Impact of Deepening on Navigational Issues in Delaware River

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ABSTRACT

This paper deals with the impact of deepening on the navigational efficiency in Delaware River and Bay based on a vessel traffic simulation model developed. In this regard, vessel calls to terminals, lightering and barge operations, tidal and navigational rules and recommendations, terminal and anchorage properties as well as vessel profiles are considered in the model. Through scenario analysis, effects of deepening and dredging on port performance measures are investigated. The statistics tracked in this respect are the overall port and terminal utilization, port times and terminal calls, anchorage visits and delays based on various vessel visits, categories and movements. The results indicate some navigational benefits for container vessels due to ample capacity in container terminals as well as for tankers due to lesser lightering activity. However, no significant efficiency for bulk and general cargo vessels is observed. The expected benefits due to lesser tidal delays are verified but the results also indicate a potential capacity issue for the major anchorages for the years to come in the planning horizon.

Keywords: Port simulation; Maritime traffic; Delaware River; Deepening; Dredging
1. INTRODUCTION

Delaware River has a history of more than 300 years as a commercial maritime route for handling import and export of raw and manufactured goods. Today it has more than 40 port facilities with their associated businesses located 60 to 100 miles up the River with about 3,000 vessels visiting each year.

The region has proximity to the densest population base in the U.S. and 27 million people living within 100 miles and 90 million within 500 miles give its ports a widespread natural consumer market. In this respect, approximately 65% of the region’s cargo tonnage is in petroleum. Other major cargoes are steel, wood products, and perishable items such as fresh fruit, nuts, cocoa beans, and meat products. Major ports covered are Wilmington, Chester, Philadelphia, Camden, and Trenton (1, 2, 3).

The River is the port of call for large 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 of the Delaware River to 45 feet has been proposed and debated over a number of years. The project consists of the navigation channel from deep water in the Delaware Bay to Philadelphia Harbor, PA and to Beckett Street Terminal, Camden, NJ. The plan introduces modifying the existing Delaware River Federal Navigation Channel from 40 to 45 feet below Mean Low Water (MLW) and provision of an anchorage to a depth of 45 feet at Marcus Hook. Accordingly, the benefits 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, both resulting from navigation improvements by means of cost reduction per ton for shipping commodities into or out of the Delaware River Port System (4, 5).

In this respect, the motivation behind this study is 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. The proposed model is also aimed to be used to examine feasibility and the effects of port expansion projects and to perform logistics and risk analysis in the Delaware River and Bay (DRB) area. These may include construction of new terminals, installation of new infrastructure facilities or energy projects such as off-shore wind farms. Clearly, such a tool can be developed for other ports and waterways for the same objectives.

2. LITERATURE REVIEW

Simulation modeling has been used in various fields where analytical models cannot be used due to complex nature of problems. Simulation studies in maritime transportation domain can be categorized under applications on port/terminal operations and logistics, modeling of vessel traffic on waterways for scenario and policy analyses and using simulation platforms as a tool to evaluate accident probabilities, risks and various economic and technical issues.

Literature on simulation modeling of vessel traffic on waterways is not large but growing. Golkar et al. (6) developed a simulation model for the Panama Canal as a tool for scenario and policy analyses. Thiers and Janssens (7) 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. (8) performed traffic density analysis which would lead later to the risk analysis for the ferry service expansion in San Francisco Bay area. Cortes et al. (9) 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). Smith et al. (10) worked on congestion in Upper Mississippi River through building a traffic simulation model and tested different operating conditions. For the Strait of Istanbul there is considerable literature bringing different perspectives in which simulation modeling was used for scenario and policy analyses. Ozbas and Or (11) and Almaz et al. (12) 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. In addition to these, in various studies vessel traffic simulation was inherently used as an environment for further analysis of accident probabilities, risks and various economic and technical issues. Uluscu et
al. (13) used a traffic simulator to test and deploy a scheduling algorithm for transit vessels in the Strait of Istanbul and Uluscu et al. (14) developed a dynamic risk analysis map based on an extensive vessel traffic simulation for the Strait of Istanbul. Somanathan et al. (15) investigated economic viability of Northwest Passage compared to Panama Canal using simulation for vessel movements and environmental conditions.

Maritime transportation studies on Delaware River and Bay are limited in number. However, the work of Andrews et al. (16) 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.

Investigation of impacts of deepening and/or dredging on port performance measures is scarce in literature. Grigalunas et al. (17) 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 for transportation savings and direct nonmarket benefits and hence tried to justify the proposed deepening project for the cosponsor’s side.

This paper presents an analysis based on a simulation model focusing on the maritime activities in the current as well as deepened scenarios in the Delaware River and Bay area. The main contribution of the paper is to emphasize the need for such analysis during dredge/deepening planning processes in any port or waterway system. To the best of our knowledge no such directly related work to deepening/dredging was located in literature.

