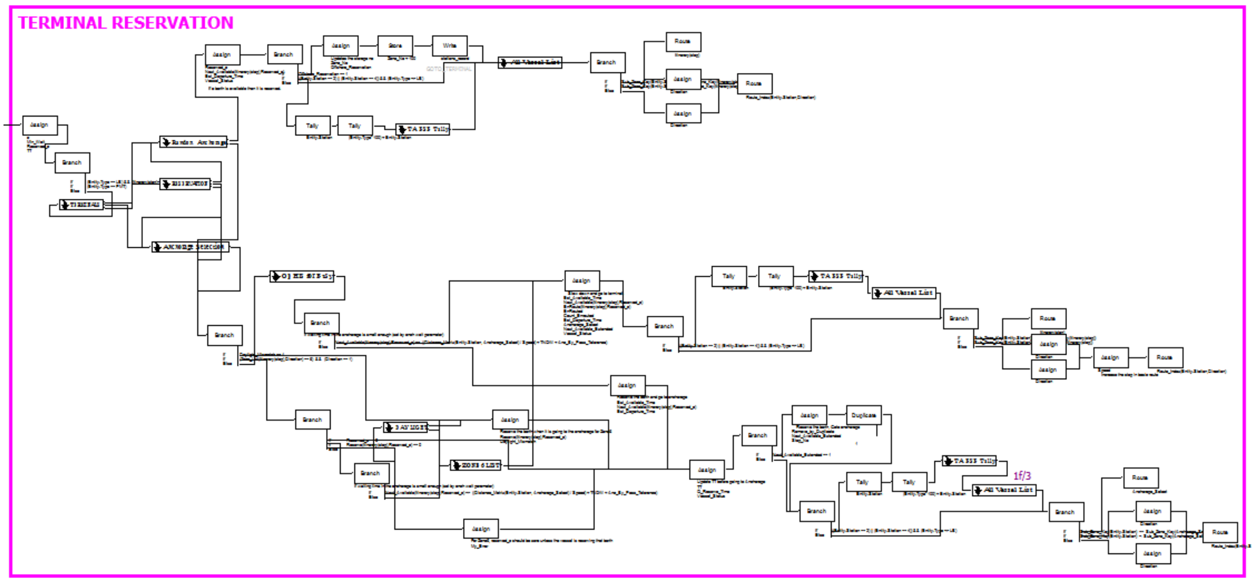


Figure 2.22. A high-level view of the model logic for terminal reservations

2.5.6. <u>Anchorages</u>

There are 7 major anchorage areas in DRB considered in the model. They are BWA and BSB at the BW entrance; Reedy Point Anchorage (RP) at the CD entrance; and Wilmington Anchorage (WA), Marcus Hook Anchorage (MHA), Mantua Creek Anchorage (MCA) and Kaighns Point Anchorage (KPA) and are included in the model.

Anchorages are used for several purposes and each anchorage in the system has its own particulars. BWA is mostly used for waiting due to tide or other needs while entering the River. BSB is primarily used for lightering purposes. All other anchorages are used prior to a terminal visit. MHA is also used for waiting due to tide for outbound vessels. The two anchorages at the BW entrance do not have capacity issues while all other anchorages have length, depth and capacity limitations (Table 2.4).

Table 2.4 - Anchorage draft, length and vessel capacity limitations

Anchorage	Draft	Length	Capacity
Kaighn's Point	≤ 30 feet	≤ 600 feet	7
Mantua Creek	≤ 37 feet	≤ 700 feet	6
Marcus Hook	≤ 40 feet	-	6
Wilmington	≤ 35 feet	≤ 700 feet	3
Reedy Point	≤ 33 feet	≤ 750 feet	5
Big Stone Beach	≤ 55 feet	-	-
Breakwater	≤ 55 feet	-	-

Anchorage visits are primarily based on decisions due to terminal berth availabilities, recommendations and regulations and minor random visits for maintenance and other possible reasons.

A high-level view of the simulation model logic regarding anchorage operations and management is given in Figure 2.23.

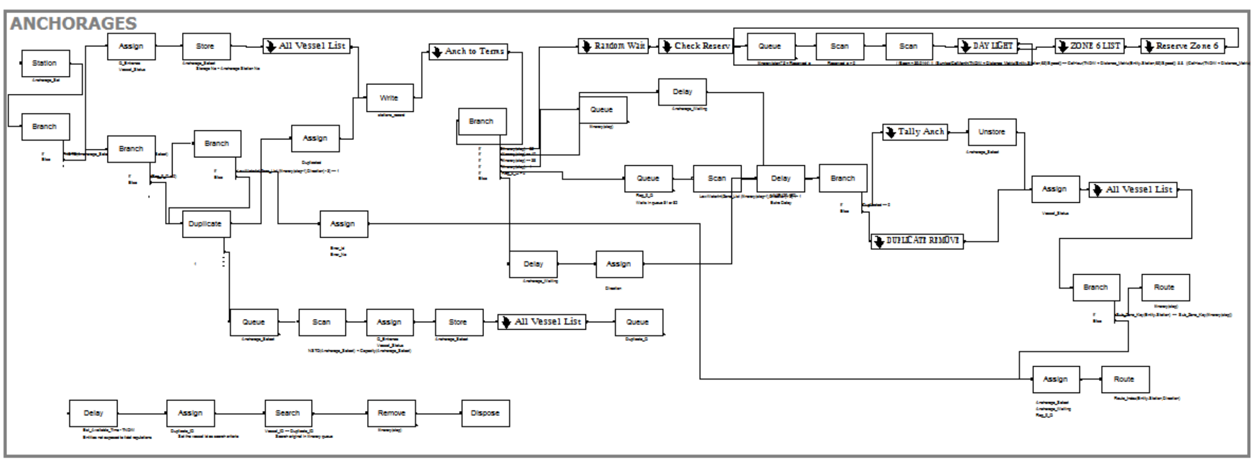


Figure 2.23. A high-level view of the model logic for anchorages

2.5.7. <u>Terminal Operations</u>

Terminal operations in the model are part of the vessel holding time which is the total time spent by a vessel in a terminal. This study does not go into details of the terminal logistics since it would not be possible to handle details of all the terminals in such a modeling effort. The model is only concerned with the berth holding times of vessels at each terminal. Holding time represents the duration between entrance and departure of a vessel from a terminal including preparation, loading, unloading, and other processes that vessels typically go through at a terminal. Vessels visiting terminals are assigned a holding time from a random probability distribution in the beginning of their trip to a terminal. Holding time distributions are vessel-type and terminal specific in order to reflect characteristics of different operations.

Once vessels dock at their reserved berths in a terminal, operation starts and continues through the holding time. When the operation is completed, a vessel makes its following reservation (if any) and departs from the terminal.

Vessel unloading times at terminals are also obtained from the MEX and statistical distributions are fitted to them. For instance, LPG vessel holding time distributions in some select terminals are given in Table 2.5.

Table 2.5 - Distributions of selected LPG vessel terminal times (min.)

GIRARD POINT PA	NORM(1.8e+003, 909)
SUN MARCUS HOOK PA	498 + 1.32e+004 * BETA(0.886, 1.76)
WILM OIL PIER	190

A high-level view of the simulation model logic for holding a vessel at a terminal is given in Figure 2.24.

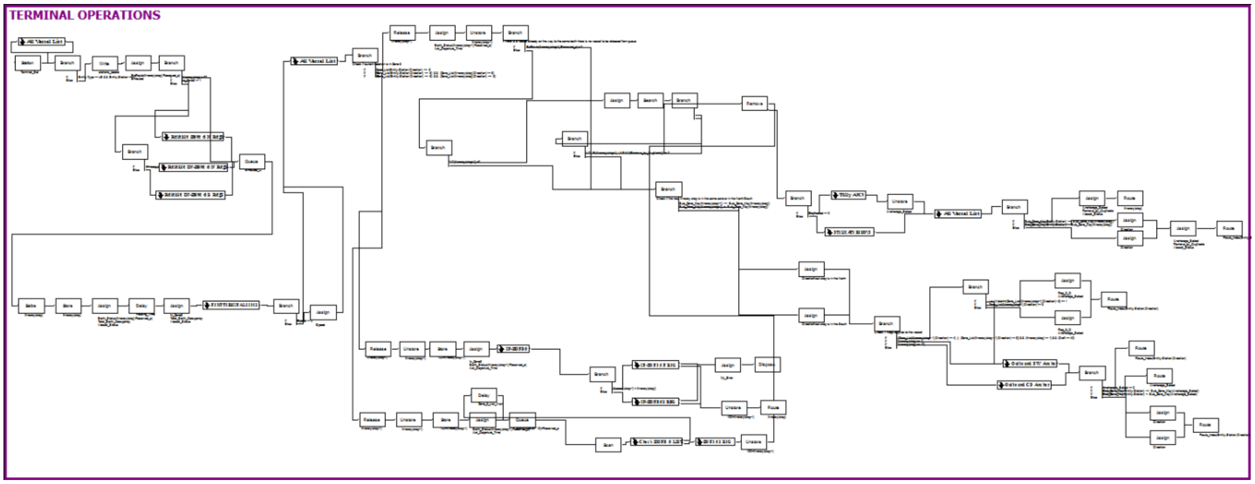


Figure 2.24. A high-level view of the model logic for terminal operations

2.6. Overall View of the Model

The simulation model for the DRMC vessel traffic is built using the ARENA simulation tool. Fundamentals of simulation and modeling using Arena can be found in the book written by Altiok et al., (2007). The model has a logic layer composed of modeling objects connected to each other to achieve the logical dynamics of the vessel movements. It has also an animation layer to show how the model dynamics take place, as shown in Figure 2.25. The animation layer is for verification and presentation purposes. It also houses a number of input and output statistics to monitor the model's progress over time.

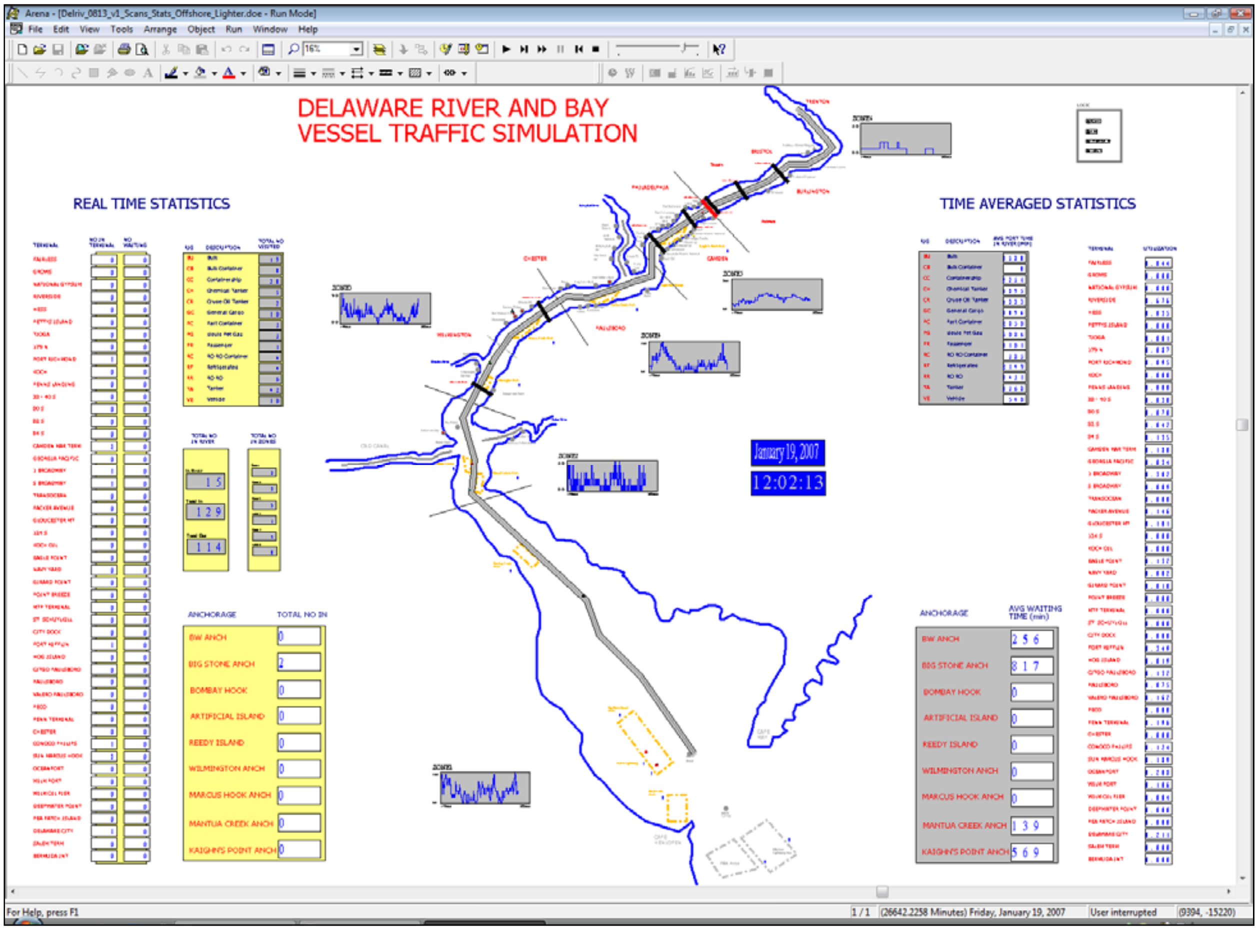


Figure 2.25. Animation window of the DRB model

The logic layer of the model includes the programming code for all the components introduced earlier. Arena brings an object-oriented approach to simulation modeling. The code in Arena consists of blocks representing mathematical and logic operations to achieve creation of entities (vessels), moving them in the river, assigning and changing particulars, checking regulations, creating tidal windows and obtaining statistics among various other operations.

Snapshots from the animation layer are presented in Figure 2.26 to Figure 2.30 to provide detailed views of the model. Note that several shapes are used to distinguish vessels from each other and for anchorages as well as terminals. Vessels, represented as colored circles, have their ID Codes written on them. Gray graphs trace the total number of vessels in each zone. White boxes in red rectangles show tidal windows.

Figure 2.26 shows part of Zone 1 and the lightering activity in the Big Stone anchorage.

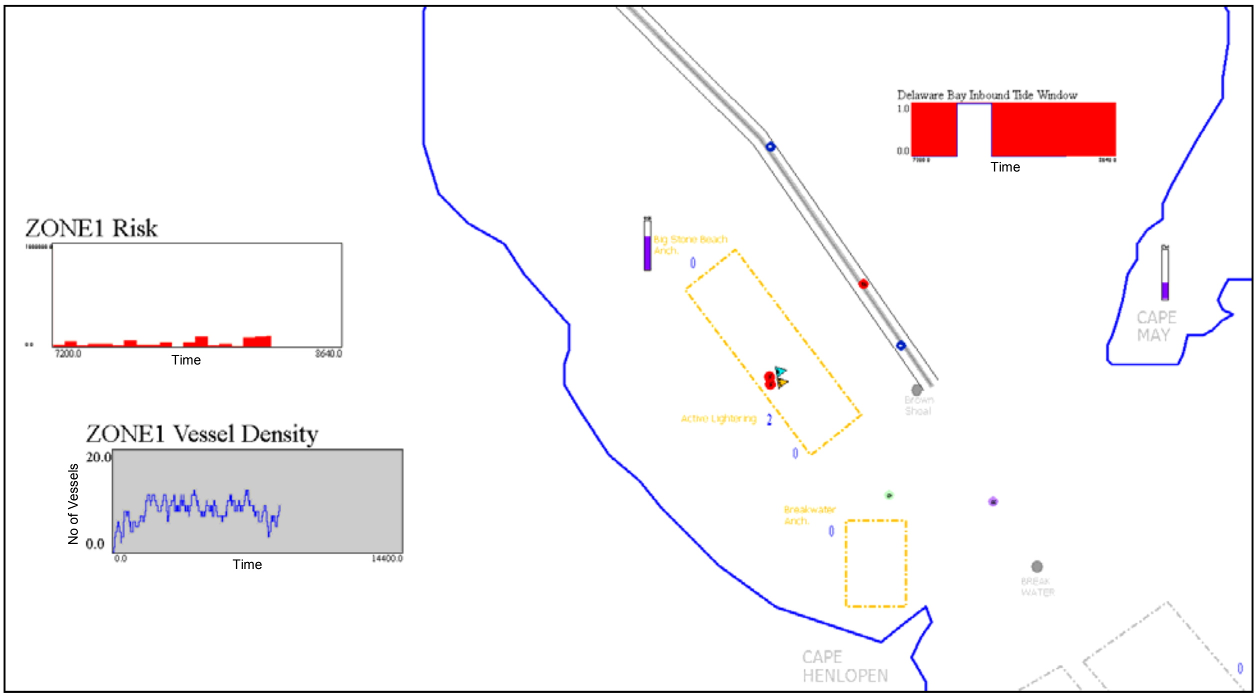


Figure 2.26. Lightering activity in the Big Stone anchorage

Figure 2.27 shows C&D Canal and Zone 2.

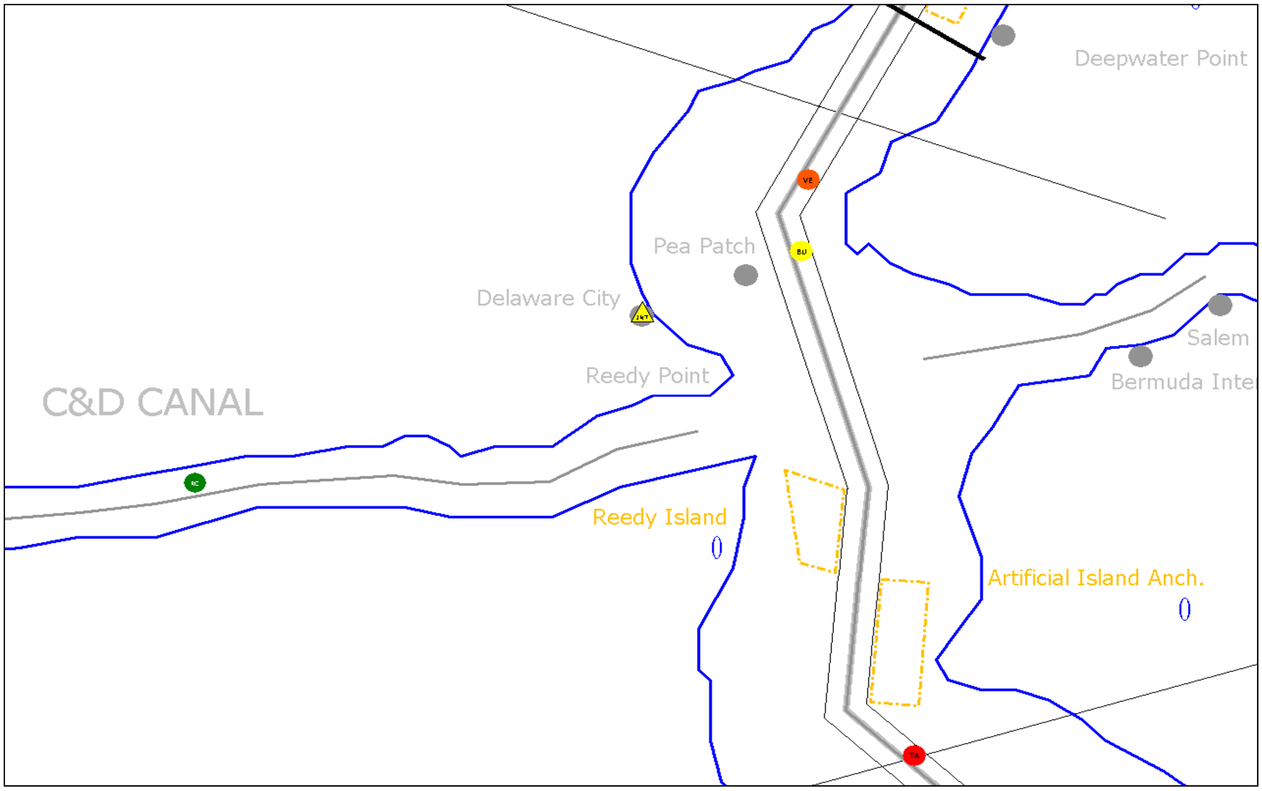


Figure 2.27. C&D Canal and Zone 2

Figure 2.28 shows Zones 3 and 4. These zones have a number of oil terminals and critical infrastructure facilities.

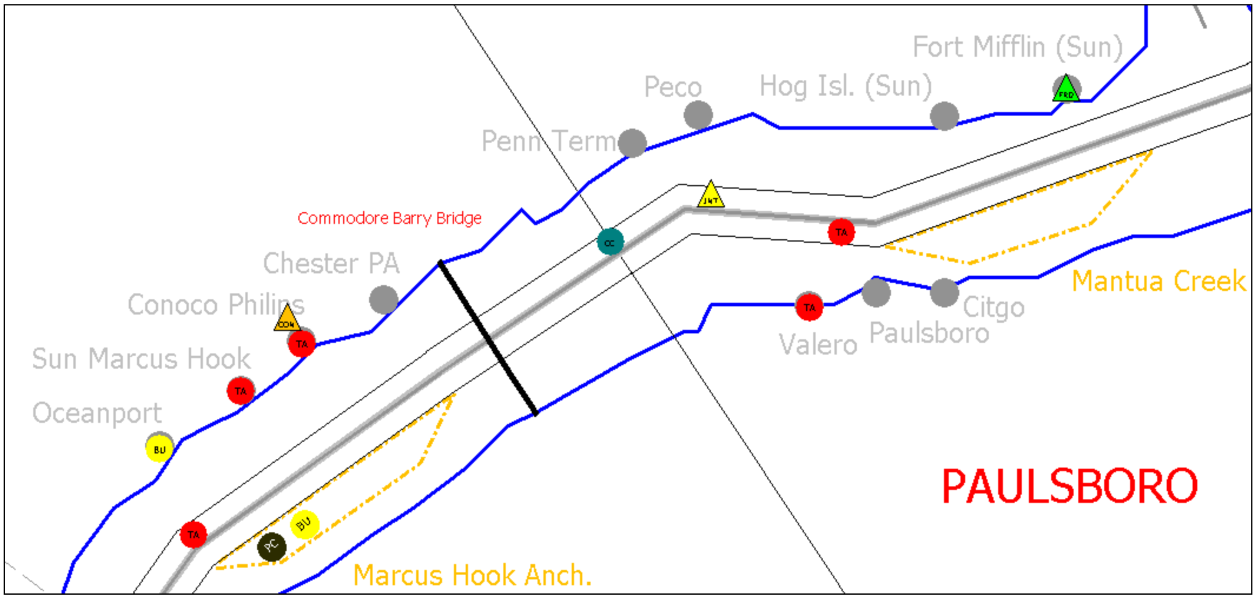


Figure 2.28. Zones 3 and 4

Figure 2.29 shows Zones 4 & 5 covering Chester, Paulsboro, Philadelphia, Camden and Burlington areas with a number of marine terminals.

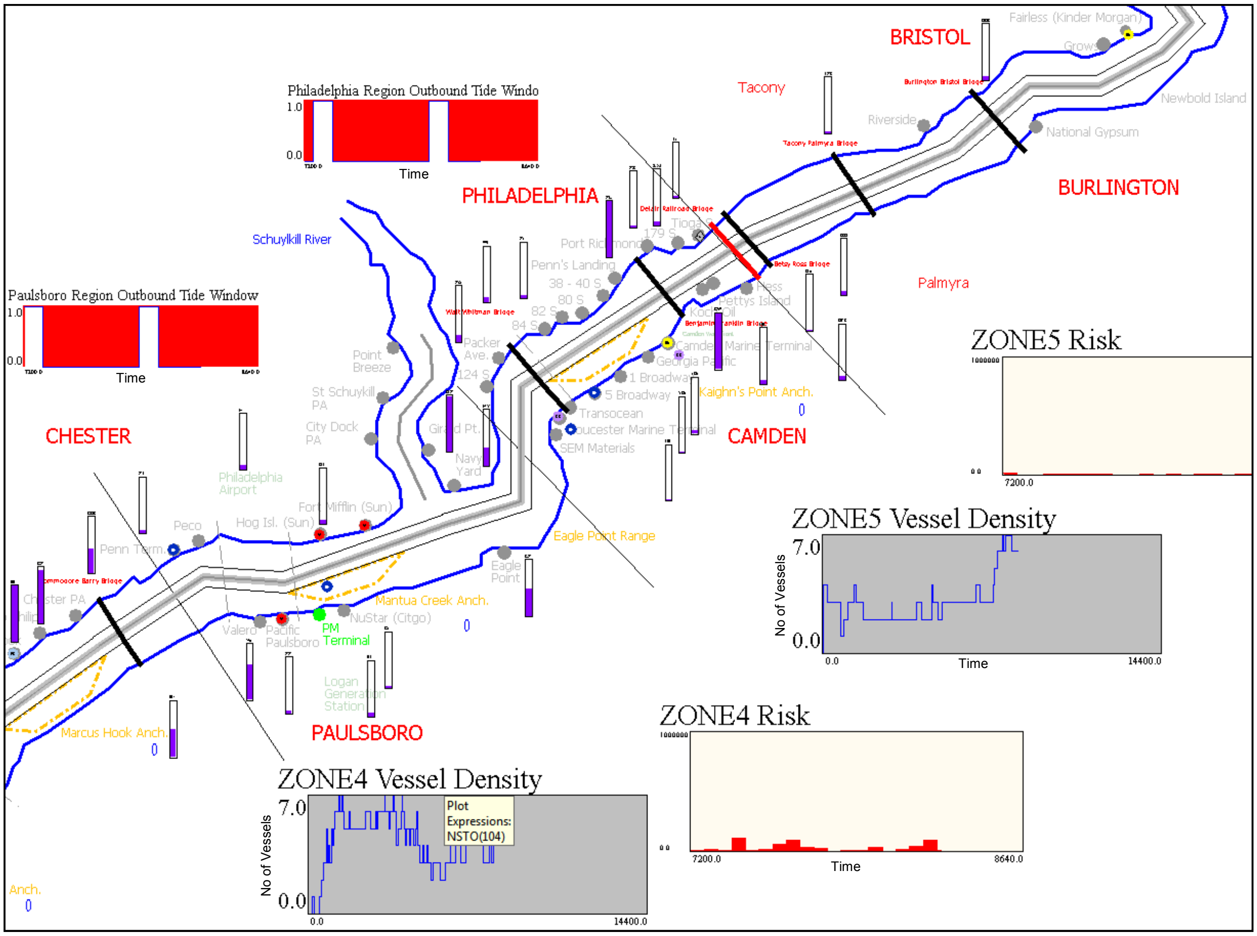


Figure 2.29. Zones 4 and 5 with ports Philadelphia and Camden

Figure 2.30 shows port Philadelphia in Zone 5 in detail with its terminals and vessels docked at some of them.

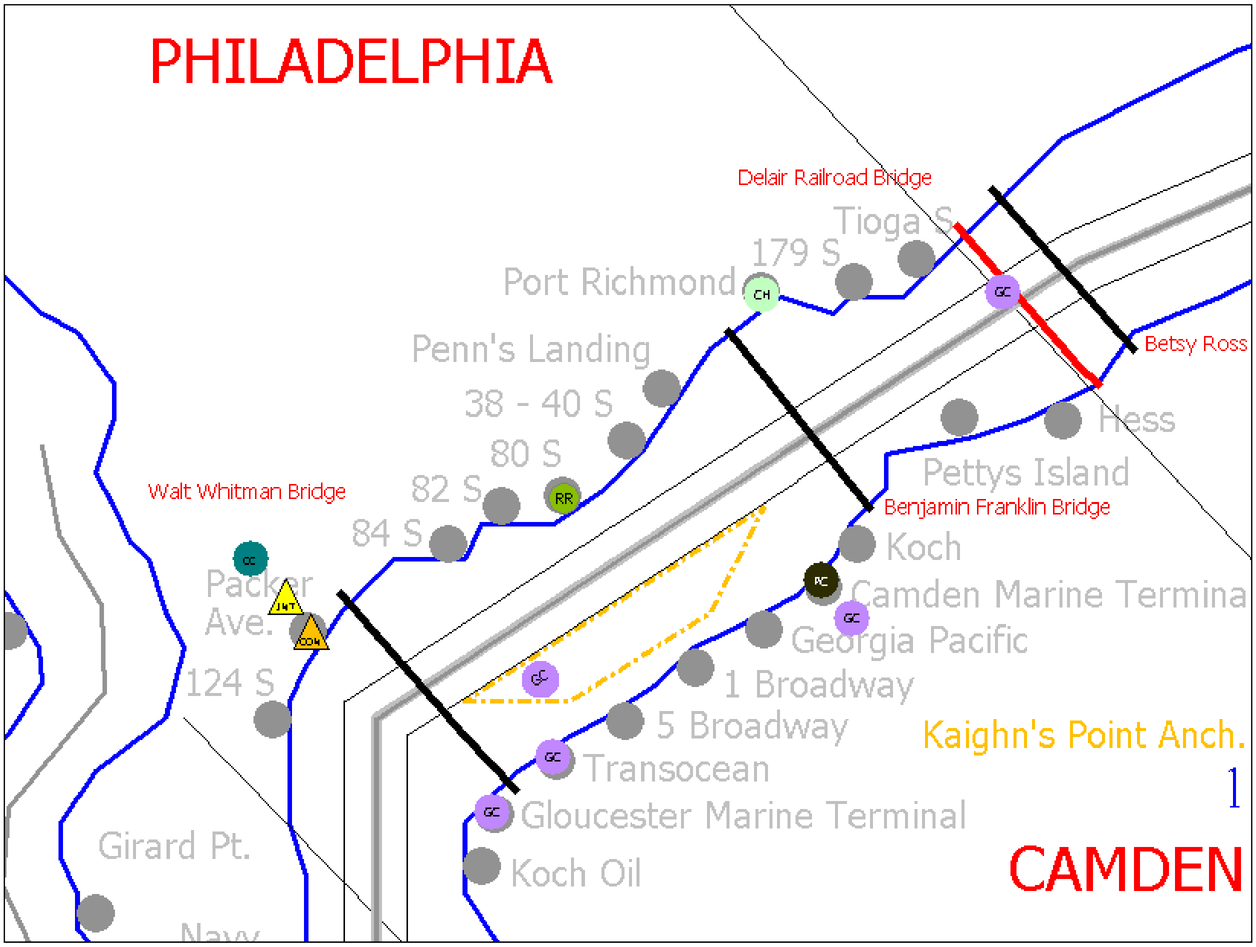


Figure 2.30. Port Philadelphia in detail

2.7. Output Statistics and Relevant Snapshots

The simulation model produces output for a set of performance measures for each vessel type and each port terminal. These are statistics regarding port performance collected during and at the end of each simulation run. These statistics can be collected as time-averaged statistics or vessel-averaged statistics presented in the form of the average, minimum, maximum and 95% confidence interval. They are summarized below.

Vessel-averaged statistics (averaged over number of vessels) are:

- Port times per vessel per vessel type,
- Anchorage delays per vessel per vessel type.

Time-averaged statistics are:

- Terminal/berth utilizations,
- Anchorage occupancy (number of vessels at any time),
- Overall Port occupancy (number of vessels at berths at any time).

Also, visit statistics include:

- Annual anchorage visits per vessel type,
- Annual port calls per vessel type.

Delaware River and Bay area is a tri-state region and accordingly different parts of the river are under the jurisdiction of different states. Furthermore, the landscape is such that bulk handling is more significant in New Jersey whereas container activity is heavier in Pennsylvania and oil and petroleum handling operations are somewhat balanced in all three states. Thus, the model also produces state-specific output. The results based on states of New Jersey (NJ), Pennsylvania (PA) and Delaware (DE) are also listed for each year in cases of increasing vessel arrivals for Bulk, Cargo Containers, General Cargo, Parts Container, Vehicle and Tanker vessel types.

Figure 2.31 shows average port times and berth utilization for a selected group of vessels and terminals. Port times are averaged over vessels and utilization values are averaged over time.

OUTPUT STATISTICS

RIG	DESCRIPTION	AVG PORT TIME IN RIVER (min)
BU	Bulk	4392
CB	Bulk Container	4211
CC	Containership	1929
CH	Chemical Tanker	4081
CR	Crude Oil Tanker	2296
GC	General Cargo	3723
PC	Part Container	5491
PG	Liquid Pet Gas	4395
PR	Passenger	1353
RC	RO RO Container	427
RF	Refrigerated	3864
RR	RO RO	3630
TA	Tanker	3819
VE	Vehicle	573

TERMINAL	UTILIZATION
FAIRLESS	0.076
GROWS	0.029
NATIONAL GYPSUM	0.014
RIVERSIDE	0.159
HESS	0.081
PETTYS ISLAND	0.000
TIOGA	0.090
179 N	0.093
PORT RICHMOND	0.107
KOCH	0.000
PENNS LANDING	0.016
38 - 40 S	0.038
80 S	0.145
82 S	0.107

Figure 2.31. Vessel port time and terminal utilization statistics

Figure 2.32 shows anchorage delays averaged over all vessels delayed.

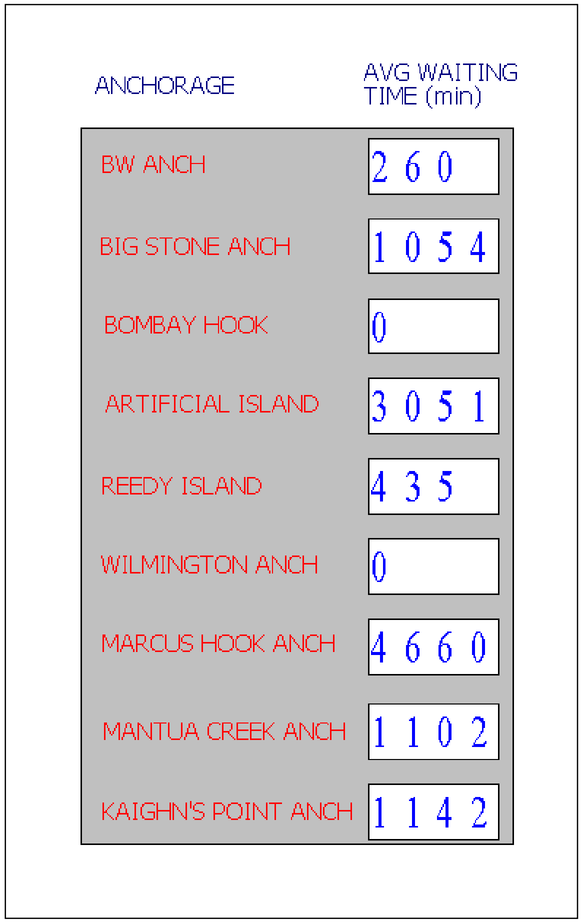


Figure 2.32. Average delays at anchorages

Figure 2.33 is a snapshot of visit statistics representing the current state of the port at the time it was observed.

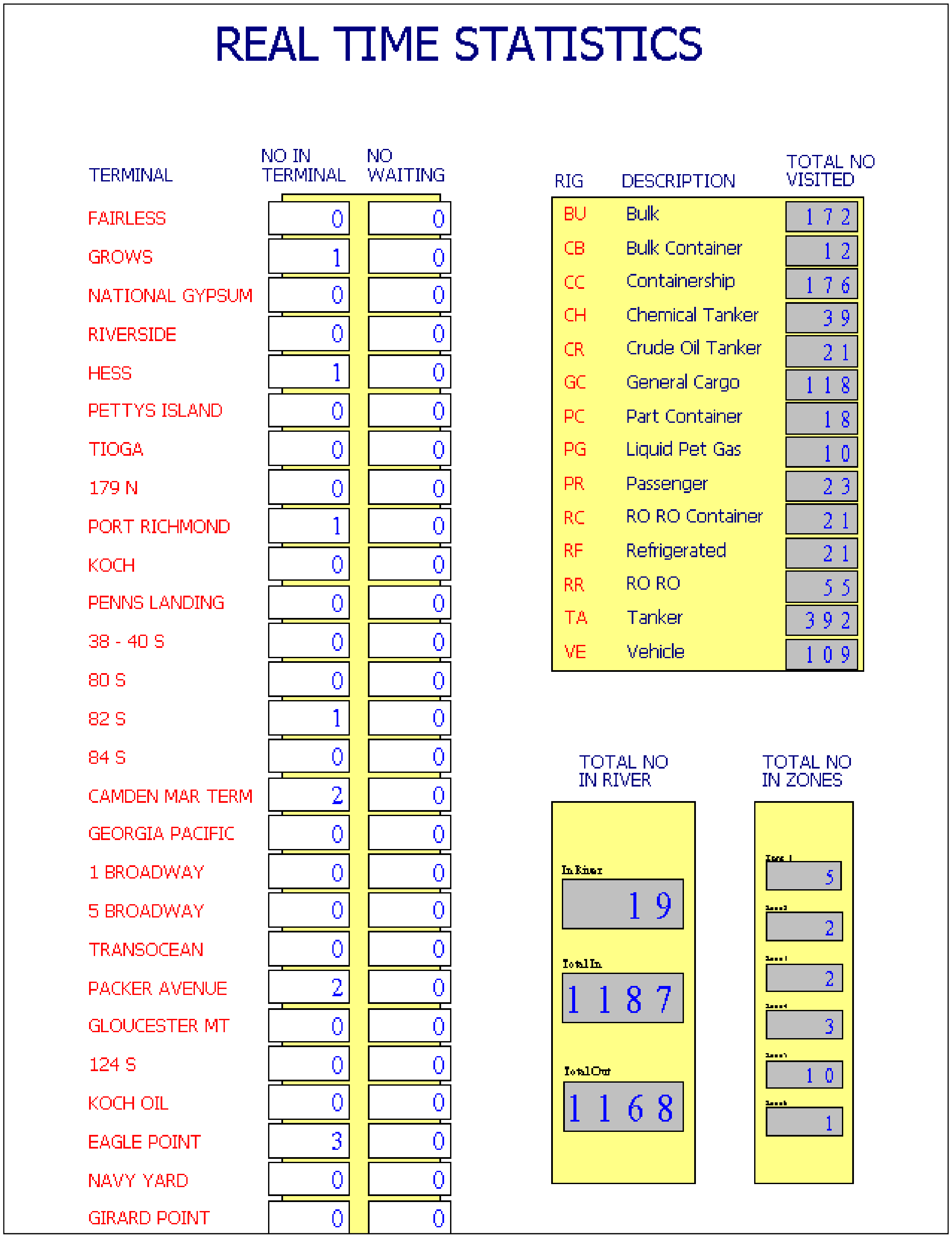


Figure 2.33. Visit statistics showing the current state of the port: Number of vessels in terminals and waiting for terminals, total number of vessels visited the port by type, and total number in each zone and the River

Figure 2.34 shows the visit statistics representing the current state for the anchorages.

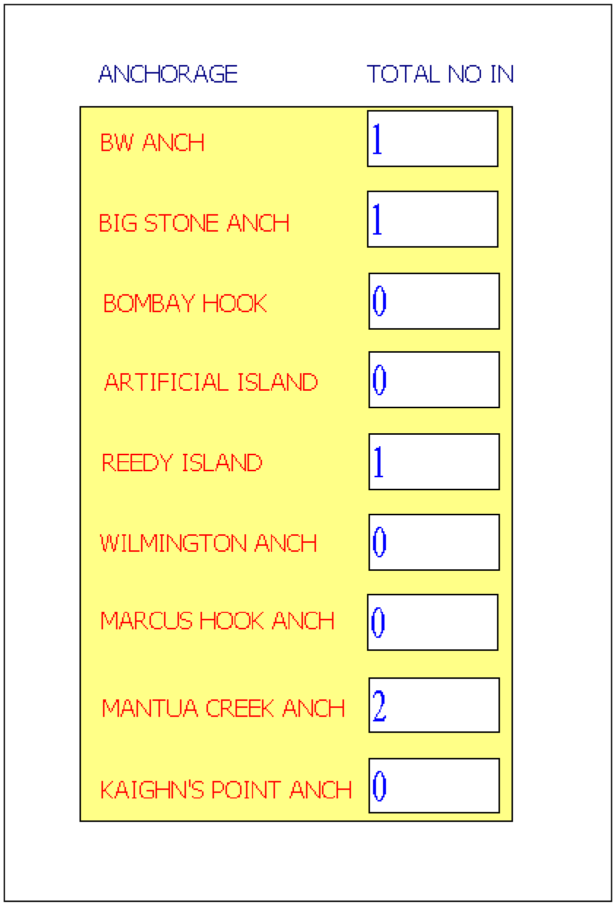


Figure 2.34. Real-time statistics for the anchorages

2.8. Verification & Validation

The model was verified in several steps to check if it is working in the way it is intended to. First, the model was developed in blocks of logical code and sub-models and therefore it lends itself for testing and monitoring in a block by block manner. This helped the verification effort significantly. Another method used throughout model development is the tracing approach. Via tracing, a detailed report of entity processing was produced and compared to manual calculations in order to check if the logic implemented in the model is as intended. Furthermore, animation is frequently used for verification purposes. Through animation, operation of the overall system is closely monitored and synchronization of events is verified.

For validation purposes, several tests were performed and various key performance measures were observed to see if they were close to their counterparts in reality. Lastly, as a conclusive test of validation, the model outputs were compared to real data on hand. The model results pertaining to averages from replications of 30 years representing the operation during 2004 to 2008 in DRB were compared to averages obtained for the same time period. These observations are based on port calls and port times, anchorage calls and delays, and terminal utilizations as shown in Table 2.6, Figure 2.35, Figure 2.36 and Figure 2.37. Note that, the model was validated for years 2004 to 2008. For future use of the model, it needs to be further validated for the following years. This involves modifying the model to bring it up-to-date (both logic and data) and compare its output to measures (again port times, utilizations and etc.) from the following years, such as 2009 and 2010.

Table 2.6 - Port times and port calls

Vessel Type	Actual Data 04 - 08		Simulation	
	Average Port Time per Vessel (min)	Average No of Vessels per Year	Average Port Time per Vessel (min) (Half Width 95% C.I.)	Average No of Vessels per Year
Bulk	5597.25	423.2	5686.9 (± 130.35)	416.9
Containership	1975.85	475.8	1980.4 (± 43.89)	463.2
Chemical Tanker	3687.37	70.6	3604.3 (± 139.76)	71.6
Non-flammable Prod.	2501.35	50.8	2494.4 (± 43.64)	50.5
General Cargo	3937.95	262.6	3715.8 (± 62.25)	260.9
Parts Container	5072.30	66.2	5055 (± 180.84)	67.0
LPG	6030.96	31.4	6307.5 (± 335.34)	32.7
Passenger	1246.05	32.6	1247.3 (± 16.73)	32.0
RO-RO Container	368.89	63.8	366.24 (± 33.51)	65.4
Refrigerated	4142.07	337.2	4171.9 (± 67.52)	336.1
RO-RO	3022.94	85.8	3076 (± 139.01)	88.8
Tanker	5011.79	921.2	4945.4 (± 109.08)	924.6
Vehicle	712.84	300.8	730.96 (± 21.12)	305.1
Tug Boat	4443.93	667.0	4191.7 (± 84.46)	675.5
Overall	**3898.43**	**3789.0**	**3839.53 (± 39.82)**	**3790.5**

Port times include all holding times at the visited terminals, travel times and anchorage delays from entrance to exit of a vessel in the system. Thus, it is the most meaningful comparison for validation purposes. Table 2.6 shows average observed port times and the estimated port times with their 95% confidence intervals. Notice that all average port time figures lie within 6 percent difference from the actual value. On the other hand, since the port calls for each vessel type is generated using a distribution or process specific to that vessel type, discrepancy from the actual data is only due to randomness. Finally, aggregate figures of the average port time and port calls indicate that the actual system is also well represented within the simulation and that the simulation model is valid (Figure 2.35).

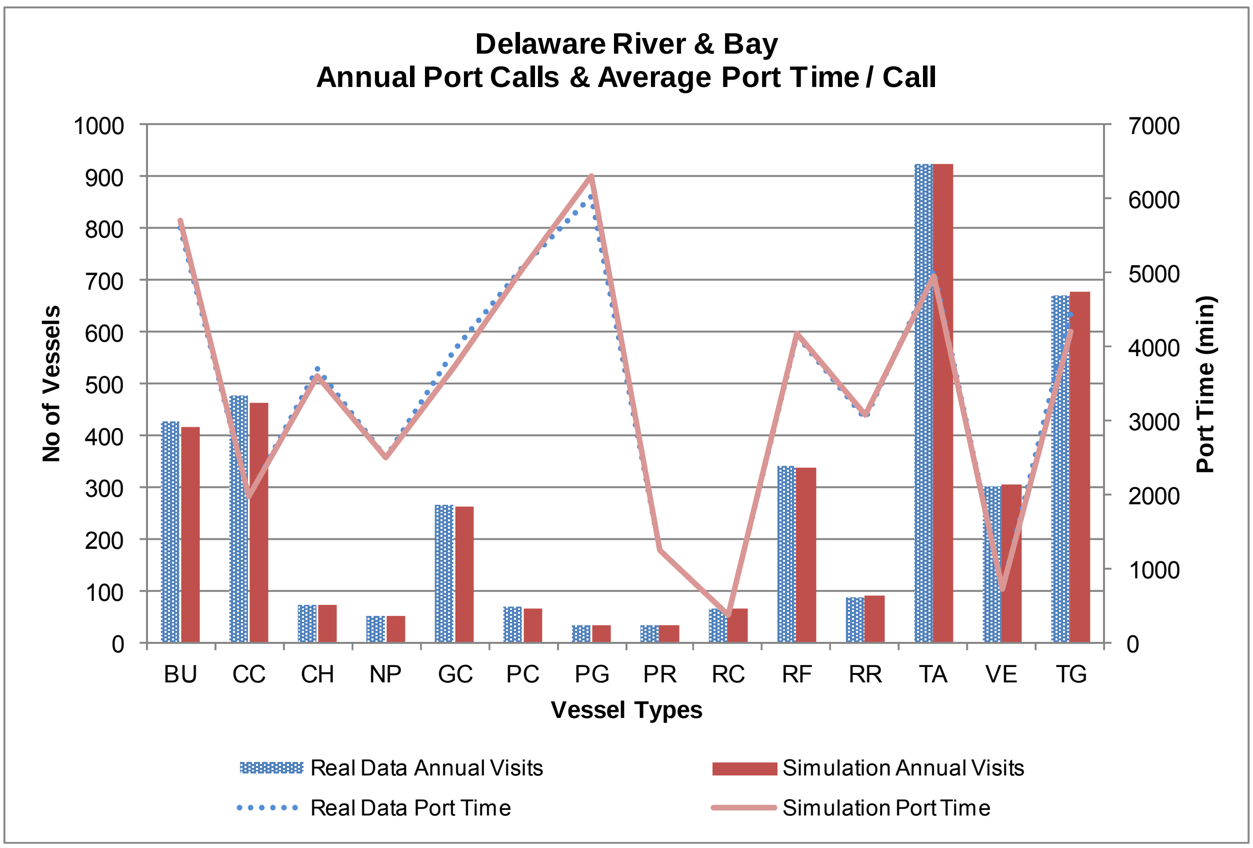


Figure 2.35. Port times and port calls

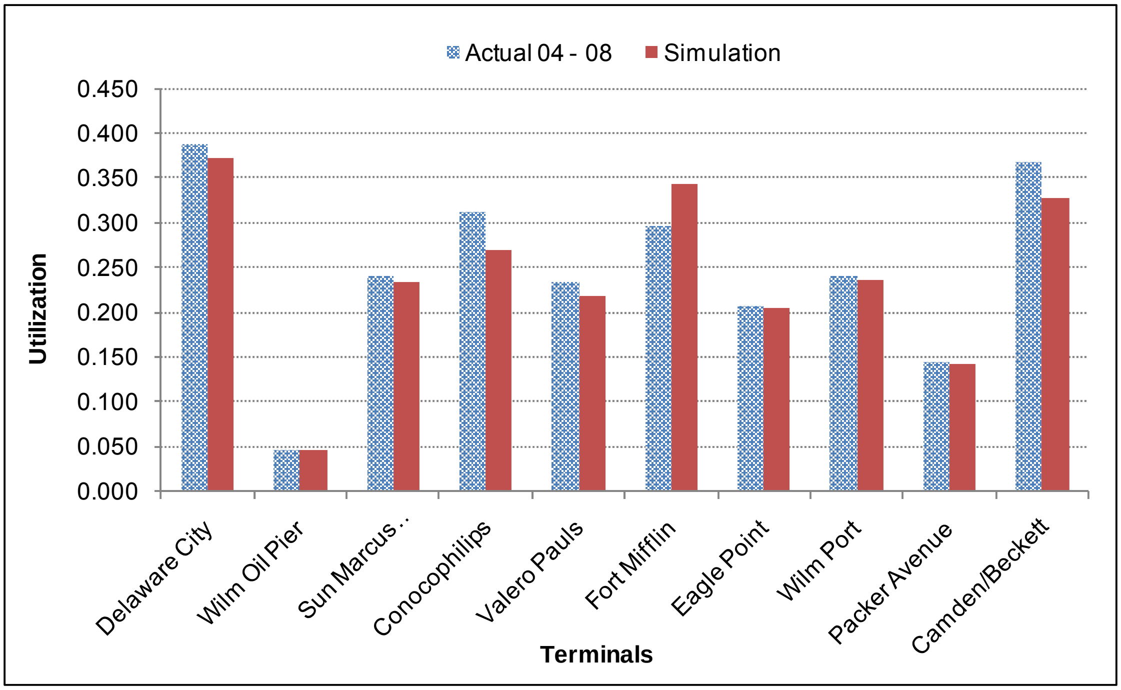


Figure 2.36. Comparison of actual and estimated berth utilizations for selected terminals

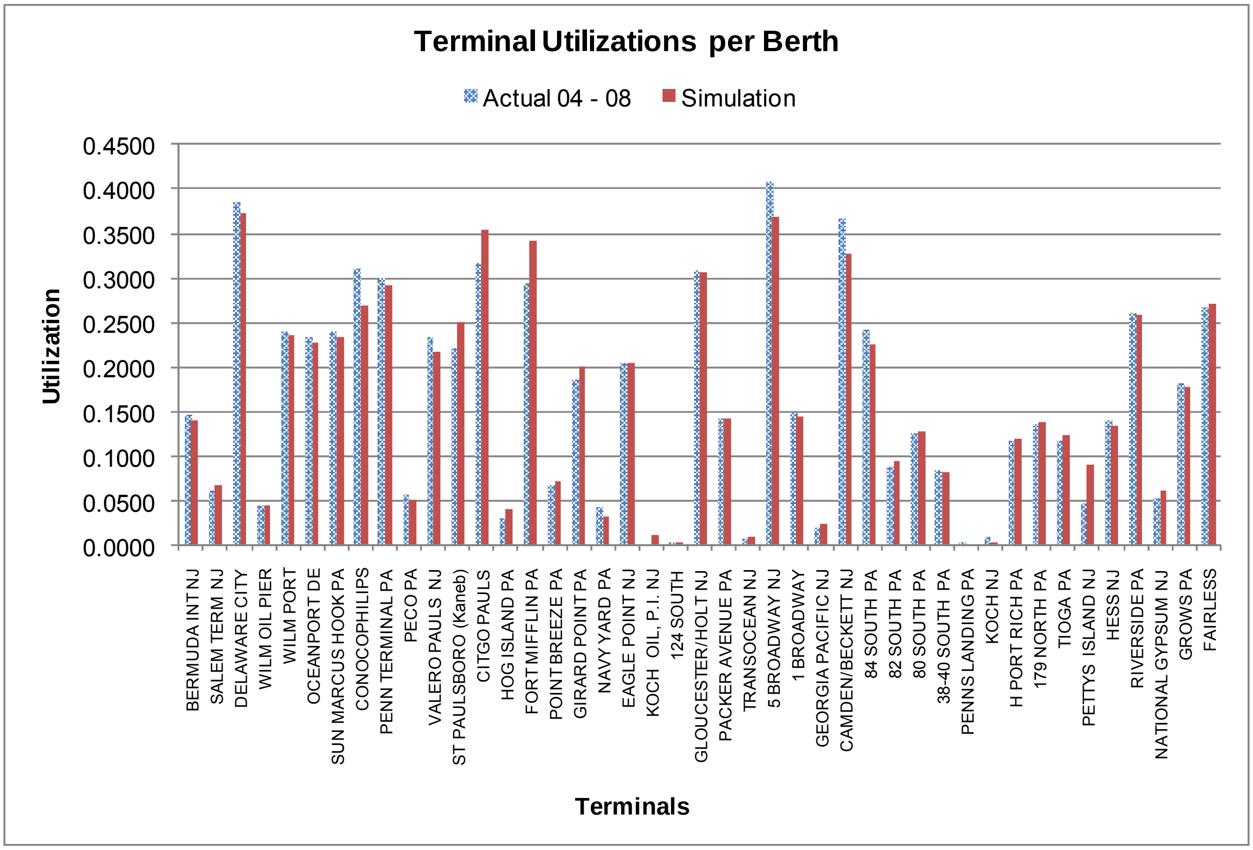


Figure 2.37. Comparison of actual and estimated berth utilizations for all terminals

Terminal berth utilizations shown in Figure 2.36 and Figure 2.37 are other key measures that are used to test the validity of the model. Among more than 40 terminals in the system, only a few of them have about 4% deviations in estimations of berth utilizations while the rest of the utilizations deviate by only 2%. Confidence intervals (95%) are also obtained for terminal utilizations to assure consistency in model’s output.

