SJPC-RU1824-1

# Port of Paulsboro – Delaware River Ship Traffic Modeling Study

Final Report

December, 2012

Submitted to

The South Jersey Port Corporation

Submitted by


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TECHNICAL REPORT STANDARD TITLE PAGE

| | | |
|---|---|---|
| 1. Report No.<br>SJPC-RU1824-1 | 2.Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>Port of Paulsboro – Delaware River Ship Traffic Modeling Study | | 5. Report Date<br>December 2012 |
| | | 6. Performing Organization Code<br>CAIT/Rutgers |
| 7. Author(s)<br>Birnur Ozbas, Ph.D.; O. Alper Almaz; Amir Ghafoori | | 8. Performing Organization Report No.<br>SJPC-RU1824-1 |
| 9. Performing Organization Name and Address<br>Center for Advanced Infrastructure and Transportation (CAIT)<br>Rutgers, The State University of New Jersey<br>100 Brett Road<br>Piscataway, NJ 08854-8014 | | 10. Work Unit No. |
| | | 11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address<br>South Jersey Port Corporation<br>2nd & Beckett Streets<br>Camden, New Jersey 08103 | | 13. Type of Report and Period Covered<br>Final Report<br>10/15/2009-12/31/2012 |
| | | 14. Sponsoring Agency Code |
| 15. Supplementary Notes | | |

16. Abstract

This is a final report summarizing the impact of the work load brought by the Paulsboro Marine Terminal on the maritime traffic in the Delaware River Main Channel. Rutgers simulation model of the vessel traffic was modified to incorporate the Paulsboro Terminal for the impact analysis. This report presents metrics on the operational performance of the terminal and the expected vessel counts at some designated locations in the River. The results show that the terminal can easily handle the workload, and the increase in the vessel counts due to the Terminal's integration is on the average one vessel a day and simply insignificant.

| | |
|---|---|
| 17. Key Words<br>Paulsboro Marine Terminal, operational performance, Simulation modeling, SJPC | 18. Distribution Statement |

| | | | |
|---|---|---|---|
| 19. Security Classif. (of this report)<br>Unclassified | 20. Security Classif. (of this page)<br>Unclassified | 21. No of Pages<br>24 | 22. Price |

Form DOT F 1700.7 (8-69)

## ACKNOWLEDGEMENT

This material is based upon work supported by the South Jersey Port Corporation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the South Jersey Port Corporation. We would like to thank South Jersey Port Corporation support and Mr. Kevin Castagnola for facilitating this grant.

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This report is dedicated in memoriam to Dr. Tayfur Altiok. Without his efforts and motivation, this project would not have been possible

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## Executive Summary

This is a final report summarizing the impact of the work load brought by the Paulsboro Marine Terminal on the maritime traffic in the Delaware River Main Channel. Rutgers simulation model of the vessel traffic was modified to incorporate the Paulsboro Terminal for the impact analysis. This report presents metrics on the operational performance of the terminal and the expected vessel counts at some designated locations in the River. The results show that the terminal can easily handle the workload, and the increase in the vessel counts due to the Terminal's integration is on the average one vessel a day and simply insignificant.

## 1. Introduction: A Brief Review of the Delaware River Main Channel (DRMC) Model

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 the data of 2004 to 2008 and produces key performance measures such as terminal utilization, average vessel waiting times in anchorages as well as average vessel port times. Overall view of the model is given in Figure 1.

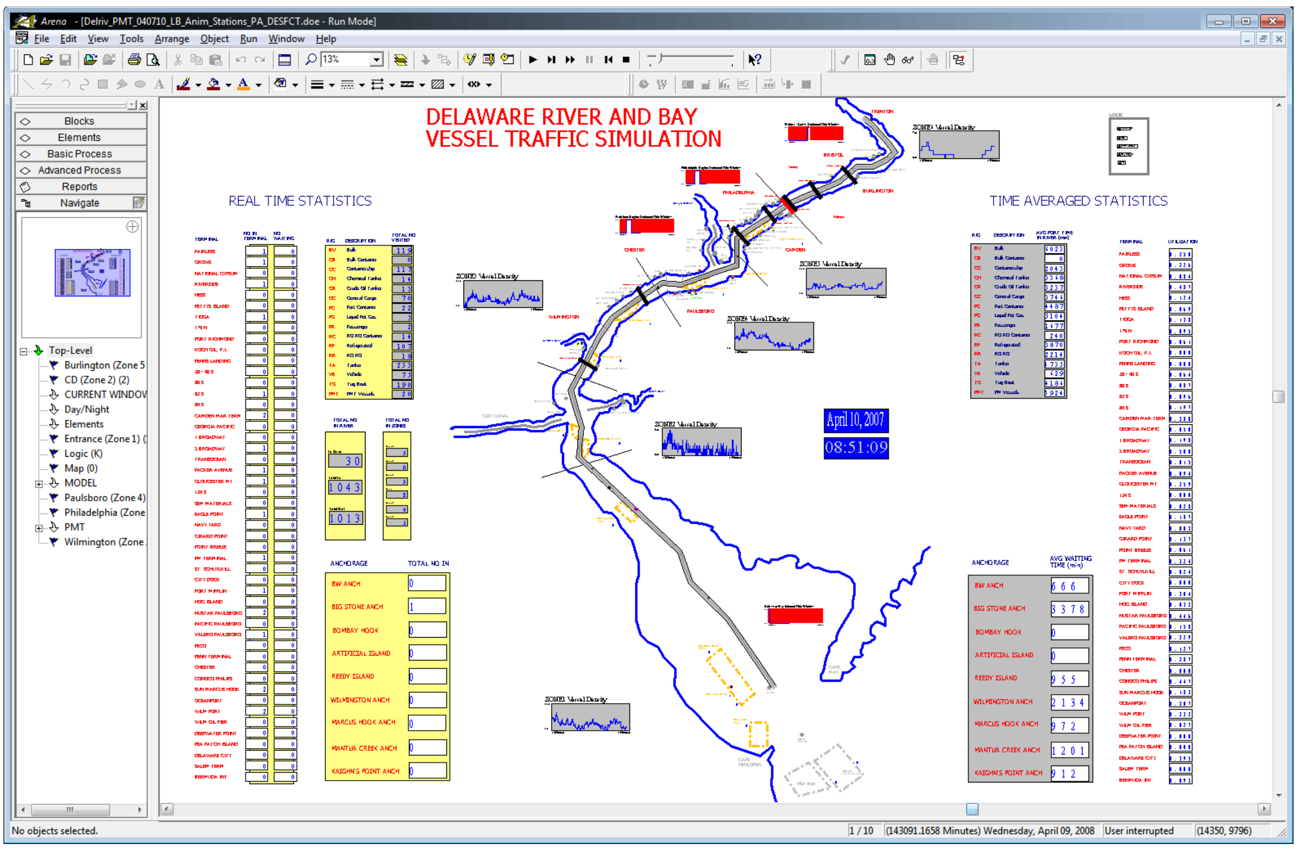


Figure 1 Rutgers simulation model of the Delaware River Main Channel

Figure 2 shows the validation results in terms of annual vessel calls and average vessel port times for various cargo vessels. It presents a comparison of the model results against data observed at the port over the years of 2004 – 2008. The bars show the average number of vessels visiting terminals per year measured against the left vertical axis and the lines show the average time each vessel type spends in the River measured against the right vertical axis, and the horizontal axis represents cargo types. As can be seen, in all cases the difference between reality and the model is negligible.