3. PORT OPERATIONS IN DELAWARE RIVER AND BAY

Delaware River is both geographically and operationally one of the most significant waterways in the East Coast. Port operations and maritime activity in 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 is through Chesapeake and Delaware Canal (CD). Vessel profiles are in line with the cargo types being carried to the terminals and are mostly tankers (TA) (30%), cargo containers (CC) (15%), bulk vessels (BU) (14%), refrigerated vessels (RF) (11%), vehicle vessels (VE) (10%) and general cargo vessels (GC) (8%). Aside of the regular cargo vessel traffic there is also tug/barge traffic carrying cargo in and out of the port.

There are rules and regulations governing the vessel traffic in the River such as the maximum fresh water draft for river transit from BW to Delair, NJ is 40 feet and from Delair to Trenton, NJ it is 38 feet.

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

Lightering is another significant activity in the system. The maximum salt-water draft in the entrance of Delaware Bay is 55 feet and Delaware River’s main channel allows travel of vessels below 40 feet fresh water draft. Based on this regulation, deep draft vessels carrying cargo that could be transferred to lightering barges (mostly tankers carrying petroleum products) can do lightering depending on the water depth at the first terminal they will be visiting. In general, there are four lightering barges serving vessels to be lightered and going up and down in the River to the terminals and to Big Stone Beach Anchorage (BSB) which is the designated lightering area.

Clearly, there is a destination terminal and possibly more than one destination for every vessel arriving at the River. There is a variety of terminals each having its own operational details. 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.

4. SIMULATION MODEL

The main goal behind the model development is to constitute an accurate platform to study key issues regarding the port’s operation via scenario analysis such as increase in vessel arrivals, deepening the river and changes in the operational/navigational policies. For this purpose, a high-fidelity simulation model of vessel traffic in DRB is developed involving all vessel types and all of the port terminal facilities along the river from entrance to Trenton (FIGURE 1). Arena 11.0 simulation software is used in the development of the model.

The simulation model involves 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 (2). Tidal activity, lightering operations and anchorage delays along with terminal operations to the extent of vessel berth holding (excluding internal terminal logistics) are also included in the model.
Almaz, O.A. and Altiok, T.

4.1 Model Objectives

The objectives of this paper 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.

4.2 Model Components

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

The details of the simulation model, probability distributions used and explanations of model components are available at Rutgers University Laboratory for Port Security research report (18).

4.3. Model Outputs

Model outputs 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.

Vessel-averaged statistics are:
• Annual port calls per vessel type,
• Port times per vessel per vessel type,
• Terminal calls per vessel type,
• Annual anchorage visits 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),
• Port occupancy,

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 (19).

4.4. Verification & Validation

The model is verified in several steps to check if it is working the way it is intended to. A powerful tool used throughout the model development phase is the tracing approach. Via tracing, a detailed report of entity processing can be compared with manual calculations in order to check if the logic implemented in the model is as intended. Animation is another useful tool for verification and validation purposes. Through animation, operation of the overall system can be followed as well as synchronization of events can be observed and verified.

For validation purposes, several tests are performed and various key performance measures are observed to see if they are close to their counterparts in reality. The simulation results of one replication for 30 years representing the current situation in DRB are compared to the observations of the years between 2004 and 2008. These observations are based on port calls and port times, anchorage calls and delays, and terminal utilizations as shown in TABLE 1 and FIGURE 2.
TABLE 1 Port Times and Port Calls¹

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>Actual Data 04 - 08</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Port Time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>per Vessel (min)</td>
<td>Average No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of Vessels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>per Year</td>
</tr>
<tr>
<td></td>
<td>5597.25</td>
<td>423.2</td>
</tr>
<tr>
<td>Bulk (BU)</td>
<td>5686.9 (± 130.35)</td>
<td>416.9</td>
</tr>
<tr>
<td>Containership (CC)</td>
<td>1975.85</td>
<td>475.8</td>
</tr>
<tr>
<td>Chemical (CH)</td>
<td>3687.37</td>
<td>70.6</td>
</tr>
<tr>
<td>Non-flammable Prod. (NP)</td>
<td>2501.35</td>
<td>50.8</td>
</tr>
<tr>
<td>General Cargo (GC)</td>
<td>3937.95</td>
<td>262.6</td>
</tr>
<tr>
<td>Parts Container (PC)</td>
<td>5072.30</td>
<td>66.2</td>
</tr>
<tr>
<td>LPG (PG)</td>
<td>6030.96</td>
<td>31.4</td>
</tr>
<tr>
<td>Passenger (PR)</td>
<td>1246.05</td>
<td>32.6</td>
</tr>
<tr>
<td>RO-RO Container (RC)</td>
<td>368.89</td>
<td>63.8</td>
</tr>
<tr>
<td>Refrigerated (RF)</td>
<td>4142.07</td>
<td>337.2</td>
</tr>
<tr>
<td>RO-RO (RR)</td>
<td>3022.94</td>
<td>85.8</td>
</tr>
<tr>
<td>Tanker (TA)</td>
<td>5011.79</td>
<td>921.2</td>
</tr>
<tr>
<td>Vehicle (VE)</td>
<td>712.84</td>
<td>300.8</td>
</tr>
<tr>
<td>Tug Boat (TG)</td>
<td>4443.93</td>
<td>667.0</td>
</tr>
<tr>
<td>Overall</td>
<td>3898.43</td>
<td>3789.0</td>
</tr>
</tbody>
</table>