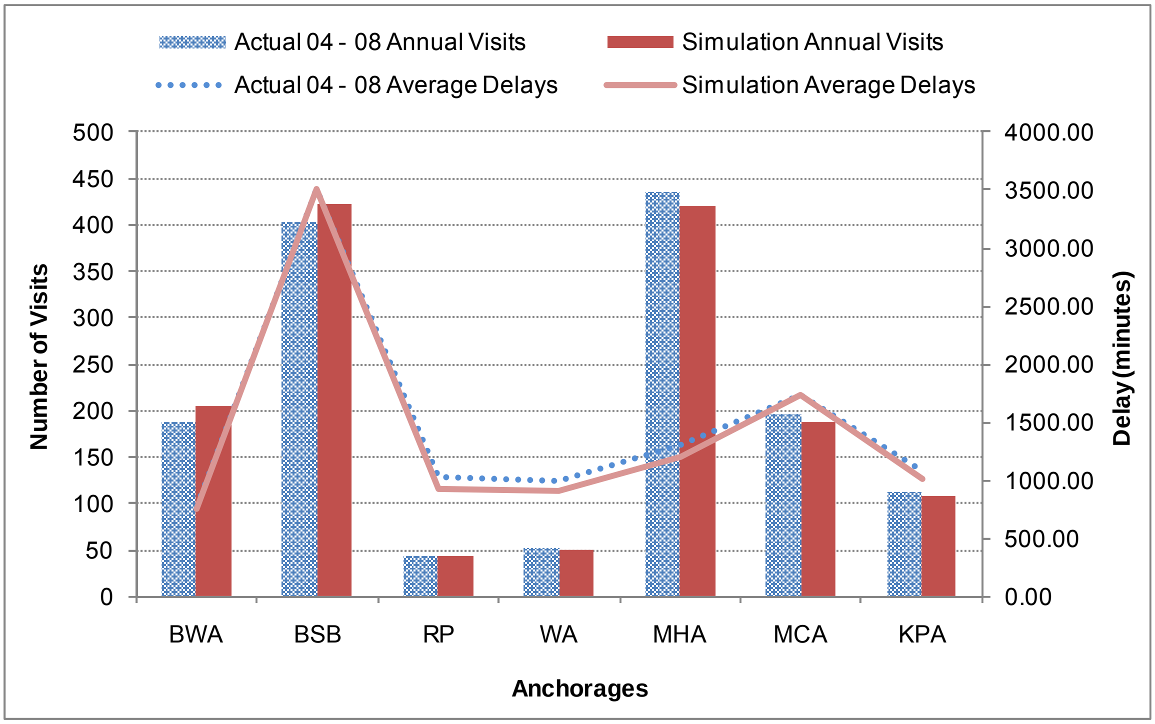


Figure 2.38. Annual anchorage visits and average delays per visit

Anchorage visits and delays are of critical importance in the validation process since these visits are mostly based on decisions rather than random events in the model. Therefore, lesser variation in these figures indicates robustness of the model. As seen in Figure 2.38, annual visits and average delays in all anchorages are highly close to their actual counterparts. In addition to the aggregate results given here, vessel-type-specific results are also collected and found to be highly close to the actual values in most of the cases.

As a result of these comparisons between the actual observed data and simulation estimates, the simulation model built to mimic the vessel traffic in the Delaware River and Bay is considered to be a valid representation of the actual system to perform scenario analyses on the issues mentioned earlier as well as to use in any relevant planning study or analysis for the region.

2.9. Conclusion for Simulation Modeling

A comprehensive simulation model was developed for the maritime traffic in Delaware River Main Channel governing goods transportation from various sources all around the world to New Jersey, Pennsylvania and Delaware destinations. It includes all types of vessels and cargo as well as most of the significant navigational rules in the river. The model was verified and validated using the data from the Maritime Exchange for the Delaware River and Bay.

The model was used to study deepening impact, risk analysis and vessel prioritization issues in this project. However, it is available to study all kinds of crucial issues in commerce, transportation, homeland security and other relevant and important areas of interest to the region. Along these lines, the model and its findings were already put into use in capacity planning for the Paulsboro terminal of the South Jersey Port Corporation. The model has potential for use in almost every critical project regarding navigation and capacity planning in the DRB area. These include, but not limited to, construction of new terminals, handling of additional traffic, anchorage capacity planning, impact of additional vessel traffic on fisheries and wetlands, handling of offshore wind farms and many others.

3. IMPACT OF DEEPENING ON PORT PERFORMANCE

3.1. Introduction

Delaware River is the port of call for deep-draft commercial ships and tug/barge units that can only navigate in the main ship channel. The River's 40-foot channel appears to be shallow when compared to other ports in the region, restricting its ability to compete for shipments via the new generation of mega-ships that require deeper drafts.

In view of the current expansion of the Panama Canal, deepening of the main ship channel in Delaware River to 45 feet has been proposed and debated over a number of years. The project consists of the main channel from the Cape May and Cape Lewes entrance in Delaware Bay to Philadelphia Harbor, PA and to Beckett Street Terminal, Camden, NJ. The plan is to deepen the existing Delaware River Federal Navigation Channel from 40 to 45 feet below Mean Low Water (MLW) and provide a two-space anchorage with a depth of 45 feet at Marcus Hook. The benefits of these improvements are expected to be the reduced costs of transportation realized through operational efficiencies (reduced lightering and light-loading), and the use of larger and more efficient vessels (economies of scale).

In this respect, the motivation behind this part of the study was to analyze the impact of deepening on navigational efficiency based on port performance measures. Navigational benefits may include shortened port time per vessel call, lesser anchorage delays and lesser tidal delays, among others. When a port is deepened, it becomes a new port and therefore, it is essential to develop a model of the current scenario to provide a practical and realistic tool for performance analysis. This helps to investigate the dynamics of vessel movements once the river is deepened, possible increases in vessel calls, possible changes in vessel particulars, and changes in navigational rules.

Model runs we conducted center around the investigation of the impacts of some key issues on port performance. These are:

- Increase in vessel arrivals due to trade growth,
- Deepening the River and dredging some terminals by 5 feet,

- Change vessel configuration and bring larger vessels

Relevant scenarios are described in the scenario analysis section below.

3.2. Literature on Impact of Deepening on Port Performance

Investigation of impacts of deepening on various port performance measures is scarce in the literature. Grigalunas et al., (2005) have analyzed benefits and costs of deepening in Delaware River from an economic perspective. In their study, they described the benefits of deepening for the state of Delaware based on share of the hinterland area population for transportation savings and direct nonmarket benefits. They also recognized unquantifiable as well as qualitative effects, and hence tried to justify the proposed deepening project for the co-sponsor's benefit.

We used the simulation model to evaluate the maritime activities in both the current and deepened conditions. To the best of our knowledge, no one has used this method to evaluate the navigational impacts of deepening, or at least if they have it is not available in the literature.

3.3. Deepening Scenarios

The scenario analysis presented in this chapter is focused on investigating effects of deepening on port performance measures based on several assumptions. For this purpose, major assumptions of increase in the vessel traffic through potential trade growth in the Delaware River, deepening the main channel and dredging berths at some specified terminals are considered and deployed in different scenarios. Data provided by the Comprehensive Economic Reanalysis Report of Delaware River Main Channel Deepening Project, prepared by the U.S. Army Corp of Engineers (USACE) are used in the analyses.

The scenarios considered in this study are as follows:

1. Current scenario (Scenario A), for which the results are given in the validation section

2. Current scenario with 30-year trade growth (Scenario B)
3. Deepen & dredge with 30-year trade growth (Scenario C)
4. Deepen & dredge and shift to a fleet of larger vessels with 30-year trade growth (Scenario D)

The major assumptions used in these scenarios are described below in detail.

3.3.1. Trade Growth

Future trade forecast for Delaware River port system was investigated in the deepening analysis report of the USACE. This report displays the projected growth in tonnage from 2000 to 2050 with ten year increments. Based on their conclusions, future vessel arrival patterns for the next 30 years are estimated annually and incorporated for almost all vessel types in the model.

Table 3.1 - Annual percentage increase in arrival rates by vessel type

Vessel Types	First 10 years	Second 10 years	Third 10 years
TA, CH, NP, PG	0.4470	0.3792	0.3038
BU, GC, RF, RR, VE	2.3229	1.0119	0.3708
CC, PC, RC	4.5424	2.5205	1.2771

Based on the data in Table 3.1, it is expected to observe higher terminal and anchorage utilizations, increase in the lightering activity and possible increase in the tidal delays and anchorage waiting times in the river over time.

3.3.2. Deepening the Main Channel and Dredging of Berths (No Change in Fleet)

As described earlier, the deepening project will increase the depth of the main channel from 40 to 45 feet from the Delaware Bay entrance to the Philadelphia Harbor, PA and to Beckett Street Terminal, Camden, NJ and will provide 45 feet depth at the MHA. Terminals in this region might benefit from the deepening project by dredging nearby their berths. Based on the USACE report, berth deepening data for designated terminals (Table 3.2) were incorporated into the scenarios.

Table 3.2 - Terminal berth dredging plans

Terminal/Company	Berth	Depth (ft.)
Fort Mifflin (Sun)	A	38 → 45
	B	37 → 45
Marcus Hook (Sun)	3C	40 → 45
	3A	remains 39
	2A	remains 37
	3B	remains 17
Paulsboro (Valero)	Berth # 1 (Tanker Berth)	40 → 45
	Berth # 2	remains 30
Eagle Point (Sun)	Berth # 1	remains 34
	Berth # 2	40 → 45
	Berth # 3	40 → 45
Conoco Philips	Berth # 1	38 → 45
Valero/Premcor Delaware City	Berth # 1	→ 45
	Berth # 2	→ 45
	Berth # 3	→ 45
Wilmington Oil Pier	Liquid Bulk Berth	38 → 45
Packer Avenue	5 front berths	40 → 45
	the bottom berth	remains 40
Beckett Street	Berth # 4	40 → 45
	Berth # 3	remains 35
	Berth # 2	remains 30
Wilmington Port	All berths in Christina River	38 → 42

As a result of increased depth in the main channel and in the terminals, lightering needs of tankers will decrease. However, this may cause increased holding times at terminals for tankers bringing more cargo. In order to represent this increase, a ratio is used based on the tonnage difference being carried to the terminal, resulting in an increased holding time.

Along with deepening of the main channel, some regulations controlling the navigation in the River needed to be revised. Since the deepening plan is limited to the Philadelphia region, tide recommendations regarding the Lower River were relaxed by 5 feet in the model. Therefore, inbound tidal delays in BWA and outbound tidal delays especially in the MHA were expected to be reduced.

Based on these assumptions, it is anticipated to see less lightering activity in the BSB due to increased depth in the main channel. However, vessel types other than tankers are not expected to see many navigational benefits since there is no change in the vessel fleet or in the cargo tonnages of the vessels.

3.3.3. <u>Shift to a Fleet of Larger Vessels</u>

A deeper channel would allow some commodities to be brought in on larger vessels, thereby reducing the total number of calls required to move the current volume of commodity. However, a shift to a fleet of larger vessels can only be accomplished for those terminals that deepen their berths. According to the USACE report, the benefits are identified especially for tankers, container ships and dry bulk vessels which correspond to TA, CC, BU, GC, PC and VE vessels in the model. Therefore, a detailed analysis should be performed with the new configuration of larger vessels of the aforementioned types visiting terminals expected to dredge.

For each vessel type visiting a dredge-designated terminal, a new fleet of larger vessels was generated by increasing the draft of each vessel by 5 feet and decreasing the total number of vessels visiting the terminal while preserving the total tonnage coming to the terminal. Due to lack of data on hand, the holding time of the new fleet is increased by the same ratio which is also used to decrease the total number of vessels. The maximum draft and gross tonnage relation, which is assumed to be in parallel with the underway draft and cargo tonnage relation, was used to calculate the ratio to decrease the number of vessel calls and increase the holding time. This procedure was repeated for the same vessel types visiting all dredge-designated terminals, and the new total number of vessels was obtained and arrival rates of the vessel types was adjusted accordingly. At the end, inter-arrival time distribution, itinerary matrix, holding time and underway draft distributions of all types of cargo vessels were revised.

A numerical example can be given as follows. There are 341 BU vessels visiting Camden/Beckett, NJ terminal in the actual data between 2004 and 2008. Total gross tonnage of these vessels is 8,226,031. When each vessel’s draft is increased by 5 feet, using maximum draft and gross tonnage regression equation on each vessel, the total gross tonnage would be 11,118,534 tones. Consequently, the required number of vessels to carry the original tonnage can be reduced by using the ratio of 1.35 (which is

11,118,534 / 8,226,031) resulting in 253. Accordingly, as an approximation (especially due to lack of data) the same ratio is used to increase the holding time for each vessel for this terminal. For other designated terminals (e.g., Packer Avenue, PA and Wilmington Port, DE) BU vessels are visiting, the same procedure is applied. This will help to determine if there is any navigational benefit in terms of port times and anchorage usage when there is a lesser number of larger vessels coming to the River. It is critical to make this observation with the trade growth assumption in effect on the River.

3.4. Results of the Scenario Analysis

The results of the scenario representing the current situation in the river based on the actual data between years 2004 and 2008 are given in the validation section. The other three scenarios described earlier are built on top of the current scenario and their simulation runs are made for 30 years, each with 100 replications. In addition to the standard output defined, detailed annual and state based (DE, NJ and PA) vessel statistics were collected for TA, CC, BU, GC, PC and VE vessel types for each scenario. These statistics are presented in a report prepared for the deepening/dredge impact analysis in Appendix A. Nevertheless, due to their significance in the system only TA, CC, BU and GC vessel types are considered in the scope of this analysis and aggregate (non-state based) results are presented accordingly.

Port times, port calls, anchorage visits and anchorage delays are reported for the first year and for the 30th year after they are averaged over 100 replications. First year values are useful to understand the impact of deepening and shifting to a fleet of larger vessels since the effect of trade growth is not observed in the first year. Therefore, first year results of the growth scenario (having same results with the current scenario given in the validation section) represent the current situation in the DRB and constitute a basis for the scenario comparisons. The 30th year results are given due to increase of vessel arrivals as a result of trade growth, thus enabling us to understand the future effects of deepening and shifting to larger vessels.

Port times and port calls are considered to be the most important measures to observe and therefore it is important to understand their behavior in each scenario considered. On the other hand, it is important to see if there is a navigational benefit when there is a shift to a fleet of larger vessels. Therefore, a new measure was defined as "port time per kiloton" brought to the River where kiloton is defined as 1,000 units in gross tonnage.

The results of the scenarios are given in Table 3.3 for the first year of simulation runs. As seen in the table, with deepening, port times are slightly decreased. This decrease is more significant in tankers due to less lightering activity. Other vessel types are mostly benefited from lesser tidal delays. As expected, bringing larger vessels increases the port time since larger vessels spend more time at the terminals and produce a longer queuing effect. On the other hand, slight increases in the port time per kiloton except container vessels indicate that there is no gain in terms of port times when the total cargo brought to the port is fixed. This indicates that CC vessels benefit from deepening. This is mainly due to the ample capacity for container vessels in the River.

Table 3.3 - First year port results with 95% confidence intervals

Scenarios - First Year Results	**Outputs**	**Vessel Types**			
		BU	*CC*	*GC*	*TA*
Scenario B	*Average Port Time per Vessel (hrs)*	93.17 ± 0.99	32.72 ± 0.31	63.51 ± 0.66	82.75 ± 0.95
Growth	*Average No of Vessels per Year*	419 ± 4	465 ± 4	260 ± 3	917 ± 6
	Average Port Time / Kton (hrs)	3.75 ± 0.04	1.36 ± 0.01	5.12 ± 0.06	1.57 ± 0.02
Scenario C	*Average Port Time per Vessel (hrs)*	92.43 ± 1.02	32.14 ± 0.25	62.63 ± 0.72	71.10 ± 0.48
Growth + Deepen	*Average No of Vessels per Year*	416 ± 5	463 ± 3	262 ± 3	919 ± 6
	Average Port Time / Kton (hrs)	3.72 ± 0.04	1.34 ± 0.01	5.05 ± 0.06	1.35 ± 0.01
Scenario D	*Average Port Time per Vessel (hrs)*	103.97 ± 1.45	37.01 ± 0.36	69.07 ± 1.00	98.48 ± 1.34
Growth + Deepen + Larger Vessels	*Average No of Vessels per Year*	383 ± 4	378 ± 3	243 ± 3	772 ± 4
	Average Port Time / Kton (hrs)	4.04 ± 0.06	1.31 ± 0.01	5.18 ± 0.07	1.62 ± 0.02

Table 3.4 shows the results for the 30th year of the simulation runs. These results could be interpreted as the maximum values to be observed towards the end of the simulation due to growth. Compared to the first year within Scenario B, all port times are increased with the container vessels having the least increase although their port calls are doubled. This is also due to ample capacity in container terminals in the River. Furthermore, tankers seem to benefit even more when the channel is deepened in Scenario C. When there is a shift to larger vessels, only container vessels improve their port times per kiloton measure compared to Scenario B. In Scenario D, all port time per kiloton values are increased compared to their first year counterparts since the total berth capacity in the port remains the same even though there are more vessels calling.

Table 3.4 - 30th year port results with 95% confidence intervals

Scenarios - 30th Year Results	Outputs	Vessel Types			
		BU	*CC*	*GC*	*TA*
Scenario B	*Average Port Time per Vessel (hrs)*	104.58 ± 1.43	33.72 ± 0.22	68.97 ± 0.82	91.42 ± 1.67
Growth	*Average No of Vessels per Year*	610 ± 5	1049 ± 5	378 ± 3	1031 ± 6
	Average Port Time / Kton (hrs)	4.21 ± 0.06	1.41 ± 0.01	5.58 ± 0.07	1.73 ± 0.03
Scenario C	*Average Port Time per Vessel (hrs)*	103.12 ± 1.57	33.40 ± 0.25	69.82 ± 0.86	72.36 ± 0.48
Growth + Deepen	*Average No of Vessels per Year*	612 ± 5	1051 ± 6	379 ± 4	1027 ± 6
	Average Port Time / Kton (hrs)	4.15 ± 0.06	1.39 ± 0.01	5.60 ± 0.07	1.37 ± 0.01
Scenario D	*Average Port Time per Vessel (hrs)*	124.47 ± 2.63	38.74 ± 0.28	79.45 ± 1.26	111.03 ± 2.48
Growth + Deepen + Larger Vessels	*Average No of Vessels per Year*	559 ± 5	854 ± 5	353 ± 4	878 ± 5
	Average Port Time / Kton (hrs)	4.83 ± 0.10	1.37 ± 0.01	5.96 ± 0.10	1.81 ± 0.04

Anchorage visits and delays are other important measures to understand vessel activity and waiting capacity in the main channel of DRB. The effect of scenarios on inbound tidal delays can be seen through the observations at the BWA. The effects on outbound tidal delays and waiting for terminal berth availability in other major anchorages (Wilmington, Marcus Hook, Mantua Creek and Kaighns Point) are aggregated (summed up) in the results as “4 Anchorages”.

First year results of the scenarios are given in Table 3.5. All scenarios have the same tidal delays at the BWA since these scenarios do not impact delays due to tide or (random) waiting due to other reasons. However, in Scenario C, the BWA visits significantly decreased while in Scenario D it is slightly increased, compared to Scenario C, due to arrival of larger vessels.

In Scenario C with deepening, since there is more depth in the main channel, outbound vessels are less affected by tide so visits to four major anchorages decreased. However, in tankers and to some extent in bulk vessels, average anchorage delays seem to increase but this is because small tidal delay values (compared to waiting times for terminals) lost their significance in the new average.

In Scenario D, vessel calls in four major anchorages seem to be similar to the one in Scenario C but anchorage delays are mostly increased. This is because larger vessels stay longer in terminals and that leads to longer delays in anchorages despite fewer vessels coming to the system when compared to Scenario C.

Table 3.5 - First year anchorage results (delays and visits)

Scenarios - First Year Results	**Outputs**		**Vessel Types**			
			BU	*CC*	*GC*	*TA*
Scenario B	BWA	*Average Delay per Vessel (hrs)*	14.74	8.28	7.16	12.02
Growth		*Average No of Visits per Year*	60	9	10	89
	4 Anchorages	*Average Delay per Vessel (hrs)*	34.49	9.24	18.83	13.01
		Average No of Visits per Year	108	19	49	368
Scenario C	BWA	*Average Delay per Vessel (hrs)*	13.73	0.00	7.40	11.95
Growth + Deepen		*Average No of Visits per Year*	40	0	8	41
	4 Anchorages	*Average Delay per Vessel (hrs)*	38.04	9.83	18.60	16.34
		Average No of Visits per Year	96	18	47	335
Scenario D	BWA	*Average Delay per Vessel (hrs)*	14.12	8.17	7.22	12.10
Growth + Deepen + Larger Vessels		*Average No of Visits per Year*	49	6	10	78
	4 Anchorages	*Average Delay per Vessel (hrs)*	54.22	9.67	33.85	17.77
		Average No of Visits per Year	96	16	42	321

Anchorage results as they are observed in the 30th year are shown in Table 3.6. Compared to the first year results, in BWA there is significant increase in the number of visits but no change in delays. In the four major anchorages, both delays and visits are significantly increased. This shows a potential capacity issue for the major anchorages in the River for the years to come in the planning horizon. In Scenario C, again there is a decrease in the number of visits to Four Anchorages since vessels are less affected by tide and thus, tidal delays lost their significance in the new average delays which are higher now. In Scenario D, the Four Anchorages visits are decreased but delays are increased for bulk and general cargo vessels. This increase is due to longer holding times of larger vessels in terminals that in turn affect waiting in the anchorages.

Table 3.6 - 30th year anchorage results (delays and visits)

Scenarios - 30th Year Results	**Outputs**		**Vessel Types**			
			BU	*CC*	*GC*	*TA*
Scenario B	BWA	*Average Delay per Vessel (hrs)*	14.83	8.44	6.85	12.18
Growth		*Average No of Visits per Year*	88	19	14	99
	4 Anchorages	*Average Delay per Vessel (hrs)*	53.86	15.00	34.30	13.82
		Average No of Visits per Year	216	77	97	425
Scenario C	BWA	*Average Delay per Vessel (hrs)*	13.83	0.00	7.27	12.19
Growth + Deepen		*Average No of Visits per Year*	59	0	13	46
	4 Anchorages	*Average Delay per Vessel (hrs)*	56.06	16.12	35.18	17.11
		Average No of Visits per Year	198	73	97	389
Scenario D	BWA	*Average Delay per Vessel (hrs)*	14.15	8.56	7.74	12.05
Growth + Deepen + Larger Vessels		*Average No of Visits per Year*	71	13	13	87
	4 Anchorages	*Average Delay per Vessel (hrs)*	95.56	17.69	63.34	18.41
		Average No of Visits per Year	178	56	83	338

As mentioned before, tanker operations is the dominant activity in the DRB port system and according to the above results tankers are benefiting the most from the deepening (Scenario C) in the River in terms of reduced port times. This is essentially due to less lightering as a consequence of deepening. Table 3.7 shows the number of visits and average delays for tankers in BSB mainly resulting due to lightering activity. As seen in the table, deepening the River decreases the number of visits to BSB and even the delays. However, bringing larger vessels moderately increases the number of visits and significantly increases the delays.

Table 3.7 - Big Stone Beach Anchorage results for Tankers

Scenarios	Outputs	First Year	30th Year
Scenario B	*Average Delay per Vessel (hrs)*	59.77	77.80
Growth	*Average No of Visits per Year*	396	443
Scenario C	*Average Delay per Vessel (hrs)*	42.80	44.29
Growth + Deepen	*Average No of Visits per Year*	237	263
Scenario D	*Average Delay per Vessel (hrs)*	66.79	95.59
Growth + Deepen + Larger Vessels	*Average No of Visits per Year*	285	326

Considering more than 40 terminals and around 100 berths in the DRB port system, port occupancy (number of vessels docked at berths at any terminal at the port) is an important measure to show how busy the port is at any point in time. This measure can be thought of as the overall utilization measure for the entire port. Figure 3.1 shows the port occupancy throughout the 30-year period for the three scenarios. While the current value is around 17.5, it reaches around 23.5 showing growth in 30 years. This trend is affected by vessel arrival rates and terminal holding times resulting in graphs similar to each other in all scenarios. However, due to longer holding times in Scenario D, the port occupancy is slightly higher than the ones in other scenarios. This observation is in parallel with slightly higher port time per kiloton values discussed earlier.

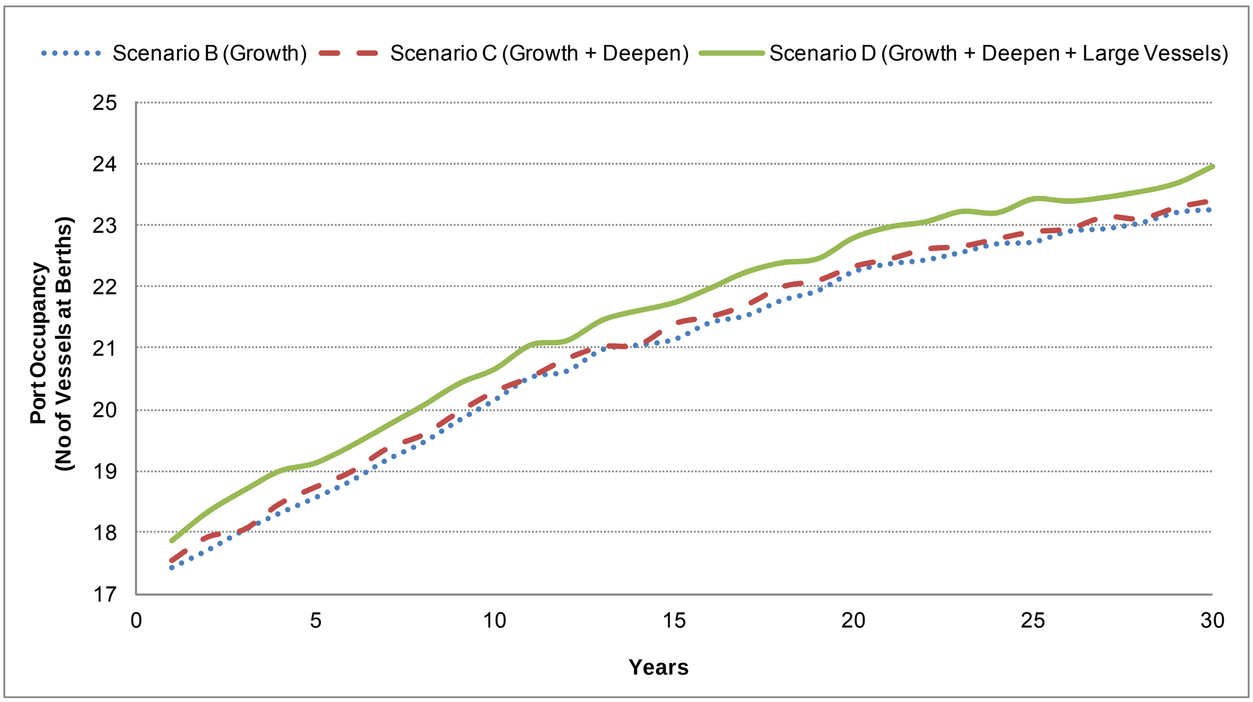


Figure 3.1. Port Occupancy in the River observed in the 30-year planning horizon

3.5. Conclusion on Deepening Analysis on Navigational Issues

The Growth Scenario (B) exhibits an increased usage of berths due to trade growth and the port seems to handle the additional load well in all vessel types as indicated in Table 3.3 and Table 3.4. Container vessels show the least increase in port times over the planning horizon due to ample capacity in container terminals, and therefore the least affected by the additional traffic in the river.

The Deepening Scenario (C) verifies the anticipated benefits due to lesser tidal delays and lightering activity. Tankers benefit the most due to decrease in their port times that is around 14% in the first year and around 21% through the end of the 30-year planning horizon. Other vessels have minor gains (decrease) in their port times.

The Larger Vessels Scenario (D) investigates presumed benefits despite the intrinsic longer port times per vessel when there is a shift to a fleet of larger vessels. Therefore, in order to evaluate navigational efficiency, port time per kiloton measure is introduced since it represents the amount of time spent to handle a unit amount of cargo. Port time per kiloton shows statistically significant benefits for container vessels in larger vessels scenario whereas most comparisons indicate no navigational benefit for other vessels. However, port time per kiloton results in Scenario B and D show that non benefit for tankers may be doubtful due to proximity of their means and magnitude of variances. Note that, these observations are very sensitive to vessel holding time of vessels at terminals, specifically to the factor used in the model to increase holding time for larger vessels. In the case of improved scheduling practices and efficient handling of larger vessels at the terminals, port time per kiloton measure will most likely exhibit navigational benefits possibly for all vessels.

Anchorage results verify the expected decrease in tidal delays both for inbound and outbound vessels and the reduced lightering activity. Lightering activity results in the beginning years of the planning horizon reveal about 40% decrease in the Deepening Scenario (C) and 28% decrease in case larger vessels are used after deepening is completed. Furthermore, the Growth Scenario (B) shows usage of major anchorages almost doubled in the long run when the total capacity in the port is kept the same, while deepening and shifting to a fleet of larger vessels (Scenario D) help reduce anchorage calls and yet with longer anchorage delays per visit, potentially due to longer holding times at terminals.

This chapter presents results on several aspects of navigational issues which impact transportation cost savings based on vessel and operational efficiencies. The findings suggest some navigational benefits for container vessels and tankers but no significant efficiency for bulk and general cargo vessels. However, this study does not evaluate potential reduction in operating costs (increased profit) due to decreased number of vessels. It is important to note that there would also be a benefit of improved safety with a reduced number of vessels.

4. RISK ANALYSIS

4.1. Introduction

This chapter deals with comprehensive risk analysis of the vessel traffic in Delaware River and Bay area. The purpose is to develop a risk model to incorporate into the simulation model we have presented in Chapter 3 earlier to study the safety risks due to the vessel traffic in the River.

A model-based mathematical risk analysis in DRB was carried out to identify which zones of the river have higher risks, what the magnitudes are and what the possible mitigation measures may be. First a probabilistic risk model was developed considering all possible accidents as suggested by the historical data in DRB. Expert opinion elicitation helped us to compute the unknown accident and consequence probabilities. The risk model was incorporated into the simulation model to evaluate risks observed in the simulation. Since the simulation model generates every possible situation in the river over a planning period, the joint risk/simulation approach makes it possible to produce a risk profile of DRB. A scenario analysis in the end was performed in order to study the behavior of accident risks and arrive at some mitigation suggestions. This analysis allowed us to investigate the impact of deepening on the risk profile of the river.

In this project, a highly practical approach was developed to evaluate risks in the maritime domain in DRB and it can be used in risk analysis in other systems of interest as well.

Risk Analysis is one of the mostly visited and diverse areas in the literature due to its strong relevance to uncertainty and its presence in design of complex systems in a variety of application areas. The concept of risk is closely related to topic of uncertainty. In mathematics, probability is one way to explain uncertainty although probability itself has different explanations with several perspectives. Frequency and degree of certainty are two widely accepted approaches to explain probability.

Kaplan (1997) explains risk using terms such as scenario, likelihood and consequences. A scenario represents a situation which can lead to an undesirable consequence.

Likelihood is the frequency or the degree of certainty of this scenario to happen. Thus, starting with Kaplan's arguments, risk can be expressed as the expected value of the undesirable consequence in a scenario. That is,

$$R_s = p_s \times C_s \tag{4.1}$$

where *s* represents the scenario, R_s is the risk of scenario, p_s is the probability of occurrence of the scenario and C_s is the consequence of the scenario in case it occurs.

Notice that risks are additive, therefore they can be added over various situations to obtain cumulative risks. Also notice that a situation can be described as an array of variables which makes the risk a function of the same set of variables.

Thus, risk analysis can be summarized as the study of scenarios with situations and possible consequences with relative probabilities. Kaplan (1997) defines a scenario tree approach showing the relation of situations and what happens next for each state. "Fault Trees" can be drawn starting from end states and going backward to the starting events giving rise to fault tree analysis. Identifying initial events and going forward to the end state is known as an "Event Tree". This gives rise to event tree analysis. Risk analysis benefits from either of them in identifying its critical elements mentioned above.

4.2. Literature Review

The literature on risk analysis in maritime domain can be categorized as applications to safety of individual vessels and structural design using the tools of reliability engineering and probabilistic consequence analysis in maritime transportation systems.

Wang, (2006) summarizes risk analysis tools used in maritime applications as follows:

1. Expert judgment and approximate reasoning approach for dealing with problems associated with a high level of uncertainty. This includes subjective safety-based decision-making method, evidential reasoning technique, fuzzy set modeling method and Dempster–Shafer method for risk modeling and decision making.
2. Safety-based design/operation optimization approach.

3. Application of methods developed in other disciplines, such as artificial neural network approach and Bayesian networks for risk estimation and decision making.
4. Methods for modeling of human and organizational factors in the design of offshore structures.

Soares and Teixeria (2001) also summarized the approaches used in risk assessment for maritime transportation. They showed, while the early applications being mostly on risks of individual vessels, more recent work have focused on decision making such as regulations to govern international maritime transportation.

Studies based on accident statistics mainly provided the evolution of levels of safety in maritime transportation, categorization of failures in different types of ships and demonstration of the overall picture of the current situation. The risk of failure in individual ships has also been studied using various approaches. Collision, grounding and sinking have been the main focus in these studies. Reliability based methods have been used in mostly structural design problems to answer questions such as ultimate failure of the structure and different modes the structure can fail. Formalized Safety Approach (FSA) is a new term devised by the International Maritime Organization (IMO) for studies that use formalized analysis and quantification of risk. FSA is mostly concerned with organizational, managerial, operational, human and hardware aspects of the collective system as described by Soares and Teixeria (2001). Ford et al. (2008) propose a methodology for evaluation and selection process for risk assessment studies. Their procedure can be used to describe properties of different methodologies and categorize them. Nevertheless, their framework does not offer a method but will establish a basis for an intelligent selection process.

Fowler and Sorgard (2000) worked on maritime safety risk under the project "Safety of Shipping in Coastal Waters" (SAFECO) which was supported by the Commission of the European Communities. In their study, Marine Accident Risk Calculation System (MARC) was used which was based on causes of significant accidents observed in the historical data. Each accident category was individually modeled in MARC. They used

Vessel Traffic System database and environment data for accident frequency calculations. Fault trees were basically used for evaluation of specific accident types. Expert judgments were also performed for evaluation of risk parameters. Degré et al. (2003) describe the general principles of risk assessment models, the nature of input data required and the methods used to collect data. They then present the SAMSON model (Safety assessment models for shipping and offshore in the North Sea) developed in the Netherlands, used to estimate the number of accidents. For this purpose, the model estimates the average casualty rates, i.e. the estimated average number of accidents per unit of risk exposure as a function of the environmental conditions in the zone in question and the level of vessel traffic management.

Simulation modeling is a common approach used for risk analysis purposes and appeared frequently in the literature. Generally, a high-fidelity simulation model is built to mimic all possible events (e.g., collision, grounding, ramming, spill, and other safety related situations) together with a choice of consequences that are transferred to a mathematical risk formulation as they take place in the simulation model. In such an approach, no events and consequences are overlooked and a risk profile of the system (port or waterway) is generated over time. This provides a platform for decision makers to generate various ways to mitigate risks. Merrick et al. (2001) carry out a risk assessment study on the Washington State Ferry System to estimate the contribution of factors to collision risk and to develop recommendations for prioritized risk reduction measures. They deploy expert judgment to estimate accident probabilities. In this approach, an expert elicitation process comes together with system simulation, statistical data analysis to capture the dynamic environment of changing situations, such as traffic interactions, visibility or wind conditions. Merrick et al. (2000) and Merrick et al. (2002) use system simulation and expert judgment elicitation for a comprehensive risk analysis study of the Prince William Sound oil transportation system. The authors also propose a systemic approach to risk assessment and management through a detailed analysis of the sub-systems, their interactions and dependencies. In van Dorp et al. (2001), as a supplement to Merrick et al. (2001), the potential consequences of collisions are modeled in order to determine the requirements for onboard and external emergency response procedures and equipment. Furthermore, potential risk reduction measures are evaluated and various risk management recommendations are made. Merrick et al. (2003) worked on traffic density analysis which would lead later to the risk analysis for the ferry service expansion in the San Francisco Bay area. They tried to estimate the frequency of vessel interactions using a simulation model they developed, in which vessel movements, visibility conditions and geographical features were included. They evaluated specific scenarios regarding ferry service expansion in the bay area and got indications for areas that high accident risks can occur. van Dorp and Merrick (2011) reviews their risk management analysis methodology which integrates simulation, data collection, expert judgment elicitation and a consequence model and describe recent advances with respect to this methodology in more detail.

Bruzzone et al. (2000) propose the development of an integrated interactive approach for risk analysis in harbor settings using simulation. They describe the general architecture of the Maritime Environment for Simulation Analysis (MESA) tool and its integration with an oil spill simulation module. Or and Kahraman (2002) investigate possible factors contributing to accidents in the Strait of Istanbul. After estimating accident probabilities, they are combined with the Strait’s characteristics and traffic regulations in the simulation model. Simulation results indicate the significant impact of transit vessel arrivals, local traffic density, and the meteorological conditions on the number of accidents in the Strait of Istanbul. Inoue et al. (2003) present a simulation model called Environmental Stress Model to evaluate the ship handling difficulties in the Strait of Istanbul which provides an opportunity to analyze vessel traffic risks quantitatively.

Szwed et al. (2006) describe a methodology for eliciting expert judgments when available information suffers from sparseness of accident data and where expert judgments serve as an important source for the estimation of the likelihood of high-consequence rare events. The authors present a Bayesian aggregation methodology using responses from experts to a questionnaire containing a series of pair-wise comparisons, to assess the ratios of relative accident probabilities. The methodologies used in Merrick et al. (2001) and van Dorp et al. (2001) were only capturing the point estimates of relative accident probabilities, not full posterior distributional results while the authors methodology also assess the distribution of relative accident probabilities. The new methodology described in Szwed et al. (2006) is also applied to Washington State Ferry System to analyze collision risks.

Uluscu et al. (2009c) implement a quantitative methodology to investigate safety risks pertaining to the transit vessel traffic in the Strait of Istanbul. As the first step of the risk analysis, they analyze the transit vessel traffic system in the Strait and a simulation model is developed to mimic maritime operations and surrounding environmental conditions. Moreover, Ulusçu et al.(2009c) developed a model for the current vessel scheduling practices and implement a detailed mathematical risk model similar to what Merrick et al., (2001) did, in order to mitigate safety risk in the Strait. The risk model makes use of subject-matter expert opinion in identifying a number of probabilities regarding instigators, accidents and consequences.

Harrald et al. (1998) describe the modeling of human error related accident event chains in a risk assessment study of the oil transportation in Prince William Sound, Alaska. A two stage human error framework and the conditional probabilities implied by this framework are obtained from system experts such as tanker masters, mates, engineers, and state pilots. Then they are combined with simulation model for a quantitative risk assessment procedure.

Another concern in the maritime industry is terminal operations and the transportation of crude oil, petroleum products or other types of hazardous cargo due to the potential environmental pollution (i.e., spills) and considerable economic losses. In early years, Atallah and Athens (1987) provide general guidelines for the application of risk assessment methodology to existing or proposed marine terminal operations. The proposed methodology includes four consecutive stages: identification of potential hazards, quantification of risks, evaluation of risk acceptability; and reduction of unacceptable risks. In particular, the authors focus on the accidental releases of hazardous flammable and/or toxic materials in or near harbors and inland waterways. Similarly, Dougligeris et al. (1997) provide a methodology for analyzing, quantifying and assigning risk estimates in maritime transportation of petroleum products. Li et al.

(1996) implement the methodology by Dougligeris et al. (1997) in a case study involving the oil transportation in the Gulf of Mexico during the 1990-1994 time period.

Trbojevic and Carr (2000) carry out a hazard identification and a qualitative risk assessment to improve safety in ports. Then they also illustrate an approach for risk quantification in which the frequency of the initiating event and the likelihood and severity of accidents are evaluated using fault tree and event tree analyses. Yudhbir and Iakovou (2005) present a mathematical oil spill risk assessment model. The goal of this model is to first determine and assign risk factors costs to the links of a maritime transportation network, and then to provide insights on the factors contributing to spills. Vinnem (2007) introduces components of risks and risk analysis for off-shore drilling sites. In their study, van de Wiel and van Dorp (2009) develop an oil outflow model for tanker collisions and groundings which can also be integrated with maritime transportation models.

Iakovou (2001) also considers the maritime transportation of crude oil and petroleum products. The paper presents the development of a strategic multi-objective network flow model, with multiple commodities, modalities and origin-destination pairs, allowing for risk analysis and routing. The authors demonstrate the development of an interactive solution methodology and its implementation via an Internet-based software package. The objective is to facilitate the government agencies to determine how regulations should be set in order to obtain advantageous routing plans.

While the above literature utilizes reliability engineering techniques and mathematical modeling, there are other studies on risk assessment heavily based on statistical analysis of the data. These are primarily based on modeling accident probabilities and consequences using statistical estimation methods of the past data as discussed below. Regression analysis is frequently used in modeling and analyzing risks focusing on the relationship between a dependent variable and one or more independent variables. Maio et al. (1991) develop a regression model as part of a study by the U.S. Department of Transportation for the U.S. Coast Guard's Office of Navigation Safety and Waterway to estimate waterway casualty rates depending on the type of waterway, average current speed, visibility, wind speed, and channel width. Kornhauser and Clark (1995) used the regression model developed by Maio et al. (1991) to estimate the vessel casualties resulting from additional oil tanker traffic through the Strait of Istanbul. Yip (2008) studies port traffic risks in Hong Kong Harbor and uses a negative binomial regression model based on historical accident data in years 2001-2005.

Clustering is also a common technique for statistical data analysis in which the data set is divided into subsets so that observations in the same cluster show similarities. Le Blanc and Rucks (1996) describe a cluster analysis performed on a sample of over 900 vessel accidents that occurred on the lower Mississippi River. The objective is to generate four groups that are relatively unique in their respective attribute values, such as type of accident, river stage, traffic level, and system utilization. In Le Blanc et al. (2001), the authors use a neural network model to build logical groups of accidents instead of using a cluster analysis. The groups generated in Le Blanc and Rucks (1996) and Le Blanc et al. (2001) are compared and found to be radically different in terms of the relative number of records in each group and the descriptive statistics representing each comparable set of groups.

Bayesian inference is another approach in which evidence or observations are used to calculate probabilities rather than having a frequency or proportions based interpretations. Or and Kahraman (2002) use Bayesian analysis to obtain estimates for conditional maritime accident probabilities for the purpose of studying factors contributing to accidents in the Strait of Istanbul. Roeleven et al. (1995) present a statistical model that forecasts the probability of accidents as a function of waterway and environmental attributes based on the data from the Dutch Ministry of Transport and Public Works. The authors conclude that environmental attributes such as visibility and wind speed are more explanatory with respect to the probability of accidents than the waterway characteristics.

Talley (1995) analyzes accident severity cause factors in order to evaluate policies for reducing vessel damage and subsequent oil spillage regarding tanker accidents and uses accident data from U.S. waters over eight years. Anderson and Talley (1995) use a similar approach to study the causal factors for oil spills, and tanker/barge accidents, and Talley (1996) investigates the main risk drivers and the severity of cargo damage in containership accidents.

Amrozowicz (1996) and Amrozowicz et al. (1997) focus on the first level of a proposed three-level risk model to determine the probability of tanker groundings. The approach utilizes fault trees and event trees to study human error. The high-leverage factors are identified in order to determine the most effective and efficient use of resources to reduce the probability of grounding. Psaraftis et al. (1998) present a statistical analysis on the factors that are important determinants of maritime transportation risks. The purpose of the analysis is to identify technologies and other measures to improve maritime safety. The study used the worldwide database developed from Lloyds' Casualty Reports. Kite-Powell et al. (1998) develop a physical risk model for ship transit risks based on a set of risk factors, including operator skill, vessel characteristics, traffic characteristics, topographic and environmental difficulty of the transit, and quality of operator's information about the transit. Their objective is to investigate the relationship between factors based on the historical data on circumstances surrounding accidents in U.S. waters.

Slob (1998) presents a study for the purpose of optimizing the responses to spills on the Dutch inland waterways and the study based on data from the working group oil and chemical combating (WOCB) of Rijkswaterstaat EnSaCo. A system is developed for the determination of risks on inland waterways classifying them into four risk-classes. The study also makes an inventory of the combat equipment and manpower during the combat of acute calamities on the inland waterways, estimate their effectiveness and cost to determine whether the amount of preparation for combating acute spills is in relation to risks expected in these locations. Finally, standard contingency plans are proposed for combating spills for different locations in the Netherlands.

Historical accident data has been used for calibration of risk model output. Moller et al. (2003) review the current status of the government-industry partnerships for dealing with oil spills originating from maritime transportation activities in 19 different seas at different regions of world (North-East Pacific, South-East Pacific, Upper South-West Atlantic, Wider Caribbean, West and Central Africa, Eastern Africa, Red Sea and Gulf of Aden, Gulf Area, Mediterranean, Black Sea, South Asian Seas, East Asian Seas, South Pacific, North-West Pacific, Baltic, North-East Atlantic, Caspian, Arctic, Antarctic). The main drivers of oil spill risks are identified, analyzed, and discussed, in relation to the oil transportation patterns of each region. They compare and calibrate their findings with real historical data obtained from major oil pollution incidents. Similarly, Merrick et al. (2001), van Dorp et al. (2001), Merrick et al. (2000), Merrick et al. (2002), Uluscu et al. (2009c) use historical accident data to calibrate risk models such that certain probability measures are legitimate.