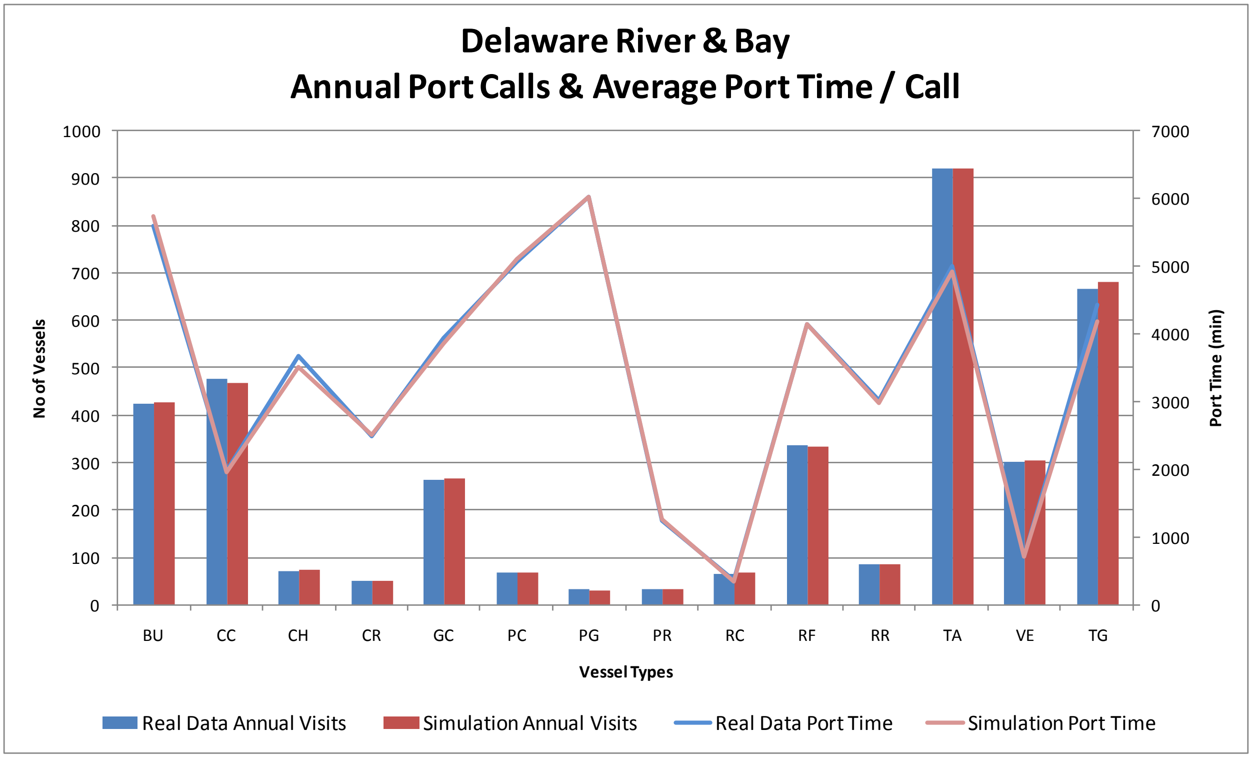


Figure 2 Validation results on vessel port calls and port times

Terminal related statistics are also generated by the model. Figure 3 shows the average berth utilization at each terminal operating in the Delaware River.

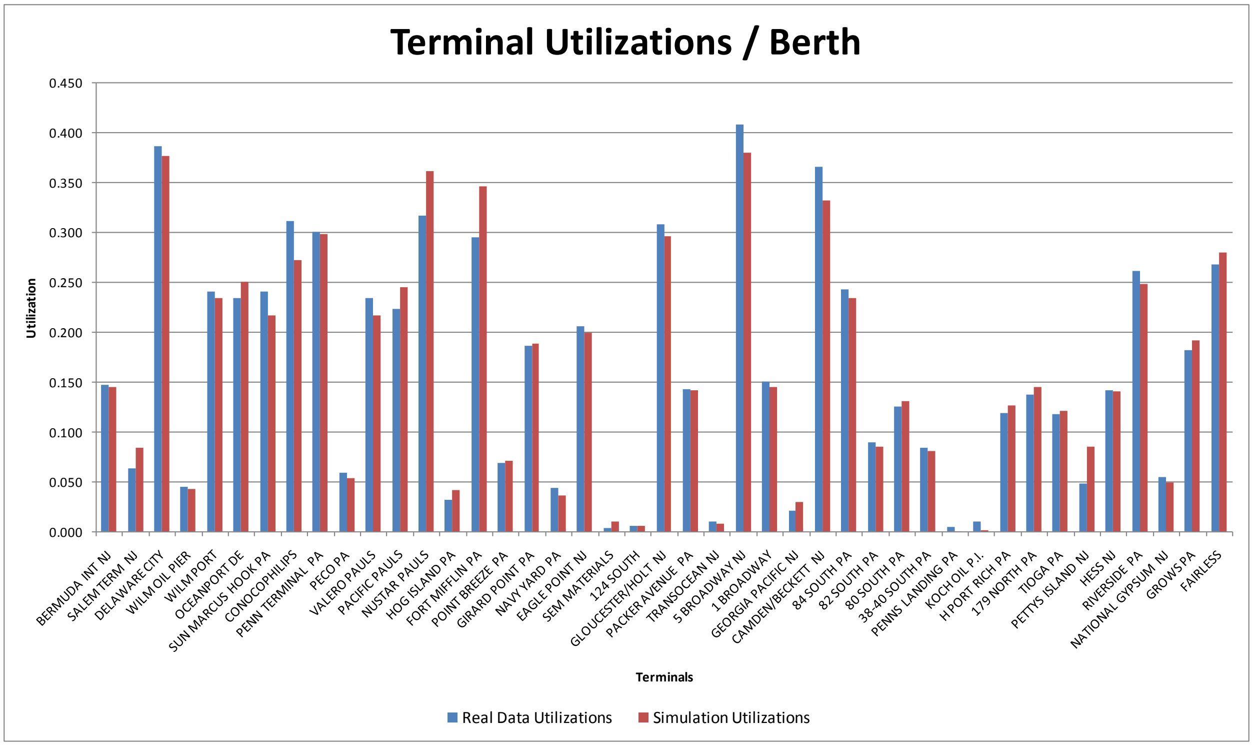


Figure 3 Validation results on terminal utilizations

## 2. Paulsboro Marine Terminal (PMT) Integration

According to the assumptions of the "Paulsboro Integration Design Criteria", a module containing all the planned details about the PMT is added to the aforementioned model to see the impact of the proposed maritime activities on the performance of the channel's operation. Figures 4 and 5 illustrate the animation layer of the proposed integration and its operational details. Both Paulsboro's planned annual vessel types and arrival rates, and terminal activities (to the level of detail provided in the SOW) are integrated into the main model of the Channel operation. Thus, the modified model provides estimates on berth utilization, crane utilization, as well as down times due to crane failures and weather stoppages at the PMT. It also provides statistics on vessel delays in anchorages and port times of the PMT bound vessels along with the information related to the rest of the port summarized earlier.