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. TABLE 1 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 per cent difference from the actual value. Aggregate figures of the average port time and port calls indicate that the actual system is well represented within the simulation.

Figure 2 illustrates the annual anchorage visits and average delays per visit.

¹ Actual Tug Boat data are based on 2004 only.
Anchorage visits and delays are of critical importance since less variation in these figures indicates robustness of the model. As seen in FIGURE 2, 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 data and simulation results, the simulation model built to mimic the vessel traffic in the Delaware River and Bay is considered to have close representation of the actual system to perform the scenario analysis on the issues mentioned earlier.

5. SCENARIO ASSUMPTIONS

The scenario analysis presented in this paper 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. In deployment of these assumptions into scenarios the 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 (4).

The scenarios presented in this paper are as follows:
A. Current scenario (results given in the validation section)
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

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

5.1. Trade Growth

Future trade forecast for Delaware River port system is investigated in the deepening analysis report of the USACE (4). Based on this analysis, future vessel arrival patterns for the next 30 years are estimated annually and incorporated for almost all vessel types in the model.

With this assumption, 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.

5.2. Deepening the Main Channel and Dredging Terminal Berths

As a result of the deepening project, terminals from Delaware Bay entrance to the Philadelphia region might benefit from the deepening project by dredging nearby their berths. Based on the USACE report, berth deepening data for dredge designated terminals given in TABLE 2 are incorporated into the scenarios operating under this assumption.

As a result of increased depth in the main channel and in the terminals, lightering needs of tankers will be lesser. 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 and holding time is increased.

Along with deepening of the main channel, some regulations controlling the navigation in the River are needed to be revised. Thus, tide regulations regarding the Lower River are relaxed by 5 feet in the model. Therefore, inbound tidal delays in BWA and outbound tidal delays especially in the MHA are expected to be reduced.

In this assumption, it is anticipated to see less lightering activity in the BSB due to increased depth in the main channel to accommodate deeper draft vessels. However, vessel types other than tankers are not expected to see much navigational benefits since there is no change in the vessel fleet or in the cargo tonnages of the vessels.
5.3. Shift to A Fleet of Larger Vessels

Under the dredging conditions, 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, shift to a fleet of larger vessels can only be practical for those terminals deepening some of their berths in order to accommodate larger vessels. 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 to estimate a new configuration of larger vessels of the aforementioned types visiting dredge-designated terminals.

For each vessel type visiting a dredge-designated terminal, a new fleet of larger vessels is generated by increasing the draft of each vessel by 5 feet and decreasing the total number of vessel 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 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, is used to calculate the ratio to decrease the number of vessel calls and increase the holding time. This procedure is repeated for the same vessel type visiting all dredge-designated terminals, and the new total number of vessels is obtained and arrival rate of the vessel type is adjusted accordingly. At the end, interarrival time distribution, itinerary matrix, holding time and underway draft distributions are 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. 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 holding time for each vessel for this terminal. For other dredge-designated terminals BU vessels are visiting, the same procedure is applied.

This assumption is important in order to test if there is any navigational benefit in terms of port times and anchorage usage when there is less number of vessels coming to the River. Besides, it is critical to make this observation with the trade growth assumption in effect in the River.
6. RESULTS OF THE SCENARIO ANALYSIS

The results of the current scenario representing the current situation in the River based on actual data between years 2004 and 2008 are given in the validation section. The other three scenarios described above are built on top of the current scenario and the simulation runs of these three scenarios are made for 30 years, each with 100 replications. In these runs, due to year-to-year growth patterns, simulation results are obtained for each year separately. In addition to the standard output defined, detailed annual and state based (DE, NJ and PA) vessel statistics are collected for TA, CC, BU, GC, PC and VE vessel types for each scenario. Nevertheless, due to their significance in the system only TA, CC, BU and GC vessel types are considered in the scope of this paper 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 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 these results help us to understand future effects of deepening & dredging and shifting to larger vessels.

Port times and port calls are considered to be the most important measures to observe and understand the effects of major assumptions among the scenarios considered. On the other hand, a new measure is defined as port time per kiloton brought to the River where kiloton is a reference to 1,000 units in gross tonnage. This measure is important to see if there is a navigational benefit when there is a shift to a fleet of larger vessels since total tonnage coming to the River is same in all scenarios.