4.3. Preliminaries to Risk Modeling

In this section, we start analyzing the risks in the DRB area by first looking into the causal chain of events from instigator occurrences to accidents and finally consequences. Accidents typically occur as a result of a chain of events rather than being independent single events. The initial step of the risk analysis process is to identify reasons and outcomes of accidents. This process can be quite detailed and yet due to data requirements, when a mathematical model is involved, the chain defining the risk framework should be limited to triggering events, major accident types and significant consequences. In view of this, Figure 4.1 shows the general risk framework for the DRB area.

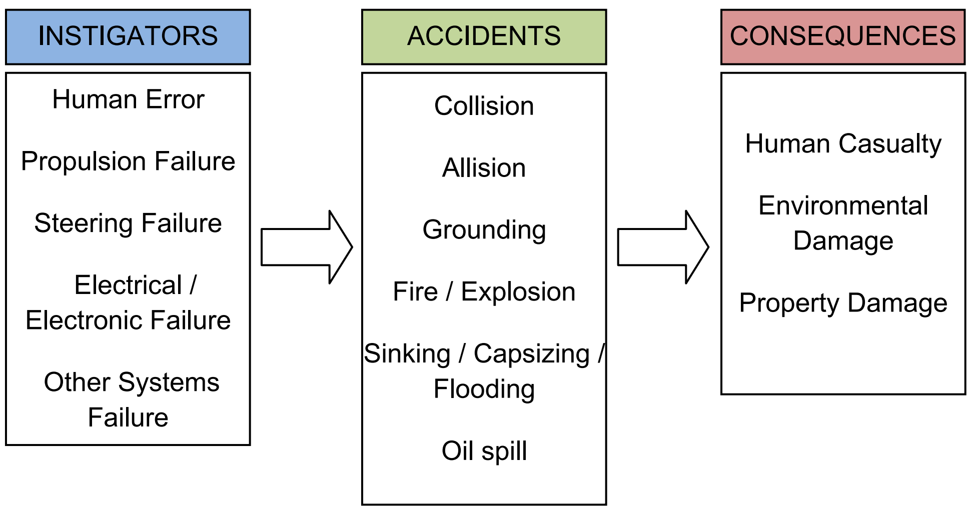


Figure 4.1. Risk framework for the DRB area

Instigators can be defined as major triggering events which may (or may not) be followed by an accident. Thus, it is assumed that an accident cannot take place just by itself unless an instigator occurs. Based on the USCG accident data for DRB, instigators are identified as shown below:

1. Human Error (HE) may include “not following the policies or best practice”, “communication breakdown”, “inadequate situational awareness” and etc.
2. Propulsion Failure (PF) may include “engine breakdown”, “contaminated fuel problem”, “propeller problem” and etc.
3. Steering Failure (SF) may include “hydraulic system failure”, “rudder problem” and etc.
4. Electrical / Electronic Failure (EF) may include “generator failure”, “computer software problems”, “navigation and communication system failure” and etc.

5. Other Systems Failure (OSF) may include “hull structure problems”, “cargo and cargo control systems failure” and etc.

Figure 4.2 presents the number and relative percentage of the aforementioned instigators happened in DRB through 17 years beginning 1992. The data was extracted from the DRB accident data provided by the USCG.

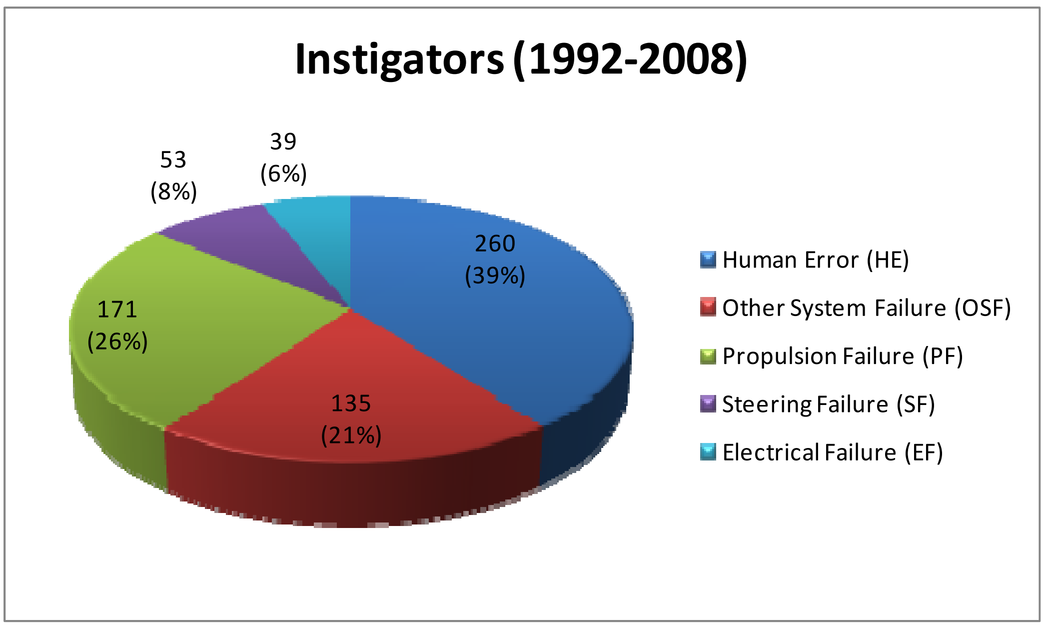


Figure 4.2. Number and share of instigators in the historical accident data from 1992 to 2008 (Data is provided by the USCG)

Accidents are the unexpected and undesirable events resulting in some sort of damage. DRB accident data suggests the following categorization of accidents:

1. Collision (C)
2. Allision (A)
3. Grounding (G)
4. Fire / Explosion (F/E)
5. Sinking / Capsizing / Flooding (S/C/F)
6. Oil spill (OS)

These types of accidents happened in Delaware River throughout 17 years as Figure 4.3 illustrates.

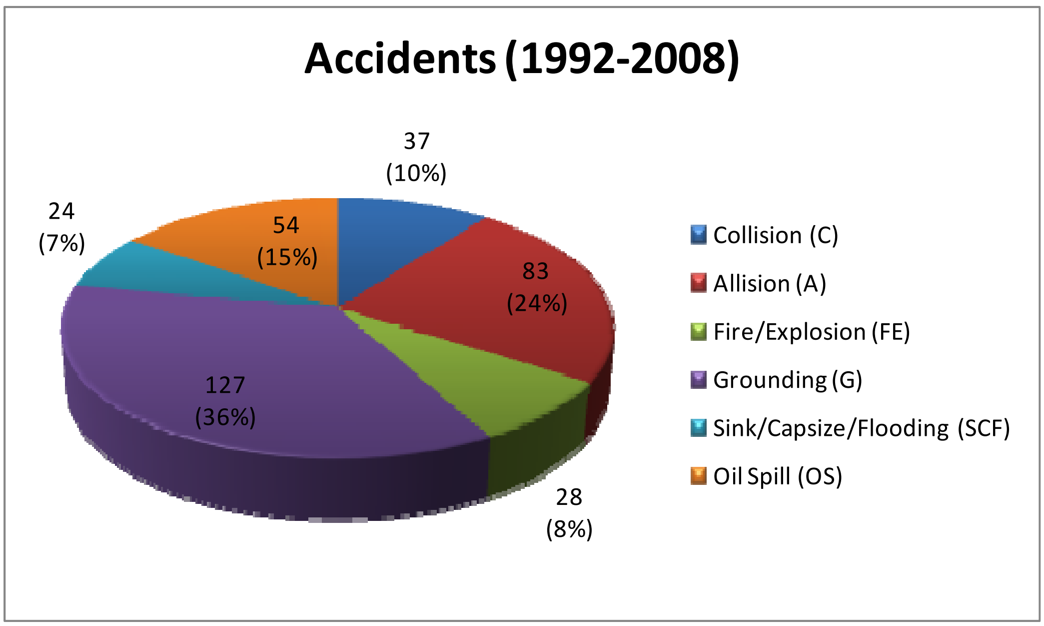


Figure 4.3. Number and share of accidents in the historical accident data from 1992 to 2008

Consequences typically are damages or harm to physical assets or humans as a result of an accident. Based on DRB accident data consequences are grouped into the following 3 categories:

1. Human Casualty (HC) may include death, permanent disabling injury, and minor injury
2. Environmental Damage (EnvD) may include impact to wild life and habitat, loss of commercial and recreational use, danger to human life and contamination of the water supply.
3. Property Damage (ProD) may include damage to the vessel or other properties involved in the accident.

Clearly, these categories cover a wide range of consequences. Hence these groups are each further classified into subcategories such as low and high; where high for human casualty may mean death, permanent disabling injury cases and low may mean minor injury. High impact to wildlife and habitat, loss of commercial and recreational use, danger to human life, moderate to large amounts of oil spills and etc. are considered to be high environmental damages. Damage to a vessel or other properties involved in an accident costing less than 10,000 dollars are typically considered as a low consequence. Accordingly, the historical data provides the categories of consequences as shown in Figure 4.4.

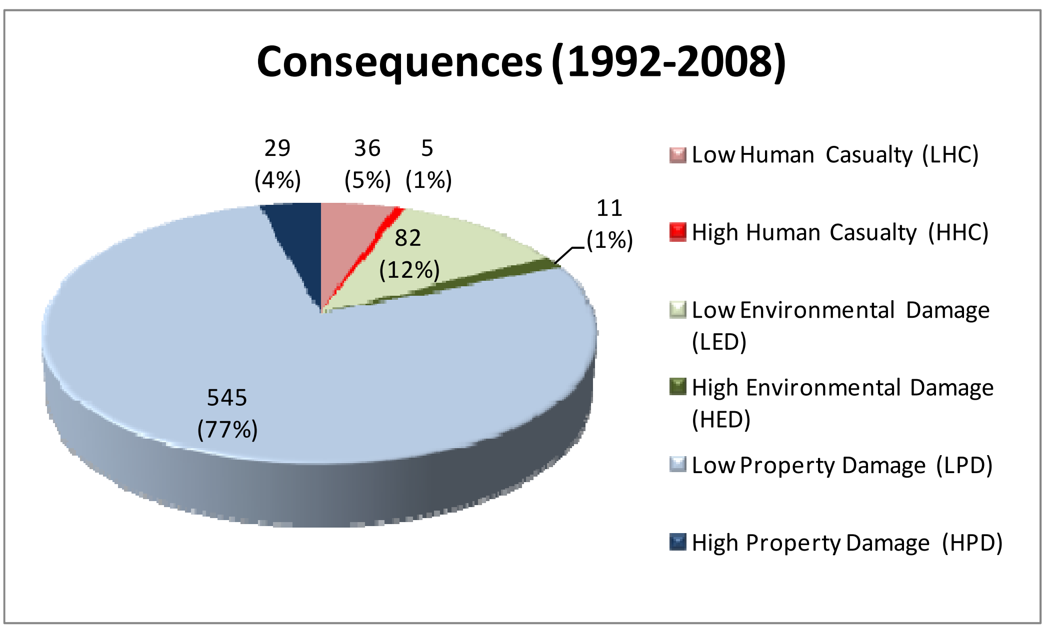


Figure 4.4. Number and share of consequences in the historical accident data from 1992 to 2008

As Figure 4.1 shows there exists a causal relationship among instigators, accidents and consequences such that instigators may lead to accidents and accidents cause consequences. Each instigator leads to specific types of accidents with a probability as shown in Table 4.1. For instance, collision occurred in 12.69% of all the human-error related incidents. Numbers in Table 4.2 also show the probability of every type of consequence as a result of accidents. For instance, human casualty occurred in 4.17% of all collisions. These numbers will be used later in the calibration process of the model. The values in Table 4.1 and Table 4.2 are calculated based on the 17 years of accident data provided by the USCG headquarters in Washington D.C.

Table 4.1 - Probability of accident occurrence given an instigator based on the historical accident data of 1992 to 2008

		Accidents					
	P(Accident | Instigator)	Collision	Allision	Grounding	Fire / Explosion	Sinking / Capsizing / Flooding	Oil Spill
Instigators	Human Error	0.1269	0.2463	0.3993	0.0560	0.0299	0.0336
	Propulsion Failure	0.0349	0.0349	0.0291	0.0174	0.0001	0.0058
	Steering Failure	0.0566	0.0377	0.0943	0.0002	0.0002	0.0755
	Electrical / Electronic Failure	0.0003	0.0256	0.0513	0.0513	0.0003	0.0003
	Other Systems Failure	0.0074	0.0662	0.0662	0.0735	0.1029	0.2941

Table 4.2 - Probability of consequence occurrence given an accident based on the historical accident data of 1992 to 2008

		Consequences		
	P(Consequence | Accident)	Human Casualty	Environmental Damage	Property Damage
Accidents	Collision	0.0417	0.0833	0.8750
	Allision	0.0435	0.0761	0.8804
	Grounding	0.0368	0.0588	0.9044
	Fire / Explosion	0.2273	0.0682	0.7045
	Sinking / Capsizing / Flooding	0.0294	0.3529	0.6176
	Oil Spill	0.0800	0.7200	0.2000

Since the relationship chain begins with an instigator, the instigator occurrence probability needs to be obtained as well. Table 4.3 shows the historical data on the probability of occurrence of each instigator for any type of vessel.

Table 4.3 - Probability of instigator occurrence based on 50,000 vessels in the historical accident data of 1992 to 2008

Instigators	**P(Instigator)**
Human Error	0.0054
Propulsion Failure	0.0034
Steering Failure	0.0011
Electrical / Electronic Failure	0.0008
Other Systems Failure	0.0027

Beside the causal relationship, there are other factors that may increase or decrease the chances of an instigator or accident happening or the scale of consequences. They are referred to as situational attributes. For example, the probability of collision may increase due to loss of visibility or due to bad weather conditions. Generally these attributes are classified into two groups; vessel attributes and environmental attributes as shown in Figure 4.5.

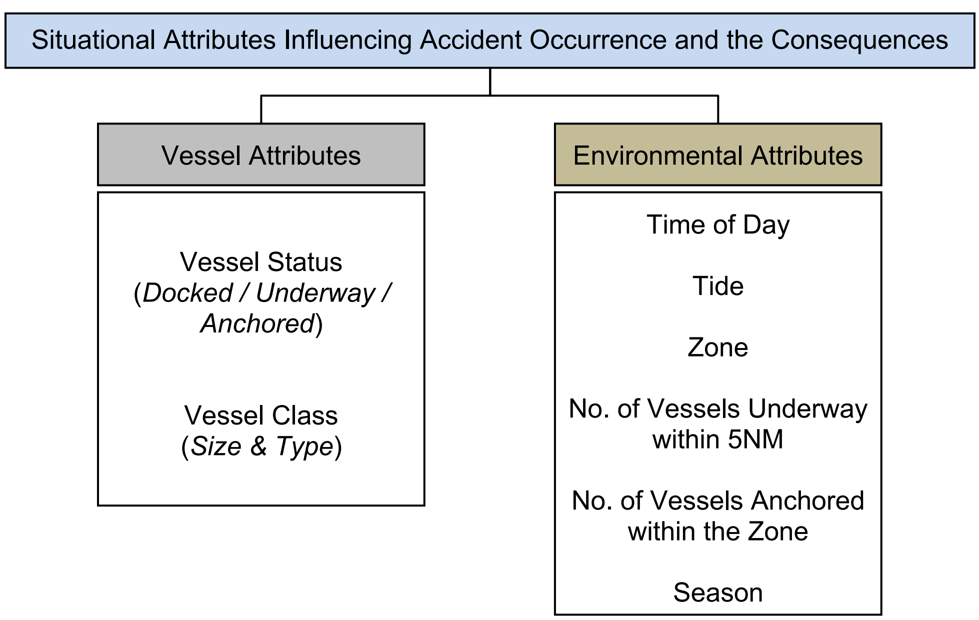


Figure 4.5. Situational attributes affecting accident occurrences and the consequences

Each situational attribute has its finite number of states. These states are given in Table 4.4 below. Note that there are a total of 25,920 different possible situations for the selected set of 8 situational attributes and the possible number of states for each attribute. This immediately justifies the need to develop a model to keep track of the dynamics of the causal chain introduced above and the evaluation of the resulting risks.

Table 4.4 - Situational attributes influencing instigators, accident occurrence and the consequences

Variable	**Situational Attribute**	**Possible Values**	**States**
X_1	Time of Day	2	Day, Night
X_2	Tide	2	High, Low
X_3	Vessel Status	3	Docked, Underway, Anchored
X_4	Vessel Class	10	General Cargo < 150m, General Cargo ≥ 150m, Tugboat / Barge, Passenger ≥ 100GT, Petroleum Tanker < 200m, Petroleum Tanker ≥ 200m, Chemical Tanker < 150m, Chemical Tanker ≥ 150m, LNG / LPG, Lightering Barge
X_5	Zone	6	Delaware Bay, CD Canal Region, Wilmington Region, Paulsboro Region, Philadelphia Region, Upper Delaware River
X_6	No. of Vessels within 5NM	3	0 or 1 vessel, 2 to 3 vessels, more than 3 vessels
X_7	No. of Vessels Anchored in the Zone	3	0 or 1 vessel, 2 to 3 vessels, more than 3 vessels
X_8	Season	4	Fall, Winter, Spring, Summer

The approach to evaluate risks in DRB will be a hybrid one in the sense that it will involve both a mathematical risk model and the simulation model presented earlier. These two models will work in lock step in such a way that the simulation model generates all possible situations and passes them on to the mathematical model for risk evaluations. Based on geography and the existing terminals, DRB is divided into 6 zones as shown in Figure 4.6. By repeating the risk evaluation process at every short time interval (say 60 minutes), it is possible to generate the zone-based risk profile of the entire river.

Details of the risk evaluation process are provided in the following sections.

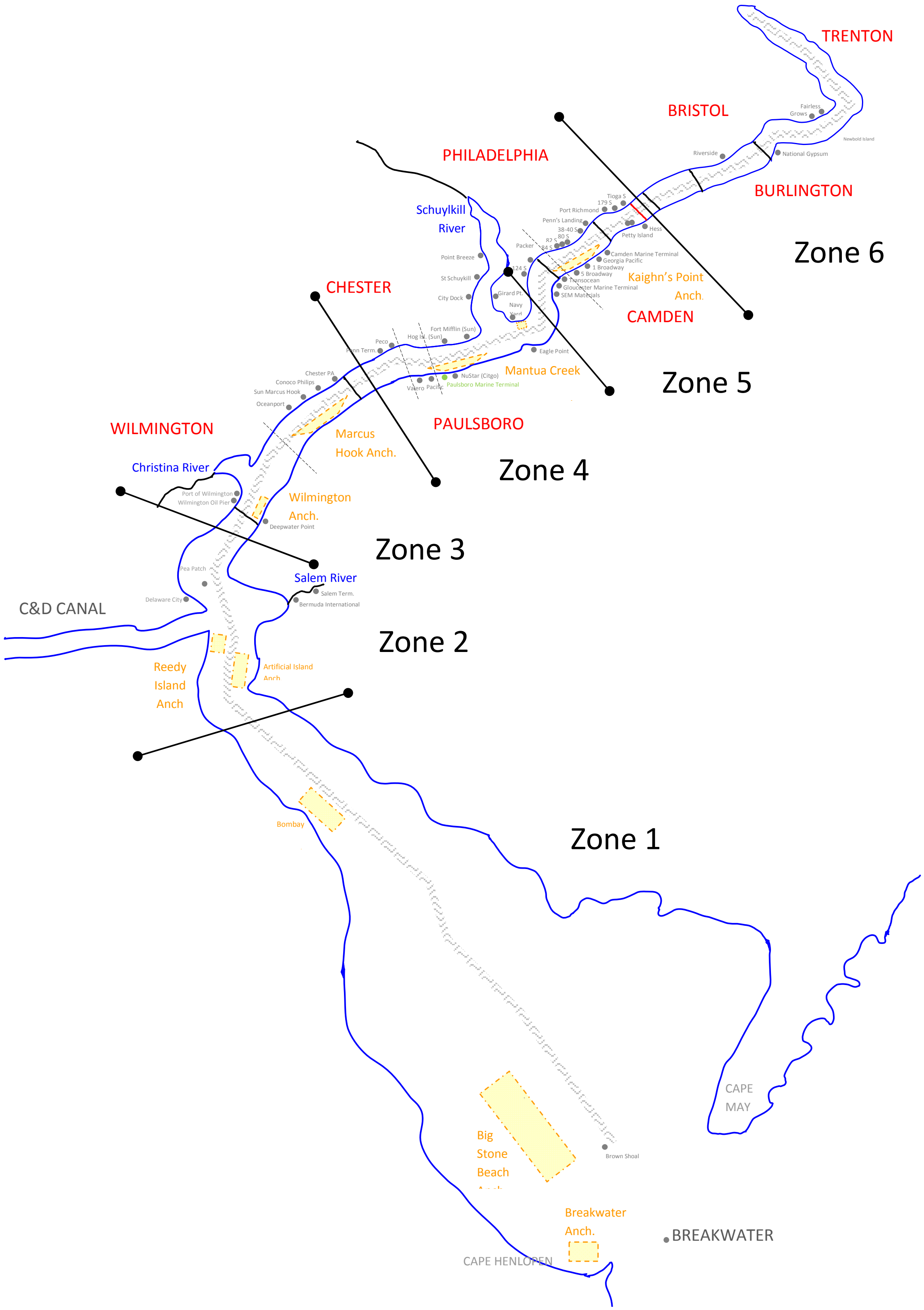


Figure 4.6. Delaware River and Bay divided into 6 zones

4.4. Mathematical Risk Model

Considering all possible situations, instigators, accidents and consequences it is possible to compute risk estimates for each region in the DRMC. The corresponding mathematical risk formulation is given below. In this formulation, $R_s(\underline{X})$ represents the instantaneous risk for a given zone *s* based on the states of the situational attributes as observed at a particular instance.

$$R_s(\underline{X}) = \sum_{v \in \mathfrak{V}_s} \sum_{j \in \mathcal{A}} \left(\sum_{k \in \mathcal{C}_j} E\left[C_{k,j,v} \middle| A_{j,v}, \underline{X}_v \right] \times \Pr\left(A_{j,v} \middle| \underline{X}_v \right) \right) \tag{4.2}$$

where

$$\Pr\left(A_{j,v} \middle| \underline{X}_v \right) = \sum_{i \in \mathcal{J}_\varphi} \Pr\left(A_{j,v} \middle| I_{i,v}, \underline{X}_{i,v} \right) \times \Pr\left(I_{i,v} \middle| \underline{X}_{i,v} \right) \tag{4.3}$$

and

s: zone no

v: vessel no

i : instigator type

j : accident type

k : consequence type

$\underline{X}_{i,v}$: Situational attribute set for instigator *i*, regarding vessel *v* in zone *s*

$I_{i,v}$: Instigator type *i*, regarding vessel *v* in zone *s*

$\underline{X}_v$: Situational attribute set regarding vessel *v* in zone *s*

$A_{j,v}$: Accident type *j* regarding vessel *v* in zone *s*

$C_{k,j,v}$: Consequence type *k* due to accident type *j* regarding vessel *v* in zone *s*

$\mathcal{I}_j : \{1,..,5\}$ is the set of instigators for accident type *j*

$\mathcal{C}_j : \{1,..,3\}$ is the set of consequences for accident type *j*

$\mathcal{A} : \{1,..,6\}$ is the set of accidents

$\mathcal{V}_s$: is the set of vessels navigating in zone *s* at the observed instance.

And finally, $E\left[C_{k,j,v} \middle| A_{j,v}, \underline{X}_v\right]$ is the expected consequence given the accident and the set of situational attributes and $\Pr\left(A_{j,v} \middle| \underline{X}_v\right)$ is the probability of accident occurrence given the set of situational attributes. Note that equation (4.2) makes risk $R_s(\underline{X})$ as the overall expected consequence based on all possible accidents.

Based on the above risk formulation, there are number of questions to be answered in order to quantify risks as shown below:

- How frequent does any particular situation occur?
- For a given situation, how often do instigators occur?
  If an instigator occurs, how likely is a particular accident?
  If an accident occurs, what would be the expected damage to human life, environment and property?

In this project, risks were quantified based on historical accident data, expert judgment elicitation and the simulation model of vessel traffic in Delaware River and Bay introduced earlier. The main use of the simulation model is to generate all the possible situations in a realistic manner (recall 25,920 situations mentioned earlier) and to make the underlying mathematical calculations. Historical accident data provides the probabilities for instigators, accidents and consequences. At last, expert judgment elicitation provides the link between all possible situations and their impact on risks.

As introduced in Figure 4.6, Delaware River is divided into 6 zones in the simulation model. The risk in each zone is calculated based on a snapshot taken at every properly chosen Δ*t* time units. In a snapshot, situational attributes for each vessel in a specified zone is available. Thus, risk contribution of each vessel in a particular zone is calculated and aggregated into the zone risk $R_s(\underline{X})$. Although instantaneous risks are not continuously tracked, taking snapshots based on a time interval provides sufficiently random and numerous data points. Therefore, the expected risk for a specific zone is obtained by averaging $R_s(\underline{X})$ over the number of snapshots taken.

Although historical data provides *expected probability of an instigator occurrence per vessel*, *expected accident probability given an instigator* and *expected probability of a consequence given an accident* these probabilities clearly affected by different situations. That is, the probability of an instigator to occur during day time compared to night time might be different. Each situation and their levels have different effects on these probabilities. Due to lack of data, given a situation estimation of any probability in this context requires expert judgment elicitation.

In this study, expert opinion elicitation was performed through direct questioning to evaluate the effects of situations and levels of situations on each *instigator*, *accident given an instigator* and *consequence given an accident*. The complete set of questionnaires is given in Appendix B. The participants in elicitation were the members of the Area Maritime Security Committee including the USCG and the port stakeholders. The participants had years of experience in navigation in waterways.

For a given event Φ, the effect of a situation (*time of day, tide, vessel class,…* etc.) is represented by *β* and the effect of a level of a situation (*day / night; high tide / low tide; tanker / general cargo;…* etc.) is represented by *X* which is also called cardinality of a level of a situation. In this formulation, P_Φ is the calibration constant which calibrates the associated probability using historical data.

$$\Pr\left(\Phi \middle| \underline{X}\right) = P_\Phi(\underline{\beta}^T \underline{X}) = P_\Phi.(\beta_1 X_1 + \ldots + \beta_n X_n) \tag{4.4}$$

4.4.1. Probability of Instigator Given Situation

Based on the discussion above, the probability of an instigator given a particular situation can be estimated using the following formulation.

$$\Pr\left(I_i \middle| \underline{X}_i\right) = P_i.(\underline{\beta}_i^T \underline{X}_i) \quad (4.5)$$

Through expert judgment elicitation process, β and X values were obtained and directly used in the risk formulations. Sample questionnaires used in expert elicitation to collect β and X values are given in Figure 4.7 and Figure 4.8 respectively.

	Instigator				
Situational Attributes	HE	PF	SF	EF	OSF
1. Time of Day	80	10	10	10	10
2. Tide	80	25	25	10	5
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*	90	90	90	90	90
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*	50	20	20	20	20
5. Zone *(e.g. 1,2,3,4,5,6)*	80	10	10	10	10
6. No. of Vessels Underway within 5 NM of your position	85	10	10	10	10
7. No. of Vessels Anchored within your Zone	60	10	10	10	10
8. Season	75	30	30	10	50

Figure 4.7. Sample questionnaire for assessing effect of situational attributes on instigator occurrence

In β questionnaires for instigators, the experts were asked to determine the effect of a situational attribute on the occurrence of an instigator in a particular vessel. Experts are expected to put a value between 0 (no relation) and 100 (direct relationship / correlation) to the blocks provided. For some questions blocks were grayed out since the combination being measured by that block would be unlikely or impossible to occur. However, answers are still permitted if the experts think that there might be a relationship. While evaluating risks, situational attribute values shown in Figure 4.7 were averaged over individual responses and later scaled down to less than 1.0.

	Instigator		
	HE	PSF	OSF
1. Time of Day			
a. Day	30	30	10
b. Night	80	50	50
2. Tide			
a. High	50	10	10
b. Low	80	30	10
3. (Your) Vessel Status			
a. Docked	0	0	10
b. Underway	90	90	50
c. Anchored	30	0	10
4. (Your) Vessel Class			
a. General Cargo	50	50	50
b. Dangerous Cargo	60	40	40
5. Zone ***(Geographical – Infrastructure only)***			
a. 1	50	50	10
b. 2	65	60	20
c. 3	60	60	20
d. 4	70	60	20
e. 5	70	60	20
f. 6	60	60	20
6. No. of Vessels Underway within 5 NM of your position			
a. 0-1	60	20	10
b. 2-3	70	40	20
c. more than 3	75	50	20
7. No. of Vessels Anchored within your Zone			
a. 0-1	20	10	10
b. 2-3	30	20	10
c. more than 3	50	30	10
8. Season			
a. Fall	60	30	10
b. Winter	80	50	20
c. Spring	70	60	10
d. Summer	50	20	10

Vessel Type	Instigator (Aggregate)
1. General Cargo < 150 (m)	60
2. General Cargo ≥ 150 (m)	50
3. Tugboat / Barge	80
4. Passenger ≥ 100 GT	10
5. Petroleum Tanker < 200 (m)	30
6. Petroleum Tanker ≥ 200 (m)	20
7. Chemical Tanker < 150 (m)	30
8. Chemical Tanker ≥ 150 (m)	20
9. LNG / LPG	10
10. Lightering Barge	90

Figure 4.8. Sample questionnaire for assessing the effects of levels of situational attributes on instigator occurrence

In *X* (cardinality) questionnaires, the experts were asked to determine the importance of a level of a situational attribute on the occurrence of an instigator in a particular vessel. Experts are again expected to put a value between 0 (no relation) and 100 (direct relationship / correlation) to the blocks provided where grayed out blocks are still optional. In order to simplify the questionnaires, vessel type question was separately asked for any type of instigator. However, these answers were weighted using vessel class values in the formulation.

4.4.2. <u>Probability of Accident Given Instigator and Situation</u>

The probability of an accident given an instigator taking place in a particular situation can be estimated using the formulation given below.

$$\Pr\left(A_j \middle| I_i, \underline{X}_i\right) = P_{j,i}.(\underline{\beta}_{j,i}^{\ T}\ \underline{X}_{j,i}) \tag{4.6}$$

Through the expert judgment elicitation process, again *β* and *X* values were obtained and directly used in the formulations. Sample questionnaires to collect *β* and *X* values are given in Figure 4.9 and Figure 4.10 respectively.

	Collision | Instigators				
Situational Attributes	HE^C	PF^C	SF^C	EF^C	OSF^C
1. Time of Day	75	30	30	40	10
2. Tide	80	70	70	10	10
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*	90	90	90	40	40
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*	20	20	20	20	20
5. Zone *(e.g. 1,2,3,4,5,6)*	90	90	90	20	10
6. No. of Vessels Underway within 5 NM of your position	90	90	90	20	10
7. No. of Vessels Anchored within your Zone	90	90	90	20	10
8. Season	80	70	70	20	10

Figure 4.9. Sample questionnaire for assessing effect of situational attributes on collision occurrence

β questionnaires for accidents were prepared for all accident types separately. In questions, the experts were asked to determine effect of a situational attribute on the likelihood of an accident, given an instigator taking place on a particular vessel.

	Accident | Instigator		
	HE	PSF	OSF
1. Time of Day			
a. Day	70	70	10
b. Night	90	90	50
2. Tide			
a. High	40	40	10
b. Low	60	60	20
3. (Your) Vessel Status			
a. Docked	90	0	10
b. Underway	70	90	10
c. Anchored	90	0	10
4. (Your) Vessel Class			
a. General Cargo	50	50	10
b. Dangerous Cargo	90	90	30
5. Zone ***(Geographical – Infrastructure only)***			
a. 1	20	30	10
b. 2	20	30	15
c. 3	50	70	20
d. 4	50	70	20
e. 5	50	70	20
f. 6	20	30	15
6. No. of Vessels Underway within 5 NM of your position			
a. 0-1	50	50	10
b. 2-3	70	60	20
c. more than 3	90	90	20
7. No. of Vessels Anchored within your Zone			
a. 0-1	50	50	10
b. 2-3	60	60	20
c. more than 3	70	70	20
8. Season			
a. Fall	60	10	0
b. Winter	80	30	10
c. Spring	70	10	0
d. Summer	20	10	0

Vessel Type	Accident | Instigator (Aggregate)
1. General Cargo < 150 (m)	60
2. General Cargo ≥ 150 (m)	50
3. Tugboat / Barge	70
4. Passenger ≥ 100 GT	50
5. Petroleum Tanker < 200 (m)	60
6. Petroleum Tanker ≥ 200 (m)	50
7. Chemical Tanker < 150 (m)	60
8. Chemical Tanker ≥ 150 (m)	50
9. LNG / LPG	50
10. Lightering Barge	80

Figure 4.10. Sample questionnaire for assessing the effects of levels of situational attributes on accident occurrence

X (cardinality) questions for accidents are combined into one questionnaire for any type of accident. The main reason for this simplification is due to the assumption that the levels of situational attributes have very similar effects on all accident types in consideration. In questions, the experts were asked to determine the importance of attribute levels on the likelihood of an accident, given an instigator taking place on a particular vessel.

4.4.3. Expected Consequence Given Accident and Situation

Expected consequence given an accident has happened in a particular situation can be estimated using the formulation given below.

$$E\left[C_{k,j}\left|A_j,\underline{X}_k\right.\right]=C_{k,j}.\Pr\left(C_{k,j}\left|A_j,\underline{X}_k\right.\right) \qquad (4.7)$$

where $C_{k,j}$ represents the impact level due of consequence type k and accident type j and the probability of a consequence given an accident has happened in a particular situation can be estimated using the formulation given below.

$$\Pr\left(C_{k,j}\left|A_j,\underline{X}_k\right.\right)=P_{k,j}.(\underline{\beta}_{k,j}{}^{T}\underline{X}_k) \qquad (4.8)$$

Through expert judgment elicitation process, again β and X values were obtained and directly used in the formulation. Sample questionnaires to collect β and X values are given in Figure 4.11 and Figure 4.12 respectively.

	Consequences | Collision		
Situational Attributes	HC	EnvD	ProD
1. Time of Day	90	80	90
2. Tide	10	95	30
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*	90	80	80
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*	90	95	90
5. Zone *(e.g. 1,2,3,4,5,6)*	80	90	90
6. No. of Vessels Underway within 5 NM of your position	90	70	90
7. No. of Vessels Anchored within your Zone	10	10	10
8. Season	80	80	70

Figure 4.11. Sample questionnaire for assessing the effects of situational attributes on consequence severity

β questionnaires for consequences were prepared based on all accident types separately. In questions, the experts were asked for the effect of a situational attribute on the severity of the consequence given an accident has happened.

	Consequence | Accident		
	Human Casualty	Environmental Damage	Property Damage
1. Time of Day			
a. Day	50	50	50
b. Night	90	90	90
2. Tide			
a. High	10	10	10
b. Low	10	60	70
3. (Your) Vessel Status			
a. Docked	10	40	20
b. Underway	90	70	90
c. Anchored	50	40	60
4. (Your) Vessel Class			
a. General Cargo	50	40	50
b. Dangerous Cargo	70	90	70
5. Zone ***(Geographical – Infrastructure only)***			
a. 1	80	70	60
b. 2	70	80	70
c. 3	75	80	70
d. 4	75	80	75
e. 5	75	80	75
f. 6	60	80	70
6. No. of Vessels Underway within 5 NM of your position			
a. 0-1	50	60	50
b. 2-3	60	70	60
c. more than 3	50	70	70
7. No. of Vessels Anchored within your Zone			
a. 0-1	70	50	50
b. 2-3	70	50	60
c. more than 3	75	50	70
8. Season			
a. Fall	50	50	60
b. Winter	90	90	60
c. Spring	50	70	70
d. Summer	20	50	90

	Consequence | Accident		
Vessel Type	HC	EnvD	ProD
1. General Cargo < 150 (m)	50	60	60
2. General Cargo ≥ 150 (m)	50	70	70
3. Tugboat / Barge	60	70	70
4. Passenger ≥ 100 GT	100	30	30
5. Petroleum Tanker < 200 (m)	80	80	80
6. Petroleum Tanker ≥ 200 (m)	80	80	80
7. Chemical Tanker < 150 (m)	80	80	80
8. Chemical Tanker ≥ 150 (m)	80	80	80
9. LNG / LPG	90	20	90
10. Lightering Barge	20	90	90

Figure 4.12. Sample questionnaire for assessing effect of levels of situational attributes on consequence severity

X (cardinality) questions for consequences were combined into one questionnaire based on any type of accident. The main reason for this simplification is due to the assumption that the levels of situational attributes have very similar effects on all consequences in consideration. In questions, the experts were asked for the importance of attribute characteristics on the severity of the consequence given an accident has happened.

4.4.4. <u>Consequence Impact Levels</u>

Evaluation of consequences is a major challenge in risk analysis. Below we summarize our efforts to quantify accident consequences as financial estimates in the DRB area.

4.4.4.1. Quantification of Human Casualty

When there is human casualty in an accident, number of injuries and deaths were estimated from the empirical distribution based on historical data. We suggest using the U.S National Safety Council comprehensive cost values from 2009 (NSC, 2009) to estimate total human casualty costs. Injury histogram given in Figure 4.13 is for all types of accidents. In addition to injury, data suggests a 10% death rate per incident for the Fire/Explosion case only.

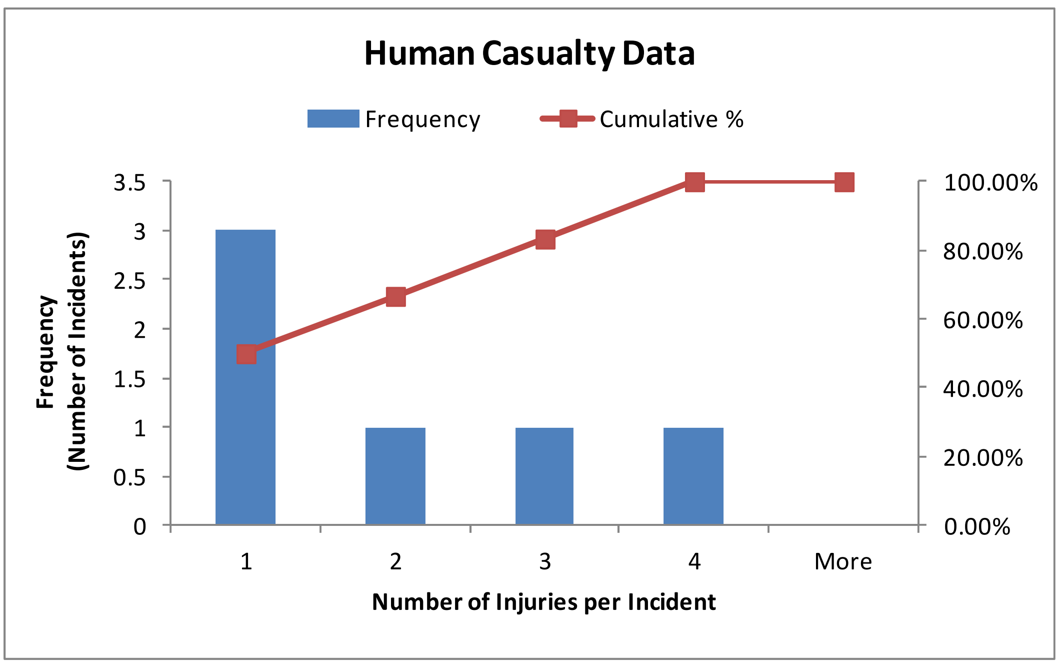


Figure 4.13. Histogram showing the number of injuries per incident when there is human casualty in the historical data from years 1992 to 2008

Table 4.5 shows the average comprehensive costs for injuries based on their severity issued by U.S. National Safety Council.

Table 4.5 - U.S. National Safety Council 2009 values for average comprehensive cost by injury severity (NSC, 2009)

Average Comprehensive Cost by Injury Severity	
Death	$4,300,000
Nonincapacitating evident injury	$55,300
No injury	$2,400

4.4.4.2. Quantification of Environmental Damage

Environmental damage costs were estimated based on oil spill historical data per given vessel type in the histograms below. It is independent of the accident type since historical data does not suggest a significant difference for different accidents. For a given incident, total oil spill was estimated from empirical distributions per vessel type and comprehensive costs from the table below was used to estimate the total costs. Oil spill data for different types of vessels are given in Figure 4.14 to Figure 4.16.

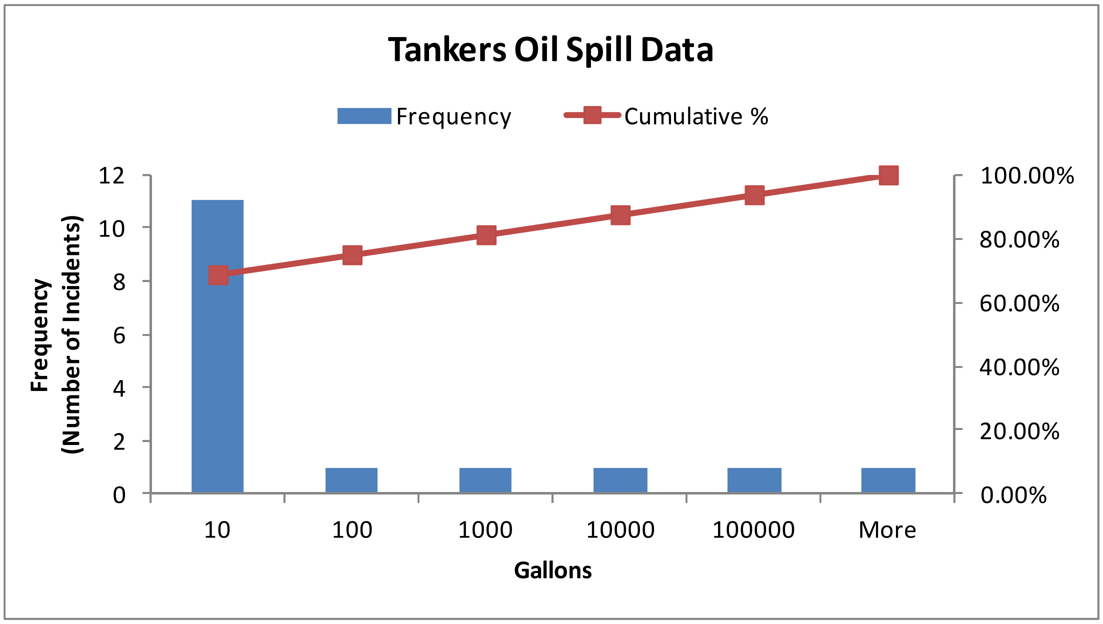


Figure 4.14. Histogram showing gallons spilled from tankers per incident when there is environmental damage in the historical data of years 1992 to 2008

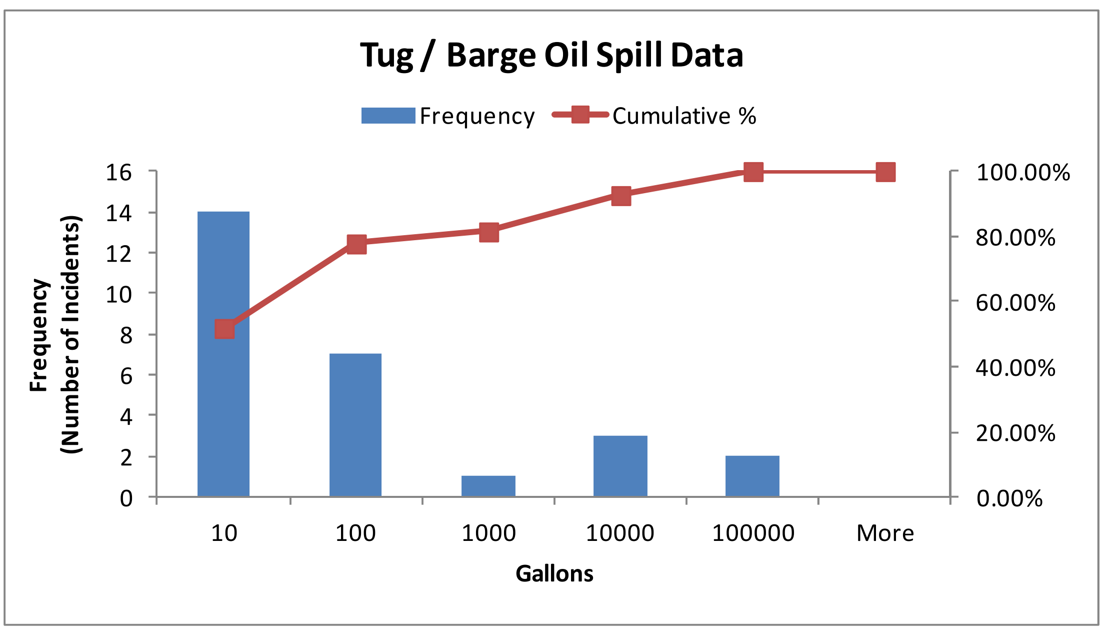


Figure 4.15. Histogram showing gallons spilled from tugs and barges per incident when there is environmental damage in the historical data of years 1992 to 2008

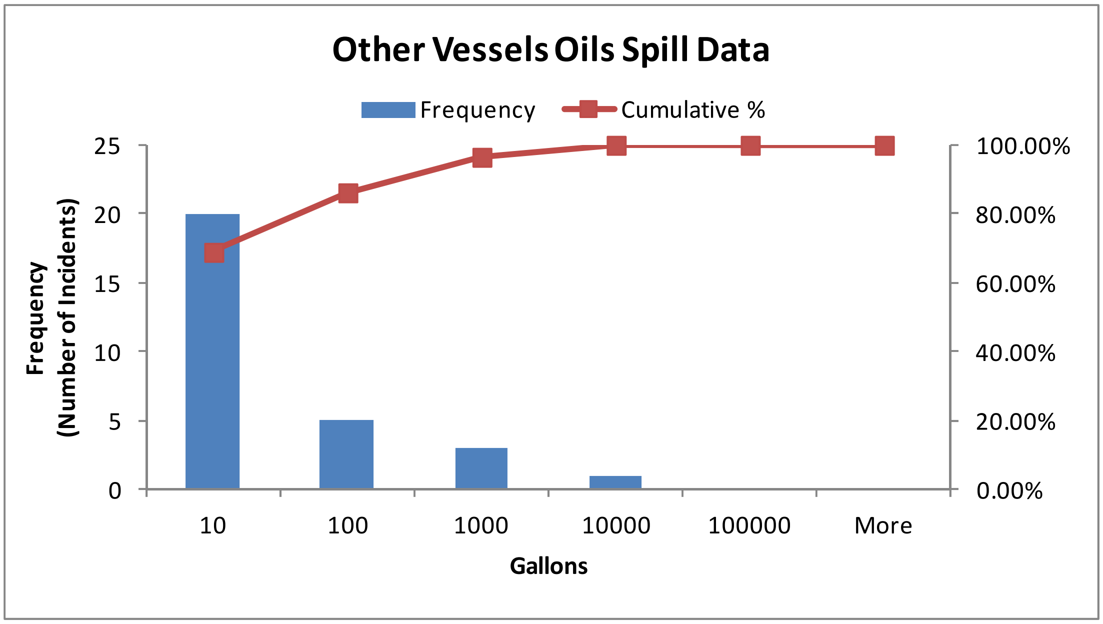


Figure 4.16. Histogram showing gallons spilled from other cargo vessels per incident when there is environmental damage in the historical data of years 1992 to 2008

Comprehensive oil spill costs including response costs, environmental damage costs, and the socioeconomic costs are given in Table 4.6, (Etkin, 2004). Note that comprehensive costs were adjusted to 2011 values with inflation rates.

Table 4.6 - Comprehensive oil spill costs based on gallons spilled from Etkin, D.S. (2004)

Oil Spill (Gallons)	***Average Response Cost/Gallon ($)***	***Environmental Cost/Gallon ($)***	***Socioeconomic Cost/Gallon ($)***	***Total Cost/Gallon ($) (Present Value)***
< 500	199	90	50	401.98
500 - 1000	197	87	200	573.92
1000 - 10K	195	80	300	681.83
10K - 100K	185	73	140	471.95
100K - 1000K	118	35	70	264.43
> 1M	82	30	60	203.96

4.4.4.3. Quantification of Property Damage

Property damage costs were estimated based on historical data for a given accident type. For each accident type, empirical distributions were fit to estimate total property damage costs. Note that costs from the historical data were adjusted to 2011 values by applying inflation rates (Figure 4.17).