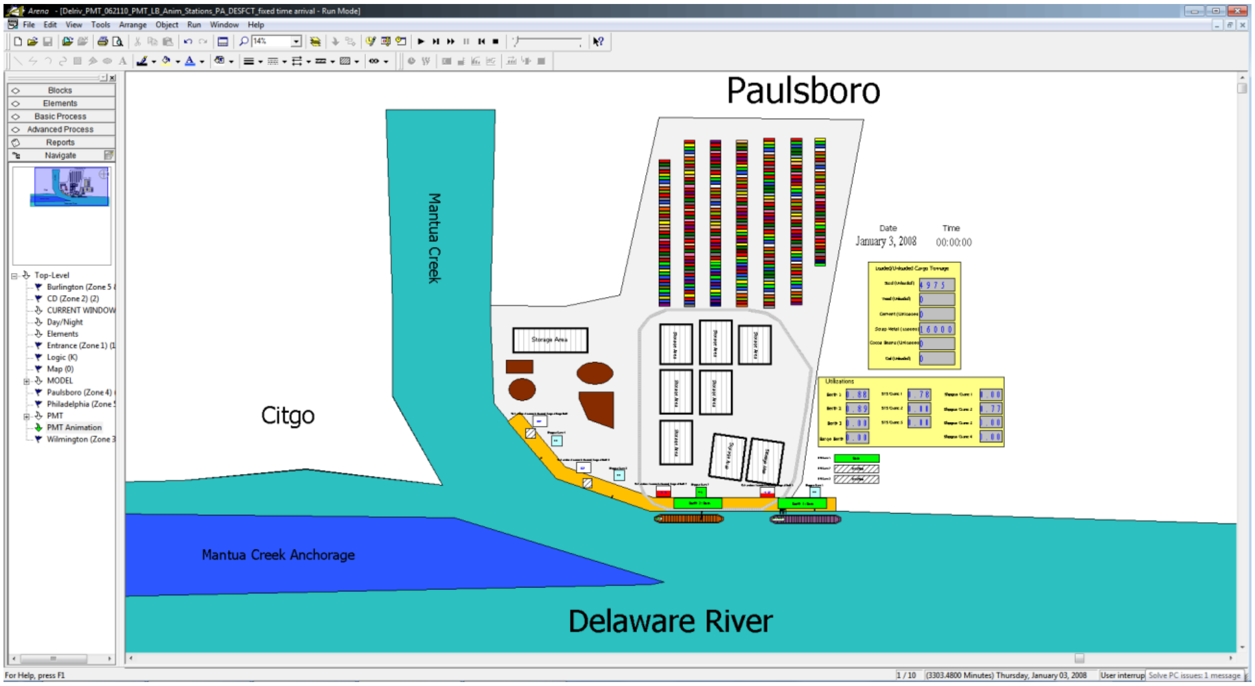


Figure 4 Animation layer of the PMT

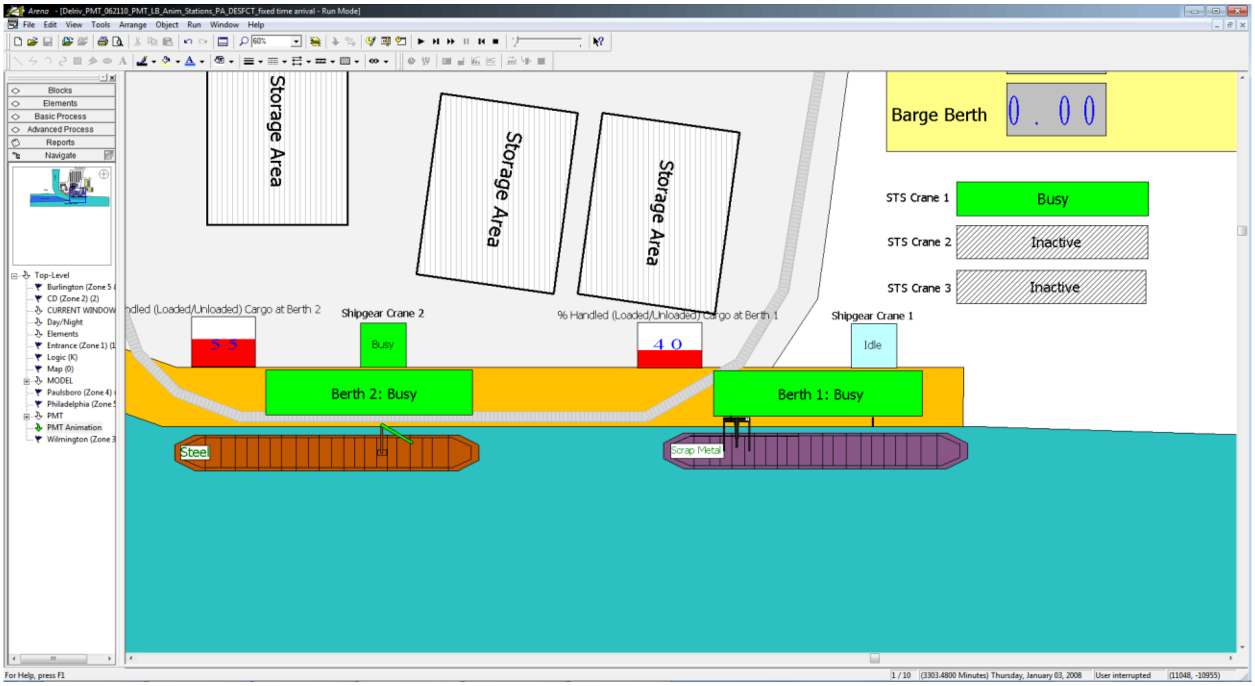


Figure 5 Operational details of the PMT

Results of the modified simulation model are presented below. There are two groups of results. Group 1 consists of the results of the case with trade growth for the River, as forecasted by the U.S. Army Corps. of Engineers in their [USACE 2002] report[1]. Port times, berth and crane utilizations, and anchorage waiting times are the statistics presented in this group. Group 2 provides the daily number of vessels passing through designated locations (in the upstream direction) as defined in the SOW.

The results are summarized below:

### 3. Group 1: Operational Performance of the PMT

This group of results is derived from the revised model that uses the USACE's trade forecasts over a 20-year planning horizon. It also includes PMT's planned workload (see the SOW in the Appendix) and the associated vessel arrivals over 20 years. The annual workload and the resulting vessel arrival rates are shown in Figure 6. Notice the temporal behavior of the overall tonnage and the resulting number of vessels over the years.

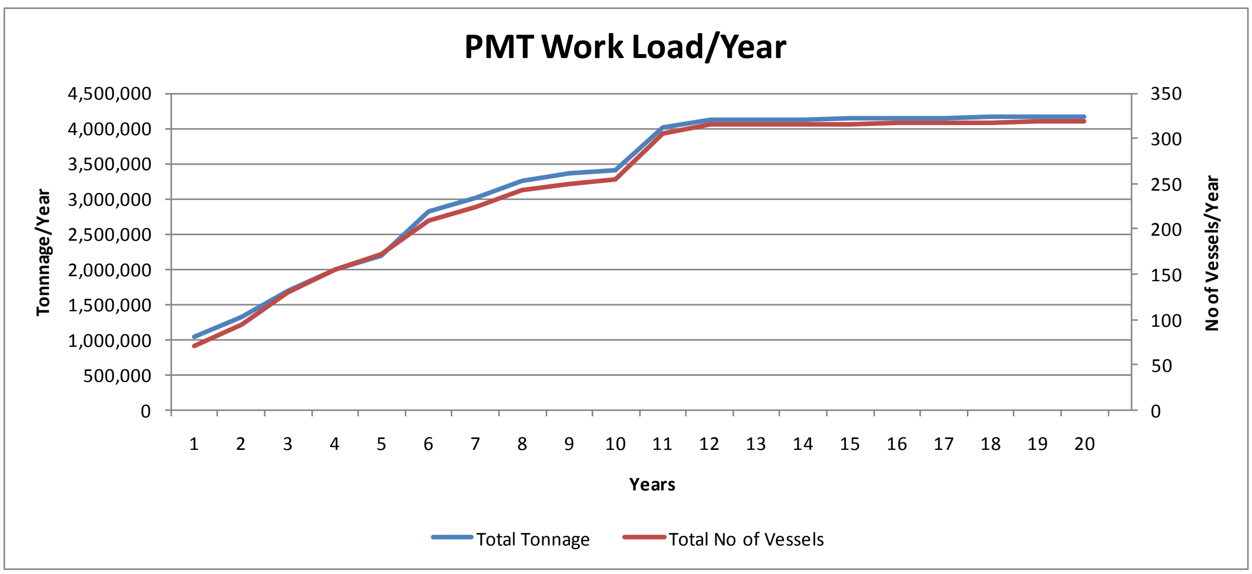


Figure 6 Annual workload and the resulting vessel arrival rates at PMT

[1] Comprehensive Economic Reanalysis Report (2002) of Delaware River Main Channel (DRMC) Deepening Project, the U.S. Army Corp of Engineers, Philadelphia District, North Atlantic Division.