The results of the scenarios with their 95% confidence intervals based on 100 replications are given in TABLE 3. The top section presents the first year results. As seen in this section, port times are slightly decreased with deepening in Scenario C. These decreases are found to be statistically significant (through two-tail tests with a 5% significance level) only for tankers due to less lightering activity. Other vessel types mostly benefit from lesser tidal delays. As expected, bringing larger vessels in Scenario D increases port times since they spend more time at terminals. In this case, port time per kiloton experiences slight increases, except for container vessels, indicating that there is no gain in terms of port times when the total cargo handled is fixed. This reveals that CC vessels benefit from deepening which is due to ample capacity for these vessels in the River, and this benefit is found to be statistically significant.

The lower section of TABLE 3 shows the results for the 30th year of the simulation runs after they are averaged over 100 replications. 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 a statistically significant manner. 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.
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 for the BWA. The effects on outbound tidal delays and waiting for terminal berth availability in other major anchorages (Wilmington, Marcus Hook, Mantua Creek and Kaighn’s Point) are aggregated in the results as four anchorages.

First year results of the scenarios are given in top section of TABLE 4. All scenarios have the same tidal delays in the BWA since these scenarios do not have impact on the 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 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 are coming to the system.

Anchorage results as they are observed in the 30th year are shown in lower section of TABLE 4. 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 4  First Year and 30th Year Anchorage Results (Delays and Visits)

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Anchorage</th>
<th>Outputs</th>
<th>Vessel Types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BWA</td>
<td>Average Delay per Vessel (hrs)</td>
<td>BU CC GC TA</td>
</tr>
<tr>
<td>First Year</td>
<td></td>
<td>Average No of Visits per Year</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 Anchorages</td>
<td>Average Delay per Vessel (hrs)</td>
<td></td>
</tr>
<tr>
<td>Scenario B</td>
<td>Growth</td>
<td>Average No of Visits per Year</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average Delay per Vessel (hrs)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Average No of Visits per Year</td>
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<td>Average Delay per Vessel (hrs)</td>
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<td></td>
<td></td>
<td>Average No of Visits per Year</td>
<td></td>
</tr>
<tr>
<td>Scenario C</td>
<td>Growth + Deepen</td>
<td>Average Delay per Vessel (hrs)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Average No of Visits per Year</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Average Delay per Vessel (hrs)</td>
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<td>Average No of Visits per Year</td>
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<td>Average Delay per Vessel (hrs)</td>
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<td></td>
<td></td>
<td>Average No of Visits per Year</td>
<td></td>
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<tr>
<td>Scenario D</td>
<td>Growth + Deepen + Larger Vessels</td>
<td>Average Delay per Vessel (hrs)</td>
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<td></td>
<td></td>
<td>Average No of Visits per Year</td>
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<td>Average Delay per Vessel (hrs)</td>
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<td>Average Delay per Vessel (hrs)</td>
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7. CONCLUSION

In this paper, simulation modeling of vessel traffic in Delaware River and Bay is presented with an objective of investigating the impact of deepening on the navigational issues.

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 Growth Scenario (B) emphasizes the need for more berths or terminals to handle the increase in vessel arrivals due to trade growth. In this regard, port occupancy measure is critical to point out overall utilization in the port in which the temporal behavior stresses the need for planning of port expansion. Among others, only container facilities have potential to handle more vessels. Besides, tankers will benefit from deepening more in the case of increased oil trade in the port.

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 they show no navigational benefits for other vessels. However, port time per kiloton results in Scenarios 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 holding time of vessels at terminals, specifically to the factor used in the model to increase holding time of larger vessels. In the case of improved scheduling practices and efficient handling of larger vessels at terminals, port time per kiloton measure will most likely exhibit navigational benefits possibly for all vessels.

Anchorage results verify the expected decreases in tidal delays both for inbound and outbound vessels and 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 dredging is completed. Furthermore, the Growth Scenario (B) shows the 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 help...
reduce anchorage usage to a certain extent. On the other hand, longer anchorage delays are also possible for larger vessels due to longer holding times at terminals.

This paper 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 cover potential reduction in operating costs due to lesser number of vessels and the economic benefits due to growth. In addition, note that categories of benefits identified for deepening includes improved safety on which reduced number of vessels sailing in the River has a positive impact.

At last, an important final product of this study is the simulation model itself, developed for Delaware River and Bay. It can be used to obtain insight on the importance of key parameters on the performance of the system, to support decision making process on various interest areas and to answer “what-if” questions since it enables experimentation with policies, operating procedures, decision rules or environmental changes. Besides, it is believed that the model provides a better understanding of the overall port system, interaction of system variables and resources.

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9. REFERENCES