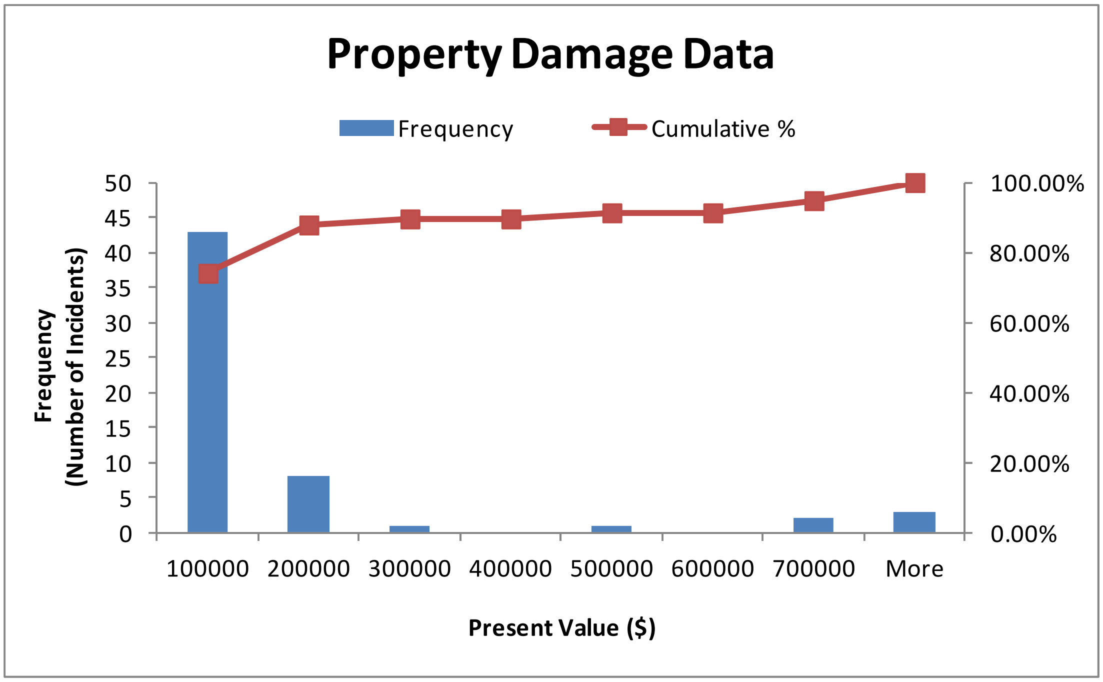


Figure 4.17. Histogram showing costs per incident when there is property damage in the historical data of years 1992 to 2008

4.4.5. <u>Calibration of Probabilities</u>

Validation process of the accident probabilities in risk calculations involves a calibration process. It is about comparing probabilities from the model with the ones from the historical data, to the extent of their availability. This was achieved by making an initial simulation run with the calibration constants in the risk model being 1.0. After running the model long enough, each probability (such as probability of collision given human error) was averaged over time and over all situations in the model. This measure is a proper value to be compared with the same probability calculated from the historical data. Hence to calculate the calibration constant, every probability from the historical data was divided by its corresponding counterpart from the model. The ratio is the calibration constant and replaced all 1.0s in the preliminary run, making it ready for risk calculations. In essence, this operation can be described by the following:

$$\Pr\left(C_{k,j}\left|A_j,\underline{X}_k\right.\right)=P_{k,j}.(\underline{\beta}_{k,j}{}^{T}\,\underline{X}_k)\quad\Rightarrow\quad P_{k,j}=\frac{\Pr\left(C_{k,j}\left|A_j,\underline{X}_k\right.\right)}{\underline{\beta}_{k,j}{}^{T}\,\underline{X}_k}\qquad(4.9)$$

4.5. Risk Evaluations

The aforementioned risk model (Equation 4.2) was integrated into the simulation model which is capable of producing all possible situations regarding both the vessel traffic and the situations in the river. The mathematical risk model and the simulation model work hand in hand in such a way that the risk model responds with the corresponding risk evaluation for every possible situation generated in the simulation model. This process is carried out at every short time interval (i.e., 60 minutes) at each zone to produce a temporal risk profile of the entire river. At every time step, using the situation attribute values, the risk model calculates probabilities of all types of accidents to occur given the situation at the time. Then the model uses these probabilities to calculate corresponding risks. Clearly, this is a process that is computationally intensive especially if the risk profiles are required to be precise indicating frequent evaluations.

Results of risk calculation in the model are saved in an output file for further analysis and demonstration purposes. Other than that, a set of graphs were introduced within the simulation model to illustrate the recent risk values of each zone, so that one can follow in what situations the risk values hit high numbers; e.g. Figure 4.18 shows a snapshot of the first zone of the river, while the graph labeled “ZONE1 Risk” shows the risk behavior over time in Zone 1 as the simulation continues. Also, “ZONE1 Vessel Density” is the number of vessels in Zone 1 over time.

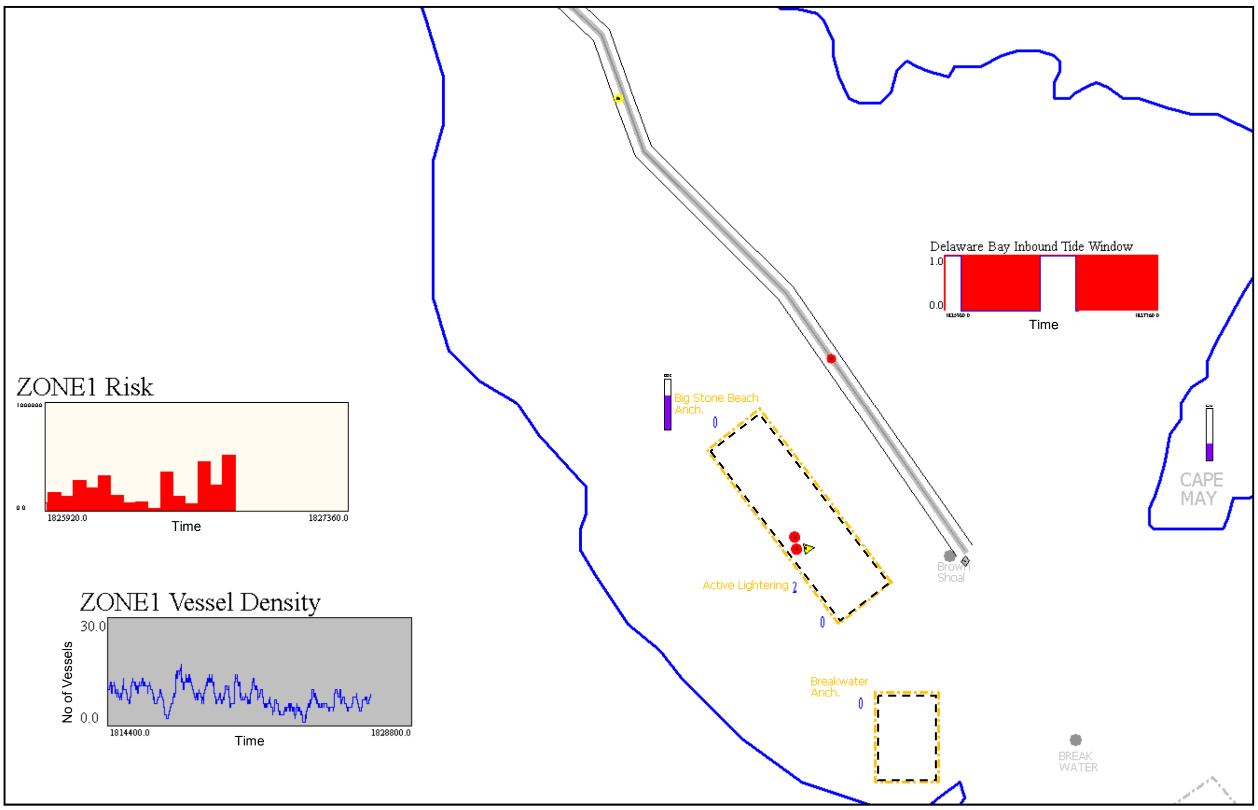


Figure 4.18. Snapshot of zone 1 (Breakwater region) in the simulation model showing risk graph

A similar snapshot of the fifth zone is illustrated in Figure 4.19.

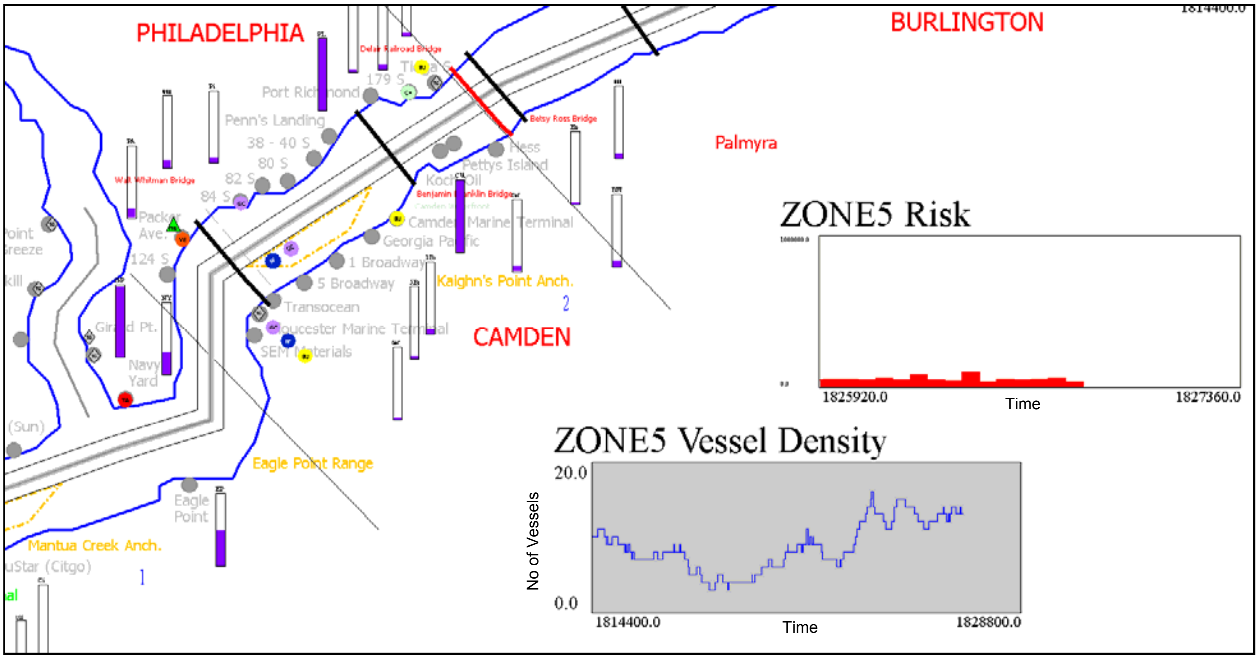


Figure 4.19. Snapshot of zone 5 (Philadelphia region) in the simulation model showing risk graph. (The vertical bars show MSRAM risks of the facilities in the region.)

4.6. Numerical Results

In this section, results of zone risk evaluations, obtained using the hybrid risk and simulation modeling approach developed earlier, are presented and also used to compare different scenarios. Recall that the risk values are expressed in dollars and presented as such in the following tables and figures in this chapter. Furthermore, efficiency-based risk mitigation suggestions are provided.

4.6.1. <u>Current Risks</u>

Figure 4.20 illustrates a 3D risk profile of DRB where calculated risks over a full year were mapped per 24-hour period to generate a risk profile for the entire river. Risks were calculated using one replication of the model over 30 years. The risk profile suggests that most of the higher risk values are observed in Zone 1 followed by Zone 4 as compared to other zones. Figure 4.20 is quite useful to compare time-based risks such as day vs. night time risks, among others.

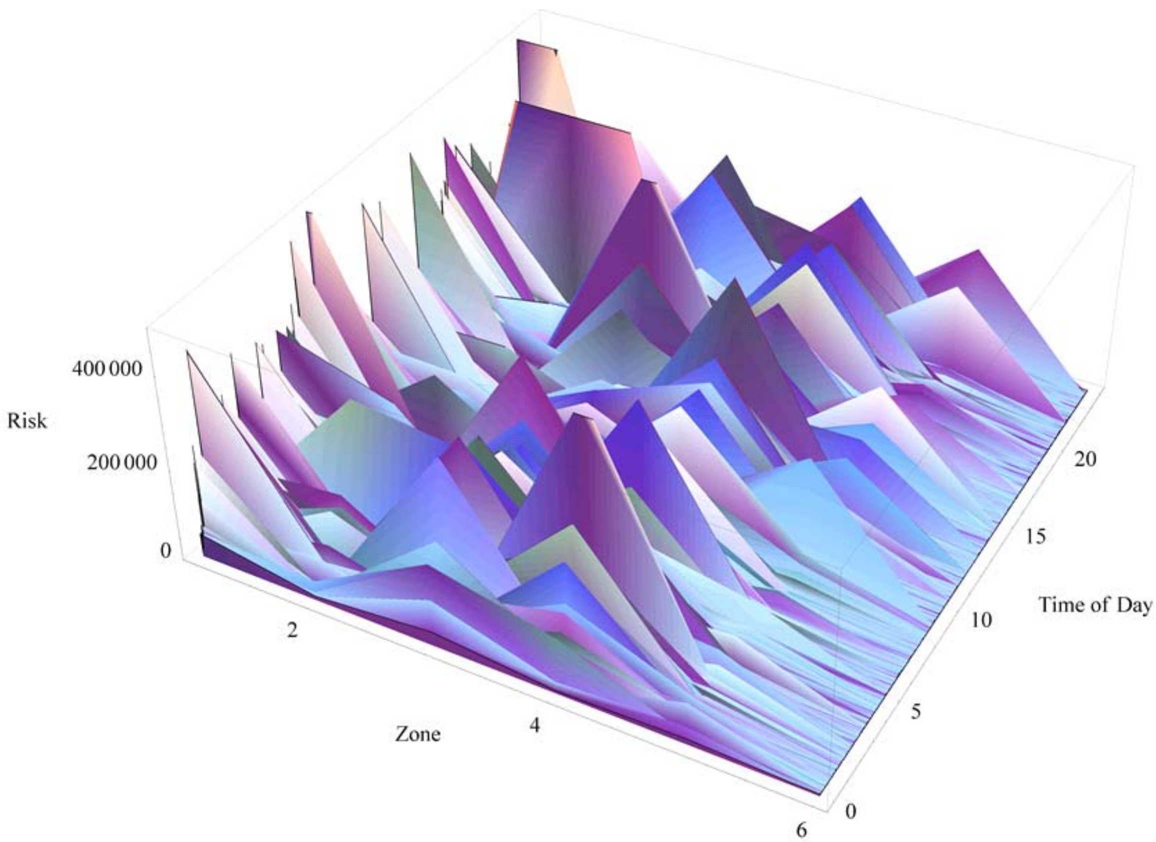
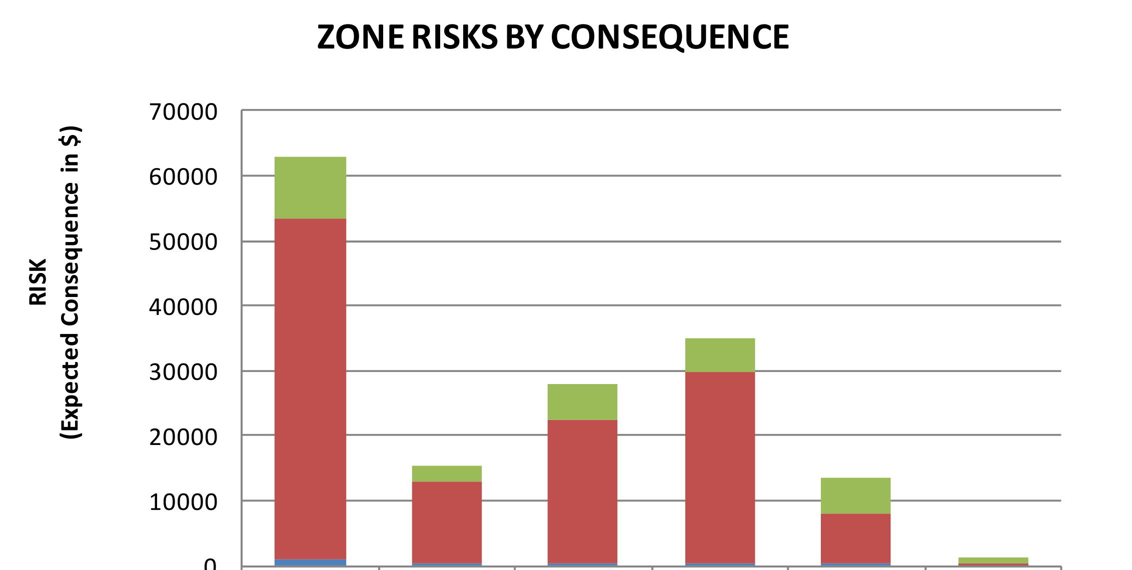


Figure 4.20. 3D risk profile of Delaware River based on zones and time of day

In Figure 4.21, bars show the average total risk for a given zone in DRB. Again the average risks for Zones 1, 3 and 4 are higher than the risks of other zones. Different colors in each bar show the relative significance of the corresponding consequence type in the total risk for that zone. Almost in all zones, environmental damage is the dominant consequence. Thus, it is possible to explain the reason for higher risk values in Zones 1, 3 and 4. In Zone 1, the risk of environmental damage is high ($52,536) due to the lightering activity in the Big Stone Beach Anchorage. Frequency of visits and length of stay for tankers in Zones 3 and 4 are higher than other zones due to higher number of oil terminals in these zones. Therefore, the expected environmental damage and expected risks are higher in the aforementioned zones. Note that the risk of human casualty consequence is only seen in Zone 1.

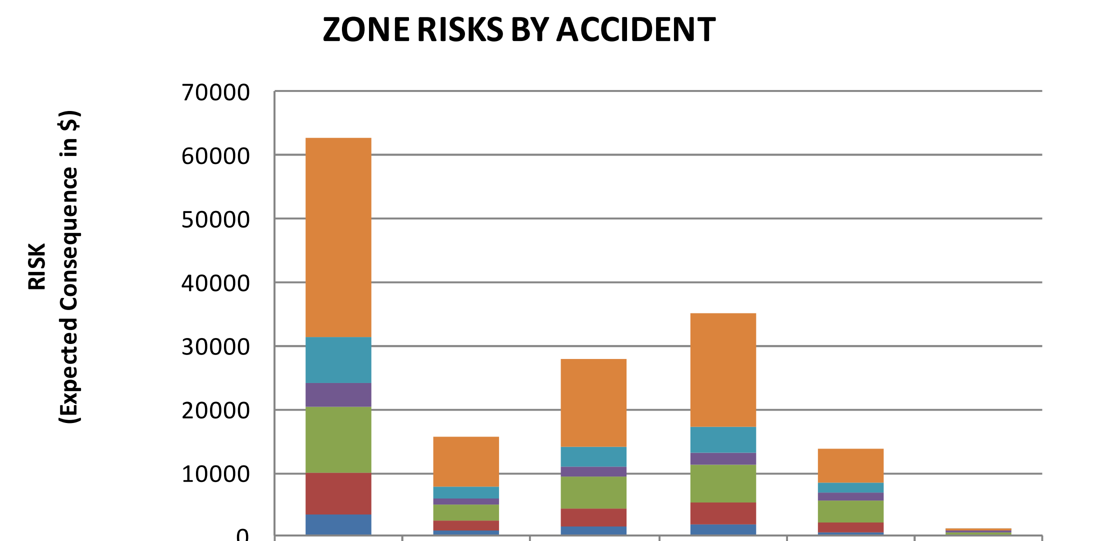


Consequence Types	1	2	3	4	5	6
Property Damage	9278.1	2592.3	5227.8	5152.1	5618.5	1022.5
Environmental Damage	52536	12671	22074	29324	7562.4	172.38
Human Casualty	955.62	264.75	498.74	483.49	501.85	91.241

Dollar values represent risks of either **Property Damage**, **Environmental Damage** or **Human Casualty** due to accidents in corresponding zones. These values are expected consequences out of all possible accidents considering their probabilities of occurrence.

Figure 4.21. Zone risks classified by the consequence type

Figure 4.22 shows the same overall risk values as in Figure 4.21 and yet the risks are classified based on accident types to provide accident-type impact on zone risks. Note that Oil Spill (OS) and Grounding (G) seem to be the major accidents having the biggest impact on risk.



Accident Types	1	2	3	4	5	6
Oil Spill	31405	7869.6	13670	17900	5213.2	237.15
Sinking / Capsizing / Flooding	7333.2	1777.9	3174.9	4035.2	1571.9	151.9
Fire / Explosion	3657	918.86	1688	1873.6	1267.7	195.86
Grounding	10319	2592.7	4940.6	5781.2	3489.1	489.76
Allision	6589.8	1566	2879.3	3556.5	1503.5	161.25
Collision	3465.8	803.48	1448.4	1813.2	637.08	50.219

Figure 4.22. Zone risks classified by accident types

Figure 4.23 provides the risk histogram for each zone obtained from the simulation. The histograms showing the risk for Zones 2, 5 and 6 exhibit low risk values while Zones 1, 3 and 4 show heavy tails to the right indicating high risks observed in these zones.

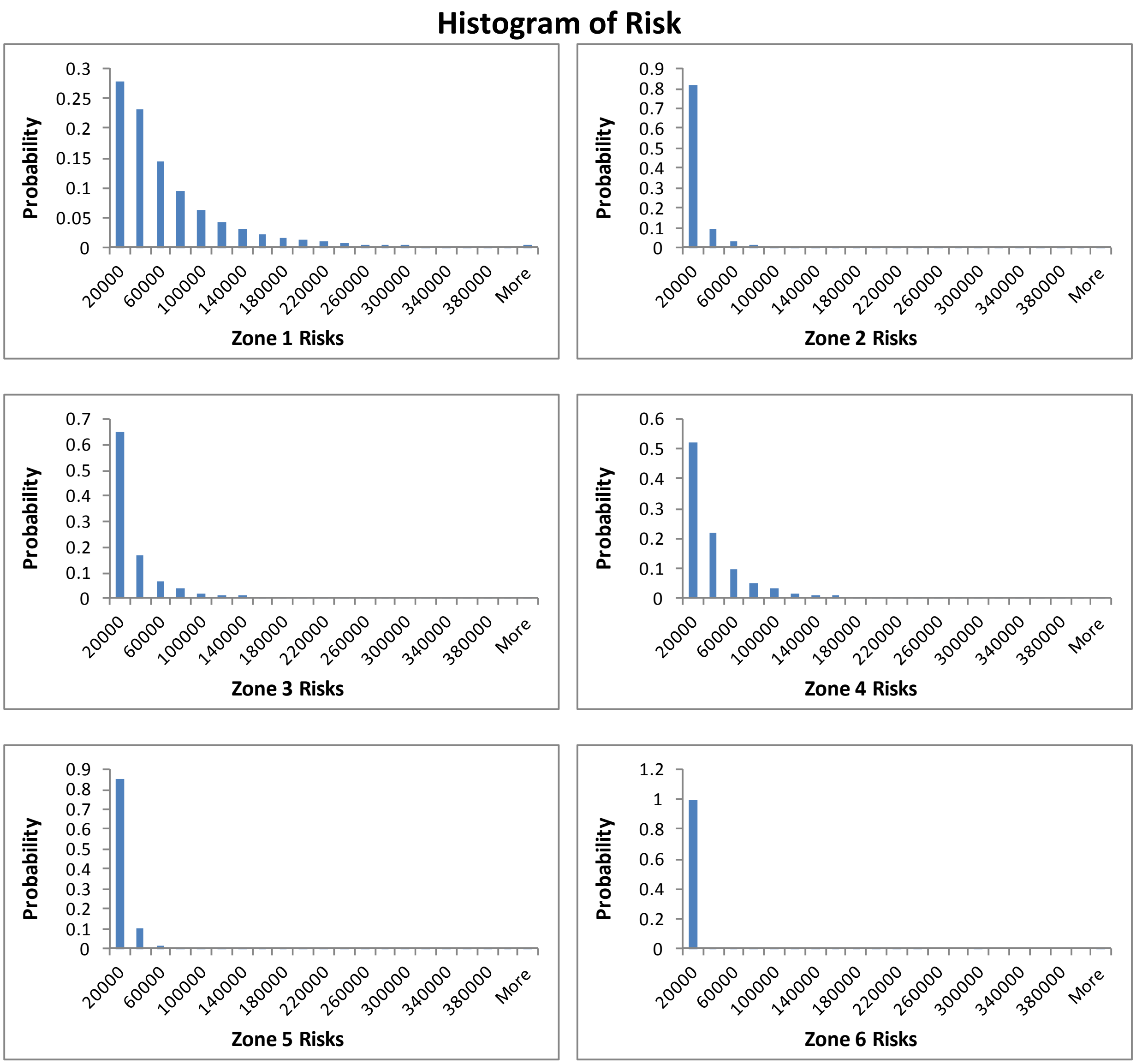


Figure 4.23. Histogram of risks for zones in DRB

4.6.2. Risk Comparisons of Deepening Related Scenarios

In this section, zone risks in the two scenarios from Chapter 3, namely Growth (Scenario B) and Deepening plus Shifting to Larger Vessels (Scenario D) scenarios are discussed and scenario comparisons are made. Each simulation run has 10 replications over 30 years.

We start with Figure 4.24 and Figure 4.25 where zone-based averages and their maximums are compared in the two scenarios, respectively. The zone risks are presented over a 30-year period and they typically exhibit increasing averages over time while their maximums fluctuate. It is still the case that Zone 1 risks are the highest in both scenarios. Comparisons of the two scenarios will be presented in this section further.

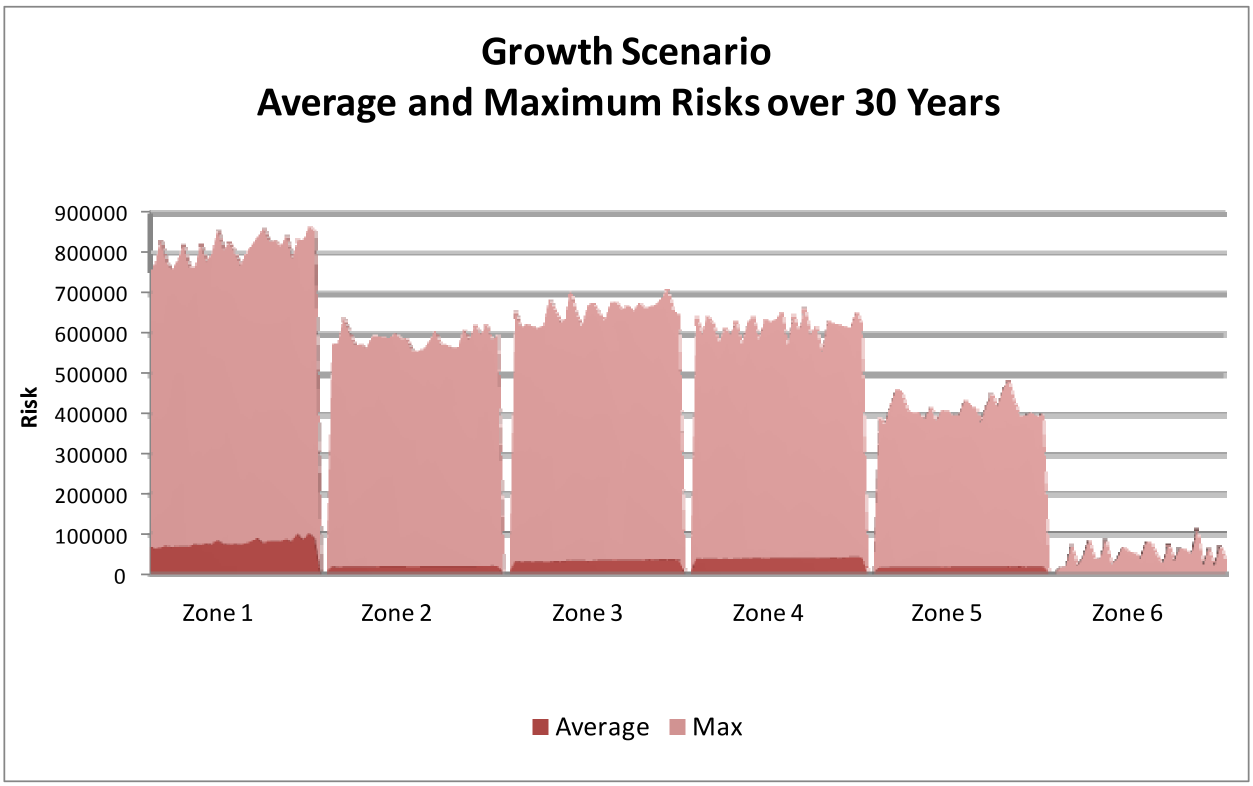


Figure 4.24. Zone based risks in the Growth Scenario

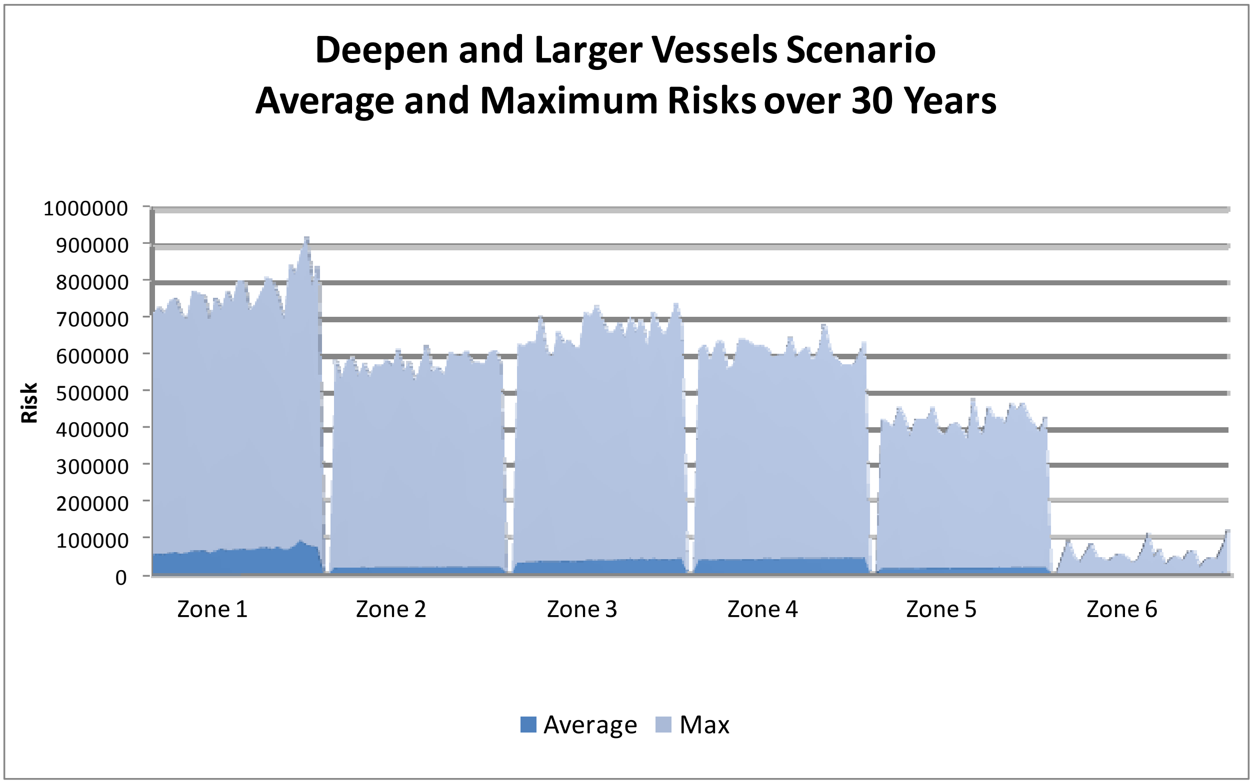


Figure 4.25. Zone based risks in the Deepen and Shift to Larger Vessels Scenario

Figure 4.26 shows the average risks for DRB over 30 years in these two scenarios. These risk values are cumulative over all zones. Notice that the risks estimated in the Deepen and Larger Vessels scenario are quite comparable to the ones in the Growth scenario (current system with 30-year growth assumption). However it would be informative to look at zone risks to observe any potential benefit one scenario has over the other. Figure 4.27 and Figure 4.28 illustrate the comparison of Scenarios B and D in their risks for Zones 1 and 4, respectively. Figure 4.27 indicates that risks in Zone 1 for Scenario D are lower than the ones in Scenario B. This is attributed to lesser number of vessels lightering (even if each vessel lighters more) and lesser number of vessels waiting due to tide in Zone 1. However, Figure 4.28 shows that risks in Zone 4 in Scenario D result in higher risks than Scenario B due to longer berth holding times in terminals.

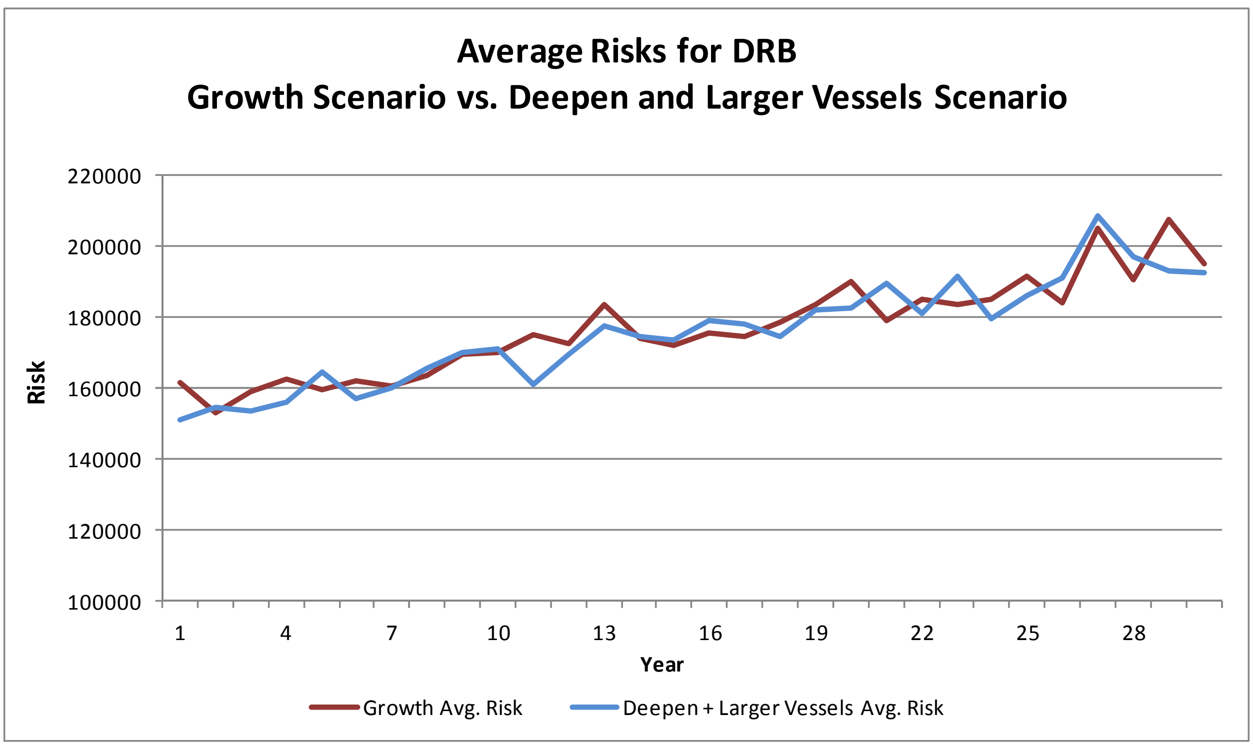


Figure 4.26. Comparison of average risks for Scenarios B and D in DRB

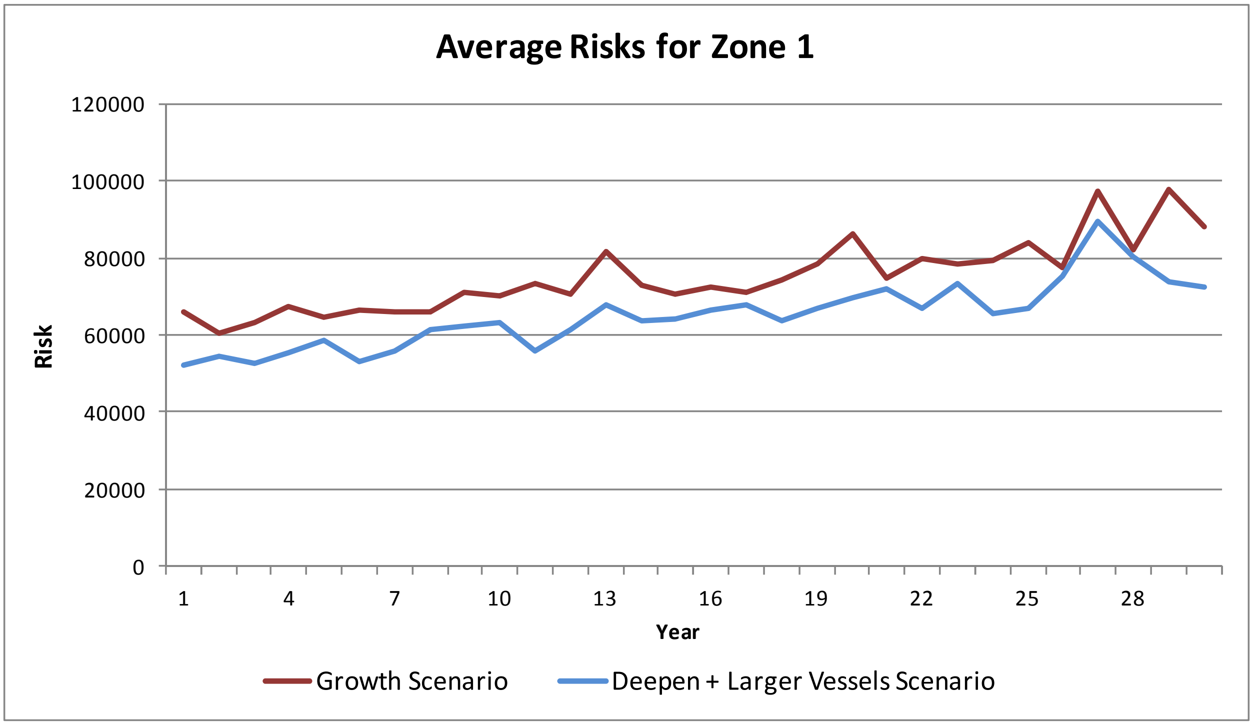


Figure 4.27. Average risks of Zone 1 for Scenarios B and D

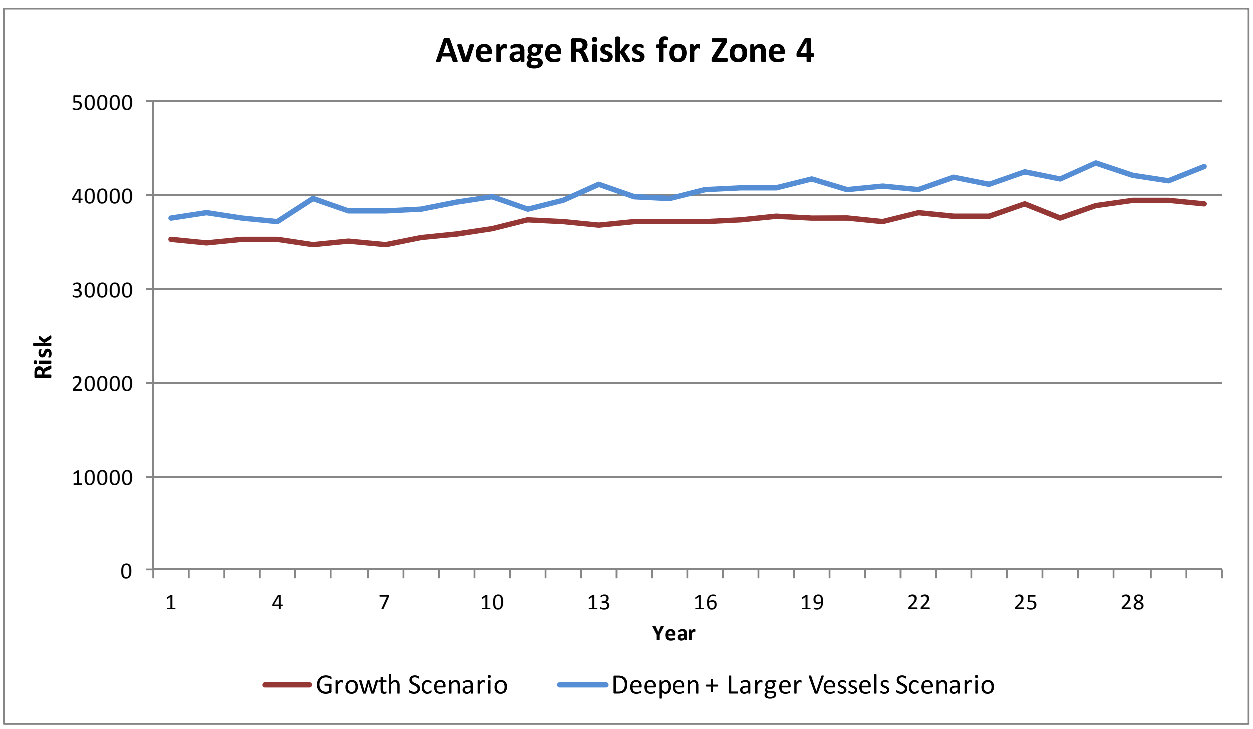


Figure 4.28. Average risks of Zone 4 for Scenarios B and D

4.6.3. A Risk Mitigation Approach: Improving Terminal Efficiencies Reduces Risk

Now that the risk profiles of the two critical scenarios are obtained, it is possible to focus on mitigation practices that are meaningful for the DRB maritime traffic and terminal operations. Here, a mitigation policy that may essentially reduce the time tankers spend in terminals will be proposed. This policy will require terminals to improve their operational efficiencies and therefore reduce the time tankers spend in terminals.

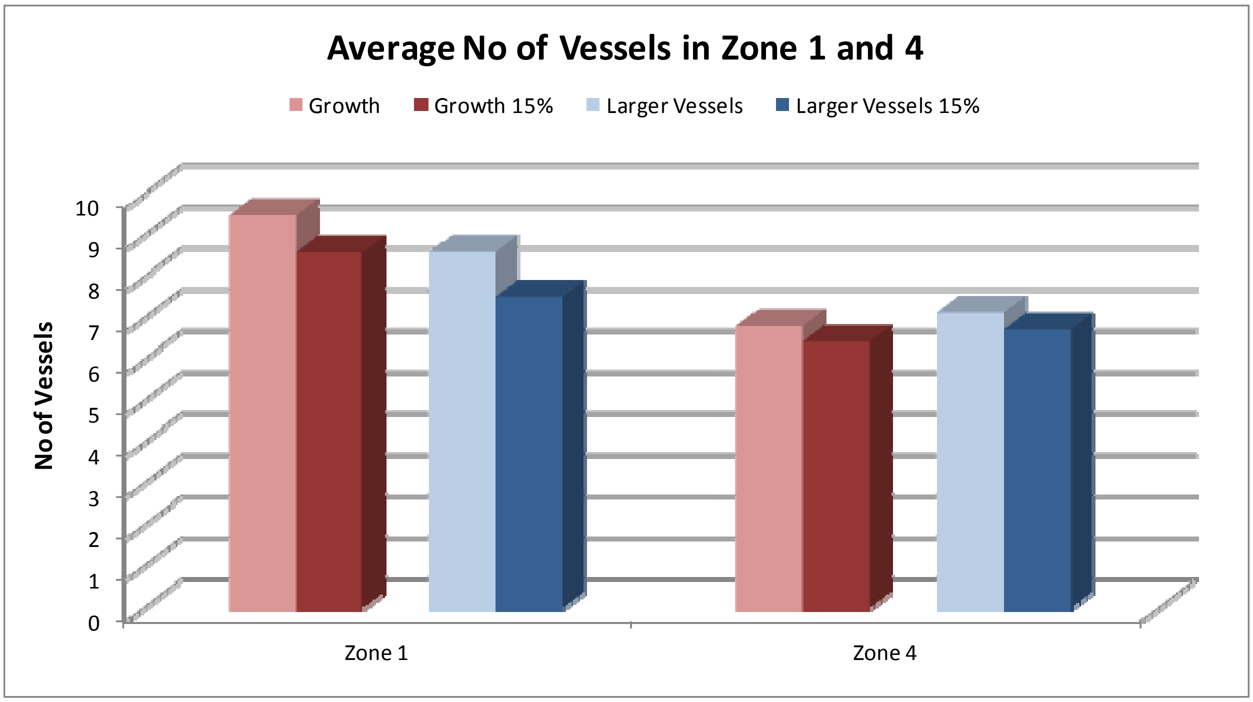


Figure 4.29. Average Vessel Density in all four scenarios in Zones 1 and 4

Accordingly, here it is assumed for experimental purposes that the operational efficiency in terminals handling tankers, including lightering operations, is improved by 15%. It will consequently reduce the number of vessels in the river at any point in time as shown in Figure 4.29. The model results over the planning horizon of 30 years with 10 replications are presented in Figure 4.30 through Figure 4.34. However, note that achieving such significant efficiency improvement may not come easy due to various technical, safety and other regulatory issues. It is considered here to be able to show that efficiency is a way to mitigate risks.

Adding this assumption to the analysis provides two reasonable comparisons:

1. Comparison of growth scenario cases before (Scenario B) and after 15% increase in efficiency (named as Scenario E).
2. Comparison of deepen and larger vessel scenario cases before (Scenario D) and after 15% increase in efficiency (named as Scenario F).

Since Zones 1 and 4 have the highest risks among all, the above comparisons were performed for these zones only. It is clear that increasing the efficiency will reduce the average risks in the growth scenario as shown in Figure 4.30 and Figure 4.31. This effect remains consistent throughout the planning horizon. Observe that efficient operation brings smoother risks to Zone 1. In the growth scenario, the average total risk estimated in Zone 1 is reduced by 16% and the average maximum risk is reduced by 28% when the operational efficiency goes up by 15%. The same action results in a 10% decrease in the average total risk and a 9% decrease in the average maximum risk in Zone 4.

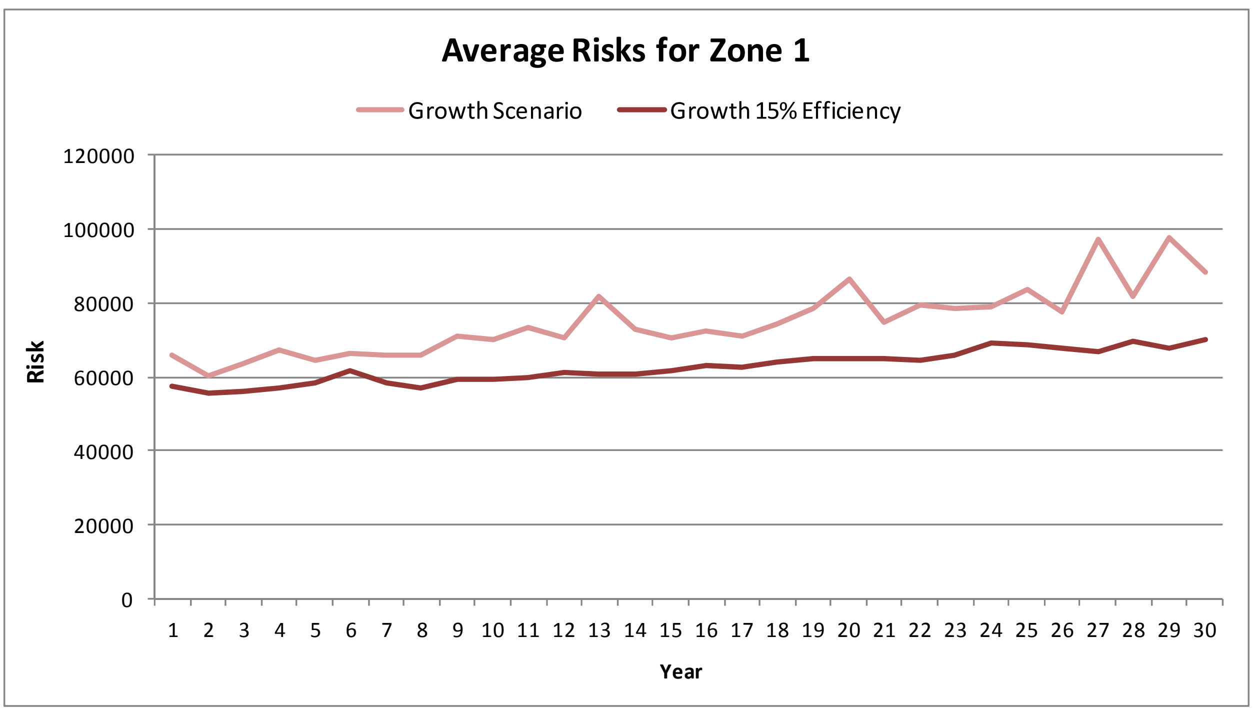


Figure 4.30. Comparison of Scenarios B and E for Zone 1

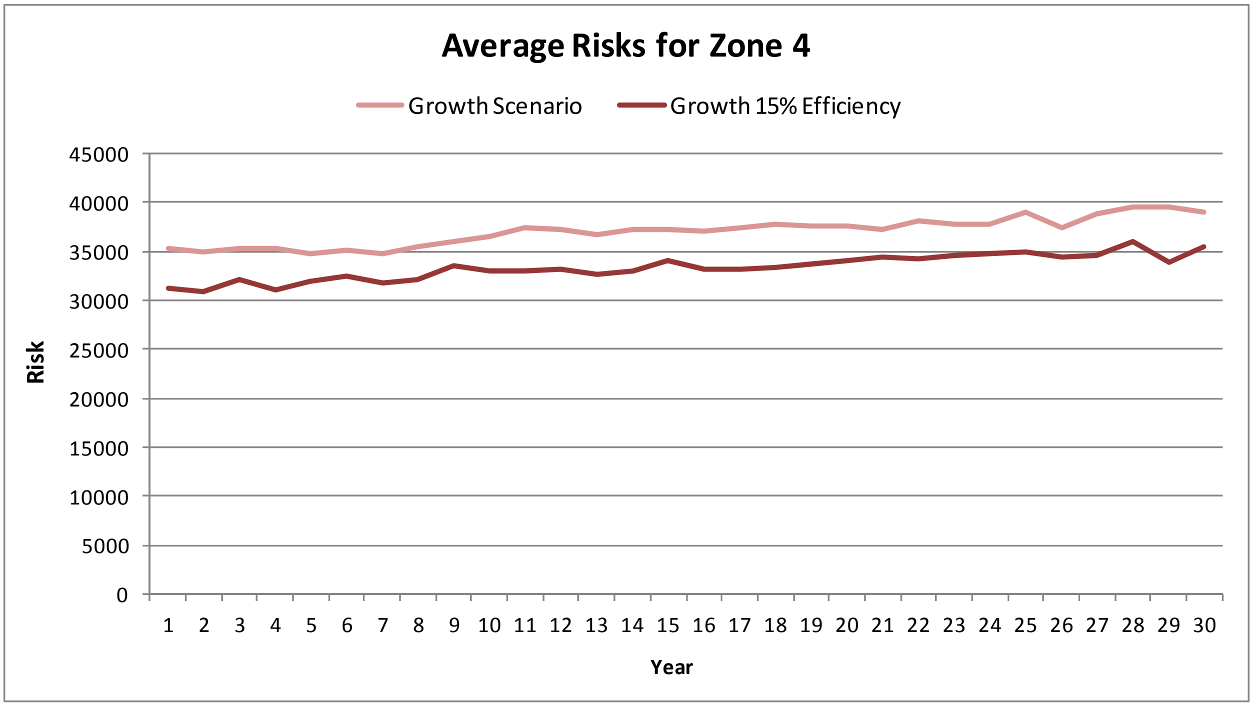


Figure 4.31. Comparison of Scenarios B and E for Zone 4

The same inference is concluded for deepen and shift to larger vessel scenarios from Figure 4.32 and Figure 4.33. Again increasing the efficiencies in lightering activities and berth operations of tankers mitigates the risk for Zones 1 and 4.