As far as berth and crane availabilities are concerned, Figures 7 and 8 show the berth construction and Ship-to-shore (STS) crane installation plans as specified in the SOW.

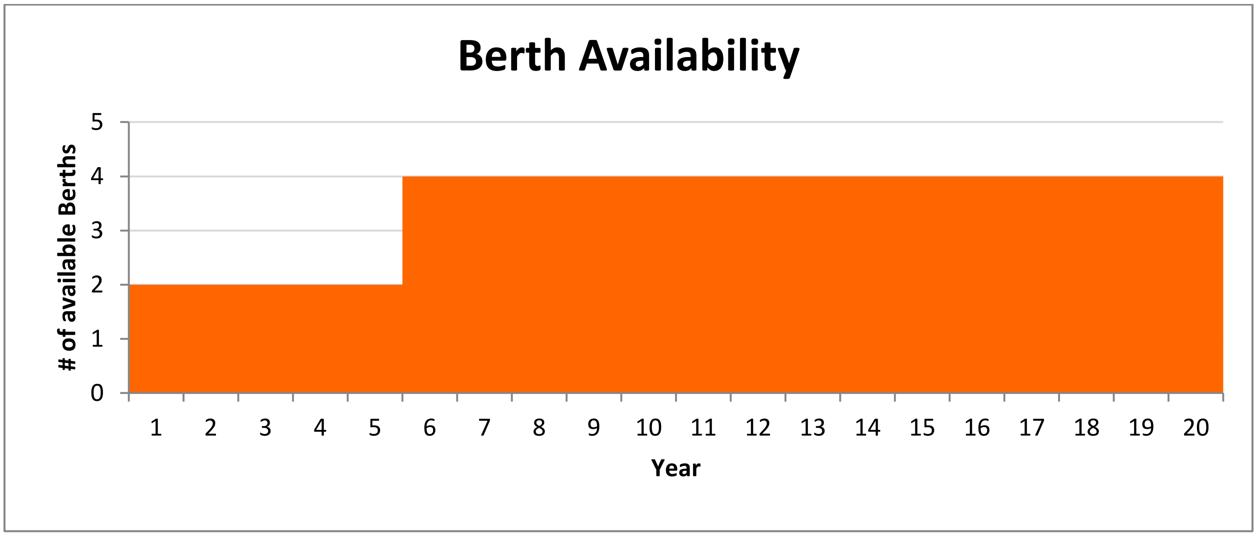


Figure 7 Berth availability at the PMT

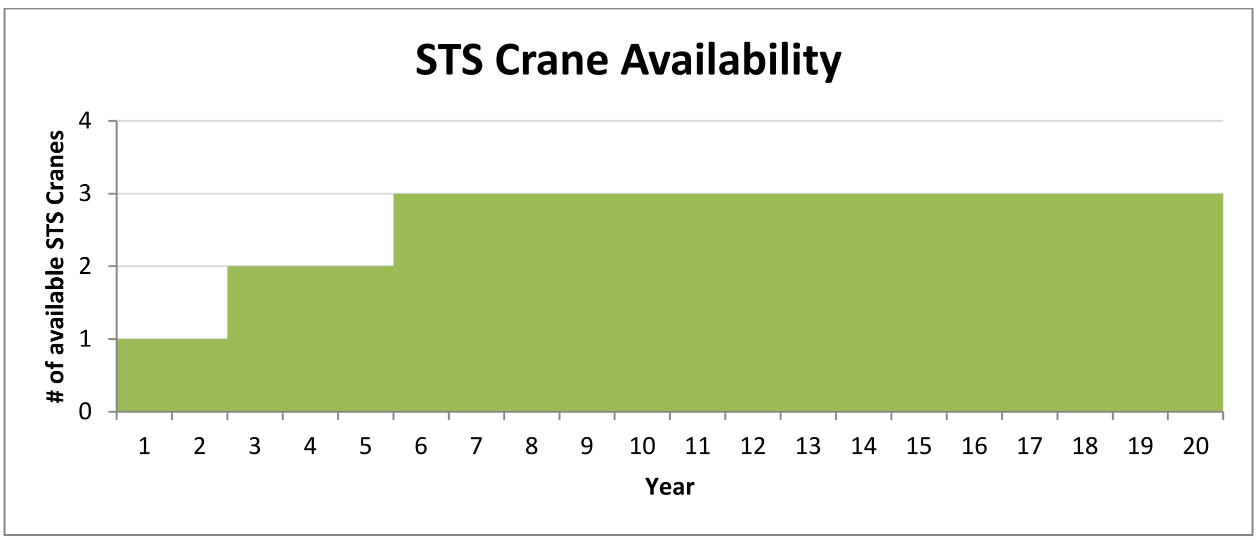


Figure 8 STS crane availability at the PMT

The resulting vessel and terminal related statistics are presented below. Considering the temporal capacity expansions and the planned workload, the estimated berth and crane utilizations are shown in Figures 9 and 10. These utilization measures are based on 16 hr operation per day.

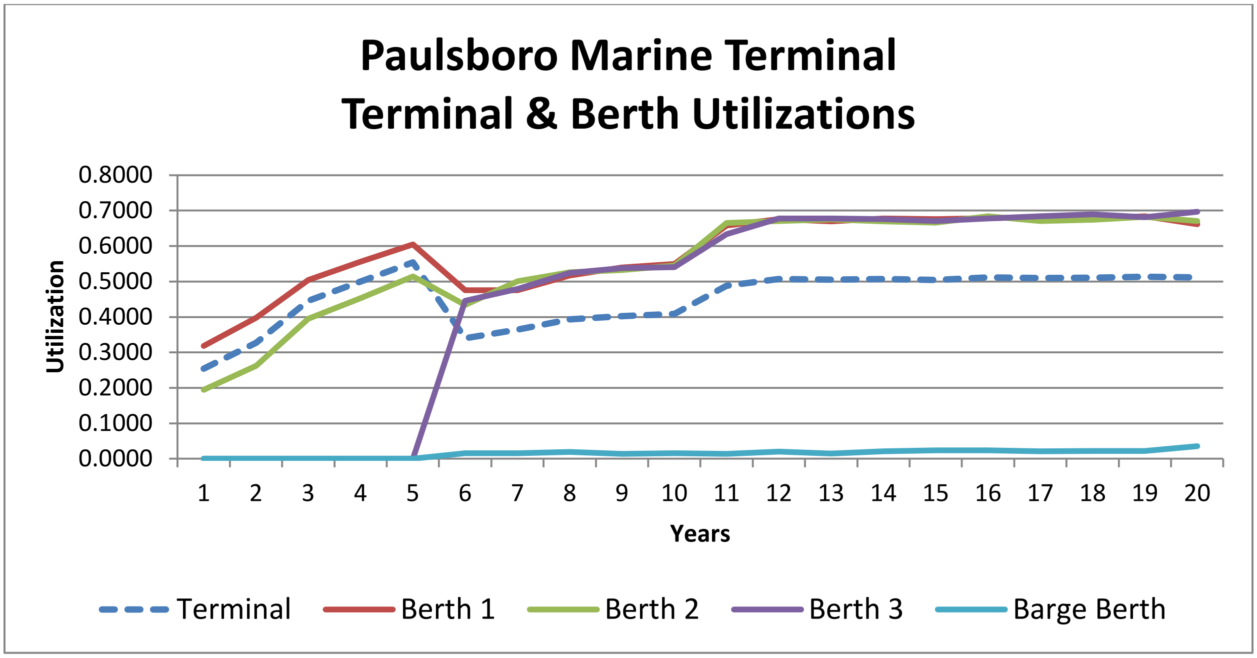


Figure 9 Berth and terminal utilization at the PMT

Dashed line shows the average terminal utilization calculated based on 3 deep water berths and the barge berth. Both terminal, berth and crane utilization show a transient behavior in the first 10 years as a result of the work load (or vessel arrivals) as well as the capacity allocations. They all show a steady behavior after year 11 in concert with the work load shown in Figure 6.

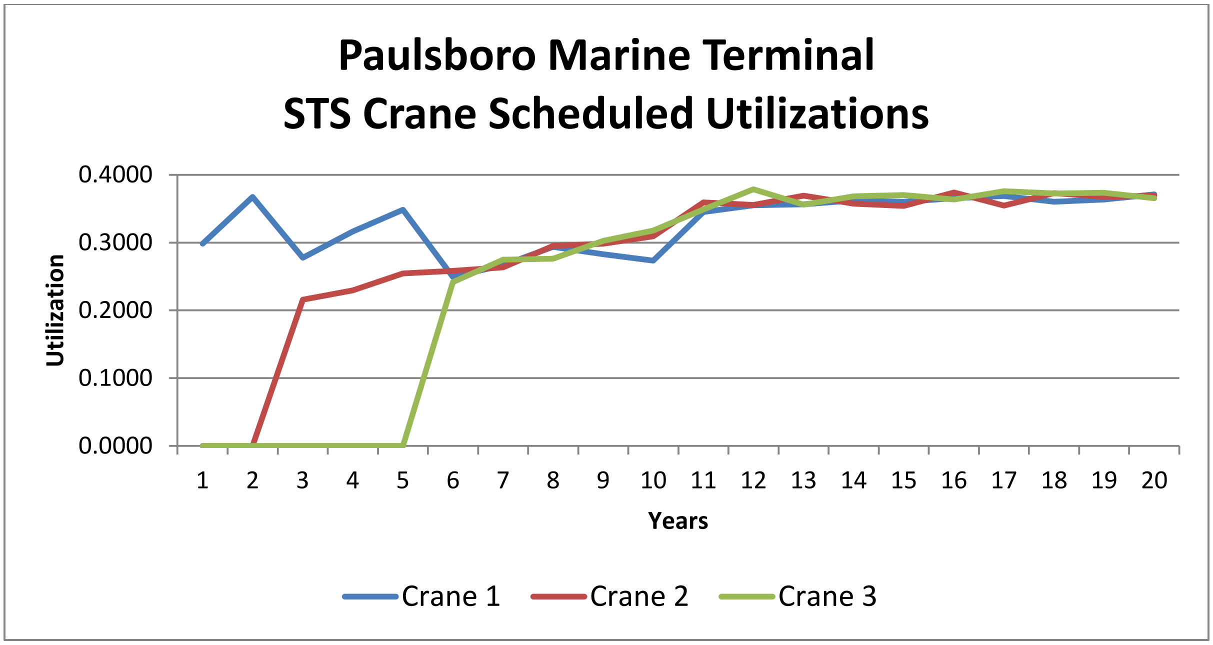


Figure 10 STS Crane utilization at the PMT

Figure 11 shows the average number of vessels visiting PMT annually and the average time these vessels spend at the port, from entrance to exit both at the Capes. Annual vessel calls reflect the planned vessel arrivals over several cargo types at the PMT (Figure 6). The estimated vessel port time is around 80 hours per vessel, averaged over all types of cargo vessels.

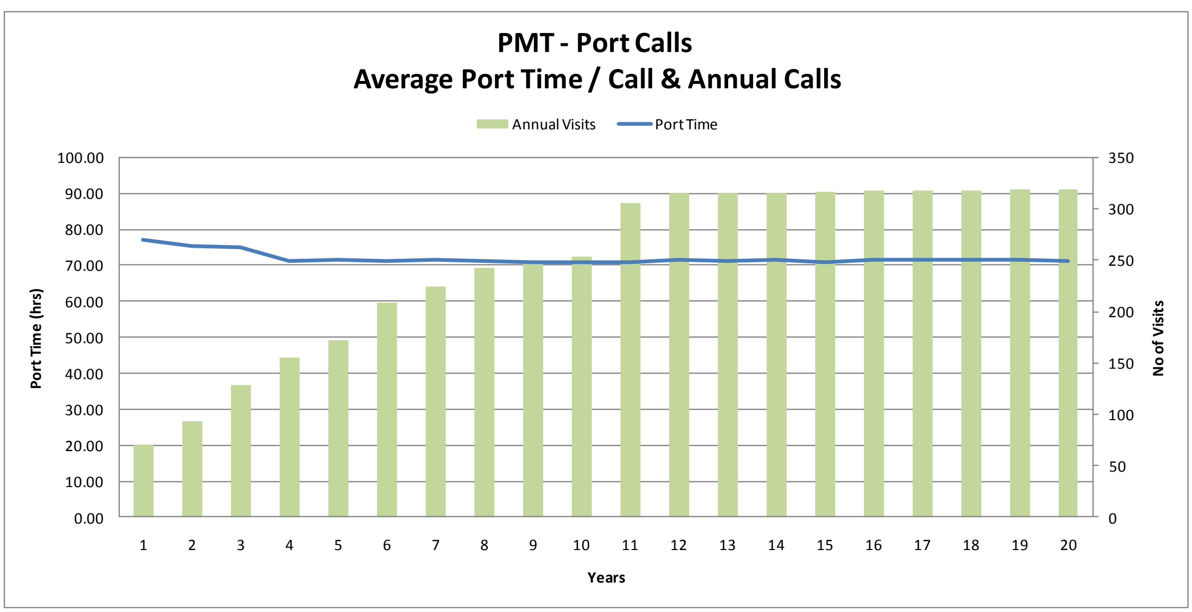


Figure 11 Average port time per call and annual number of calls at the PMT

Figures 12 through 14 show the anchorage statistics for vessels heading to the PMT. Some of the vessels may need to wait in the Breakwater anchorage due to tide. Figure 12 shows annual number of vessels that wait for tide in the Breakwater anchorage and the average waiting time per vessel. Vessel hits at Breakwater reflect the PMT's yearly increase in the planned vessel arrivals (Figure 6), ranging from 5 to 20 vessels over 20 years. Average vessel delay is simply due to tide and is about 4 hours, regardless of the volume of traffic.

Vessels already in the River calling for the PMT may wait at the Marcus Hook anchorage (for vessels with drafts more than 37 ft.) and Mantua Creek anchorage (for vessels with drafts less than 37 ft.) for various reasons including berth unavailability. Figures 13 and 14 show the annual number of anchorage hits and average waiting times. Number of vessels waiting at the Marcus Hook anchorage is minimal and at most 2 vessels wait a year over 20 years. Average delays are typically less than 10 hours. A similar picture can be observed during the first 10 years at the Mantua Creek anchorage. However during the second decade in the planning horizon, the vessel hits in Mantua Creek increase to roughly 20 vessels per year, again due to the planned work load at the PMT, but still keeping the average delays under 10 hours per vessel.