Observe that efficient operation brings smoother risks to Zone 1 in this scenario as well. The average total risk estimated in Zone 1 is reduced by 18% and the average maximum risk is reduced by 33% when the operational efficiency goes up by 15%. The same action results in a 10% decrease in the average total risk and a 11% decrease in the average maximum risk in Zone 4.

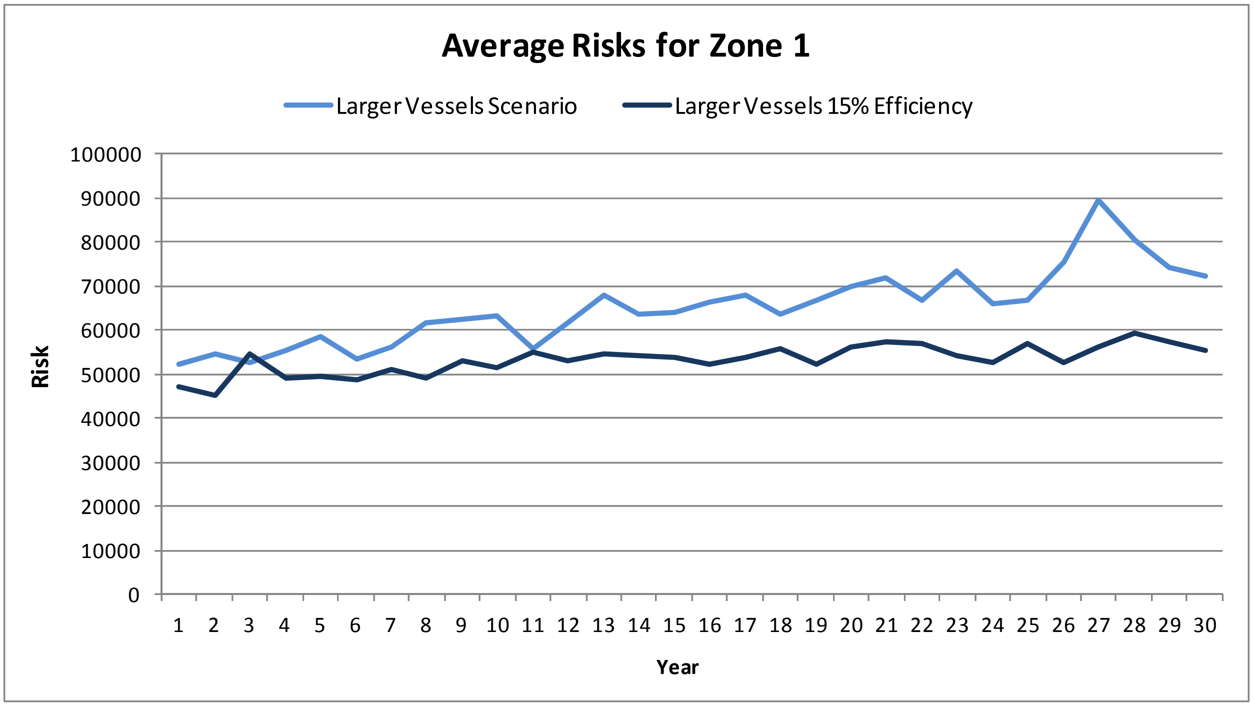


Figure 4.32. Comparison of Scenarios D and F for Zone 1

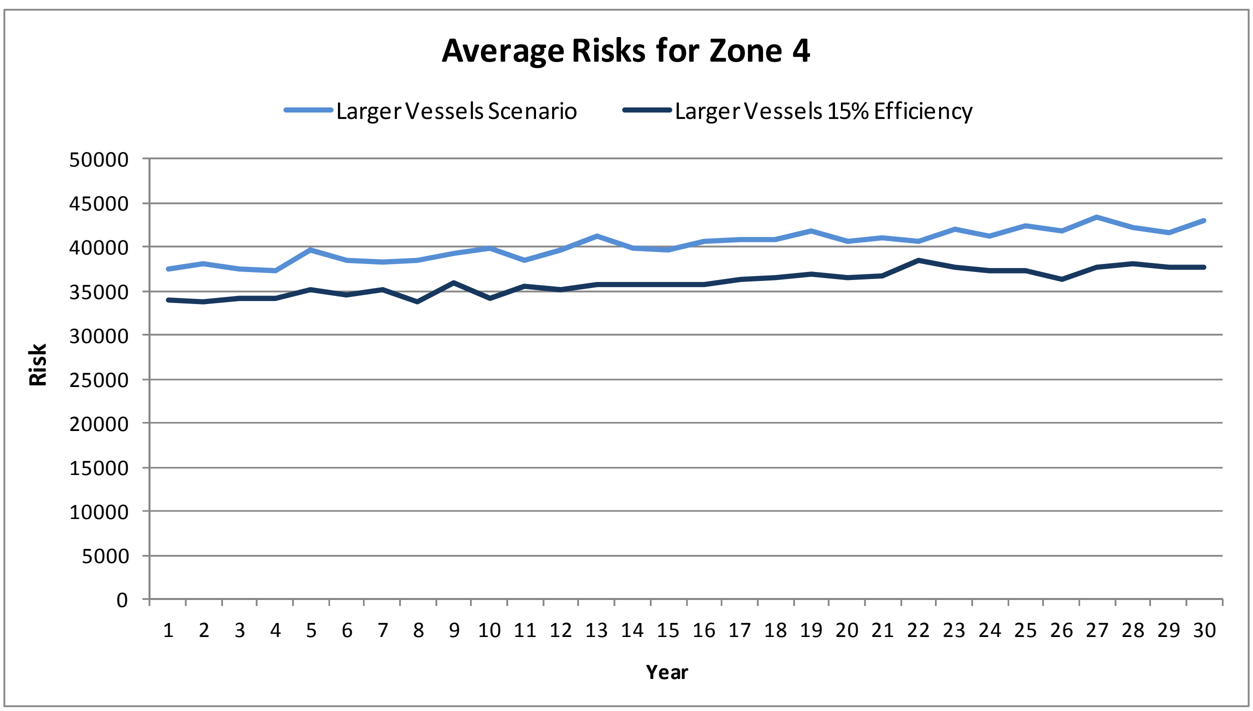


Figure 4.33. Comparison of Scenario D and F for Zone 4

Figure 4.34 provides an overall comparison of average total risks for all scenarios (B, D, E and F). It shows total risks (cumulative over zones) in the river averaged over each 10 years of the planning horizon. The figure reinforces the claim that higher operational efficiency decreases the average total risks in the river. It also emphasizes the risk advantage of the large vessel scenario (recall that the large vessel scenario is the one where the river is deepened and large vessels are brought in).

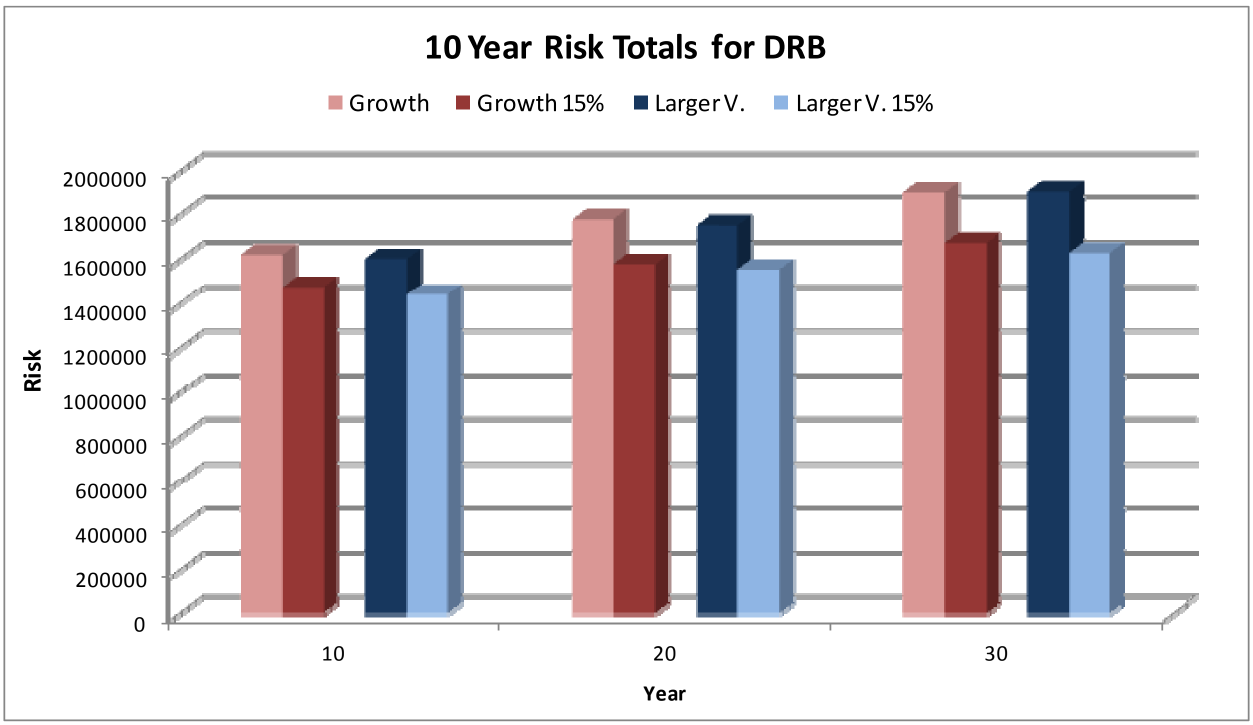


Figure 4.34. Total risk comparison of all 4 scenarios

4.7. Conclusions on Risk Analysis

Delaware River has a number of major petroleum refineries processing crude and other chemicals making it one of the most critical petroleum infrastructures in the U.S. The SAFE Port Act of 2006 (PL 109-711) requires Area Maritime Security Plans to ensure that commerce is quickly restored to US ports following a transportation security incident. Accordingly, this motivates the need to study the risks inherent in Delaware River and Bay vessel traffic, to better prepare strategies for post incident recovery.

In view of this, we have developed a model-based risk analysis approach to study potential incidents that would result in stoppages of maritime traffic in the river. The approach considers the causal chain of events with all the possible instigators, accidents and consequences, and uses the classical approach of (*Probability* × *Consequence*) to evaluate risks over all situations. To implement this approach, a mathematical risk model was developed to evaluate the risks of all possible situations as they are generated by the simulation model. Running the two models in lock step, a risk profile is obtained to show dynamic maritime risks in each of the 6 zones over several years. The risk profile shows where the higher levels of safety risks are in the river and suggests mitigation practices.

The approach has suggested that the risks in Zones 1, 3 and 4 are much higher compared to the rest of the river. This is mainly due to tanker and crude handling operations including lightering in Big Stone Beach Anchorage and loading and unloading operations in terminals upstream.

Numerical results indicate the following conclusions:

- Environmental consequences are higher than property damage and human casualty in all zones and especially so in Zone 1. This is also due to the fact that oil spill and grounding accidents are more frequent than others in almost every zone and especially Zone 1.

- Over the planning horizon, deepening and bringing larger vessels result in lesser risks in Zone 1 and slightly higher risks in Zone 4. It is also observed that average risks exhibit an increasing trend over 30 years.
- Due to the fact that the channel serves a number of industrial facilities, we have proposed a risk mitigation approach based on increased terminal efficiencies including the lightering operation. Such a mitigation approach would not only encourage the facilities to be more efficient in vessel handling and cost effective but also produce risk savings by moving vessels out of the system faster and resulting in a lesser number of them in the channel. A demonstration showed that a 15% increase in operational efficiency produced maximum risk reductions between 28% to 33% in scenarios including deepening.

5. VESSEL PRIORITIZATION FOR RESUMPTION OF TRADE

5.1. Introduction

Delaware River is a major port of entry for energy commodities, such as crude oil (petroleum), and liquefied petroleum gas (LPG) and other important commodities such as chemicals, food products, cars, steel coils and many others essential to the U.S. economy. The U.S. national economy is highly dependent on imported energy products, which are shipped from overseas in tankers. To wit, in 2005, approximately 55% of the nation's crude oil supply and approximately 3% of the natural gas supply was imported by tankers. Daily maritime-based imports of crude oil averaged about 8.5 million barrels, or equivalently four super tankers a day. A global supply chain moves energy commodities to the U.S. from international sources (e.g., crude oil from Venezuela, Mexico, Saudi Arabia, and Nigeria, and LNG from Algeria and Caribbean nations). This supply chain involves loading (typically under the control of foreign public and private organizations), transporting (in vessels belonging to numerous companies) over international routes, and unloading at petrochemical port facilities in the U.S. Delaware River houses a number of oil/petroleum terminals (e.g., Fort Mifflin (DE), Marcus Hook (PA), Valero Paulsboro (NJ), Conoco Philips (PA), Delaware City (DE) Wilmington Oil Pier (DE)).

Maritime trade in DRB is achieved via maritime transportation and operations at the terminals in the river. Clearly, any length of port closure will hinder the flow of cargo in and out of the port and it needs to be resolved as rapidly as possible. The incident may be safety related or security related. The common understanding is that the response to an incident must not unreasonably affect the free flow of goods, while simultaneously reducing risk to an acceptable level.

As required by the SAFE Port Act, trade resumption and prioritization of maritime cargo, which represents 95 percent of the cargo tonnage that comes to the United States receives special attention. Such tactical plans will be or have been developed with input from the trade community, though the final plans may by nature remain classified or sensitive.

In this part of the project, we are concerned with the resumption of trade which is the final stage of recovery from an incident. Clearly, faster recovery is desirable. The measure of resiliency is dependent on how fast the port recovers. As part of this process, once the incident is cleared, decisions are made, by the AMSC and the USCG sector commander, on the priorities of the resumption of trade.

5.2. Literature Review

While vessel prioritization is known and considered an important issue in port and waterway management, literature on this topic is quite weak. In fact, to the best of our knowledge, no directly related published work exists in this area. In this section, some prior work in disaster recovery that is related to our interest in this study will be reviewed below.

Altay and Green (2006) present a review of OR/MS[3] literature on disaster operations management. The authors indicate that typical recovery activities include debris cleanup, financial assistance to individuals and organizations, rebuilding of roads, bridges and key facilities, sustained mass care for displaced human and animal populations and full restoration of lifeline services, among others.

DeBlasio (2004) presents a case study of four U.S. disasters and what actions were taken to mitigate them in the days after the disaster. It highlights advance preparation, technical communication systems usable during the incident, advanced ITS facilities and traffic management centers and systems that are redundant and resilient.

Bryson (2002) proposed mathematical modeling techniques for disaster recovery planning based on arguments of feasibility, completeness, consistency, and reliability. An example of a mixed integer linear programming model was developed to select the best disaster recovery plan under limited resources. Ham (2005) discusses reconstruction of interregional commodity flow over a transportation network after a major earthquake.

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[3] Operations Research and the Management Sciences

Lee and Kim (2007) propose strategies for post-event reconstruction to minimize time of recovery and economic loss. They proposed a model to minimize total time for recovery that is calibrated to favor shorter recovery even at greater economic loss. Selection of optimal recovery strategies is done via a genetic algorithm and simulated for use over bridges in the Chicago area.

Friedman et al. (2009) DIETT[4] provides a means to adapt Microsoft Access, and Excel for use in evaluating transportation choke points (TCP's) in a regional or state setting. The value of this electronic product rests in the adapted algorithms allowing a user to enter data about their transportation network, and be provided with a relative risk of TCP's for further evaluation, and for use in traffic planning situations for emergency purposes.

5.3. Prioritization for Resumption of Trade

Objective in vessel prioritization is to identify the set of products that the region has immediate needs and deliver them on a timely manner. While doing that, it must be understood that every shipper's products are important but some have urgency over others such as heating oil in winter food products at any time have more urgency when compared to TV sets or music players.

At the local level, for the incident site or region, the Incident Commander or Unified Command will work with local stakeholders to analyze conveyance, facility-specific information and needs, incorporating national, regional and local priorities for bidirectional commodity flow as well as sequencing into the local decision making process.

Local prioritization for cargo or commodity movement is achieved based on several factors: These are safety, security and commodity based factors summarized below:

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[4] Disruption Impact Estimating Tool-Transportation (DIETT): A Tool for Prioritizing High-Value Transportation Choke Points

The security status of the vessel:

- Is the vessel cleared for entry into a United States seaport based on established or incident specific screening procedures?
- Are resources available to inspect or otherwise clear the vessel for entry, if necessary?
- Is any of the cargo on the vessel suspect, or deemed 'high risk' by CBP's ATS using any new revised risk scoring based upon the incident?
- Are resources available to implement required security measures on the vessel's inbound and outbound transit?
- Is the vessel operated by a trusted partner, such as a validated participant in the C-TPAT program?

The ability of vessels to transit to and from its berth:

- Are there berthing/space/facility issues?
- Are there waterway functionality issues (no obstructions, operating Aids to Navigation (ATON), etc.)?

The capacity of the port infrastructure to offload the cargo or commodity and move it from the port:

- Are there labor issues?
- Are there inter-modal issues?
- Are there space or facility issues?
- Is there CBP resource availability to clear cargo or commodities once landed?

Commodity needs:

- What are the national priorities?
- What are the regional priorities?
- What are the local priorities (seasonal, etc.)?

- The need for the vessel to move cargo out of the port (e.g., grain shipments needed to be shipped in order to avoid shutting down other transportation modes such as railways).

These factors must be continually assessed and integrated by the Incident Commander/Unified Command, in consultation with the USCG COTP/FMSC, the CBP Port Directors, the TSA Federal Security Director, ocean carriers, and terminal operators to establish daily priorities for vessel/cargo movement both into and out of port.

At the national level, the Secretary of Homeland Security, the Domestic Readiness Group (DRG), or agency leadership as appropriate may set national priorities for vessel and cargo movement based on the incident specific and extended impacts. The Commandant of the Coast Guard, the TSA Administrator, and the Commissioner of CBP will continually assess the security or intelligence status, as the situation dictates, to make adjustments to nationally established security requirements for cargo and vessels. This may include changes in security levels and/or changes in the risk factors (or weights on the risk factors) to be assessed in the vessel, cargo or commodity screening and clearance processes. This assessment will be coordinated with the Department of Transportation with respect to intermodal connection of cargo movement via rail, highway and pipeline from/to the port cargo terminals.

National commodity priorities may cover, but are not exclusive to:

- Emergency Needs: those goods necessary for the saving and continuation of life. (Examples include personnel and supplies for medical response, restoration of power, and potable water.)
- Response Needs: personnel and equipment necessary to conduct response operations at the incident site (i.e. fire boats).
- Commodity Needs: the incidents may create immediate shortages of necessary commodities that must be addressed. (Examples are crude oil, heating oil and chemicals necessary for industrial continuity, and drinking water.) Community needs may also have a delayed time component based upon “on hand” stocks.

Industry, either via the Planning Section Recovery Unit, national advisory committees, and subject matter experts must be queried to identify these commodities.

- National Security: the incident may impact national security concerns, such as cargo movements via strategic load-out ports in support of Department of Defense assets, requiring specific coordination or prioritization of support assets, e.g. small vessels to conduct escort duties.

Assuming that vessel security and safety issues are handled by the USCG and other agencies, in this project, we focus on the issues regarding sequencing of vessels and decisions regarding the direction of the flow (inbound or outbound) to resume trade. Below, we first briefly review the case of Athos I which was a grounding resulting in a major oil spill in DRB. Later we provide the scenarios considered in this project.

5.4. The Case of Athos I in 2004

On Friday, November 26, 2004, at approximately 9:15 p.m., the 750-foot, single-hull tanker Athos I, registered under the flag of Cyprus, was reported to be leaking oil into the Delaware River en route to its terminal at the CITGO asphalt refinery in Paulsboro, New Jersey. It had two punctures in its hull (Source: University of Delaware).

On January 18, 2005, the Coast Guard released photographs of an anchor that has been removed from the Delaware River for analysis as part of their continuing investigation into the spill incident. The anchor and an 8-by-4-foot slab of concrete were found in the tanker's path to the refinery dock. Approximately 265,000 gallons of oil spilled into the Delaware River from the T/S Athos I.

The spill has affected approximately 115 miles of shoreline along the tidal portion of the Delaware River, from the Tacony-Palmyra Bridge, which links northeast Philadelphia to Palmyra, New Jersey, south to the Smyrna River in Delaware. In response to the initial threat, Public Service Enterprise Group (PSEG) temporarily closed two reactors at the Salem Nuclear Power Plant along the river at Artificial Island, New Jersey.

After a three-day shutdown of the Port of Philadelphia immediately after the spill, commercial vessels were allowed back into the port, but were required to undergo a decontamination process prior to leaving the affected area.

5.5. Incident Scenarios to be Considered for Investigation

In this project, an incident was considered to take place in Paulsboro blocking the traffic in the main channel. The incident is similar to the case of Athos I, described earlier. Three cases were considered, two with a major oil spill and cleanup effort (Cases A and B) and the other with medium level environmental consequence (Case C). The duration of the closure is assumed to be 3 days for Cases A and B (as was the case of Athos I incident) and 2 days for Case C.

Details of the three cases are described below.

Case A involves a major oil spill with a potential of spreading to other parts of the channel and therefore restricts vessel movements in the river. Case B is a variation of A in that it delays the inbound vessels up to a certain time before they start moving in. Case C, on the other hand, while keeping the channel closed, still allows vessel movements in the southern points of the incident. This will allow vessels to go from one terminal to another in their respective parts of the channel without crossing the blockage point. Thus, Cases A and B nearly put the channel into a state of freeze until the incident is cleared, while Case C retains some flexibility in vessel movements. In both cases, resumption of flow will be achieved based on a prioritization mechanism which is the focus of this part of the project.

Vessel prioritization has a direct impact on vessel waiting times to enter the channel and port times. In both cases tankers and reefer vessels carrying food products will be given higher priority over other vessels. Below we discuss each case in detail.

Case A: Major Consequence Channel Closure

This case involves a major spill with a potential of spreading to other parts of the channel and therefore vessel movements in the river are restricted. Vessels that are already on the move either south or north of the spillage point when it occurs are asked to anchor at the closest location possible. Loading/unloading operations at terminals continue unaffected; however the vessels that are ready to leave will not be permitted to do so until the incident is completely cleared. Also, no new vessels are allowed to enter the channel until the incident is over. Once the incident is over, vessels already in the river continue their navigation. Vessels at terminals are allowed to leave. Inbound flow of vessels will be based on a prioritization mechanism.

Case B: Major Consequence Channel Closure with Delay in Inbound Flow

Case B is a variation of Case A where the inbound vessels are delayed up to a point in time which may be determined by the number of vessels remaining in the river (e.g., inbound flow starts when there are a total of 10 vessels in the river) or by a time threshold (e.g., inbound flow starts in 5 hours after the incident is cleared). Thus in this case, the inbound flow starts after some delay giving the system a chance to release some outgoing vessels before the inbound flow starts.

Case C: Medium Consequence Channel Closure

This case, while keeping the channel closed, still allows vessel movements in the southern points of the incident. This will allow vessels to go from one terminal to another in the southern part without crossing the blockage point. This is a common practice in such incidents and geographies if the incident does not pose a threat to operations in major parts of the waterway and yet keeps the channel closed. Vessel entrances to and departures from terminals south of the blockage will be done in a normal manner at any point in time. Once the incident is cleared, vessels in the northern part of the incident will continue their movements from the point of interruption. New arrivals destined to northern points will be allowed to move upriver based on a prioritization mechanism.

Vessel handling during as well as after the incident will be as follows:

In all cases, vessels arriving during the incident are placed into a queue at both entrances, referred to as closure queues. Even after the incident is cleared, new arrivals are placed into these queues as long as there are vessels in them. After the incident is cleared, vessels from closure queues proceed to the river in a sequence arranged according to a priority and a vessel pursuit distance. In prioritizing vessels in closure queues, higher priorities are given to tankers and refrigerated vessels. Also, 15 and 45 minute pursuit distances were evaluated to better understand the impact of pursuit distance on performance and risk behaviors. Clearly, both priority and the pursuit distance have an impact on the vessel waiting time in the queue.

In all these cases, we have focused on how fast the system returns to normal after the incident is cleared. Here we propose to define "Time to Return to Normal" as the time from the incident occurrence to the point in time when there is no vessel left in the queue. This is probably the most important measure in planning for disaster preparedness scenarios and exercises. From this point on no arriving vessel is put in this queue and normal operations resume. Various types of information about the queue such as waiting times and numbers of vessels waiting are obtained from the simulation model.

Note that there is the risk component in managing the vessel queue. As soon as the incident is cleared, there will be a number of vessels moving into the river and clearly there will be increased vulnerability to accidents with potentially high consequences. Mitigating these risks during the recovery process is a major challenge, and both priority and pursuit distance have impact on the resulting risks. Experiments in the following section will shed some light on the performance and risk issues surrounding the priority queue in entering the river.

5.6. Experiments with the Model of DRB

In this section, various experiments that were carried out with the traffic simulation model are introduced and the results discussed. The experiments centered on the impact of priority (PR) and pursuit distance (PD) on time to normal, waiting times and risk outcomes of the recovery process.

The incident was set on November 1st (the 305th day of the year) with a duration of 3 days in Cases A and B and 2 days in Case C. The model was run for 1 year with 30 replications to create a reasonable sample size to make reliable estimations.

In each case, performances of the following three policies were tested in numerical experimentation.

- First-In-First-Out (FIFO) service in closure queues with 15-minute pursuit distance in BW entrance,
- Priority service in closure queues with 15-minute pursuit distance in BW entrance,
- Priority service in closure queues with 45-minute pursuit distance in BW entrance.

Closure queue performance is expressed using the following measures:

Closure queue clearance time is the time to clear closure queues from the point in time the first vessel is picked up from the queue until the time when no vessel remains in the queues.

Time to normal is the time the incident starts until the time when no vessel remains in the queues.

Cumulative waiting time is the total time of all the vessels visiting closure queues.

Total number of vessels in queue is the total number of vessels visiting closure queues.

All vessels – waiting time is the average waiting time of all vessels visiting closure queues.

Tankers – waiting time is the average waiting time of all tankers visiting closure queues.

Refrigerated vessels – waiting time is the average waiting time of all refrigerated vessels visiting closure queues.

Other vessels – waiting time is the average waiting time of all vessels other than tankers and refrigerated vessels visiting closure queues.

Results of the experiments are discussed below.

5.7. Performance Implications of Vessel Prioritization

Table 5.1 provides a comprehensive summary of the results for priority and pursuit distance alternatives in all cases showing results for key performance measures regarding closure queues.

In Case A, both priority and FIFO service disciplines affect all measures equally except that tankers and refrigerated waiting times are shorter when there is priority. As expected, the average waiting time is the only measure that changes when comparing FIFO against PR discipline. Waiting times of other vessels are slightly longer in the priority scenario. The pursuit distance of 15-minute results in 6 hours of closure queue clearance time while the extended 45-minute pursuit distance produces a 30 hours clearing time.

In Case B, due to the delay until 10 vessels remain in the system, longer clearance times, longer times to normal (resulting in larger number of vessels in the closure queue) and longer waiting times are produced when compared to Case A.

The reason for tanker waiting times being shorter in the 45-minute (as opposed to 15-minute) pursuit distance priority scenario (also true for Case A) is that the tankers arriving after the incident is over and still visiting the closure queue have much shorter waiting times compared to the ones already in the system during the incident. This reduces the average waiting times in the priority case.

Prioritizing tankers and refrigerated vessels will again result in shorter waiting times when comparing priority and FIFO scenarios in each of 15-minute and 45-minute pursuit distances. All-vessel waiting times and times to normal tend to remain unchanged in each of the priority and FIFO cases.

Case C is the closest to no-incident or normal operation scenario and therefore all the performance measures are much smaller than their counter parts in Cases A and B. In particular, there are much smaller numbers of vessels in closure queues and therefore priority or FIFO scenarios do not change in their behaviors.

Thus, conclusions from Table 5.1 include Case C is the most desirable among all cases with minimum waiting times, queue clearance times as well as times to normal. Thus, if possible, the channel should operate like the one in Case C in the case of an incident. This is the best performing operation. If it is not possible, Case A is the next choice based on time to normal and clearing times. If it is a necessity, Case B may be chosen provided that it offers some other benefits not considered here. Whatever case is selected, prioritizing tankers and refrigerated vessels over using the FIFO discipline in closure queues is beneficial with respect to waiting time measures while keeping time to normal unchanged. The priority scenario will perform even better in scenarios with longer pursuit distances. The choice of the pursuit distance whether it is 15 minutes or 45 minutes (or some other interval) should be based on another measure such as risk, which will be discussed later in this section.

Table 5.1 - River Closure Scenarios and Reopening Results

Performance Measures *(Time in minutes)*		*Closure Queue Clearance Time*	*Total Time to Normal*	*Cumulative Waiting Time*	*Total No of Vesssels in Queue*	*All Vessels - Waiting Time*	*Tankers - Waiting Time*	*Refrigerated Vessels - Waiting Time*	*Other Vessels - Waiting Time*
Case A - Complete Closure	FIFO (PD: 15min)	489	4824	77235	35	2201	2209	2323	2179
	Priority (PD: 15min)	486	4821	75741	35	2171	2092	1642	2246
	FIFO (PD: 45min)	1958	6293	99629	46	2169	2144	2150	2177
	Priority (PD: 45min)	1872	6207	96316	45	2152	1774	1822	2319
Case B - Complete Closure with Inbound Delay	FIFO (PD: 15min)	672	6361	138880	48	2818	2852	2810	2825
	Priority (PD: 15min)	647	6568	138330	46	2875	2679	2526	2991
	FIFO (PD: 45min)	2441	8529	180250	58	2974	3016	2827	2967
	Priority (PD: 45min)	2555	8537	192500	60	3020	2216	2800	3348
Case C - Partial Closure	FIFO (PD: 15min)	179	3074	17465	12	1444	1635	880	1420
	Priority (PD: 15min)	169	3064	16553	11	1458	1431	767	1484
	FIFO (PD: 45min)	575	3470	17691	13	1397	1228	871	1422
	Priority (PD: 45min)	645	3540	21640	15	1471	1178	1251	1557

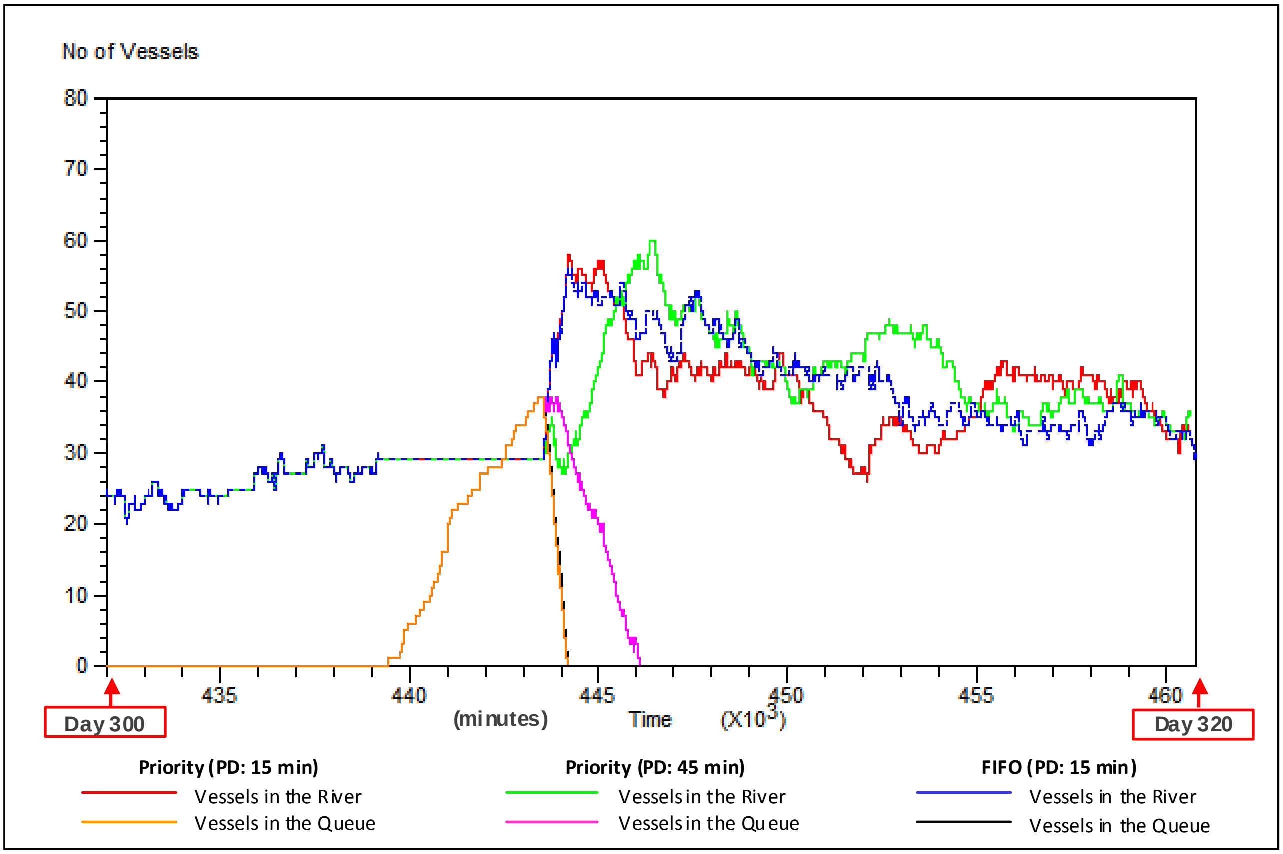

Figure 5.1. Number of Vessels in the River and in the Closure Queue between Days 300 and 320 in Case A – Full Closure (PDs are given in parenthesis)

Next let us look at the behavior of the number vessels in the system around the time of the incident and thereafter. Figure 5.1 shows the number of vessels in the river and in the Closure Queue between Days 300 and 320 in Case A. The incident occurs right before 440,000th minute in the run and the number of vessels in the system remains the same until the incident is over at around 444,000th minute at which point vessels start moving into the river. As can be seen, the number in the closure queue keeps increasing during the closure and rapidly zeros itself after the incident, increasing the number of vessels in the river in all three scenarios. Both of the 15-minute scenarios rapidly increase the number in the river almost in the same manner, as expected, while the 45-minute scenario gives a chance to the system to release some vessels and build slowly. In the remaining time all three scenarios seem to be quite comparable.

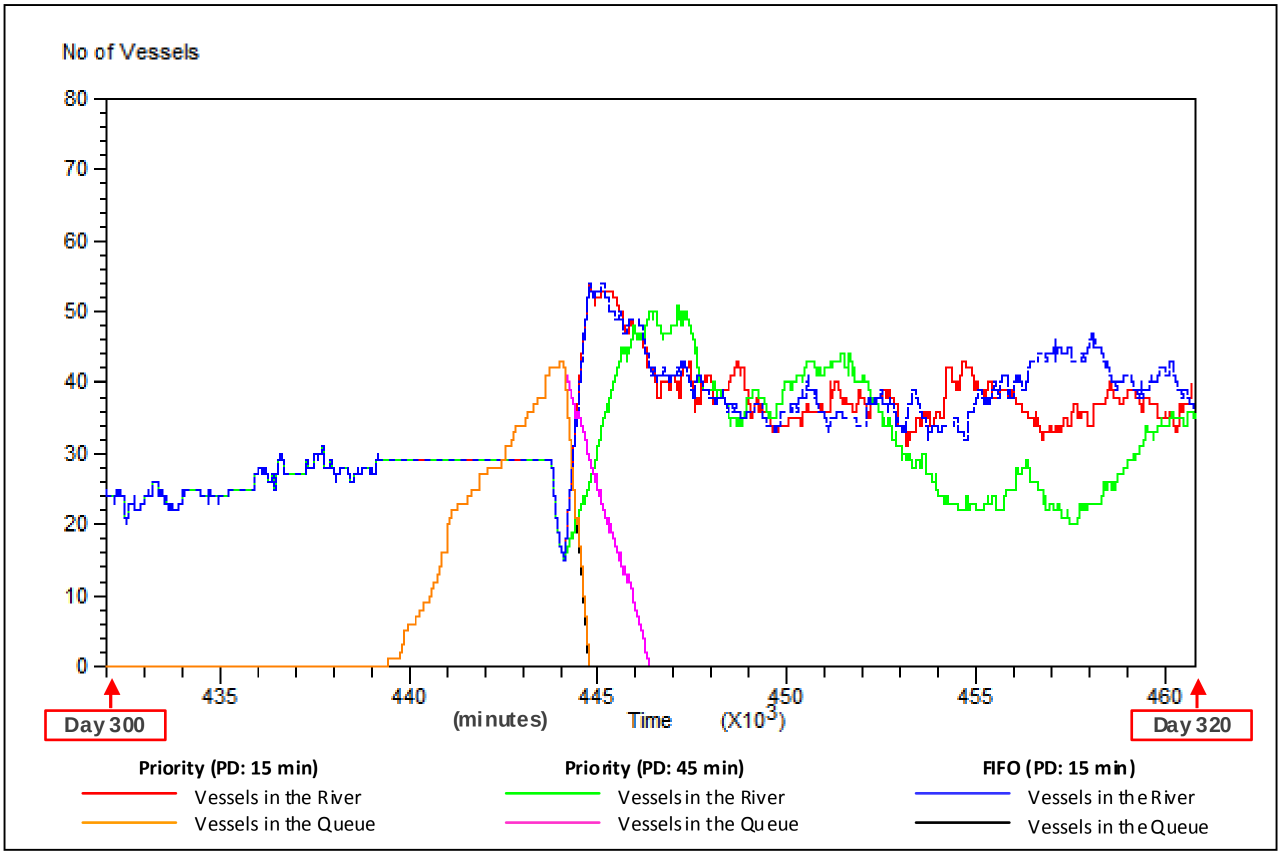

Figure 5.2. Number of Vessels in the River and in the Closure Queue between Days 300 and 320 in Case B – Full Closure with Inbound Delay (PDs are given in parenthesis)

Figure 5.2 shows a similar behavior except that river opens with a delay and vessels keep accumulating in the closure queue up to the point of opening after which the number in the queue rapidly drops to zero increasing the number in the river. Again, the 15-minute scenarios build vessels in the system rapidly as compared to 45-minute scenario and the behavior after that is quite similar to Case A.

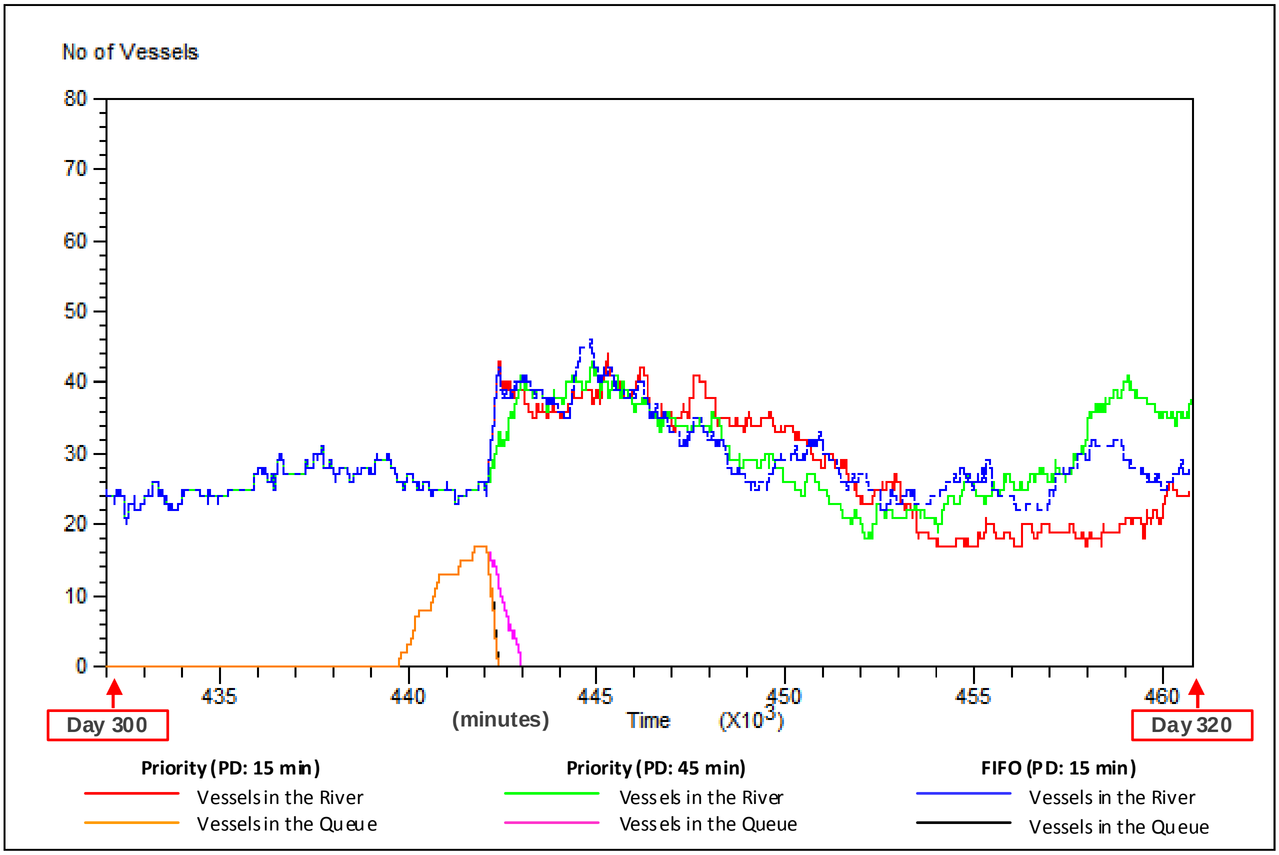

Figure 5.3. Number of Vessels in the River and in the Closure Queue between Days 300 and 320 in Case C – Partial Closure (PDs are given in parenthesis)

Figure 5.3 shows again a similar behavior except that accumulation in the closure queue is not much due to the fact that the operation at the south of the incident is close to normal conditions. After opening, the number in the closure queue rapidly drops to zero slightly increasing the number in the river. The three cases here exhibit a very similar behavior and operate close to normal conditions.

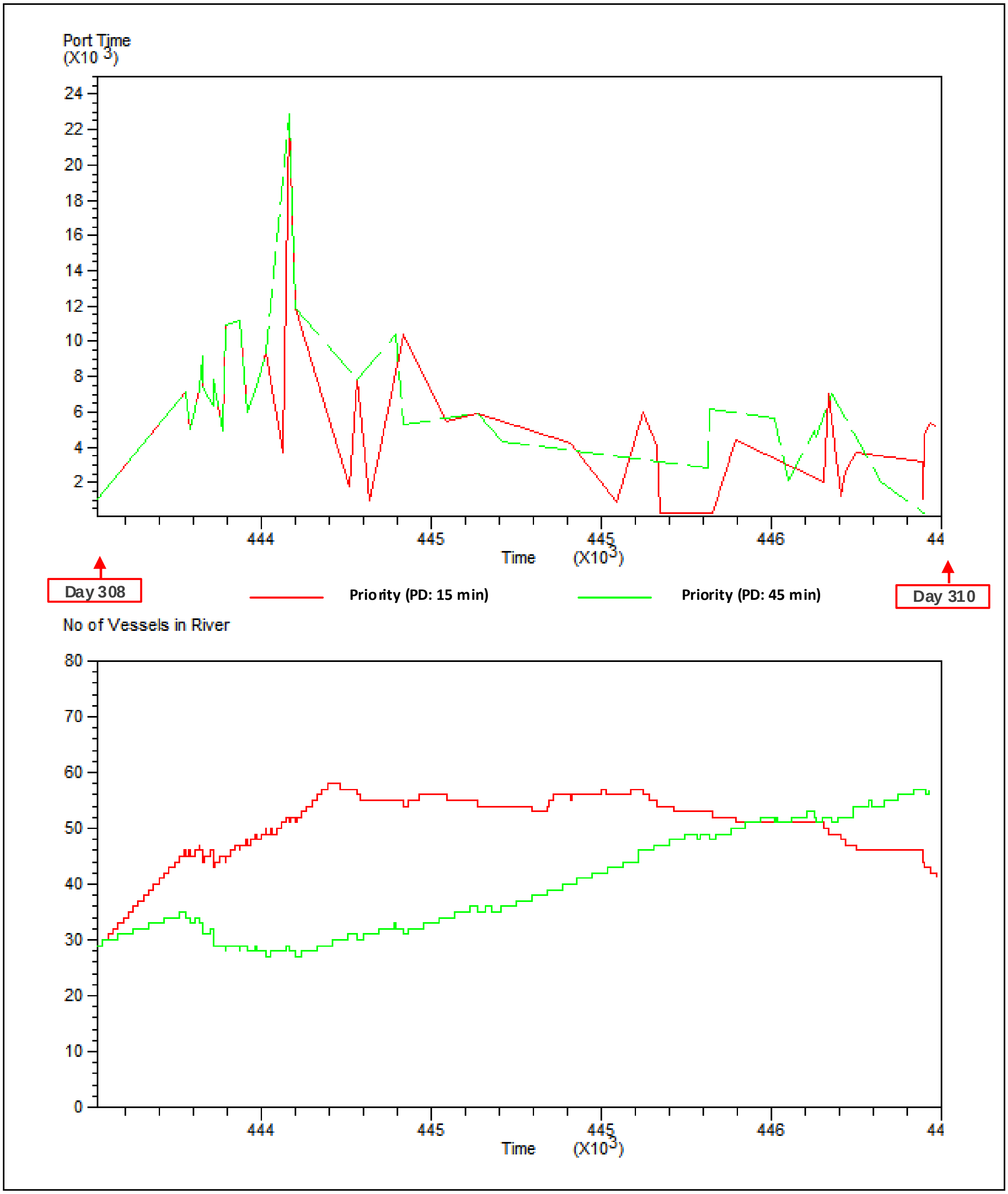

Figure 5.4. Vessel Port Times and Number of Vessels in the River between Days 308 and 310 in Case A – Full Closure (PDs are given in parenthesis)

Figure 5.4 shows vessel port times and the number of vessels in the river between days 308 and 310 in Case A. Vessel port times are slightly higher in the 45-minute scenario after the incident is over and this behavior continues after a while until the system returns to normal operation. The buildup in the 15-minute scenario is clear in the number of vessels in the system.

In Case B, as Figure 5.5 indicates, the port times are completely dominated by the 45-minute scenario and the number in the queue is dominated by the 15-minute scenario. Again, there should be added benefits to work with this case in reopening ports.

Case C, in Figure 5.6, shows a behavior very similar to operation under normal conditions. Both port times and the number of vessels in the closure queues show very similar behaviors under the two 15-minute scenarios. Again, clearly this is the most preferable case in reopening ports for resumption of trade.

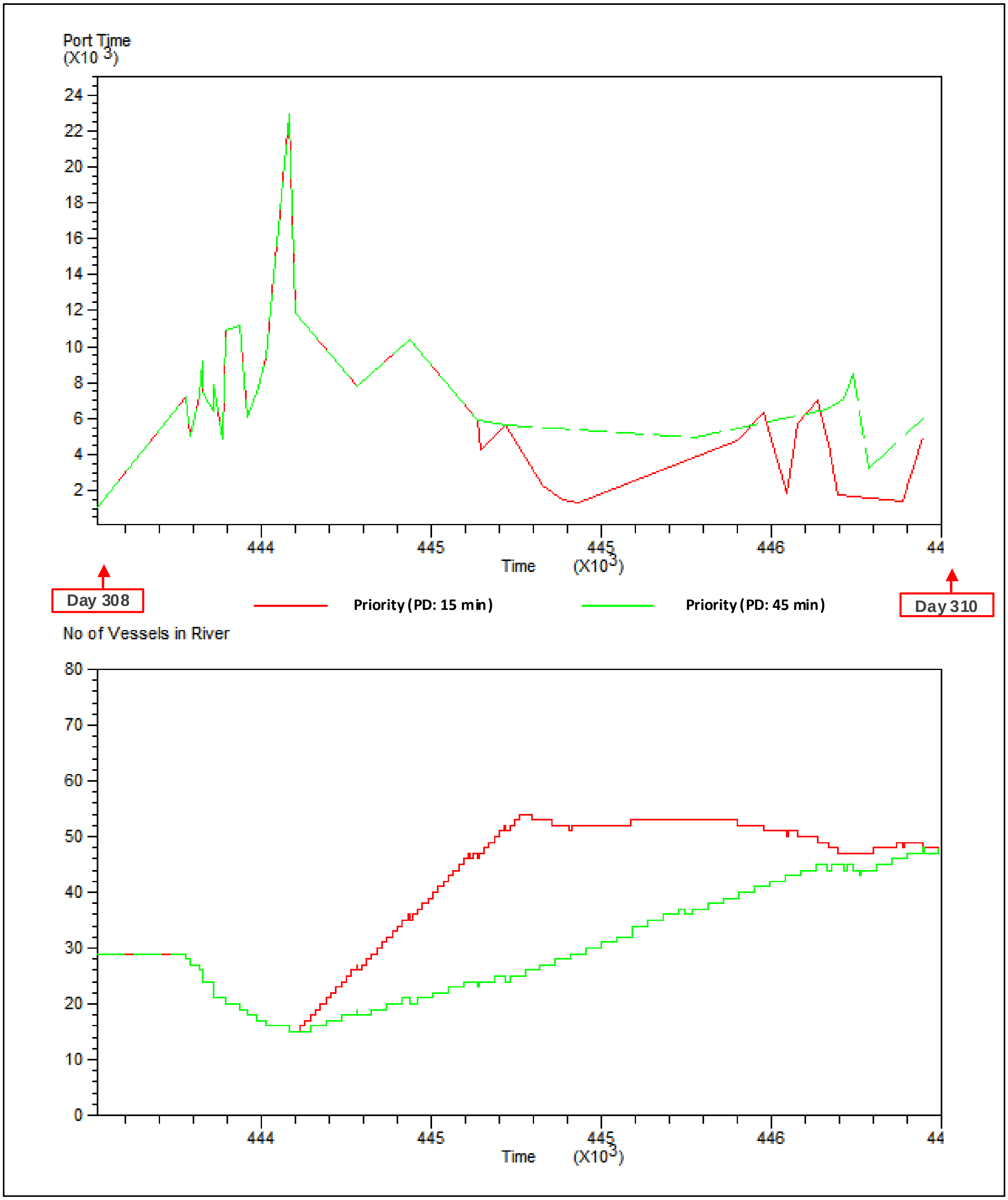

Figure 5.5. Vessel Port Times and Number of Vessels in the River between Days 308 and 310 in Case B – Full Closure with Inbound Delay (PDs are given in parenthesis)

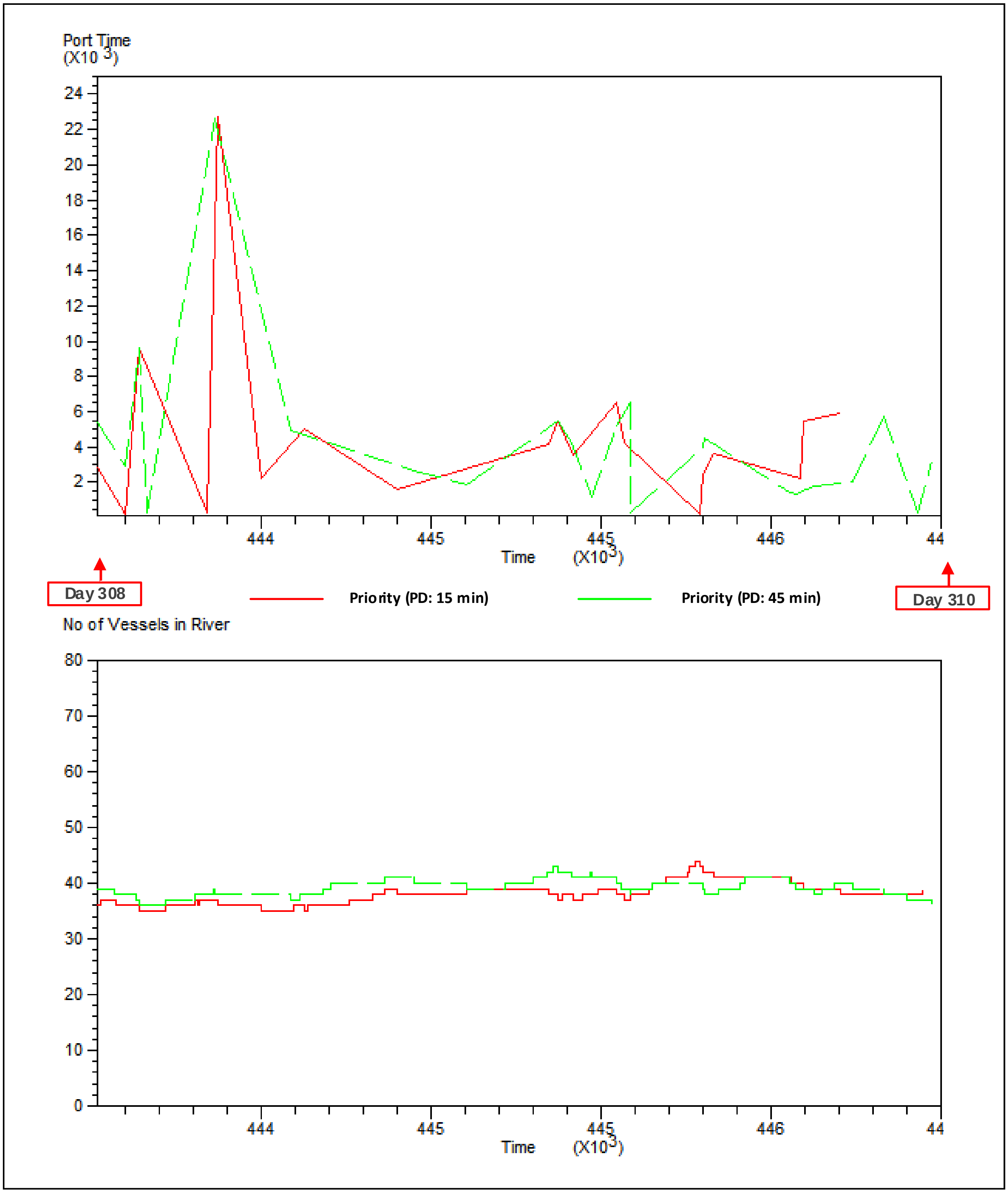

Figure 5.6. Vessel Port Times and Number of Vessels in the River between Days 308 and 310 in Case C – Partial Closure (PDs are given in parenthesis)

5.8. Risk Implications of Vessel Prioritization

In this section, the risk implications of Cases A through C with service discipline and pursuit distance scenarios are investigated. In other words, risks resulting from policies used to manage closure queues are to be discussed. Safety risks in Zones 1 and 4 will used to compare each case and scenarios.

Figure 5.7 shows risks of the three pursuit distance scenarios for Case A in Zone 1. The spike in risks is clearly visible after the closure queue opens up on day 308. Table 5.2 on the other hand shows statistics of risks obtained after day 308 up to day 320 which appears to be the time the system behavior returns to normal. In the twelve days after opening, the risks of the priority scenario with 45-minute distance produce greater average risk with a lesser maximum. It also produces lesser variation as compared to the 15-minute distance case. Greater risk is due to accumulation of more tankers during the clearance time and their prioritization to the front of the queue. That is, 45-minute distance scenario brings tankers closer to each other between days 308 and 320 into the system and therefore increases the risks. The 15-minute scenario on the other hand serves the closure queue faster and lets the remaining tankers move into the system as they arrive. This produces much higher risks at the beginning but reduces them later in the same time frame up to day 320.

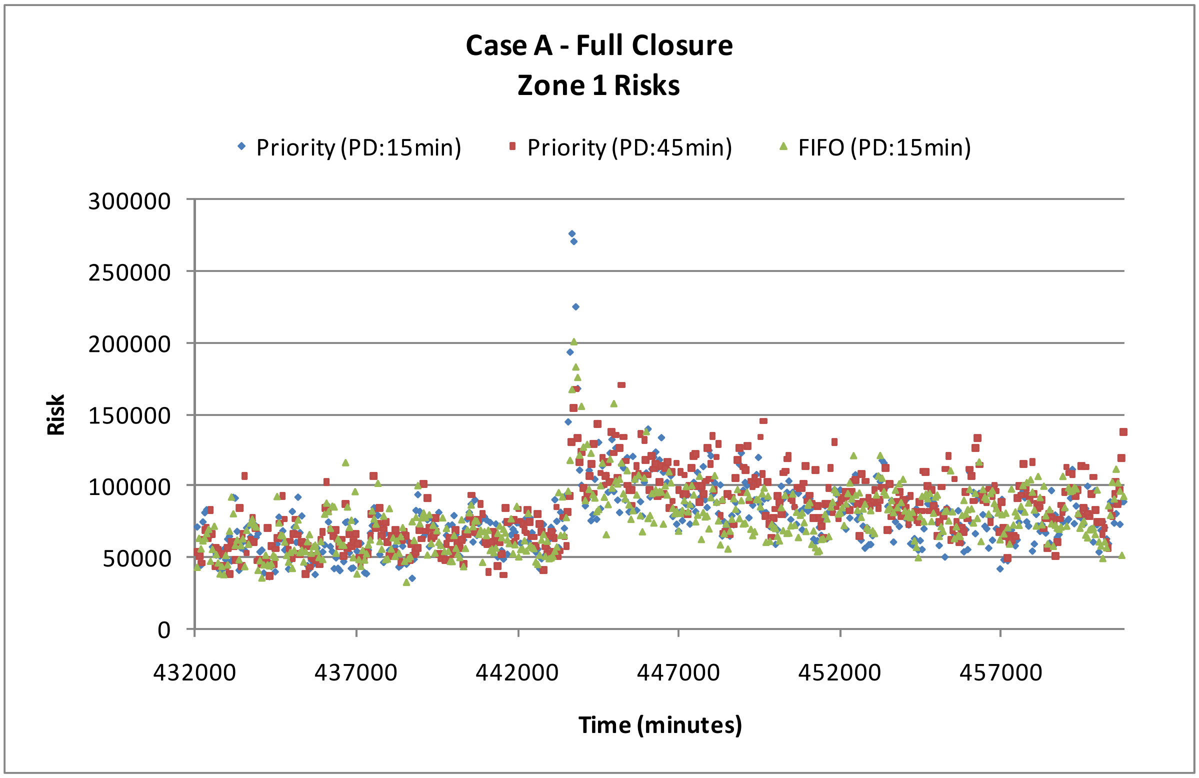

Figure 5.7. Zone 1 Risks between Days 300 and 320 in Case A – Full Closure

Table 5.2 - Zone 1 Risks between Days 308 and 320 in Case A – Full Closure

Scenario	Average Risk	Maximum Risk	Standard Deviation
Priority (15min)	86357	276407	26674
Priority (45min)	96067	170481	20053
FIFO (15min)	85524	200431	20215

Figure 5.8 shows risks of the three pursuit distance scenarios for Case B in Zone 1. Higher average risk is observed in the scenario with 15-minute distance after the opening of queues without spikes. In the twelve days after opening, the risks of the priority scenario with 15-minute pursuit distance appear to dominate the others. This is due to the fact that more tankers accumulate in queues due to the delay in opening and they are released into the river with 15 minute intervals. This generates more tankers in the system when compared to FIFO or the 45-minute distance scenarios. The average, maximum and standard deviation of the risks over days 308 and 320 in Zone 1 averaged over 30 replications are given in Table 5.3.

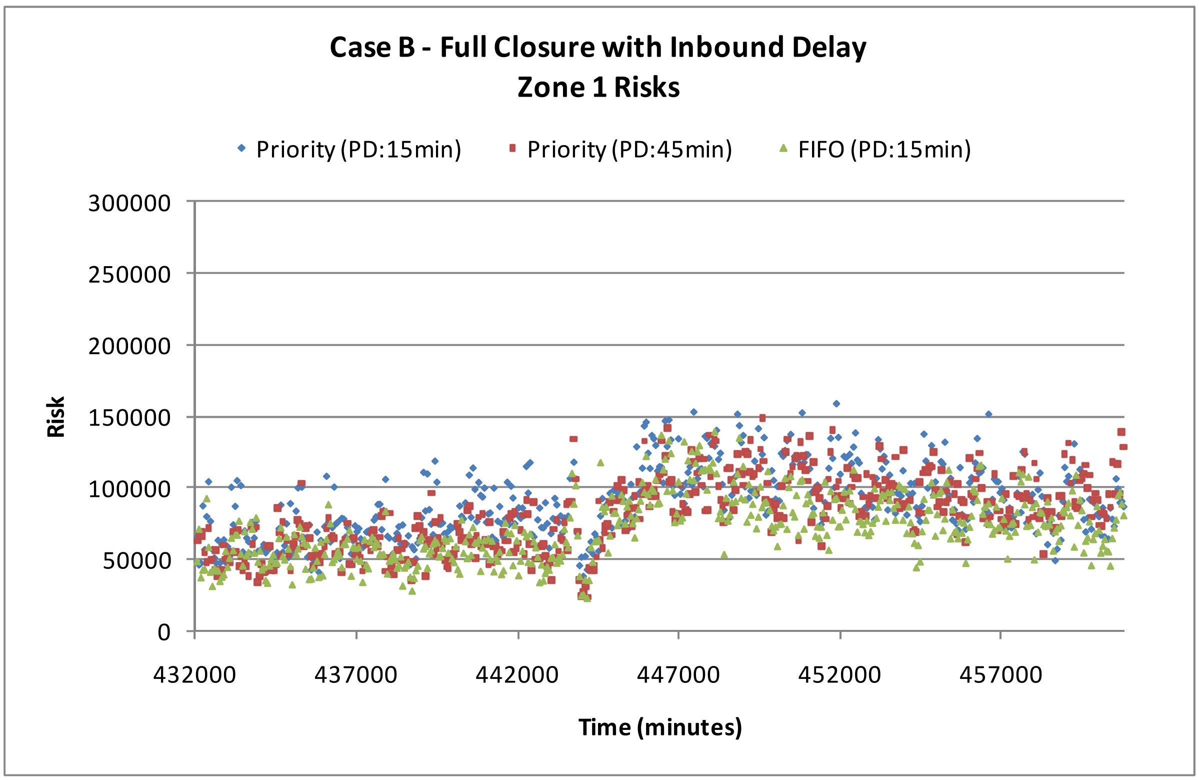

Figure 5.8. Zone 1 Risks between Days 300 and 320 in Case B – Full Closure & Delay in Inbound

Table 5.3 - Zone 1 Risks between Days 308 and 320 in Case B – Full Closure & Delay in Inbound

Scenario	Average Risk	Maximum Risk	Standard Deviation
Priority (15min)	99984	158420	22637
Priority (45min)	95276	149204	21147
FIFO (15min)	83503	138688	19536

Figure 5.9 and Table 5.4 show risks for Case C with the three pursuit distance scenarios in Zone 1. The risks behave similarly to the ones in Case A where 45-minute distance scenario produces the higher average. Note that Case C is the least risk case among the three cases and therefore the more desired case to operate under as it was concluded in the performance implications discussion.

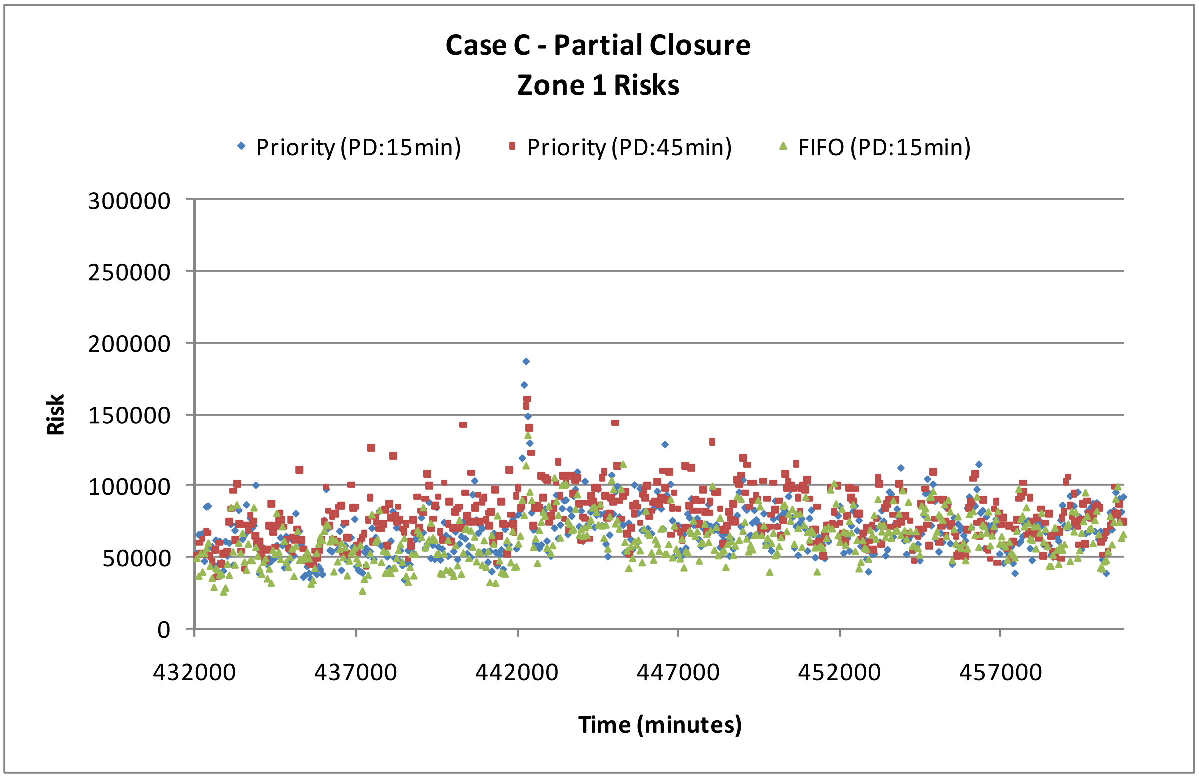

Figure 5.9. Zone 1 Risks between Days 300 and 320 in Case C – Partial Closure

Table 5.4 - Zone 1 Risks between Days 307 and 320 in Case C – Partial Closure

Scenario	Average Risk	Maximum Risk	Standard Deviation
Priority (15min)	73685	187332	17821
Priority (45min)	82303	160565	17930
FIFO (15min)	68252	135589	14995

It should also be mentioned that higher maximum risks are observed more frequently in Cases A and C as opposed to Case B as evidenced in Tables 5.2 through 5.4. Case B produces lower maximum risks due to the fact that system is already mostly cleared (10 vessels in the system) when the closure queue opens up.

Figure 5.10 to Figure 5.12 and Table 5.5 to Table 5.7 show risk behaviors of the three scenarios in Cases A through C in Zone 4. All three cases exhibit lower risks in Zone 4 when compared to Zone 1. Figure 5.10 and Table 5.5 show risks and related statistics of the three pursuit distance scenarios in Zone 4 and they both indicate higher risks in priority cases and especially the 45-minute distance scenario even though statistics of all scenarios are quite close to each other.

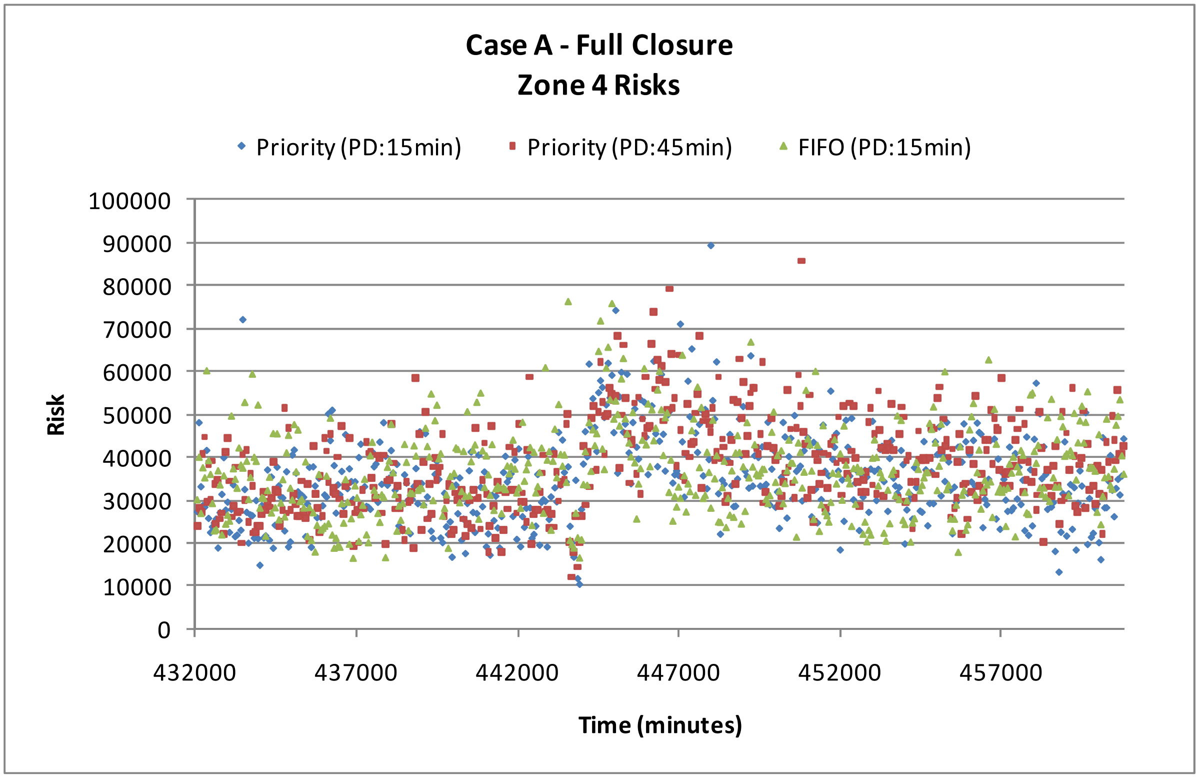

Figure 5.10. Zone 4 Risks between Days 300 and 320 in Case A – Full Closure

Table 5.5 - Zone 4 Risks between Days 308 and 320 in Case A – Full Closure

Scenario	Average Risk	Maximum Risk	Standard Deviation
Priority (15min)	38187	89400	10989
Priority (45min)	42102	85814	10715
FIFO (15min)	38100	76264	10713

Figure 5.11 and Table 5.6 show risks and related statistics of the three pursuit distance scenarios for Case B in Zone 4. Similar to Table 5.3, Table 5.6 indicate that the 15-minute distance scenario produces higher average and maximum risks for the same reason mentioned earlier for Case B, again even though statistics of all scenarios are quite close to each other.

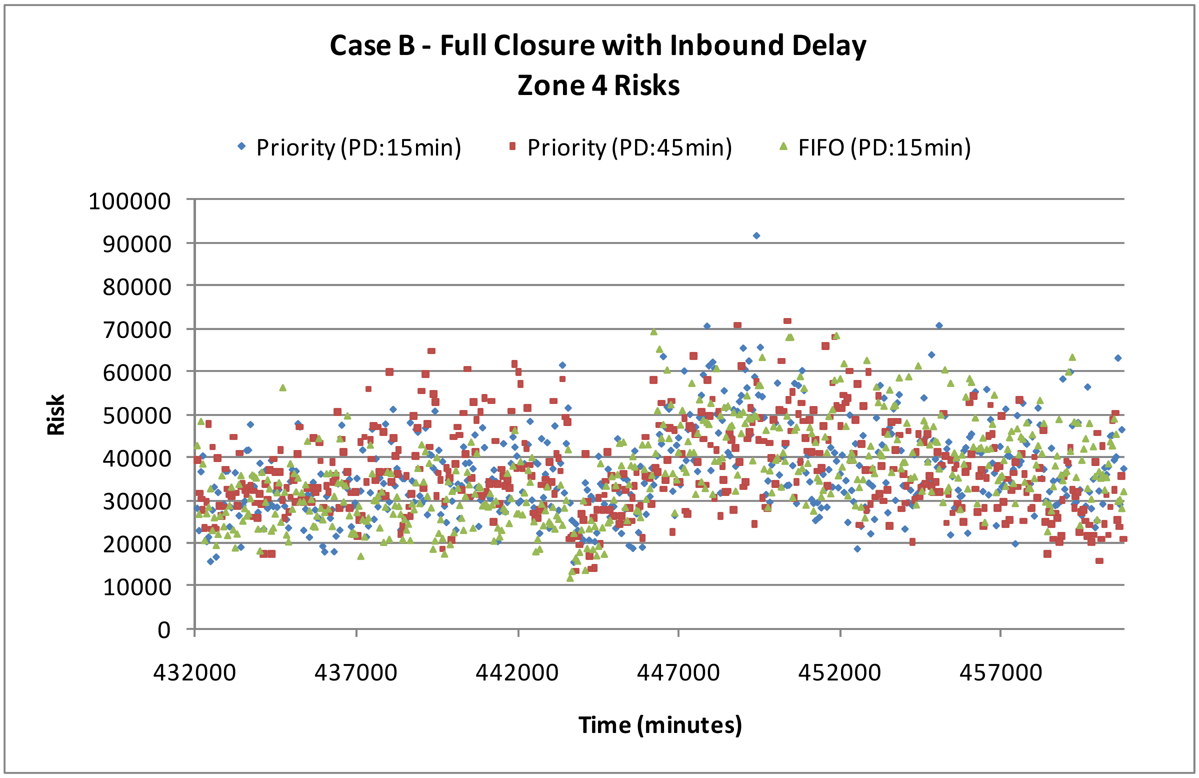

Figure 5.11. Zone 4 Risks between Days 300 and 320 in Case B – Full Closure & Delay in Inbound

Table 5.6 - Zone 4 Risks between Days 308 and 320 in Case B – Full Closure & Delay in Inbound

Scenario	Average Risk	Maximum Risk	Standard Deviation
Priority (15min)	38832	91564	11417
Priority (45min)	37043	71719	11047
FIFO (15min)	40089	69216	10766

Finally, Figure 5.12 and Table 5.7 show risks for Case C and indicate higher risks for the priority scenarios even though statistics of all scenarios are quite close to each other.

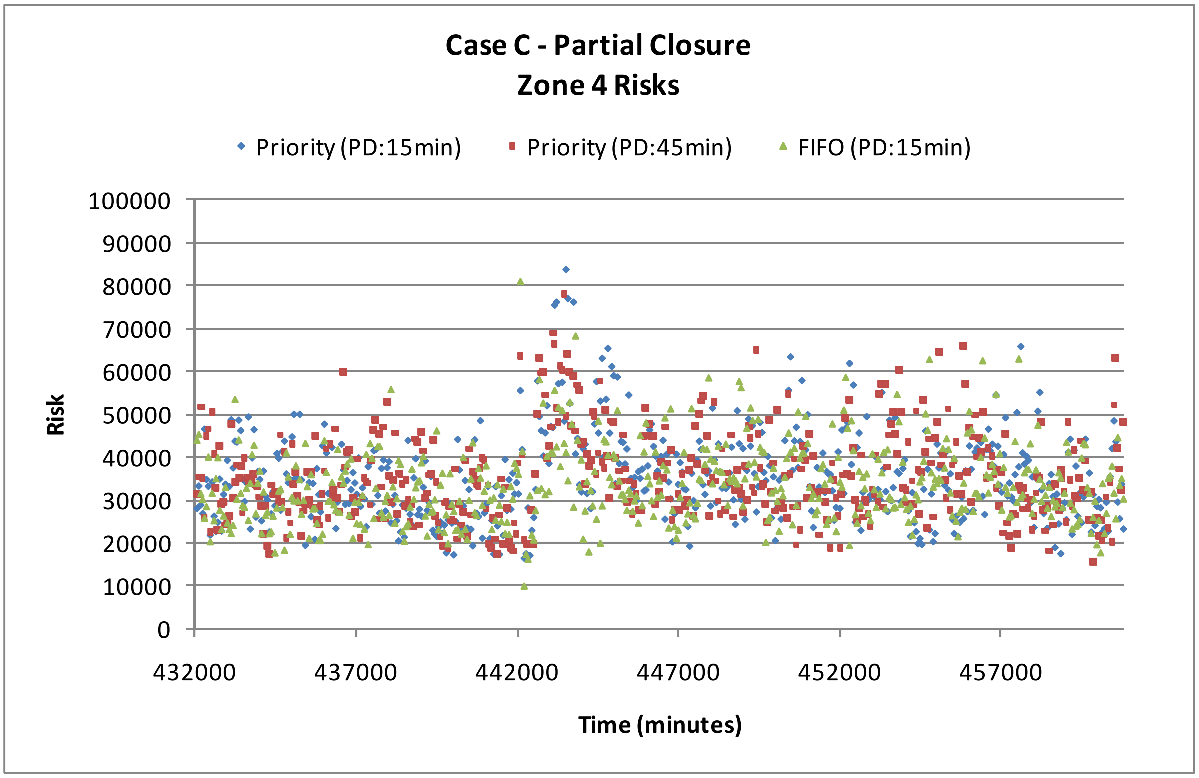

Figure 5.12. Zone 1 Risks between Days 300 and 320 in Case C – Partial Closure

Table 5.7 - Zone 4 Risks between Days 307 and 320 in Case C – Partial Closure

Scenario	Average Risk	Maximum Risk	Standard Deviation
Priority (15min)	37279	83901	11151
Priority (45min)	37272	78144	10998
FIFO (15min)	35163	81089	9510

5.9. Conclusions on Vessel Prioritization for Resumption of Trade

In this Chapter, the issue of vessel prioritization is studied in an incident similar to the case of Athos I, happened in Paulsboro in November of 2004. Three cases are considered, two with a major oil spill and cleanup effort (Cases A and B) and the other with medium level environmental consequence (Case C). The duration of the closure is assumed to be 3 days for Cases A and B as in the case of Athos I and 2 days for Case C.

Extensive numerical experimentation was carried out focusing on prioritizing tankers and refrigerated vessels in entrance queues (referred to as closure queues) and vessel pursuit distances.

Risk estimations and discussions in Section 5.8 guide us to conclude that placing tankers into closure queues with higher priorities eventually moves them into the channel within close proximity of each other and thereby increases the risks in Zone 1 and slightly impacts the risks in Zone 4 in the same direction. Larger pursuit distances (e.g., 45 minutes) tend to increase average risks and reduce maximum risks in Cases A and C. Thus, these cases may be preferable due to lower maximums which are disaster indicators even thought they exhibit higher average risks. Case B on the other hand is special in the sense that it empties the system out until some number of vessels remains and then opens the queue. A larger pursuit distance scenario may be preferred in Case B not only due to a smaller maximum but also a smaller average risk. Furthermore recall that, as discussed in Section 5.7, priority scenarios better perform when higher pursuit distances are employed. Thus, one may conclude that priority scenarios with larger pursuit distances may play an important role in effective resumption of trade resulting in better performance for critical cargo vessels (e.g., tankers) in the sense of lower average and/or maximum risks.

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APPENDIX A: DEEPENING/DREDGING IMPACT ON NAVIGATIONAL EFFICIENCY IN THE DELAWARE RIVER MAIN CHANNEL

RUTGERS
Center for Advanced Infrastructure
and Transportation

Deepening/Dredging Impact on Navigational Efficiency in the Delaware River Main Channel

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Deepening/Dredging Impact on Navigational Efficiency in the Delaware River Main Channel

SUMMARY REPORT

By

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Executive Summary

Rutgers University's CAIT-LPS team developed a high-fidelity simulation model for the maritime traffic in the DRMC in a project funded by the NJDOT's Maritime Resources Program and supported by the AMSC leadership of the Sector Delaware Bay. The model uses information on all cargo vessel types, their particulars, arrival patterns, their trips in the river, anchorage and terminal activities, navigational rules, tidal activity and various other details from 2004 to 2008 and produces key performance measures such as terminal berth utilization, average vessel waiting times in anchorages as well as average vessel port times.

As part of the project, the model was used with the data provided in the Comprehensive Economic Reanalysis Report (2002) of Delaware River Main Channel Deepening Project [USACE (2002)], providing the 30-year outlook, prepared by the U.S. Army Corp of Engineers, Philadelphia District, North Atlantic Division. The analysis solely focused on the potential impact of deepening/dredging on navigational efficiency in the DRMC. Navigational benefits may include shortened port time per vessel call or per ton of cargo, lesser anchorage waiting times and lesser tidal delays, among others.

A number of scenarios involving cases of deepening and no-deepening were studied using the model. This report summarizes four important scenarios of

a. Current Scenario(no deepening)
b. Current Scenario and 30-year trade growth (no deepening)
c. Deepen/dredge and 30-year trade growth
d. Deepen/dredge, bring large vessels and 30-year trade growth

In each of the above scenarios, Bulk vessels (BU), General cargo vessels (GC), Containerized cargo vessels (CC), Tankers (TA) were considered, among others, for New Jersey, Pennsylvania and Delaware since all three states have cargo port activity in the River. Results indicate the following:

Bulk and Break Bulk Vessels (BU and GC)

It appears deepening, dredging, and furthermore bringing deeper vessels do not seem to generate navigational benefits for BU and GC vessels, mainly due to queueing effect. Navigational efficiency can be improved, if additional berth space is generated for deeper vessels at port Camden. Bringing deeper vessels (or not) with the suggested trade growth will require additional space for MH, MC and KP anchorages further in the outlook.

Container Vessels (CC)

Deepening, dredging and bringing deeper vessels generate reasonable navigational efficiency for container (CC) vessels. The port will be able to handle the increased traffic under the suggested growth levels, deepened or not.

Tankers (TA)

Deepening, dredging and bringing deeper vessels generate some navigational efficiency for tankers and that is due to lesser lightering. The port will be able to handle the increased traffic under the suggested trade growth, deepened or not.

1. Introduction

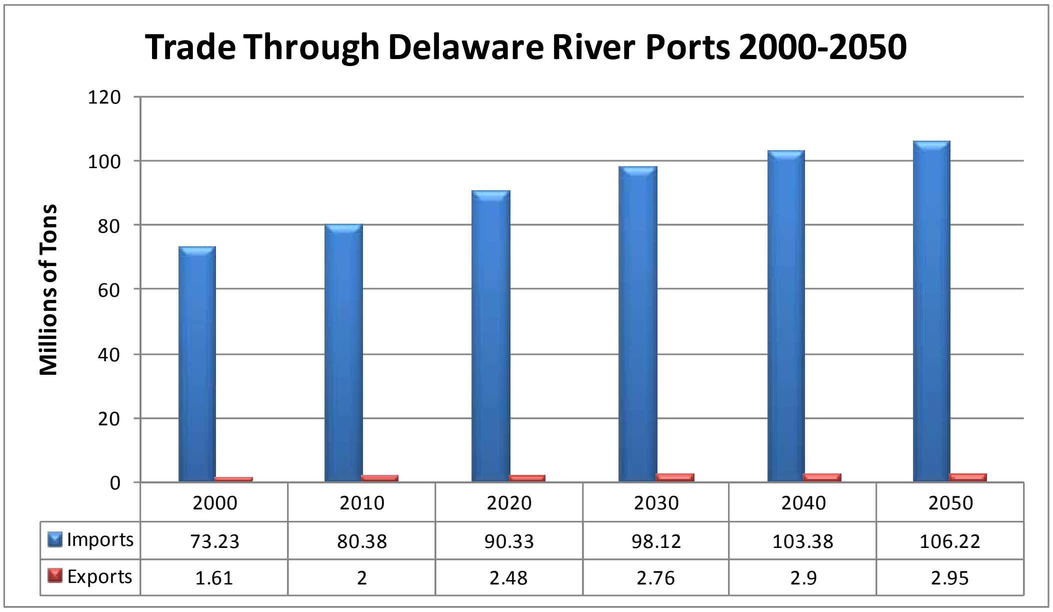
This report summarizes the findings of the Rutgers' CAIT-LPS team in their analysis of the impact of deepening/dredging on the navigational efficiency in the DRMC. The Channel affords deep draft (40 foot) navigation nearly 110 miles, from the mouth of Delaware Bay to Trenton, NJ. The Delaware River shoreline has six major petroleum refineries that process nearly 1 million barrels of crude oil per day, as well as other chemicals associated with the refining process, making it one of the most critical petroleum infrastructures in the U.S. Collectively, the Ports of Philadelphia, Camden and Wilmington, DE combine to be the largest general cargo port complex in the nation. With one third of the entire U.S. population living within 5 hours of the Port of Philadelphia, the Delaware River Channel and its surrounding facilities are of critical importance to the nation's economy.

In view of the current expansion of the Panama Canal, deepening of the Channel to 45 feet has been proposed and debated over a number of years. The proposed deepening will be located within the Delaware River and Bay and the borders of the Commonwealth of Pennsylvania, and the States of New Jersey and Delaware. It extends over 100 river miles of the Delaware River and Bay, from Trenton including the City of Philadelphia to the mouth of the river. The project consists of the navigation channel extending from deep water in the Delaware Bay to Philadelphia Harbor, Pennsylvania and to Beckett Street Terminal, Camden New Jersey, a distance of about 102.5 miles. The deepening/dredging plan provides for modifying the existing Delaware River Federal Navigation Channel (Delaware River, Philadelphia to the Sea and Delaware River in the Vicinity of Camden) from 40 to 45 feet below Mean Low Water (MLW). The channel width remains the same as the existing 40-foot project, and would range from 400 feet in Philadelphia Harbor to 800 feet from Philadelphia Navy Yard to Bombay Hook and then 1,000 feet in Delaware Bay. The plan includes widening 12 of the 16 existing channel bends as well as provision of a two-space anchorage for safety purposes to a depth of 45 feet at Marcus Hook.

With the support of NJ DOT's Maritime Resources Program, the Rutgers team developed a detailed simulation model of the maritime traffic in the Delaware River and Bay Area (DRB) utilizing existing maritime data obtained from the Maritime Exchange of Delaware River and Bay. The data included information on all cargo vessel types, their particulars, arrival patterns, their trips in the river, anchorage and terminal activities, navigational rules, tidal activity and various other details from 2004 to 2008. The model is used with the data provided in the Comprehensive Economic Reanalysis Report (2002) of Delaware River Main Channel Deepening Project [USACE (2002)], prepared by the U.S. Army Corp of Engineers, Philadelphia District, North Atlantic Division. The analysis focuses on the potential impact of deepening/dredging on navigational efficiency in DRMC. Navigational benefits may include shortened port time per vessel call or per ton of cargo, lesser anchorage waiting times and lesser tidal delays, among others.

2. Trade Growth in the Delaware River

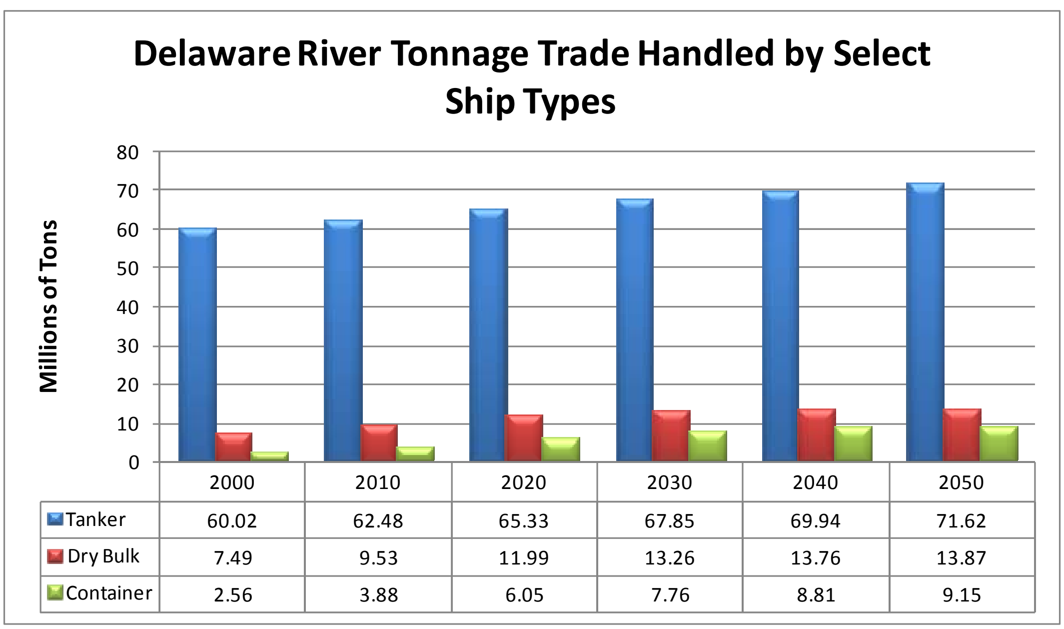
Based on the [USACE (2002)] reanalysis, the trade growth outlook for the Delaware River ports up until 2050 is given in Fig. 1. The growth data from Fig. 1 is used to estimate future vessel arrival patterns in the model in this study.



	2000	2010	2020	2030	2040	2050
Imports	73.23	80.38	90.33	98.12	103.38	106.22
Exports	1.61	2	2.48	2.76	2.9	2.95

Fig. 1 Trade growth in Delaware River ports (2000 – 2050) due to [USACE (2002)]

Estimates of the annual cargo tonnages (by tanker, dry bulk and container) are given in Fig. 2 from 2000 to 2050.



	2000	2010	2020	2030	2040	2050
Tanker	60.02	62.48	65.33	67.85	69.94	71.62
Dry Bulk	7.49	9.53	11.99	13.26	13.76	13.87
Container	2.56	3.88	6.05	7.76	8.81	9.15

Fig. 2 Annual cargo tonnages by vessel type from 2000 to 2050 due to [USACE (2002)]

3. Berth Dredging at the Delaware River Terminals

The river deepening project focuses on the main channel. Berth dredging at terminals is the responsibility of the terminal operators. Based on [USACE (2002)], Table 1 shows data for berth dredging at various refineries (liquid bulk/oil terminals). Note that some of these terminals may not be in operation either at present or at some future point in time. For example, Eagle Point is currently idle and Valero Paulsboro is not operating at capacity.

Past data and the projections from Fig. 1 and 2 are used to generate results from the Rutgers model.

Table 1. Oil terminal berth dredging plans

Terminal/Company	Berth	Depth (ft.)
Fort Mifflin (DE)	A	38 → 45
	B	37 → 45
Marcus Hook (PA)	3C	40 → 45
	3A	remains 39
	2A	remains 37
	3B	remains 17
Valero Paulsboro (NJ)	1 (Tanker Berth)	40 → 45
	Berth # 2	remains 30
Eagle point (NJ)	Berth # 1	remains 34
	Berth # 2	40 → 45
	Berth # 3	40 → 45
Conoco Philips (PA)	Berth # 1	38 → 45
Valero/Premcor Delaware City (DE)	Berth # 1	→ 45
	Berth # 2	→ 45
	Berth # 3	→ 45
Wilmington Oil Pier (DE)	Liquid Bulk Berth	38 → 45

Table 2 shows data for berth dredging at various container, bulk, break-bulk and general cargo facilities.

Table 2. Dredging plans for container, bulk, break-bulk and general cargo facilities

Name of Terminal	Berth	Depth (ft.)
Packer Avenue (PA)	5 front berths	40 → 45
	the bottom berth	remains the same
Beckett Street (NJ)	Berth # 4	40 → 45
	Berth # 3	remains 35
	Berth # 2	remains 30
Wilmington Port (DE)	All in Christina River other than the oil pier	38 → 42

The terminals indicated in Tables 1 and 2 will be referred to as dredge-designated terminals (DDTs) in the following sections.

Also, Marcus Hook anchorage is proposed to be deepened to 45".

4. Scenarios Considered

As mentioned earlier, Rutgers team at the CAIT's Laboratory for Port Security (LPS) developed a detailed simulation model for the maritime traffic in DRMC as part of the project currently funded by NJDOT. The model was modified to evaluate the navigational impact of the channel deepening activity. The model used the trade outlook information presented in Section 2 and the berth dredging activity data of Section 3 to produce the results presented in the following sections.

The scenarios presented in this summary are as follows:

e. *Current Scenario(no deepening)*
f. Current Scenario and 30-year trade growth (no deepening)
g. Deepen/dredge and 30-year trade growth
h. Deepen/dredge, bring large vessels and 30-year trade growth

In each of the above scenarios, the team considered the following vessel types, among others, for New Jersey, Pennsylvania and Delaware since all three states have cargo port activity in the River.

- Bulk vessels (BU)
- General cargo vessels (GC)
- Containerized cargo vessels (CC)
- Tankers (TA)

In the following section, a summary of the simulation results is presented.

5. Model Results

The simulation model was validated using the vessel movement data supplied by the Maritime Exchange for the Delaware River and Bay by comparing the model's results on port performance measures such as vessel port times, anchorage waiting times, tidal delays and terminal berth utilizations, among others against their existing counterparts. In scenario (a), the average port utilization is about 17.5% (average of all berth utilizations at the port). In scenarios (b)-(d), the average port utilization goes up to an average of 23.4 % in the 30th year. This is roughly a 30 % increase in port utilization due to the anticipated increase in trade growth (see Fig 1). Below, results are presented for BU, GC, CC cargo vessels and tankers (TA) for each scenario.

a. <u>Current Scenario</u>

This scenario focuses on the present case and the results are based on data from 2004-2008. Each state has almost the same amount of bulk vessel activity in DRB. NJ and PA each have about 40 % of the GC activity in the River. PA has the majority, 80%, of the CC traffic with the majority of the container vessels visiting Packer Avenue terminal that has ample berth capacity.

NJ's DDTs have 35% of the incoming tankers while PA's have 42 % and DE's have 23 % of the incoming tankers. NJ, PA and DE each have a significant number of vessels among their tanker flows, destined to DDTs.

The average annual port calls (simulated over 30 years) for the considered vessel types visiting DDTs in each state are given in Fig. 3.

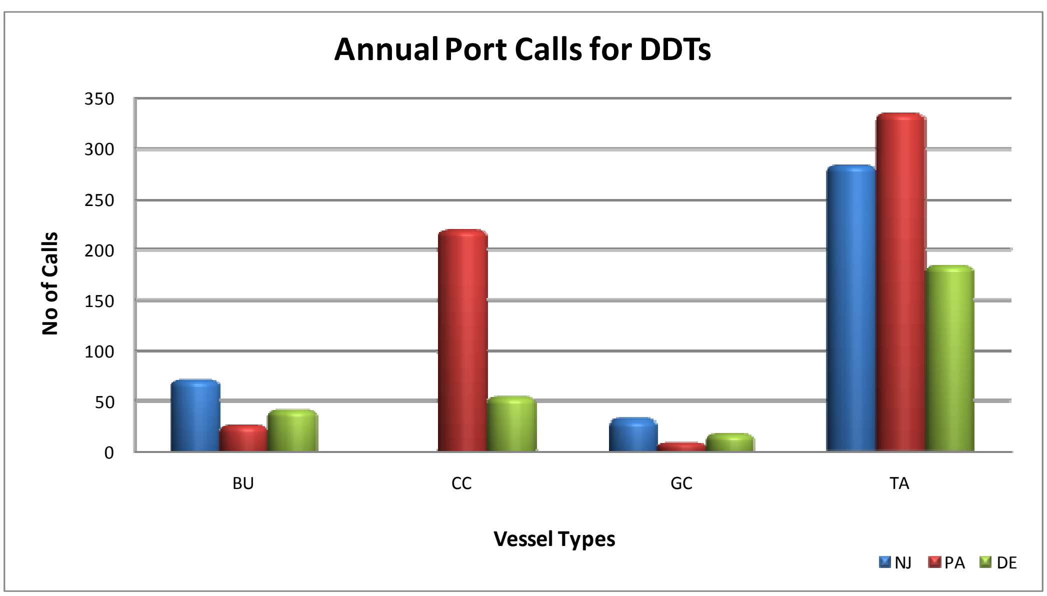


Fig. 3 Annual port calls for DDTs per vessel types and states

Furthermore, the average port time per vessel call (simulated over 30 years) for the considered vessel types visiting DDTs in each state are given in Fig. 4.