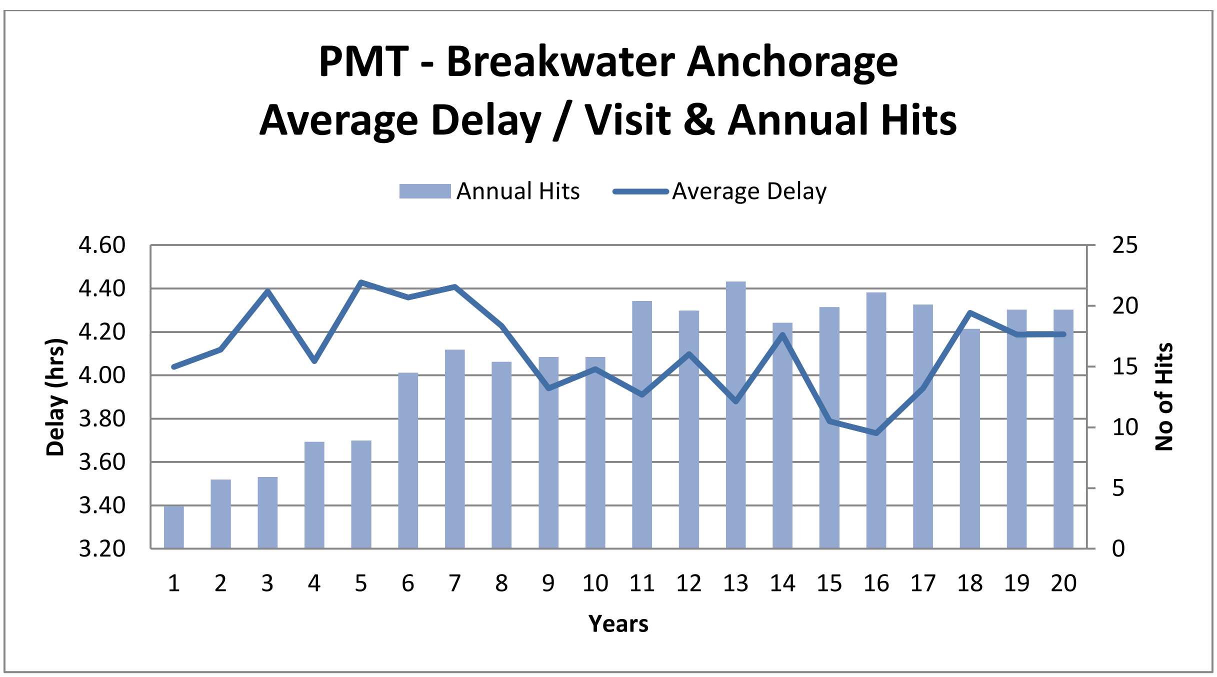


Figure 12 Average delays per visit and annual visits at the Breakwater anchorage

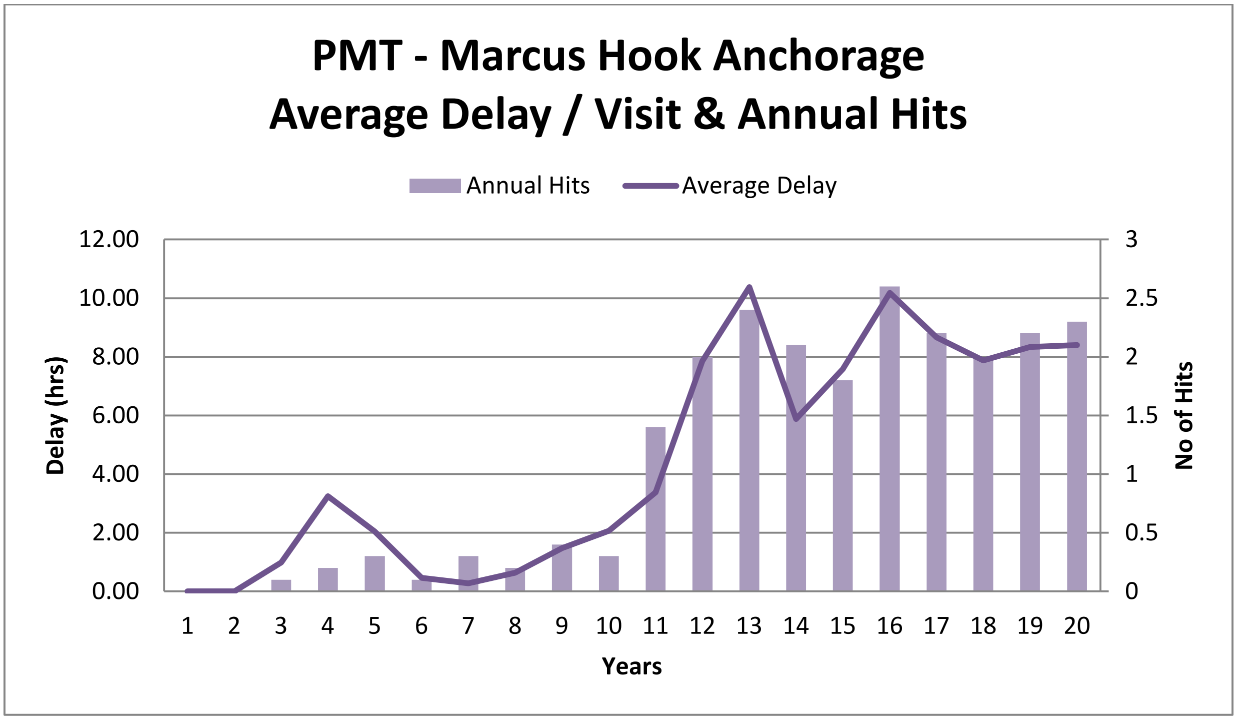


Figure 13 Average delays per visit and annual visits at the Marcus Hook anchorage

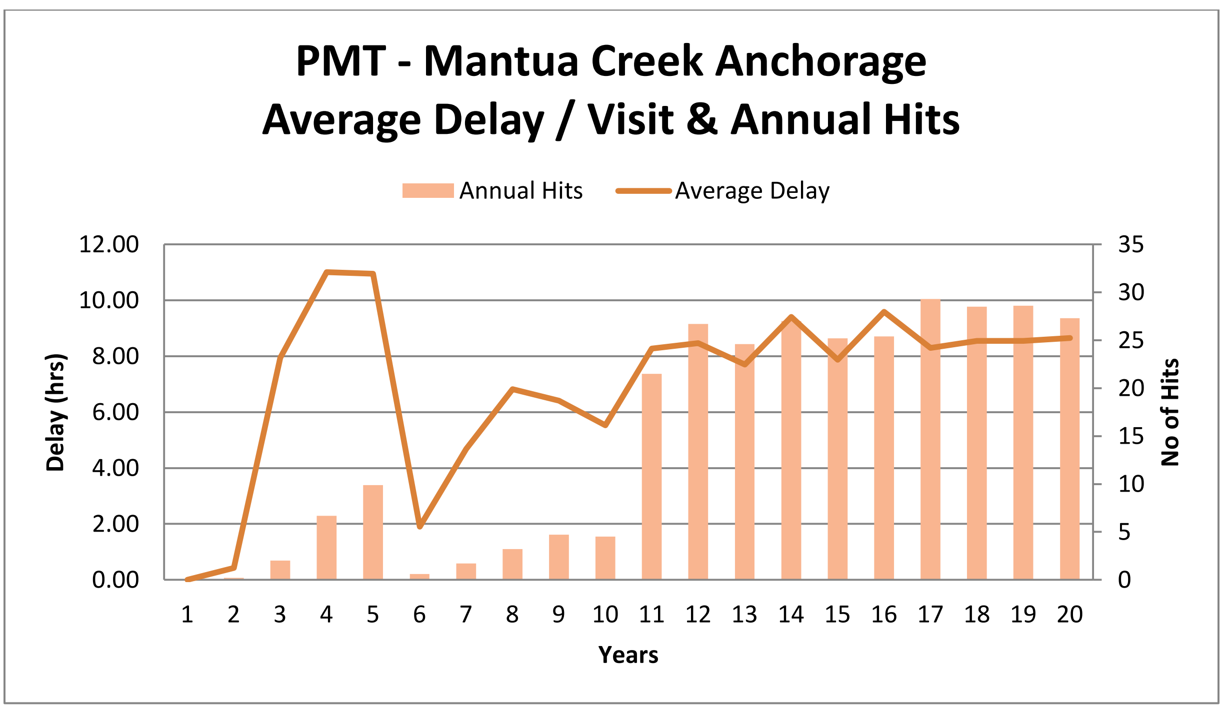


Figure 14 Average delays per visit and annual visits at the Mantua Creek anchorage

## 4. Group 2: Vessel Counts at Designated Locations in the Delaware River

In this section, we provide vessel counts at certain designated locations in the river (SOW) as estimated from the model. These locations are

Breakwater
C&D Canal entrance
Christina River entrance
Marcus Hook
Gibbstown
Paulsboro
Camden

Three sets of counts are considered in this group.

i) Counts showing daily number of vessels passing through the locations while neither Paulsboro terminal exists nor trade growth forecast is assumed. This is the so called “Base Case” in which the data from 2004 to 2008 is used.

ii) Counts resulting from applying trade growth forecasts along with using 2004-2008 data but without considering the PMT. This case is referred to as the “Growth Case”.

iii) The last set of counts considers both trade growth and the integration of the Paulsboro terminal and is called the “PMT Scenario”.