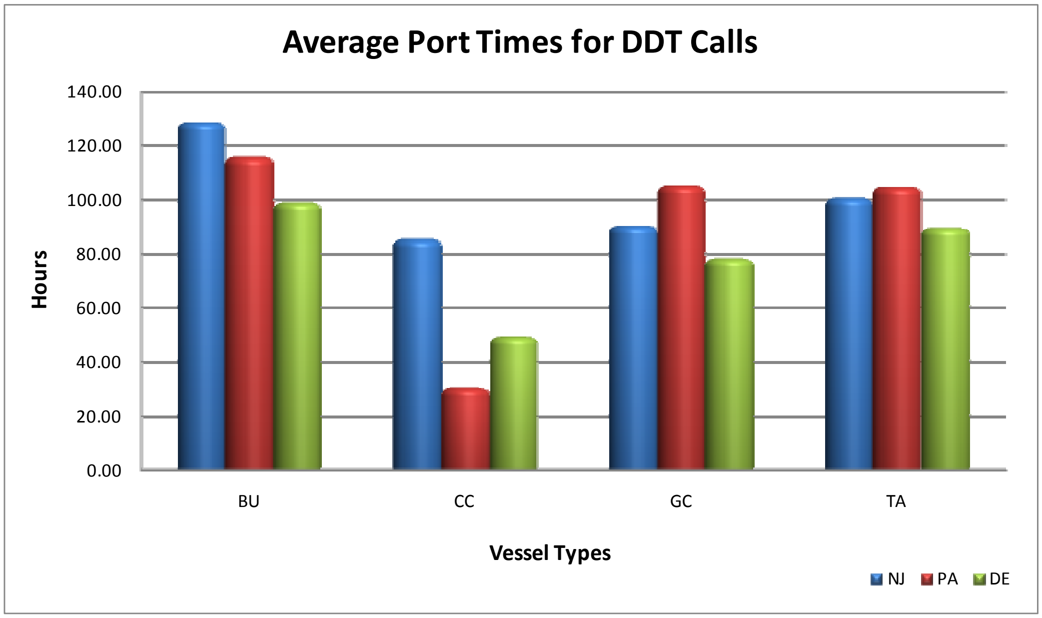


Fig. 4 Average port time per vessel call for DDTs in different states

Annual anchorage visits for the 4 key anchorages (W, MH, MC, KP[5]) and the Break Water anchorage, and per-visit anchorage waiting times are presented in Fig. 5 and Fig. 6 below. In Fig. 5, the four anchorage visits are lumped together via a simple arithmetic average at the expense of not presenting detailed per-anchorage information.

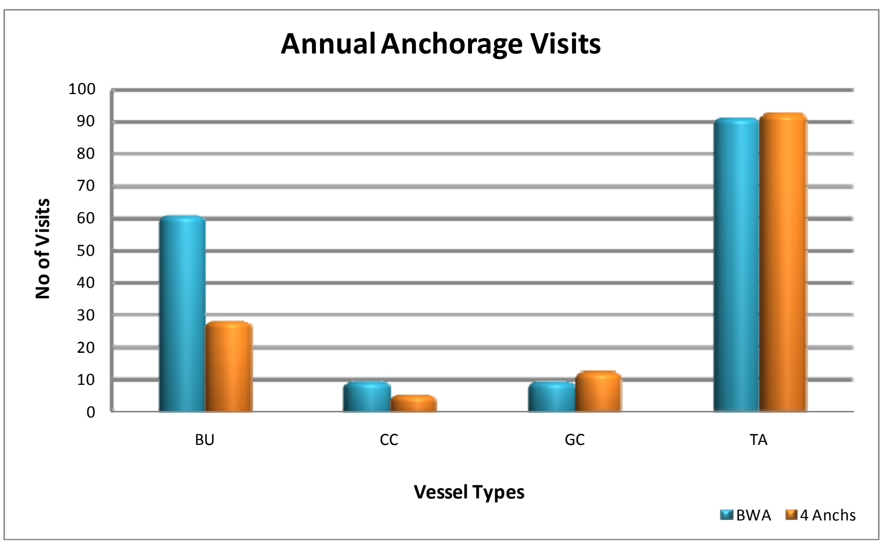


Fig. 5 Annual anchorage visits

[5] W: Wilmington, MH: Marcus Hook, MC: Mantua Creek, and KP: Kaighns Point

Fig. 6 below presents weighted anchorage waiting times averaged using visit ratios.

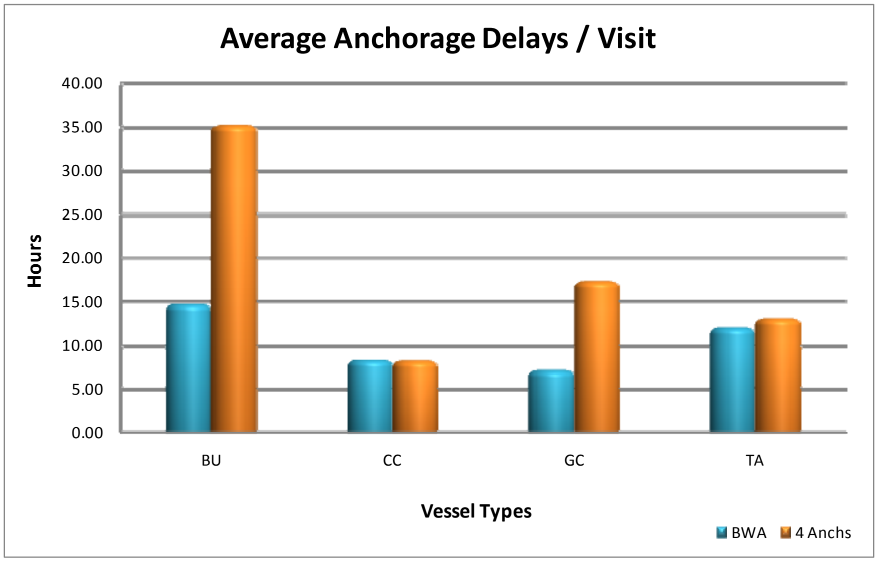


Fig. 6 Average anchorage waiting times per visit

On the lightering side, the average annual number of lightered tankers visiting DDTs in NJ, PA and DE are 133, 222 and 96, respectively. So, PA-bound tankers outnumber others.

Thus, some port performance measures for the present operations in the Delaware River are presented above. Below are some of the future scenarios.

b. Current Scenario with the 30-Year Outlook

This scenario emphasizes current conditions, that is no deepening, and the assumption of the 30-year trade outlook. The trade outlook indicates those percent increases in vessel arrivals, shown in Table 3 below, and are used in scenarios (b)-(d).

Table 3. Percent increases in vessel arrivals in the 30-year outlook

	Year					
	5	**10**	**15**	**20**	**25**	**30**
BU	12	26	32	40	42	44
GC	12	26	32	40	42	44
CC	25	56	77	100	113	127
TA	2	5	7	9	10	12

The annual average vessel port calls and the average port time per call per vessel type and per state are presented in Fig. 7 and 8 below. Darker portions on top of the bars indicate the maximum values. Notice that the largest expected increase over the 30-year horizon is observed in container vessels visiting PA's Packer Avenue container terminal.

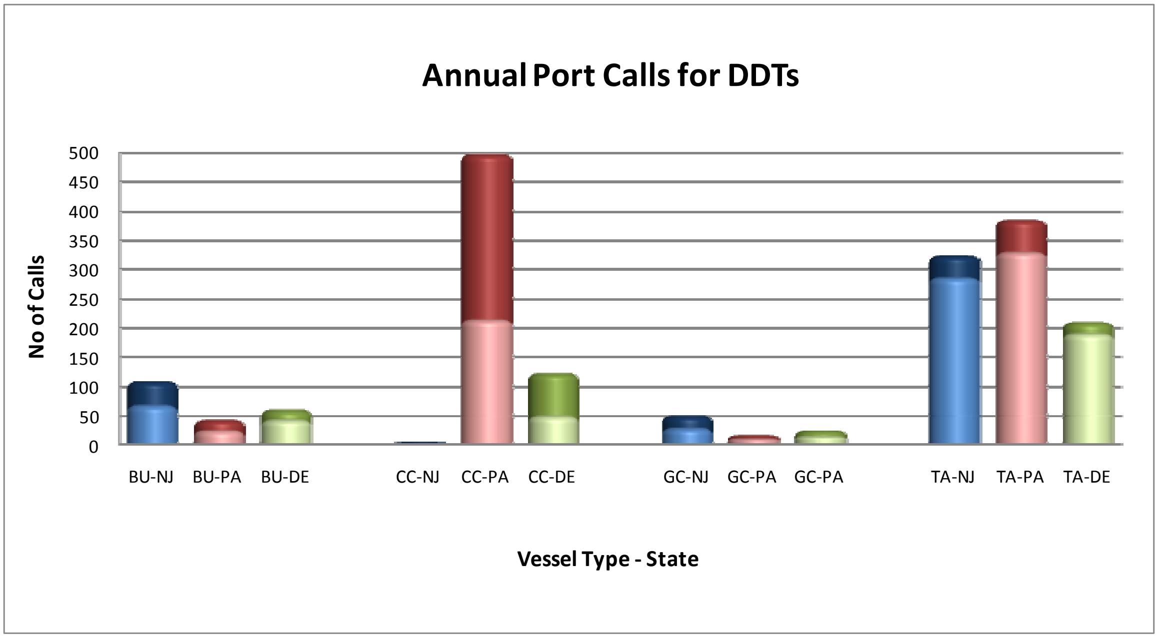


Fig. 7 Average annual port calls with the first-year and maximum values

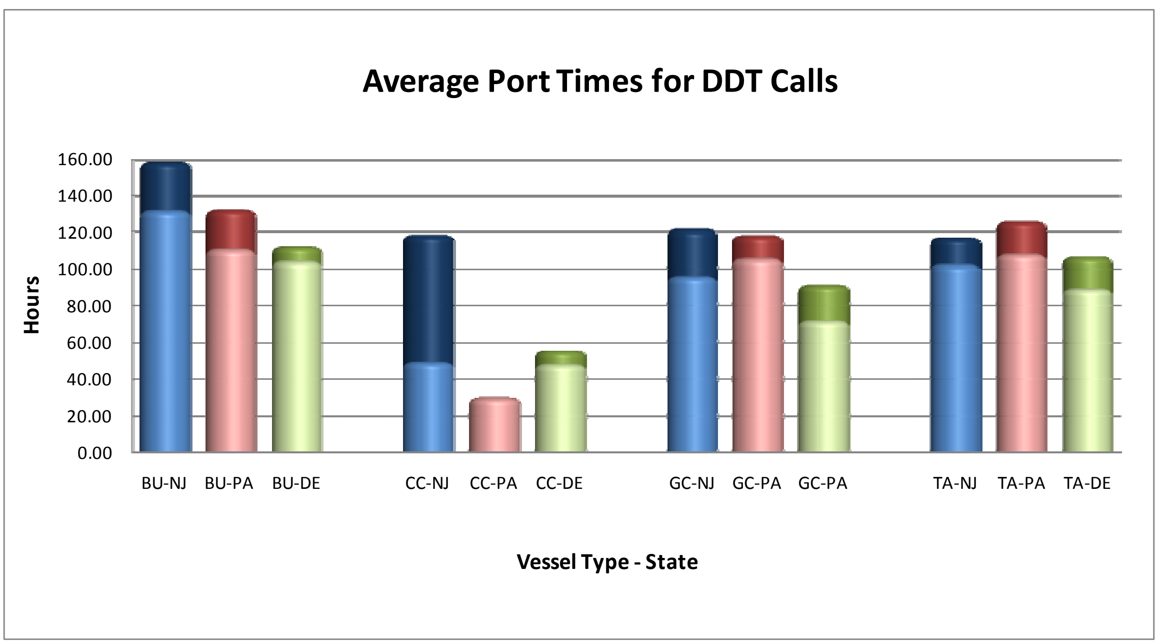


Fig. 8 Average port times with the first-year and maximum values

The BU overall port calls (for DDTs <u>and</u> others) increases by about 48% over 30 years, which is significant, yet the average port time per bulk vessel increases by only 12%. The overall GC port calls increases by about 53% over 30 years, which is significant, yet the average port time per bulk vessel increases only by less than 13%.

Even though CC overall port calls over 30 years more than doubles, the port is predicted to handle the increased traffic with ease. That is, port times practically do not change. Furthermore both PA and DE dredged-designated terminals seem to handle the additional cargo over the years with relatively no delays.

The average TA port calls and their average port times (for DDTs <u>and</u> others) for the whole port increase by about 15% over 30 years, which are not significant.

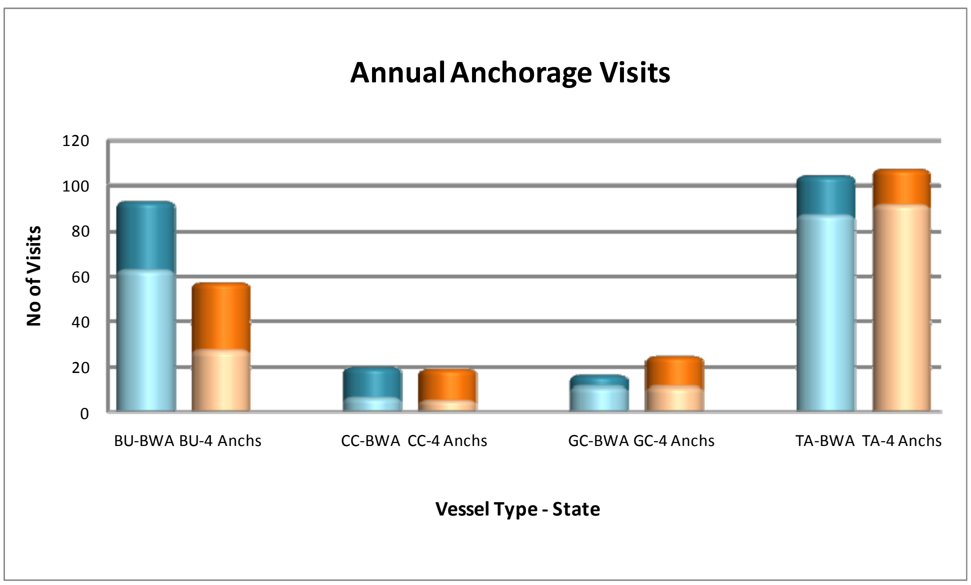


Fig. 9 Average annual anchorage visits

As expected, the increase in port calls for bulk vessels shows up as increase in anchorage calls. The anchorage visits and waiting times are presented in Fig. 9 and 10. The average annual BU visits for the 4 major anchorages shows an increase of over 107% from its first year value to its maximum with an increase of 50% in waiting time per visit. The maximum waiting time at MH is expected to be over 70 hours. It would appear that the port will be able to handle the increases in calls and waiting times without additional impact. However, anchorages MH, MC and KP will need space to accommodate the additional traffic in later years of the outlook.

The average annual GC visits for the 4 major anchorages increase from the first year to its maximum value by 115% with an increase of 58% in waiting time per visit. MH, MC, and KP each experience an average maximum waiting time of over 40 hours. The port seems to handle the increases in calls and waiting times with minimal impact. However, anchorages MH, MC and KP will need space to accommodate the additional traffic.

In the case of CC vessels, even though the anchorage visits more than triples, waiting times are insignificant. This is due to the satisfactory berth capacity at the Packer Avenue terminal. For TAs, the anchorage visits and waiting times over 30 years are all insignificant and the port seems to handle this trade growth again with minimal impact.

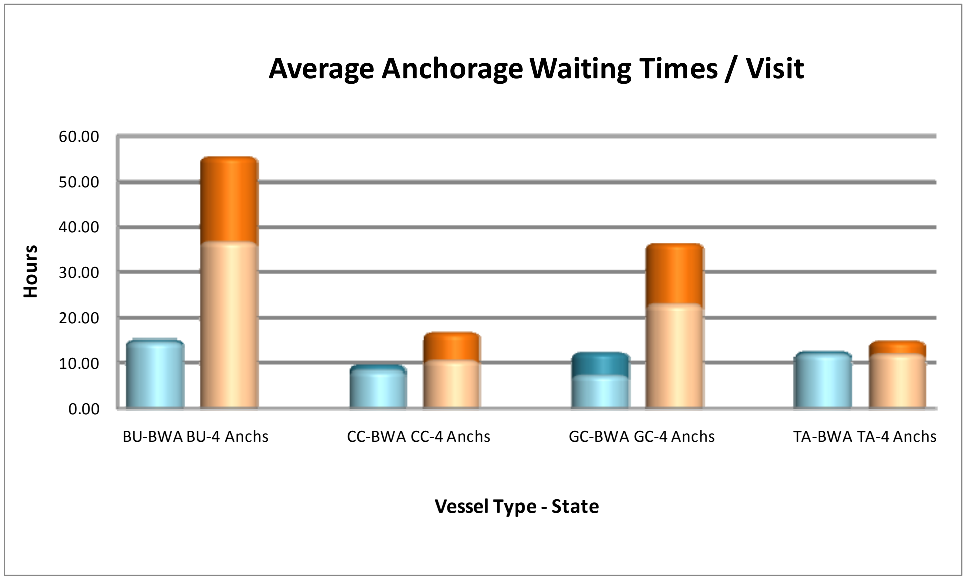


Fig. 10 Average anchorage waiting times per visit

On the lightering side, the number of lightered tankers per state in the 30-year horizon is given in Table 4 below.

Table 4. Annual number of lightered tankers

	Annual Avg. Number of Lightered Tankers	
	First Year	Max
NJ	138	154
PA	224	259
DE	97	113

c. <u>Deepen/Dredge and 30-Year Trade Growth</u>

This scenario focuses on deepening and dredging as well as bringing more vessels based on the 30-year trade outlook. The objective is to see how the dredged port will perform if the trade outlook projections materialize. The average annual port calls for DDTs and the average port times are presented in Fig. 11 and 12.

Among the DDTs, NJ has the largest increase in BU and GC vessel arrivals over time while PA has the largest increase in CC vessel arrivals over the outlook.

Among the DDTs, both NJ and PA have significant increases in TA arrivals over 30 years. Under this scenario, the port handles the increase in tanker traffic over 30 years with no relative impact to current operations.

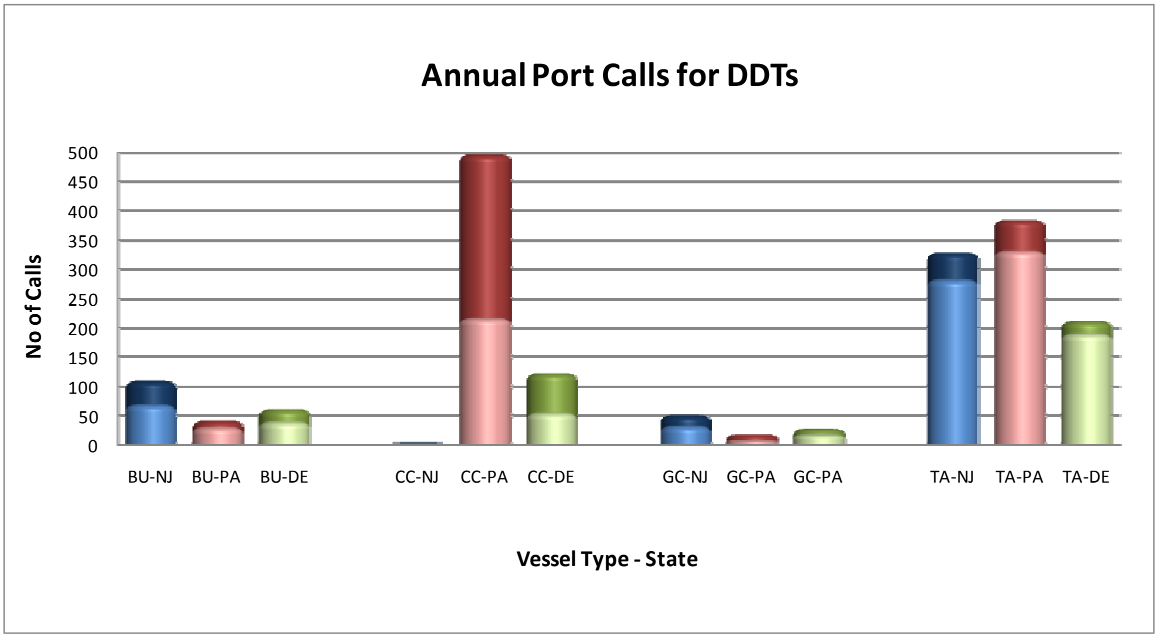


Fig. 11 Average annual port calls with the first-year and maximum values

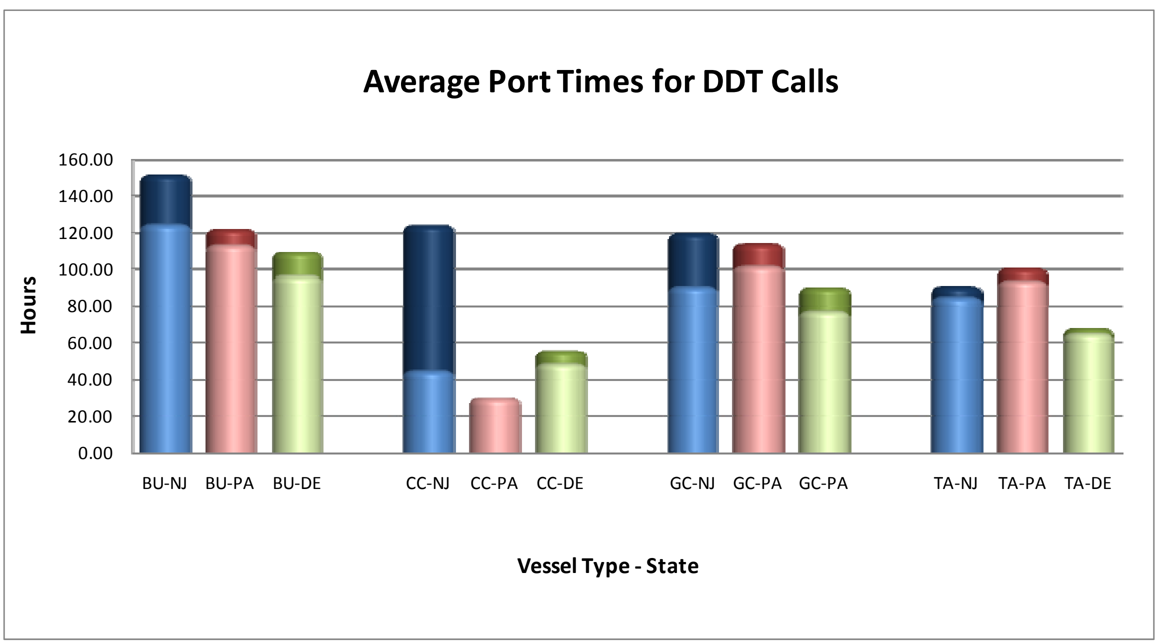


Fig 12. Average port times with the first-year and maximum values

Data for anchorage visits and waiting times are presented in Fig. 13 and 14. Due to increased volume of traffic, BU vessel anchorage visits increase over 100% in 30 years and yet the port can still handle the vessel traffic. BU 4 major anchorage waiting times increase by 68% with MH waits average around 93 hours after 26 years. This is a significant increase resulting in potentially excessive anchorage waiting times. This is solely due to lack of berth capacity for bulk vessels within the port and in particular at the South Jersey Port Corporation facilities.

The GC vessel anchorage visits increase over 119% in 30 years while the anchorage waiting times increase by 129% but yet still remain in the acceptable region.

Due to increased volume of vessel traffic, the CC anchorage visits increase over 350% in 30 years. Anchorage waiting times increase by 63% with MC waiting times averaging around 18 hours after 27 years, and it is predicted that the port will be able to handle the traffic.

The TA anchorage visits increase by a mere 22% in 30 years. The anchorage waiting times increase by 24% with all average anchorage waiting times being below 24 hours.

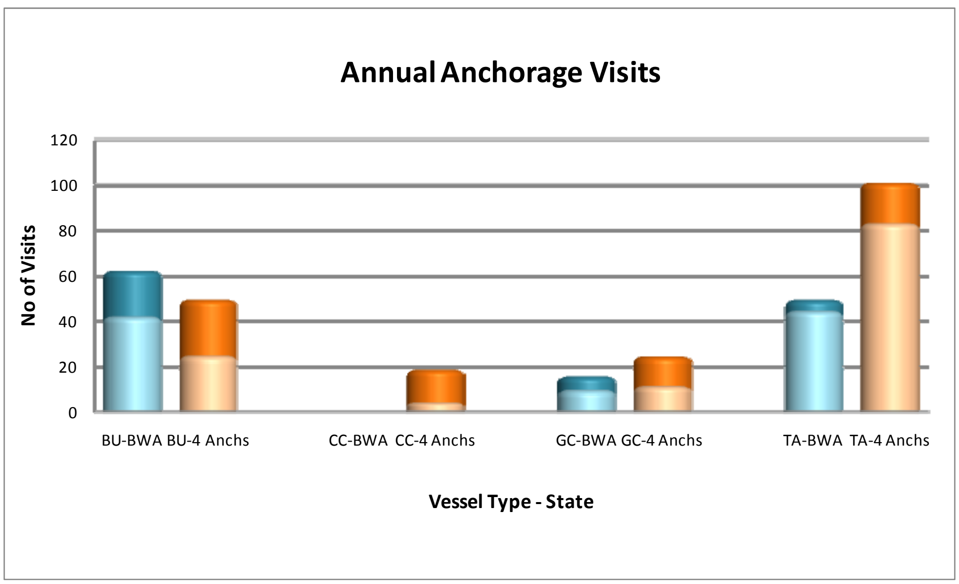


Fig. 13 Average annual anchorage visits

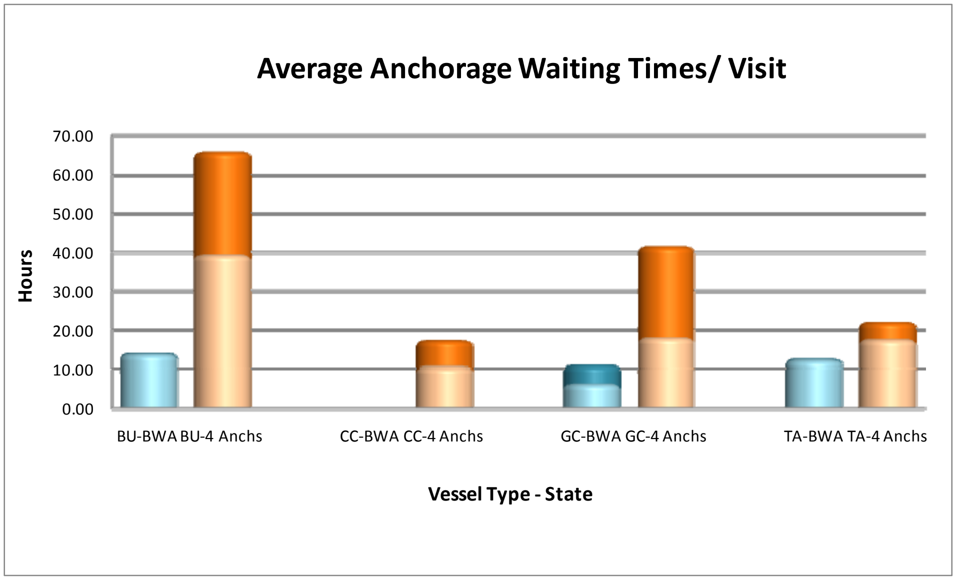


Fig. 14 Average anchorage waiting times per visit

On the lightering side, the annual average number of lightered tankers destined to DDTs over 30 years are given in Table 5 below.

Table 5. Annual number of lightered tankers

	Annual Avg. Number of Lightered Tankers	
	First Year	Max
NJ	76	92
PA	167	196
DE	18	20

Notice the reduction in the number of lightered tankers due to deepening and dredging when compared to scenario (a). NJ experiences (22%, 38% - first year max value) less number of tankers lightering while this reduction is (28%, 19%) for PA and (60%, 82%) for DE.

d. <u>Deepen/Dredge, bring large vessels and 30-year trade growth</u>

In this scenario, larger and lesser number of vessels is brought in to Delaware River ports every year over 30 years. Annual cargo volumes are kept at levels indicated by the trade outlook. The assumption here is that some vessels will actually be larger in size (length, beam and draft) and others may do less light loading and therefore have deeper drafts. The annual port calls and vessel port times are presented in Fig. 15 and 16.

NJ DDTs receive 54 BU vessels in year 1 and it increases to 82 vessels in year 26 with 181 hours of port time in year 1 and up to 289 hours in year 28. NJ dredge-designated terminals receive 20 GC vessels in year 1 and it increases to 32 vessels in year 28 with 164 hours of port time in year 1 and 249 hours in year 26. Port times of BU and GC vessels increase significantly over the years indicating that Port Camden may need additional berth space to handle larger vessels. This is mainly due to the fact that larger vessels require longer berth times which in turn cause longer queuing delays.

PA DDTs receive 146 CC vessels in year 1 and it increases to 337 vessels in year 30 with 37 hours of port time in year 1 and 38 hours in year 30. PA DDTs, (mainly Packer Avenue terminal) seem to handle the additional CC cargo over the years very well. This is due to sufficient berth capacity at the Packer Avenue terminal.

Among the dredge-designated terminals, each state has slight increases in TA arrivals over 30 years (less than 20% each). These values are obtained after 30 years of operation under the assumed trade growth. Under this scenario, the port handles the increase in tanker traffic over 30 years with minimal impact.

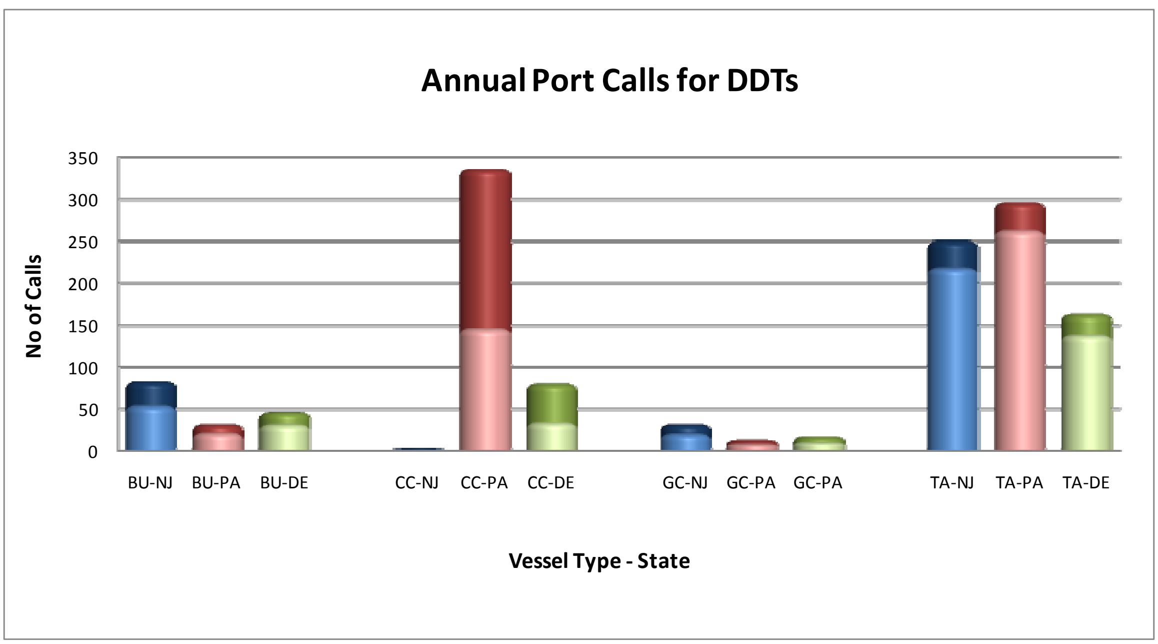


Fig. 15 Average annual port calls with the first-year and maximum values

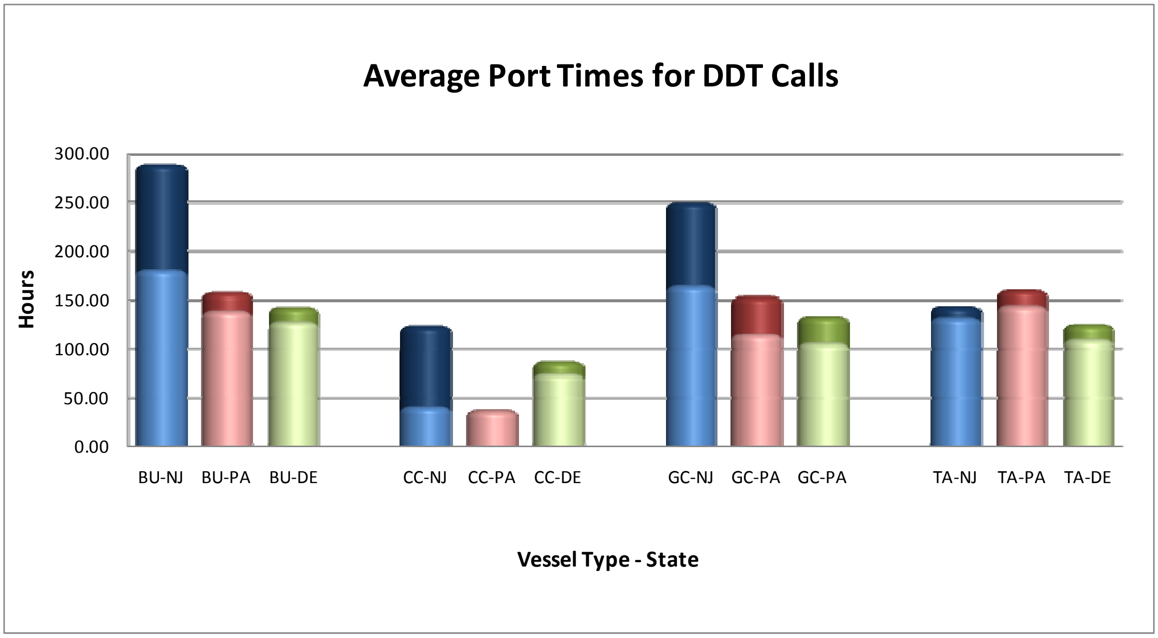


Fig 16. Average port times with the first-year and maximum values

The average BU vessel anchorage wait times is predicted to go up by 70% at their peak with MH experiencing 120 hours of waiting time per visit, which becomes unacceptable. Additional anchorage space will be needed at that time, if the trade growth is realized.

The average GC anchorage waiting times (all 4 major anchorages) go up by 119% at their peak with MH experiencing 138 hours of waiting times per visit (in year 26) which becomes unacceptable. Additional anchorage space will be needed at that time, if the trade growth is realized and larger and deeper draft vessels are brought in.

Average anchorage waiting times for CC vessels go up by 40 % at their peak.

Due to increased volume of traffic, 4 major anchorage TA visits increase by a mere 16% in 30 years. Anchorage waiting times increase by 24% with all of the average anchorage waiting times being below 25 hours.

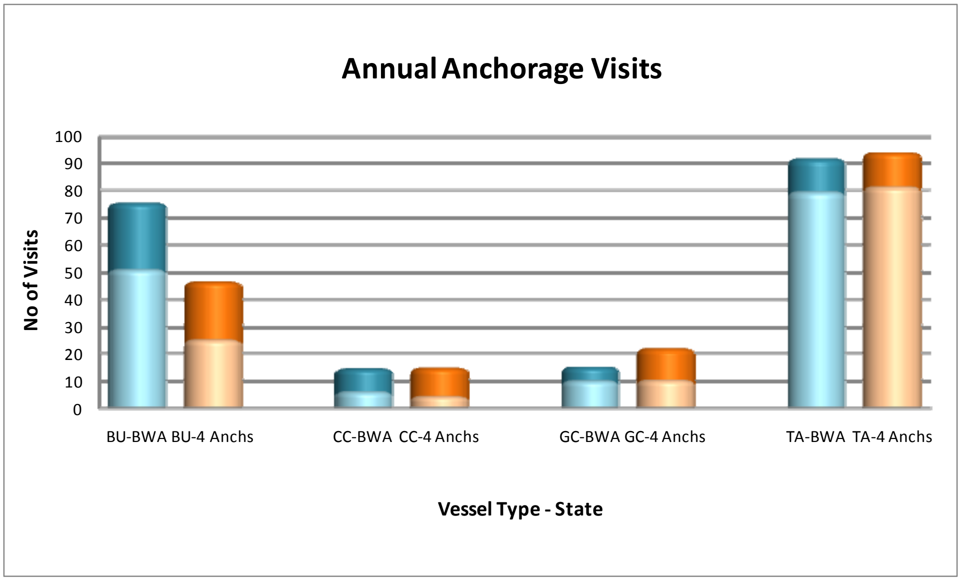


Fig. 17 Average annual anchorage visits

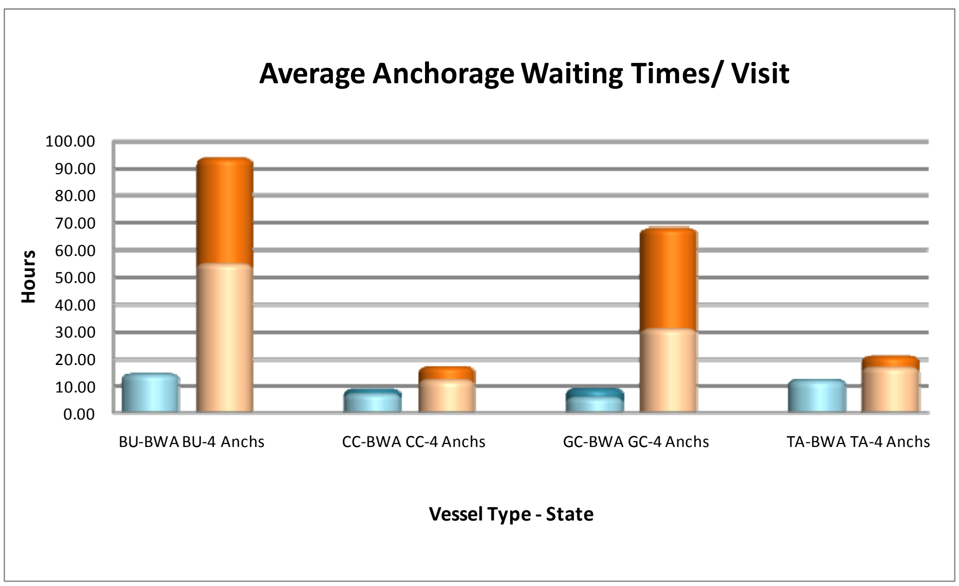


Fig. 18 Average anchorage waiting time per visit

The annual average number of lightered tankers destined to DDTs over 30 years are given in Table 6 below.

Table 6. Annual number of lightered tankers

	Annual Avg. Number of Lightered Tankers	
	First Year	Max
NJ	106	118
PA	166	183
DE	57	67

Notice that each state has a significant reduction in their lightering activity as compared to the current scenario.

6. Conclusions

Major conclusions are[6]:

Bulk and Break Bulk Vessels (BU and GC)

Though benefits of deepening the main channel are realized overall all, based on this model, it appears deepening, dredging, and furthermore bringing deeper vessels do not seem to generate navigational[7] benefits for BU and GC vessels. However, it can be assumed that the benefit ratio will increase with additional cargo – increased trade levels. Navigational efficiency can be improved, if additional berth space is generated for deeper vessels at port Camden. It is clear that Paulsboro Marine Terminal, when completed, will certainly generate navigational gains since it will bring three deep water berths (45’).

Bringing deeper vessels with the suggested trade growth will require additional space for MH, MC and KP anchorages.

[6] It is important to reiterate here that this report addresses only the navigational benefits of deepening the channel. It does not address economic impacts.

In the case of no deepening, the suggested trade growth will in any case require additional space for MH, MC and KP anchorages.

Container Vessels (CC)

Deepening, dredging and bringing deeper vessels generate reasonable navigational efficiency for container (CC) vessels. The port will be able to handle the increased traffic under the suggested growth levels, if it is dredged or not.

Tankers (TA)

Deepening, dredging and bringing deeper vessels generate some navigational efficiency for tankers and that is due to lesser lightering.

The port will be able to handle the increased traffic under the suggested trade growth, if it is dredged or not.

Notes:

In general, contrary to the common belief, bringing larger and lesser number of vessels may not generate navigational efficiency for maritime traffic due to increased berth holding times and resulting higher utilizations. This seems to be the case for bulk and break bulk vessels at the moment. Due to the extended berth holding times, vessels wait to get into service for extended periods of time increasing their port times. This situation can be remedied by building additional berths and providing necessary load/unload capacity. Any additional efficiency in loading/unloading and downtimes as well as improvements in vessel scheduling will bring even more navigational efficiency to the port, regardless of deepening.

This study does not take the planned expansion in Paulsboro Terminal into account. Clearly the three planned berths (all to 45 ft depth) will be instrumental in gaining navigational efficiency regardless of deepening and dredging.

In the final analysis, deepening/dredging will be justified economically if additional trade growth is achieved by bringing more of deeper vessels and more cargo, and not by navigational efficiency.

An economic analysis can be done, using a model like the one developed in this study, to understand at what level of additional cargo arrivals deepening/dredging can be justified.

APPENDIX B: RISK ANALYSIS QUESTIONNAIRES FOR EXPERT ELICITATION

RUTGERS UNIVERSITY
DELAWARE RIVER VESSEL TRAFFIC STUDY

Dear Professional Mariner:

You are one of a select group of professional mariners who is being asked to do a "test run" of the attached Delaware River vessel traffic survey. This survey is part of an important study being conducted by the Laboratory for Port Security at Rutgers University, in partnership with the U.S. Coast Guard Sector Delaware Bay, representatives from the Sector's Area Maritime Security Committee (AMSC), and other stakeholders from the maritime community.

Over the past several years, the Rutgers team has conducted a detailed study of the type and volume of maritime traffic on the Delaware River. The study, funded in part by grants from the New Jersey Department of Transportation and the U.S. Department of Homeland Security, is intended to provide mariners, Coast Guard officials, and first responders with a better understanding of the diversity of vessel traffic on the Delaware River, so that vessel movements and related port operations - under both normal conditions and in the event of disruptions- can be coordinated in the safest, most efficient manner possible, thereby ensuring minimal interruption to commerce on this economically important and environmentally significant waterway.

Understanding vessel traffic characteristics is vitally important for several reasons. First, the planned deepening of the Delaware River's main navigation channel from 40 to 45 feet is intended to both increase traffic volume, and allow larger vessels into port. Secondly, the SAFE Port Act of 2006 requires Area Maritime Security Plans to include salvage plans that ensure that commerce is rapidly restored to U.S. ports following a transportation security incident. Finally, future terminals will create additional vessel traffic.

The Rutgers team has already completed a detailed simulation model of vessel traffic on the Delaware River, and has compiled U.S. Coast Guard casualty data covering the past 20 years. The Rutgers team is now looking at various factors that could influence the likelihood of incidents that could disrupt normal port operations. As professional mariners, you are in the best position to help us identify and evaluate these various factors, and ultimately, help develop policies and practices which will maximize safety, protect the environment and minimize the likelihood of costly and disruptive interruptions to vital commerce. Taking this attached "test run" survey, and providing the team with candid feedback on how it could be improved (e.g., instructions unclear, takes too long, leaves things out, need better examples, etc.) will help us ensure the final version gets a higher response rate from a wider cross section of the Delaware River maritime community, and that the data we capture from the survey will help improve port operations and navigation safety.

WHAT DOES THIS SURVEY DO?

The attached survey looks at a number of factors, how those factors relate to each other, and how they may contribute to potential disruptions to port operations. You are asked to rank these factors on a scale of 0 (indicating no effect or relationship) to 100 (indicating a direct effect or strong relationship). The factors being considered in the survey include:

- *situational attributes*- these are conditions like the time of day, type of vessel you're operating, what part of the Delaware River you're operating in, and season of the year; the survey also breaks these *situational attributes* down into more specific characteristics, like day or night, dangerous cargo compared to general cargo, winter compared to summer, etc.

- *instigators*- these are various types of events that can occur while operating a vessel, such as human errors, propulsion failures, steering failures, or other vessel system failures that can lead to certain *accidents*.

- *accidents*- these are events such as collisions/allisions, groundings, fires, sinking, oil spills, etc., that may occur directly and immediately as the result of an *instigator*.

- *consequences*- these are the results from an *accident,* for example, human injuries or fatalities, environmental damages, economic losses, etc.

HOW IS THIS SURVEY ARRANGED?

The survey has three sections, set up in a matrix format.

In the first section, page 4, you are asked to rank the relationship between the eight listed *situational attributes* and the five listed *instigators*. For example, the matrix sets up the relationship between "time of day" and the likelihood of a "human error". If, based upon your experience, you think that time of day strongly influences the likelihood of human errors occurring, you'd fill in that block with a number on the high end of the 0-100 scale. Continuing with another example, another relationship being measured is how your "vessel's status" (underway, docked, anchored) influences the likelihood of a "propulsion failure". If you think that vessel status is loosely related to the likelihood of propulsion failure, you'd also fill in that block with a lower number on the 0-100 scale.

In the second section, pages, 5-10, you are asked to rank how one of the eight situational attributes affects the likelihood that a particular type of accident will occur if triggered by one of the five listed instigators.

In the third section, pages 11-16, you are asked to rank how one of the eight *situational attributes* affects the likelihood that one of three levels of *consequences* will result from a particular type of *accident*.

You'll note that certain blocks are already blacked out, since the combination being measured by that block would be unlikely or impossible to occur. However, if you still think that there might be a relation, please fill in the blacked out block with an appropriate value from the 0-100 scale.

WILL MY PARTICIPATION BE CONFIDENTIAL?

Yes. We will not compile personally identifiable information when reviewing these surveys. Our intent is to get the most candid responses from survey respondents.

PLEASE E-MAIL YOUR QUESTIONS OR A SAVED COPY OF YOUR RESPONSE TO:

Alper Almaz, Ph.D. student
Ph: (732) 216-1822
E-mail: alperalmaz@hotmail.com

We appreciate your cooperation in evaluating this "test-run" survey, and we look forward to your responses and suggestions for improvement. Your response and comments received within 2 weeks would be most helpful so we can incorporate your feedback and develop the final version of the survey at the earliest possible.

Sincerely,

Dr. Tayfur Altiok

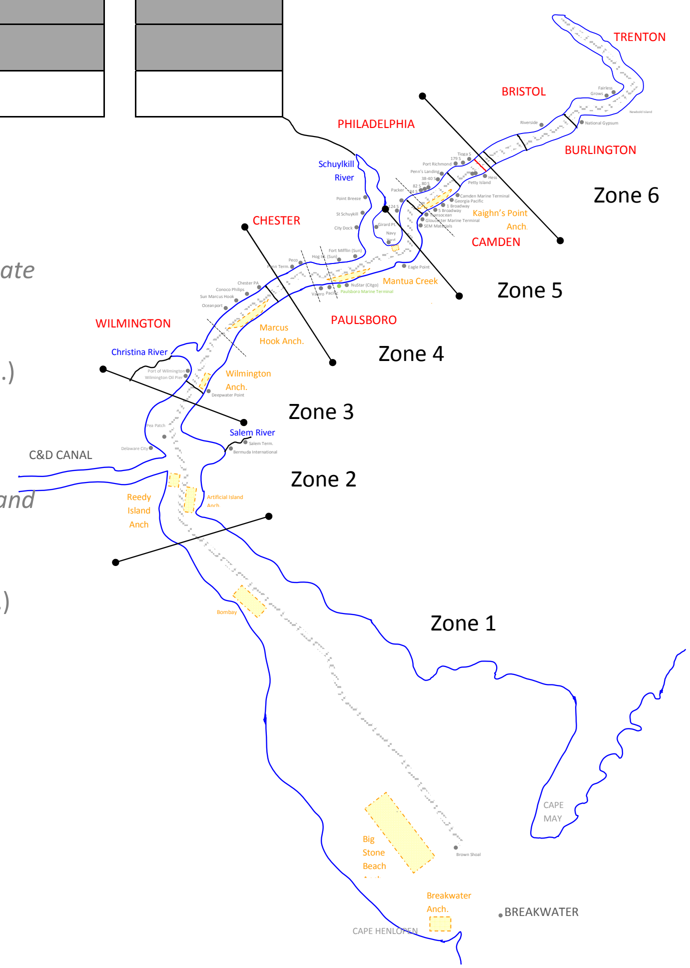
CAIT - Laboratory for Port Security (LPS)
100 Brett Road, Piscataway, 08854, NJ
Ph: (732) 445-0579 x-133
Fax: (732) 445-3325
Email: altiok@rci.rutgers.edu

INSTIGATORS

What is the effect of <u>a situational attribute</u> on the occurrence of an <u>instigator</u> in your vessel?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

Situational Attributes	Instigator				
	HE	PF	SF	EF	OSF
1. Time of Day					
2. Tide					
3. (Your) Vessel Status *(e.g. Docked, Underway,*					
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous*					
5. Zone *(e.g. 1,2,3,4,5,6)*					
6. No. of Vessels Underway within 5 NM of your position					
7. No. of Vessels Anchored within your Zone					
8. Season					



Example: What is the effect of ***Time of Day*** on the occurrence of a **Human Error (HE)** in your vessel?

HE: Human Error (may include "*not following the policies or best practice*", "*communication breakdown*", "*inadequate situational awareness*" and etc.)

PF: Propulsion Failure (may include "*engine breakdown*", "*contaminated fuel problem*", "*propeller problem*" and etc.)

SF: Steering Failure (may include "*hydraulic system failure*", "*rudder problem*" and etc)

EF: Electrical / Electronic Failure (may include "*generator failure*", "*computer software problems*", "*navigation and communication system failure*" and etc.)

OSF: Other Systems Failure (may include "*hull structure problems*", "*cargo and cargo control systems failure*" and etc.)

General Cargo: Containers, Break Bulk, Rolling Stock, Grain, Ore and etc. including Passenger Vessels and Tugboats/Barges

Dangerous Cargo: Petroleum, Chemicals, LNG/LPG

How important are the following <u>attribute characteristics</u> on the occurrence of an <u>instigator</u> in your vessel?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

	Instigator		
	HE	PSF	OSF
1. Time of Day			
a. Day		(shaded)	
b. Night		(shaded)	
2. Tide			
a. High			
b. Low			
3. (Your) Vessel Status			
a. Docked			
b. Underway			
c. Anchored			
4. (Your) Vessel Class			
a. General Cargo			
b. Dangerous Cargo			
5. Zone *(Geographical – Infrastructure only)*			
a. 1		(shaded)	
b. 2		(shaded)	
c. 3		(shaded)	
d. 4		(shaded)	
e. 5		(shaded)	
f. 6		(shaded)	
6. No. of Vessels Underway within 5 NM of your position			
a. 0-1		(shaded)	
b. 2-3		(shaded)	
c. more than 3		(shaded)	
7. No. of Vessels Anchored within your Zone			
a. 0-1		(shaded)	
b. 2-3		(shaded)	
c. more than 3		(shaded)	
8. Season			
a. Fall			
b. Winter			
c. Spring			
d. Summer			

Example: What is the effect of ***Day (vs. Night)*** to lead to a **Human Error (HE)** in your vessel?

How important are the following vessel types on the occurrence of an instigator in your vessel?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

Vessel Type	Instigator
1. General Cargo < 150 (m)	
2. General Cargo ≥ 150 (m)	
3. Tugboat / Barge	
4. Passenger ≥ 100 GT	
5. Petroleum Tanker < 200 (m)	
6. Petroleum Tanker ≥ 200 (m)	
7. Chemical Tanker < 150 (m)	
8. Chemical Tanker ≥ 150 (m)	
9. LNG / LPG	
10. Lightering Barge	

Example: What is the effect of a ***General Cargo Vessel < 150 (m) (vs. others)*** to lead to **an instigator** in your vessel?

Instigators

HE: Human Error

PSF: Propulsion / Steering Failure

OSF: Other Systems Failure

COLLISION | INSTIGATOR

Given an <u>instigator</u> is taking place in your vessel, what is the effect of a <u>situational attribute</u> on the likelihood of a <u>Collision (C)</u>?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

	Collision | Instigators				
Situational Attributes	HE^C	PF^C	SF^C	EF^C	OSF^C
1. Time of Day					
2. Tide					
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*					
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*					
5. Zone *(e.g. 1,2,3,4,5,6)*					
6. No. of Vessels Underway within 5 NM of your position					
7. No. of Vessels Anchored within your Zone					
8. Season					

Example: Given a **Propulsion Failure (PF)** is taking place in your vessel, what is the effect of

No. of Vessels Underway within 5 NM of your position on the likelihood of a **Collision (C)**?

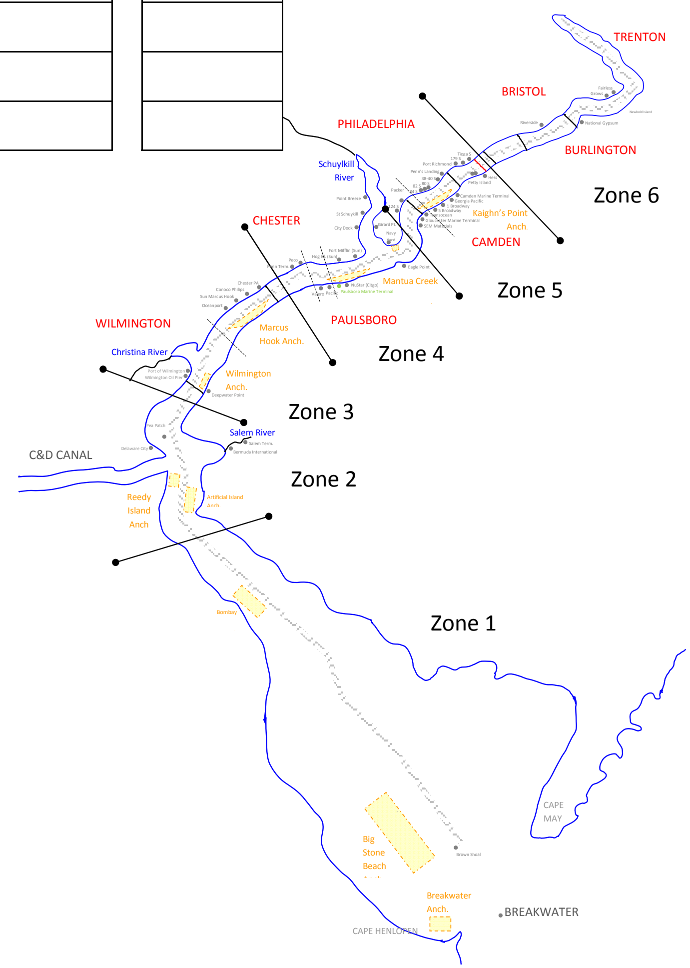
HE^C: Collision given Human Error

PF^C: Collision given Propulsion Failure

SF^C: Collision given Steering Failure

EF^C: Collision given Electrical / Electronic Failure

OSF^C: Collision given Other Systems Failure

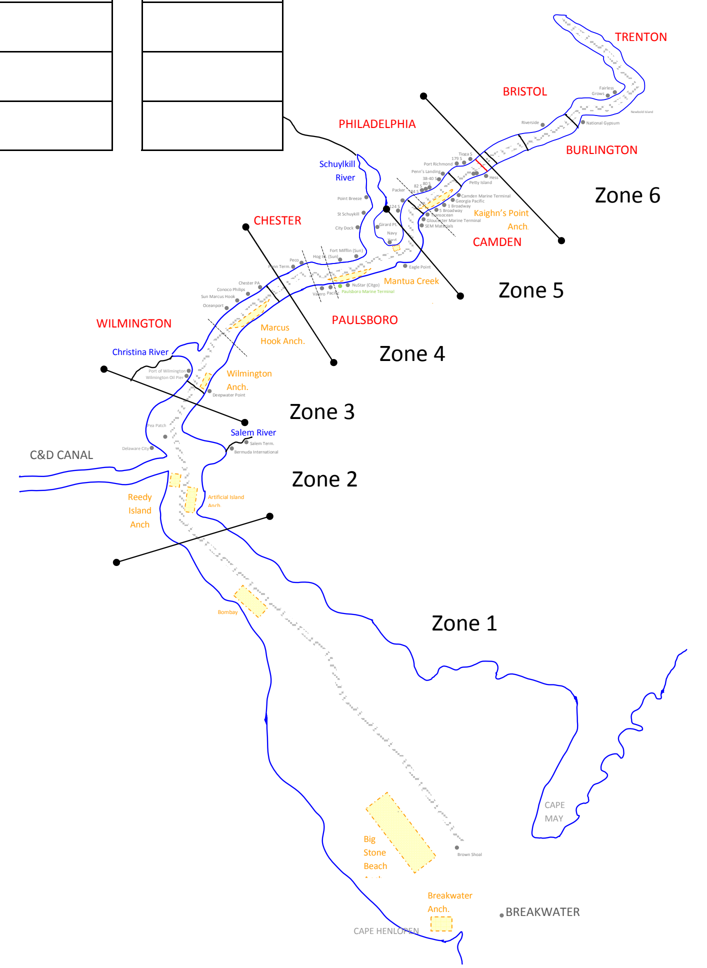


ALLISION | INSTIGATOR

Given an instigator is taking place in your vessel, what is the effect of a situational attribute on the likelihood of an Allision (A)?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

	Allision | Instigators				
Situational Attributes	HE^{A}	PF^{A}	SF^{A}	EF^{A}	OSF^{A}
1. Time of Day					
2. Tide					
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*					
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*					
5. Zone *(e.g. 1,2,3,4,5,6)*					
6. No. of Vessels Underway within 5 NM of your position					
7. No. of Vessels Anchored within your Zone					
8. Season					



Example: Given a **Steering Failure (SF)** is taking place in your vessel, what is the effect of

No. of Vessels Anchored within your Zone on the likelihood of an **Allision (A)**?

HE^{A}: Allision given Human Error

PF^{A}: Allision given Propulsion Failure

SF^{A}: Allision given Steering Failure

EF^{A}: Allision given Electrical / Electronic Failure

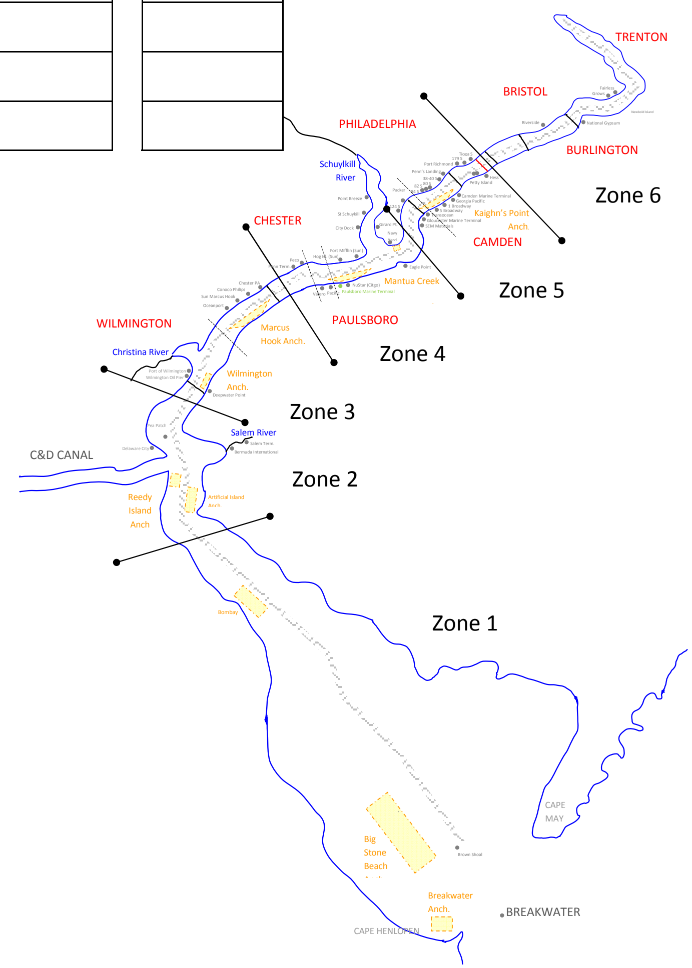
OSF^{A}: Allision given Other Systems Failure

GROUNDING | INSTIGATOR

Given an <u>instigator</u> is taking place in your vessel, what is the effect of a <u>situational attribute</u> on the likelihood of <u>Grounding (G)</u>?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

Situational Attributes	Grounding | Instigators				
	HE^G	PF^G	SF^G	EF^G	OSF^G
1. Time of Day					
2. Tide					
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*					
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*					
5. Zone *(e.g. 1,2,3,4,5,6)*					
6. No. of Vessels Underway within 5 NM of your position					
7. No. of Vessels Anchored within your Zone					
8. Season					



Example: Given a **Human Error (HE)** is taking place in your vessel, what is the effect of ***Tide*** on the likelihood of **Grounding (G)**?

HE^G: Grounding given Human Error

PF^G: Grounding given Propulsion Failure

SF^G: Grounding given Steering Failure

EF^G: Grounding given Electrical / Electronic Failure

OSF^G: Grounding given Other Systems Failure

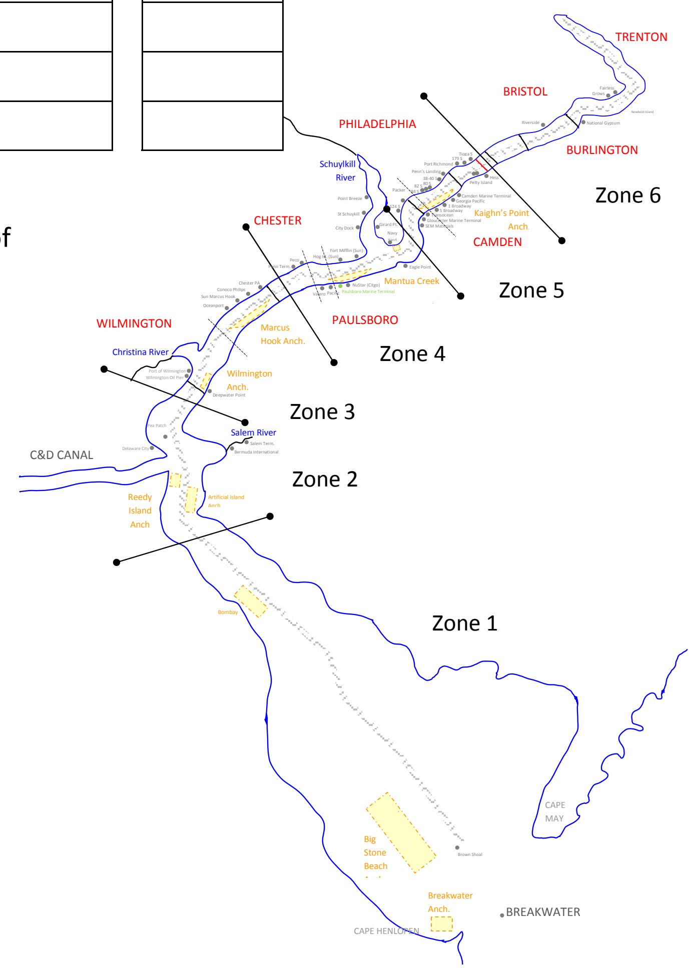
FIRE or EXPLOSION | INSTIGATOR

Given an instigator is taking place in your vessel, what is the effect of a situational attribute on the likelihood of Fire or Explosion (FE)?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

Situational Attributes	Fire or Explosion | Instigators				
	HE^{FE}	PF^{FE}	SF^{FE}	EF^{FE}	OSF^{FE}
1. Time of Day					
2. Tide					
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*					
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*					
5. Zone *(e.g. 1,2,3,4,5,6)*					
6. No. of Vessels Underway within 5 NM of your position					
7. No. of Vessels Anchored within your Zone					
8. Season					

Example: Given an **Electrical / Electronic Failure (EF)** is taking place in your vessel, what is the effect of ***Your Vessel Class*** on the likelihood of **Fire or Explosion (FE)**?



HE^{FE}: Fire or Explosion given Human Error

PF^{FE}: Fire or Explosion given Propulsion Failure

SF^{FE}: Fire or Explosion given Steering Failure

EF^{FE}: Fire or Explosion given Electrical / Electronic Failure

OSF^{FE}: Fire or Explosion given Other Systems Failure

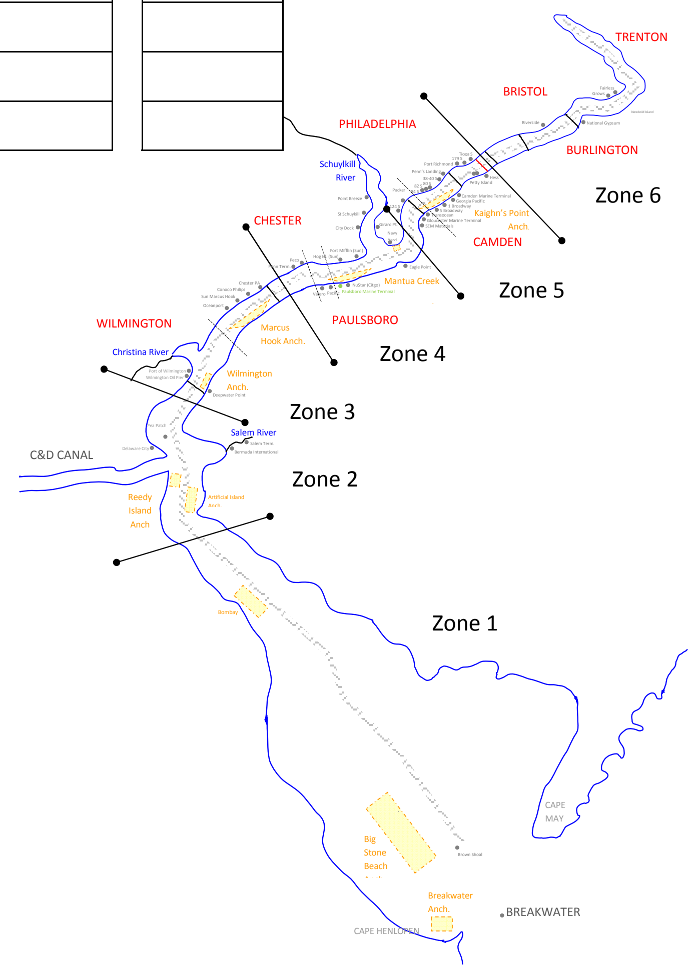
SINKING or CAPSIZING or FLOODING[8] | INSTIGATOR

Given an <u>instigator</u> is taking place in your vessel, what is the effect of a <u>situational attribute</u> on the likelihood of <u>Sinking or Capsizing or Flooding (SCF)</u>?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

	Sinking or Capsizing or Flooding | Instigators				
Situational Attributes	HE^{SCF}	PF^{SCF}	SF^{SCF}	EF^{SCF}	OSF^{SCF}
1. Time of Day					
2. Tide					
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*					
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*					
5. Zone *(e.g. 1,2,3,4,5,6)*					
6. No. of Vessels Underway within 5 NM of your position					
7. No. of Vessels Anchored within your Zone					
8. Season					

Example: Given an **Other Systems Failure (OSF)** is taking place in your vessel, what is the effect of ***Zone*** on the likelihood of **Sinking or Capsizing or Flooding (SCF)**?



HE^{SCF}: Sinking or Capsizing or Flooding given Human Error

PF^{SCF}: Sinking or Capsizing or Flooding given Propulsion Failure

SF^{SCF}: Sinking or Capsizing or Flooding given Steering Failure

EF^{SCF}: Sinking or Capsizing or Flooding given Electrical / Electronic Failure

OSF^{SCF}: Sinking or Capsizing or Flooding given Other Systems Failure

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[8] SCF is the immediate outcome of the instigator and not a secondary outcome of another accident (such as grounding).

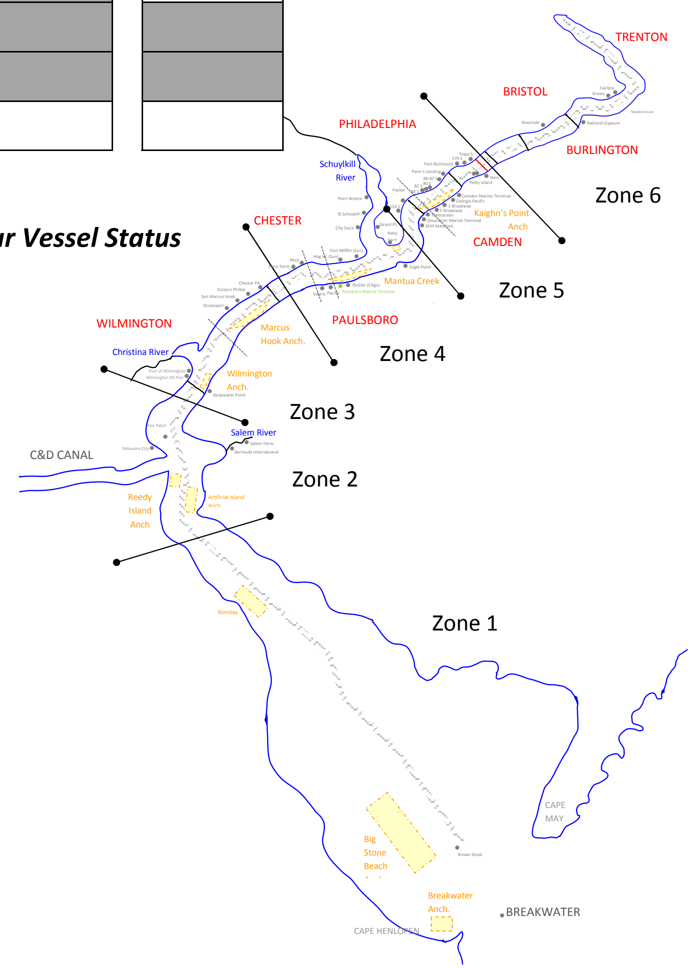
OIL SPILL | INSTIGATOR

Given an instigator is taking place in your vessel, what is the effect of a situational attribute on the likelihood of an Oil Spill (OS)?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

Situational Attributes	Oil Spill | Instigators				
	HE^{OS}	PF^{OS}	SF^{OS}	EF^{OS}	OSF^{OS}
1. Time of Day					
2. Tide					
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*					
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*					
5. Zone *(e.g. 1,2,3,4,5,6)*					
6. No. of Vessels Underway within 5 NM of your position					
7. No. of Vessels Anchored within your Zone					
8. Season					

Example: Given an **Other Systems Failure (OSF)** is taking place in your vessel, what is the effect of ***Your Vessel Status*** on the likelihood of an **Oil Spill (OS)**?



HE^{OS}: Grounding given Human Error

PF^{OS}: Grounding given Propulsion Failure

SF^{OS}: Grounding given Steering Failure

EF^{OS}: Grounding given Electrical Failure

OSF^{OS}: Grounding given Other Systems Failure

Given an instigator is taking place in your vessel, what is the importance of the following attribute characteristics on the likelihood of an Accident?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

	Accident | Instigator		
	HE	PSF	OSF
1. Time of Day			
a. Day			
b. Night			
2. Tide			
a. High			
b. Low			
3. (Your) Vessel Status			
a. Docked			
b. Underway			
c. Anchored			
4. (Your) Vessel Class			
a. General Cargo			
b. Dangerous Cargo			
5. Zone *(Geographical – Infrastructure only)*			
a. 1			
b. 2			
c. 3			
d. 4			
e. 5			
f. 6			
6. No. of Vessels Underway within 5 NM of your position			
a. 0-1			
b. 2-3			
c. more than 3			
7. No. of Vessels Anchored within your Zone			
a. 0-1			
b. 2-3			
c. more than 3			
8. Season			
a. Fall			
b. Winter			
c. Spring			
d. Summer			

Example: Given a **Propulsion / Steering Failure (PSF)** is taking place in your vessel, what is the effect of ***0-1 Vessels Underway within 5NM of your position (vs. 2-3 and more than 3)*** to lead to an **Accident**?

Given an instigator is taking place in your vessel, what is the importance of the following vessel types on the likelihood of an accident?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

Vessel Type	**Accident | Instigator**
1. General Cargo < 150 (m)	
2. General Cargo ≥ 150 (m)	
3. Tugboat / Barge	
4. Passenger ≥ 100 GT	
5. Petroleum Tanker < 200 (m)	
6. Petroleum Tanker ≥ 200 (m)	
7. Chemical Tanker < 150 (m)	
8. Chemical Tanker ≥ 150 (m)	
9. LNG / LPG	
10. Lightering Barge	

Given an **instigator** is taking place in your vessel, what is the effect of a ***Tanker ≥ 200 (m) (vs. others)*** to lead to **an accident**?

Accidents

C: Collision

A: Allision

G: Grounding

FE: Fire or Explosion

SCF: Sinking or Capsizing or Flooding

OS: Oil Spill

CONSEQUENCES | COLLISION

Given a <u>Collision (C)</u> has happened, what is the effect of a <u>situational attribute</u> on the severity of the <u>consequence</u>?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

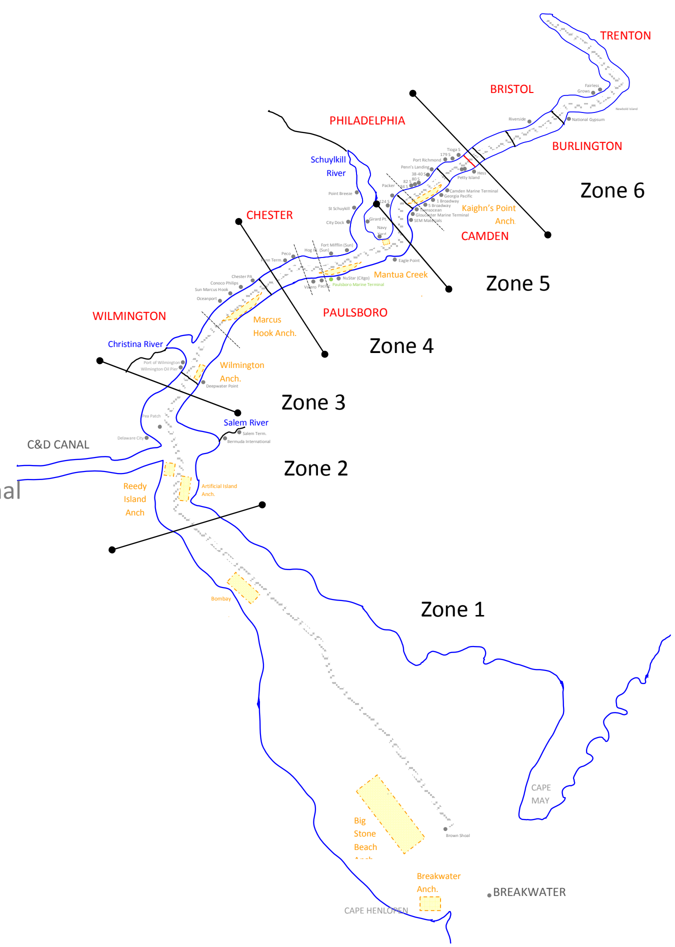
	Consequences | Collision		
Situational Attributes	HC	EnvD	ProD
1. Time of Day			
2. Tide			
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*			
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*			
5. Zone *(e.g. 1,2,3,4,5,6)*			
6. No. of Vessels Underway within 5 NM of your position			
7. No. of Vessels Anchored within your Zone			
8. Season			

Example: Given a **Collision (C)** has happened, what effect does ***Time of Day*** have on the severity of **Human Casualty (HC)**?

HC: **Human Casualty** (may include death, permanent disabling injury, and minor injury)

EnvD: **Environmental Damage** (may include impact to wild life and habitat, loss of commercial and recreational use, danger to human life, oil spill and etc.)

PropD: **Property Damage** (may include damage greater than $10,000.)



CONSEQUENCES | ALLISION

Given an Allision (A) has happened, what is the effect of a situational attribute on the severity of the consequence?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

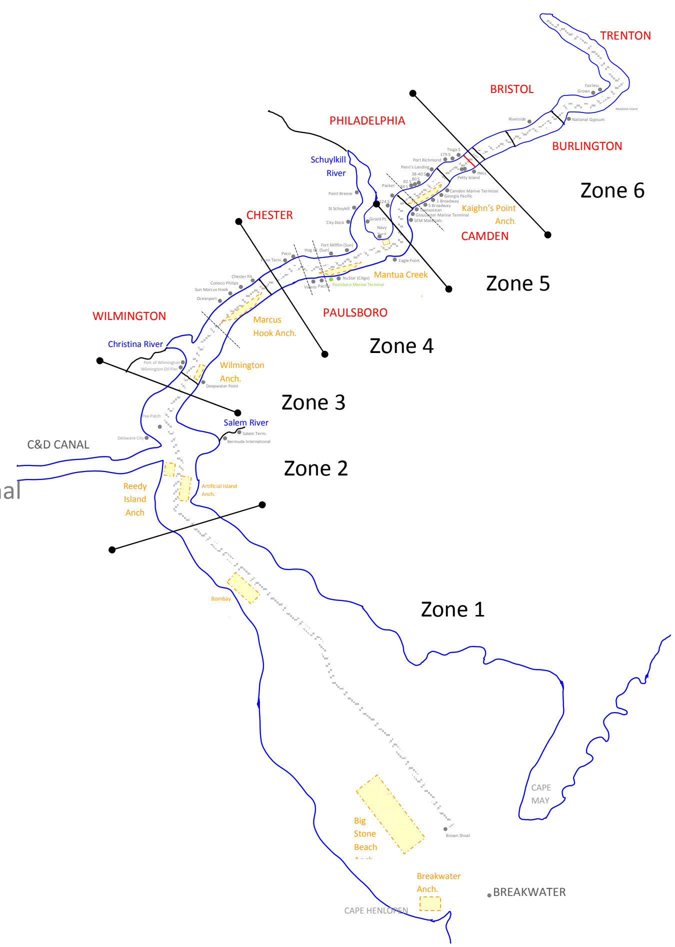
	Consequences | Allision		
Situational Attributes	HC	EnvD	ProD
1. Time of Day			
2. Tide			
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*			
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*			
5. Zone *(e.g. 1,2,3,4,5,6)*			
6. No. of Vessels Underway within 5 NM of your position			
7. No. of Vessels Anchored within your Zone			
8. Season			

Example: Given an **Allision (A)** has happened, what effect does ***Zone*** have on the severity of **Property Damage (ProD)**?

HC: **Human Casualty** (may include death, permanent disabling injury, and minor injury)

EnvD: **Environmental Damage** (may include impact to wild life and habitat, loss of commercial and recreational use, danger to human life, oil spill and etc.)

PropD: **Property Damage** (may include damage greater than $10,000.)



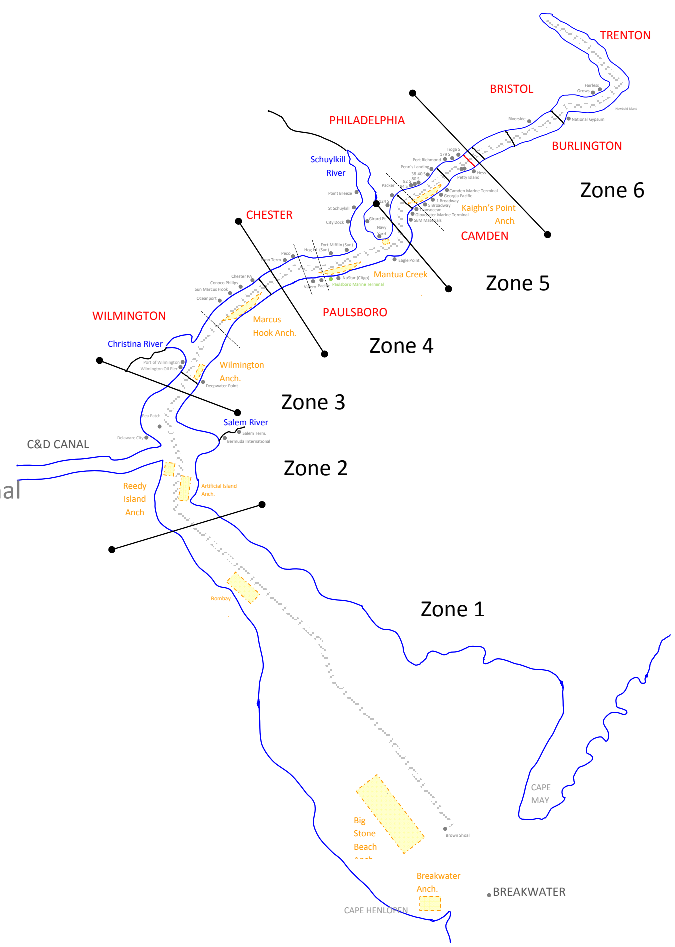
CONSEQUENCES | GROUNDING

Given a Grounding (G) has happened, what is the effect of a situational attribute on the severity of the consequence?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

	Consequences | Grounding		
Situational Attributes	HC	EnvD	ProD
1. Time of Day			
2. Tide			
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*			
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*			
5. Zone *(e.g. 1,2,3,4,5,6)*			
6. No. of Vessels Underway within 5 NM of your position			
7. No. of Vessels Anchored within your Zone			
8. Season			

Example: Given a **Grounding (G)** has happened, what effect does ***Your Vessel Class*** have on the severity of **Environmental Damage (EnvD)**?



HC: **Human Casualty** (may include death, permanent disabling injury, and minor injury)

EnvD: **Environmental Damage** (may include impact to wild life and habitat, loss of commercial and recreational use, danger to human life, oil spill and etc.)

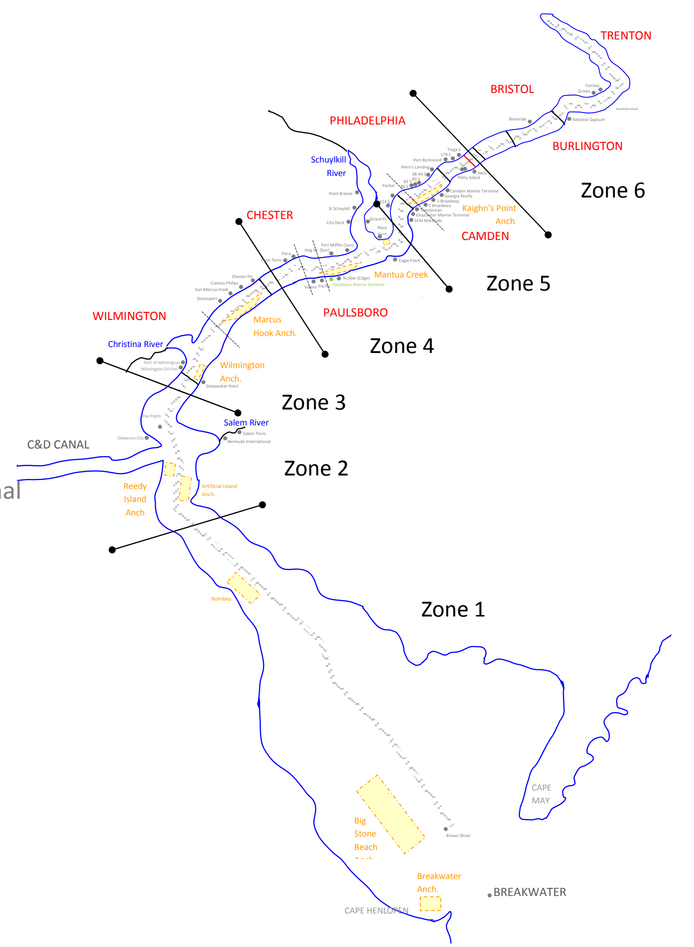
PropD: **Property Damage** (may include damage greater than $10,000.)

CONSEQUENCES | FIRE or EXPLOSION

Given a Fire or Explosion (FE) has happened, what is the effect of a situational attribute on the severity of the consequence?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

	Consequences | Fire or Explosion		
Situational Attributes	HC	EnvD	ProD
1. Time of Day			
2. Tide			
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*			
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*			
5. Zone *(e.g. 1,2,3,4,5,6)*			
6. No. of Vessels Underway within 5 NM of your position			
7. No. of Vessels Anchored within your Zone			
8. Season			



Example: Given a **Fire or Explosion (FE)** has happened, what effect does ***Your Vessel Status*** have on the severity of **Human Casualty (HC)**?

HC: **Human Casualty** (may include death, permanent disabling injury, and minor injury)

EnvD: **Environmental Damage** (may include impact to wild life and habitat, loss of commercial and recreational use, danger to human life, oil spill and etc.)

PropD: **Property Damage** (may include damage greater than $10,000.)

CONSEQUENCES | SINKING or CAPSIZING or FLOODING

Given a Sinking or Capsizing or Flooding (SCF) has happened, what is the effect of a situational attribute on the severity of the consequence?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

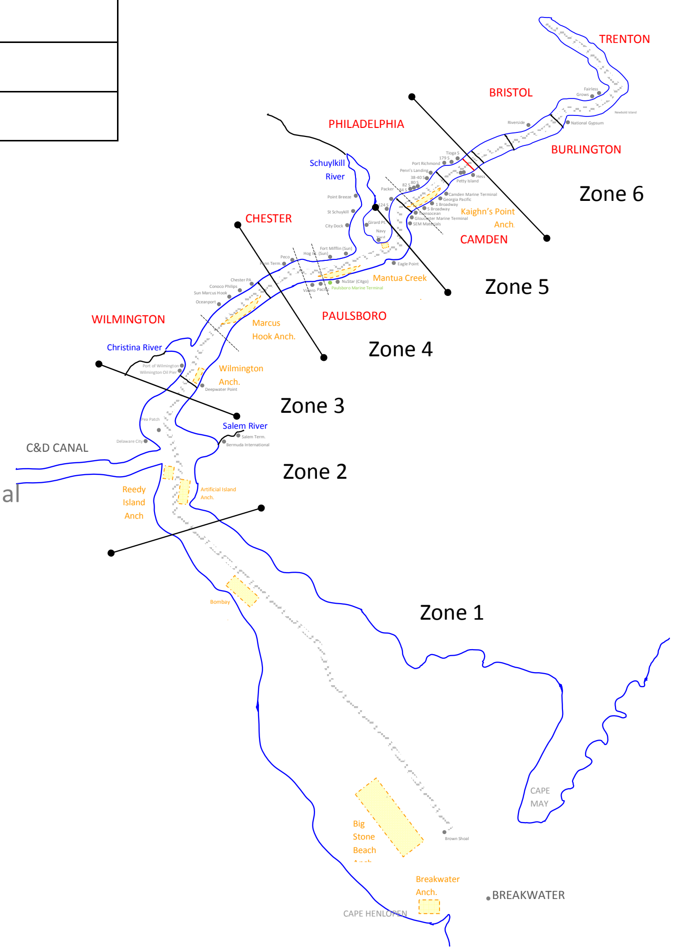
	Consequences | Sinking or Capsizing or Flooding		
Situational Attributes	HC	EnvD	ProD
1. Time of Day			
2. Tide			
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*			
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*			
5. Zone *(e.g. 1,2,3,4,5,6)*			
6. No. of Vessels Underway within 5 NM of your position			
7. No. of Vessels Anchored within your Zone			
8. Season			

Example: Given a **Sinking or Capsizing or Flooding (SCF)** has happened, what effect does ***Season*** have on the severity of **Property Damage (ProD)**?

HC: **Human Casualty** (may include death, permanent disabling injury, and minor injury)

EnvD: **Environmental Damage** (may include impact to wild life and habitat, loss of commercial and recreational use, danger to human life, oil spill and etc.)

PropD: **Property Damage** (may include damage greater than $10,000.)



CONSEQUENCES | OIL SPILL

Given an Oil Spill (OS) has happened, what is the effect of a situational attribute on the severity of the consequence?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

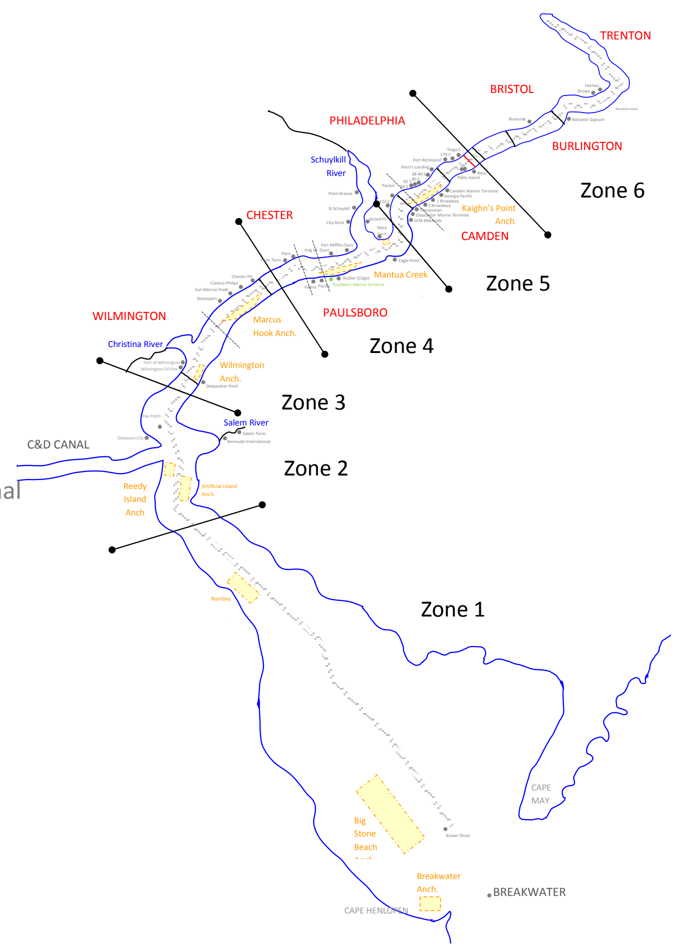
	Consequences | Oil Spill		
Situational Attributes	HC	EnvD	ProD
1. Time of Day			
2. Tide			
3. (Your) Vessel Status *(e.g. Docked, Underway, Anchored)*			
4. (Your) Vessel Class *(e.g. General Cargo, Dangerous Cargo)*			
5. Zone *(e.g. 1,2,3,4,5,6)*			
6. No. of Vessels Underway within 5 NM of your position			
7. No. of Vessels Anchored within your Zone			
8. Season			

Example: Given an **Oil Spill (OS)** has happened, what effect does ***Time of Day*** have on the severity of **Environmental Damage (EnvD)**?

HC: **Human Casualty** (may include death, permanent disabling injury, and minor injury)

EnvD: **Environmental Damage** (may include impact to wild life and habitat, loss of commercial and recreational use, danger to human life, oil spill and etc.)

PropD: **Property Damage** (may include damage greater than $10,000.)



Given an Accident has happened, how important are the following attribute characteristics on the severity of the consequence?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

	Consequence | Accident		
	Human Casualty	Environmental Damage	Property Damage
1. Time of Day			
a. Day			
b. Night			
2. Tide			
a. High			
b. Low			
3. (Your) Vessel Status			
a. Docked			
b. Underway			
c. Anchored			
4. (Your) Vessel Class			
a. General Cargo			
b. Dangerous Cargo			
5. Zone *(Geographical – Infrastructure only)*			
a. 1			
b. 2			
c. 3			
d. 4			
e. 5			
f. 6			
6. No. of Vessels Underway within 5 NM of your position			
a. 0-1			
b. 2-3			
c. more than 3			
7. No. of Vessels Anchored within your Zone			
a. 0-1			
b. 2-3			
c. more than 3			
8. Season			
a. Fall			
b. Winter			
c. Spring			
d. Summer			

Example: Given an **Accident** has happened, what effect does ***Day (vs. Night)*** have on the level of **Human Casualty (HC)**?

Given an accident has happened, how important are the following vessel types on the severity of the consequence?

Enter your answer as a value between 0 (*no relation*) and 100 (*direct relationship/correlation*).

	Consequence | Accident		
Vessel Type	Human Casualty	Environmental Damage	Property Damage
1. General Cargo < 150 (m)			
2. General Cargo ≥ 150 (m)			
3. Tugboat / Barge			
4. Passenger ≥ 100 GT			
5. Petroleum Tanker < 200 (m)			
6. Petroleum Tanker ≥ 200 (m)			
7. Chemical Tanker < 150 (m)			
8. Chemical Tanker ≥ 150 (m)			
9. LNG / LPG			
10. Lightering Barge			

Example: Given an **accident** has happened, what effect does ***LNG / LPG (vs. others)*** have on the level of **Environmental Damage (EnvD)**?

Consequences

HC: Human Casualty

EnvD: Environmental Damage

ProD: Property Damage

COMMENTS

Please write here any comments on how this survey could be improved.

APPENDIX C: SCHOLARLY ACTIVITY GENERATED BY THE PROJECT TEAM

The Appendix presents articles, both refereed and non refereed, special volumes in scholarly journals, presentations in professional and academic conferences and conference organization activities of Dr. Altiok and his PhD students Alper Almaz and Amir Ghafoori during the course of this project. The material presented below is directly related to Delaware River vessel Traffic project.

Articles

Altiok, T., “Port Security/Safety, Risk Analysis, and Modeling,” Annals of Operations Research, Vol. 187, 2011.

Altiok, T., “Model-based Risk”, Cargo Security International, December 2009/January 2010 Issue, pp. 22-24. Featured article in the Maritime and Port Security Section.

Altiok, T., “Model Solution”, Cargo Security International, August/September 2009 Issue, pp. 52-54.

Altiok, T., “In Defense of Goods, “Research Validates Simulation’s Role in Port Security,” Industrial Engineer, pp. 34-37, January 2009.

Almaz, A., T. Altiok and A. Ghafoori, “Simulation Modeling of the Vessel Traffic in Delaware River: Impact of Dredging on Navigational Issues,” Submitted to Simulation Modelling Practice and Theory.

Altiok, T., Port Security/Safety, Risk Analysis, and Modeling, Invited Special Dedicated Volume (Editor: T. Altiok), Annals of Operations Research, Vol. 187, 2011.

Presentations

Altiok, T., “Risk Analysis and Simulation Modeling,” Summer Computer Simulation Conference, June 2011, The Hague, Netherlands (Keynote Speaker).

Altiok, T., “Continuous Material Flow Networks: Application to Bulk Ports,” Stochastic Models of Manufacturing and Service Operations, SMMSO, May, 2011, Kusadasi, Turkey (Keynote Speaker).

Altiok, T.,”Risk Analysis for Maritime Transportation in Ports and Waterways,” IERC, May 21-25, 2011, Reno, NV (Featured Speaker).

Almaz, A. and T. Altiok, “Modeling of Vessel Arrivals in Delaware River Port terminals,” IERC, May 21-25, 2011, Reno, NV.

Ghafoori, A. and T. Altiok, “A Grid-Based Approach to Underwater Sensor Placement to Mitigate Risks in Ports and Waterways,” IERC, May 21-25, 2011, Reno, NV.

Altiok, T., “Simulation Modeling and Risk Analysis in the Maritime Domain,” Rutgers University, Bloustein School of Planning and Public Policy, February, 2011, New Brunswick, NJ (Invited).

Altiok, T., “Simulation Modeling and Analysis of Ports and Waterways,” USCG, R&D Center,

February, 2011, New New London, CT (Invited).

Altiok, T., “Impact of Dredging on the Navigational Efficiency in the Delaware River Main Channel,” Delaware Valley Regional Planning Commission, January 11, 2001, Philadelphia, PA.

Almaz, A., T. Altiok, “Simulation of Vessel Traffic and Dredging Impact Analysis in Delaware River ,” INFORMS Conference, November, 2010, Austin, TX (Invited).

Ghafoori, A., “A Risk-Based Sensor Allocation Problem, INFORMS Conference, November, 2010, Austin, TX.

Altiok, T., “Risk Analysis– Qualitative/Quantitative Tools,” CREATE Maritime Risk Symposium, University of Southern California, November 16-17, Los Angeles, CA (Invited).

Altiok, T., “Port Security and Safety Issues, ” Conference on Hurricane and Homeland Security in Texas and the Gulf Coast Region, Texas Hurricane Center and The University of Houston , August 6, 2010, Huston, TX (Invited).

Altiok, T., “Large-Scale Simulation Modeling of Ports and Waterways: Approaches and Challenges,” Workshop on Grand Challenges in Modeling, Simulation and Analysis for Homeland Security, March 2010, Arlington, VA (Invited).

Altiok, T., “Modeling of the Maritime Traffic in Delaware River Main Channel,” Delaware Valley Regional Planning Commission, October 2010, Philadelphia, PA (Invited)

Altiok, T., A. Almaz, “Risk Analysis of the Vessel Traffic in Delaware River and Bay Area,” Annual Meeting of the Society of Risk Analysis, December, 2009, Baltimore, MD (Invited).

Modeling of Vessel Traffic in Delaware River and Bay, US Army core of Engineers, Philadelphia. District, October, 2009.

Altiok, T. “Research Issues in Homeland Security,” INFORMS, San Diego, CA, October, 2009 (Invited Panel Member).

Altiok, T., “Modeling Safety and Security Risks in Ports and Waterways,” Applied Physics Laboratory, Johns Hopkins University, Baltimore, MD,   September, 2009 (Invited).

Altiok, T. “Risk Analysis in Ports and Waterways,” IIE Research Conference, Miami, FL, May 2009 (Invited).

Altiok, T., “On the Security of the Delaware River and Its Ports,” Ballard Spahr Meeting on Port and Economic Development in in the Delaware River and bay Area, Voorhees, NJ, January 2008. (Invited Panel member to around 200 members of the South Jersey Business Community, accompanying Kris Kolluri, Comissioner, NJDOT)

Conference Organizations

Co-Chair, Algorithmic Decision Theory for Robust Ports, Workshop, May 2011, CoRE Building, Rutgers University, Piscataway, NJ.

Advisory Board, Conference on Hurricane and Homeland Security in Texas and the Gulf Coast Region, Texas Hurricane Center and The University of Houston, August, 2010.

Program Comm. Member, 8th IEEE International Conference on Intelligence and Security Informatics (IEEE ISI-2010), May, 2010, Vancouver, BC.

Program Comm. Member, 7th IEEE International Conference on Intelligence and Security Informatics (IEEE ISI-2009), June 8 – 11, 2009, Dallas, TX.

Co-Chair, Workshop on Port Security/Safety, Inspection, Risk Analysis and Modeling, November 17-18, 2008, CoRE Building, Rutgers University, Piscataway, NJ.

Future Presentations

Ozbas, B. and T. Altiok, “Safety Risk Analysis of Maritime Transportation: A Review,” Submitted to Transportation Research Board’s 91th Annual Meeting, Washington, D.C., 2012.

Almaz, A., T. Altiok, A, Ghafoori, “Impact of Dredging on Navigational Issues in Delaware River and Bay,” Submitted to Transportation Research Board’s 91th Annual Meeting, Washington, D.C., 2012.

Almaz, A., and T. Altiok, “Model-Based Risk Analysis in the Delaware River,” Submitted to Transportation Research Board’s 91th Annual Meeting, Washington, D.C., 2012.