At each point, these three scenarios are compared at 6 points of time (1st, 6th, 11th, 16th and 20th year) in the 20-year planning horizon. The average, the expected minimum and expected maximum of the vessel counts are provided for each scenario. The lower value provides the minimum number of vessels expected to pass through that location (in the upstream direction) in a day throughout the year. The middle value shows the average daily count of vessels passing through the location throughout the year and the higher value presents the maximum number of vessels expected to pass through the location. These average values are obtained across 10 replications of the modified simulation model. Figures 15 – 22 show the vessel count statistics.

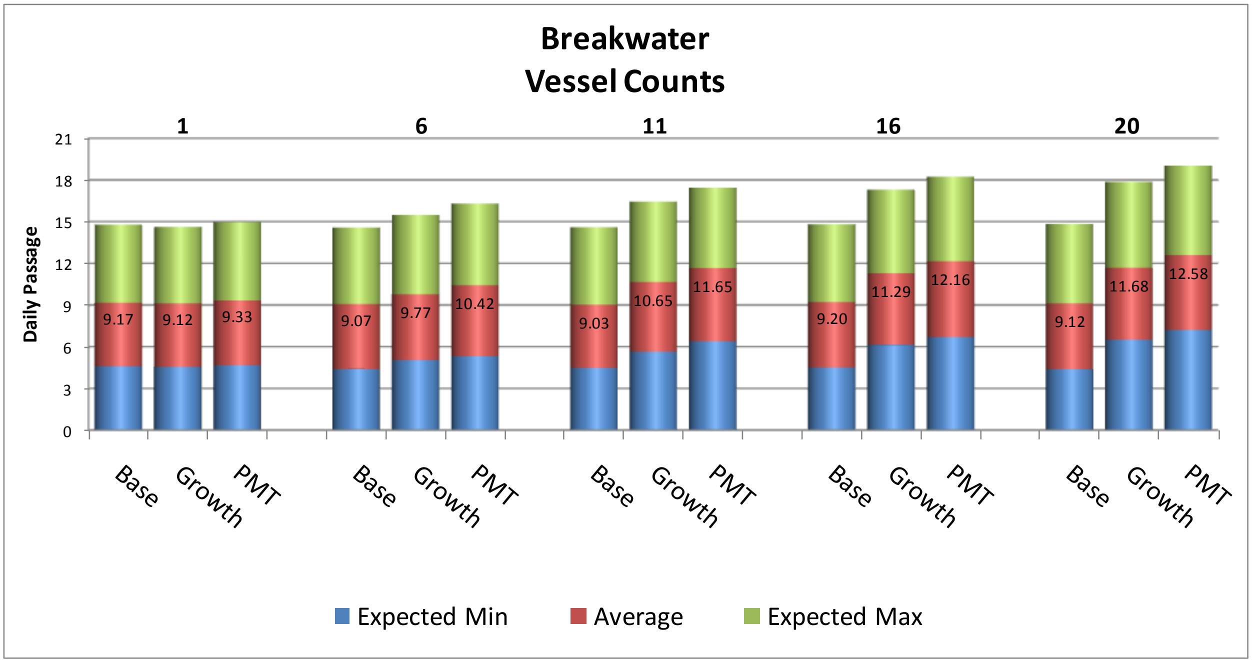


Figure 15 Daily vessel counts in years 1, 6, 11, 16 and 20 at Breakwater

For example, Figure 15 indicates that during the sixth year, an average of 9.77 vessels enter from Breakwater in the Growth Case while addition of the Paulsboro terminal (PMT Scenario) increases this number by 0.65 to 10.42.

Figure 16 shows the daily vessel counts at Breakwater during the 20th year of the PMT scenario. This is to show the behavior of the vessel count statistics and fluctuations over the year.

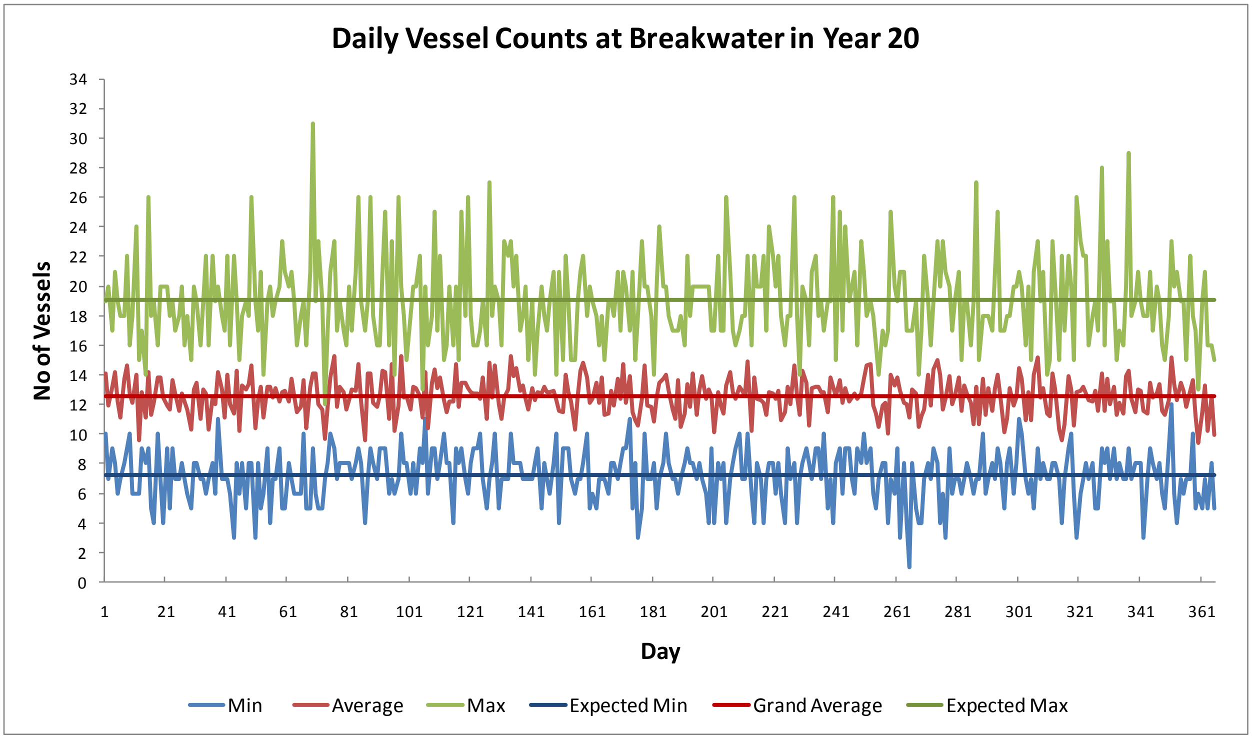


Figure 16 Daily vessel counts at Breakwater during year 20 in the PMT Scenario

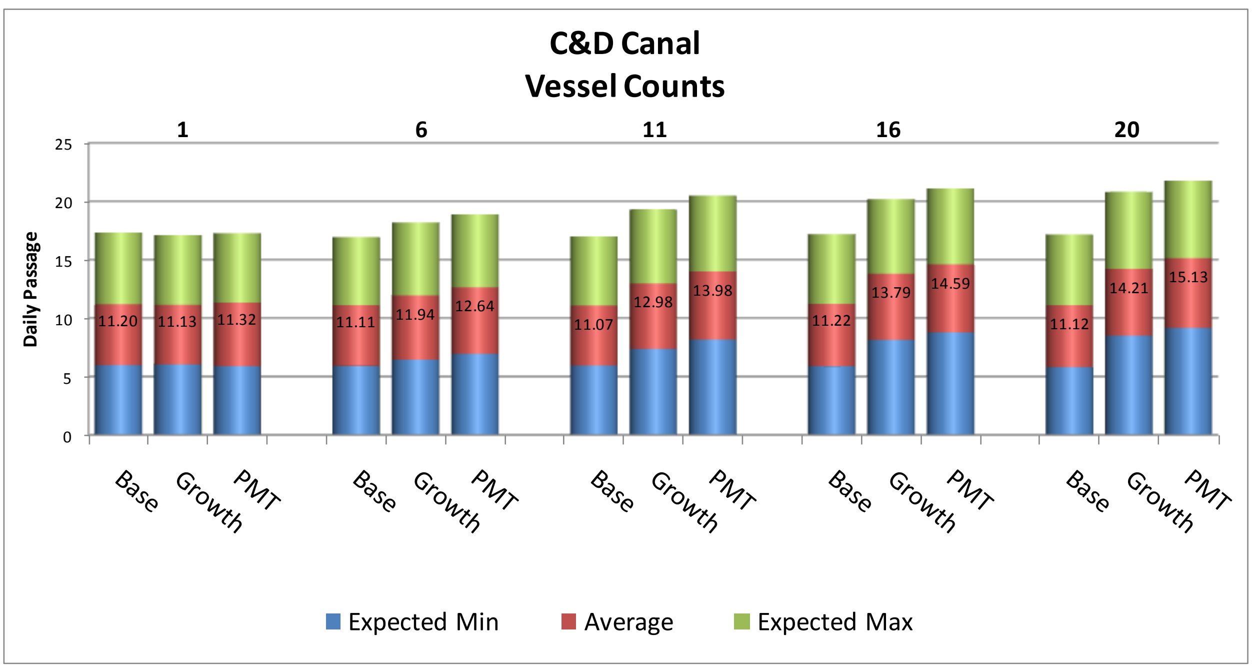


Figure 17 Daily vessel counts at the C&D Canal entrance

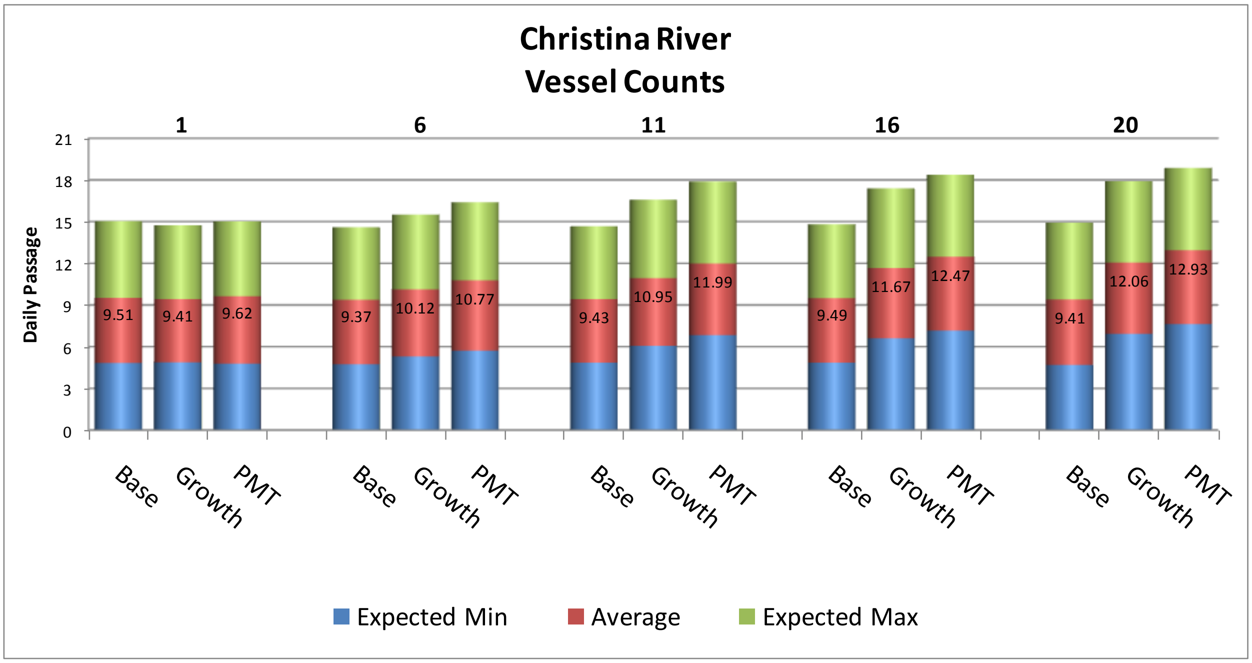


Figure 18 Daily vessel counts at the Christina River entrance

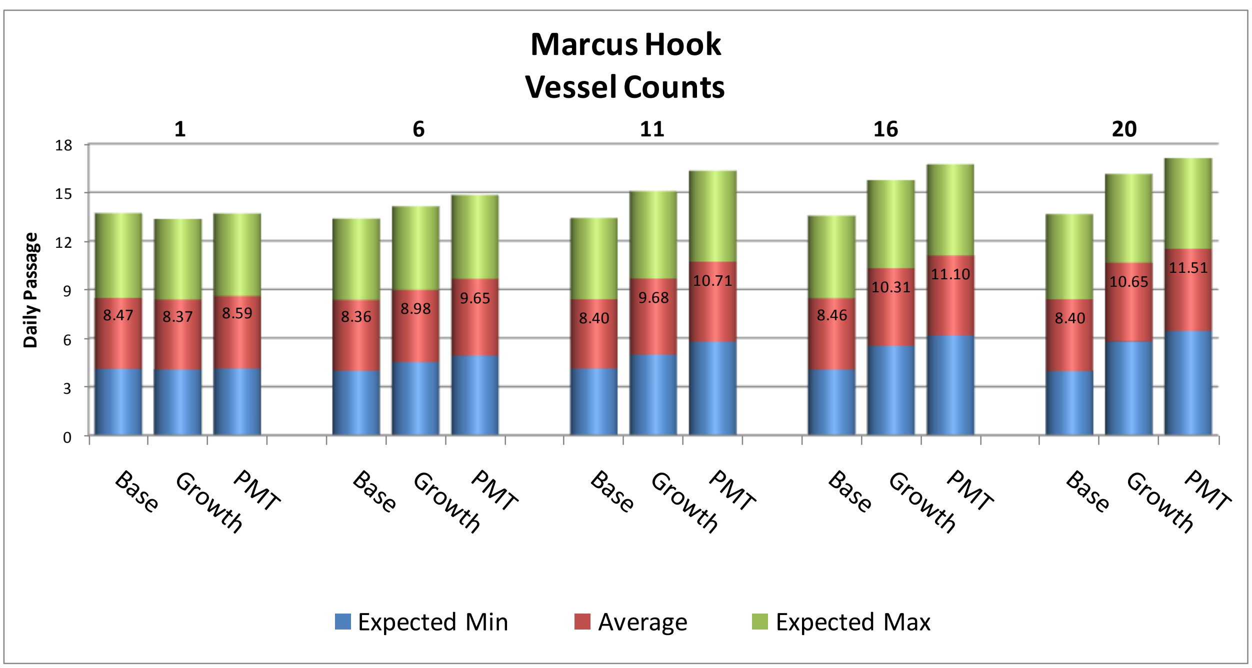


Figure 19 Daily vessel counts at Marcus Hook

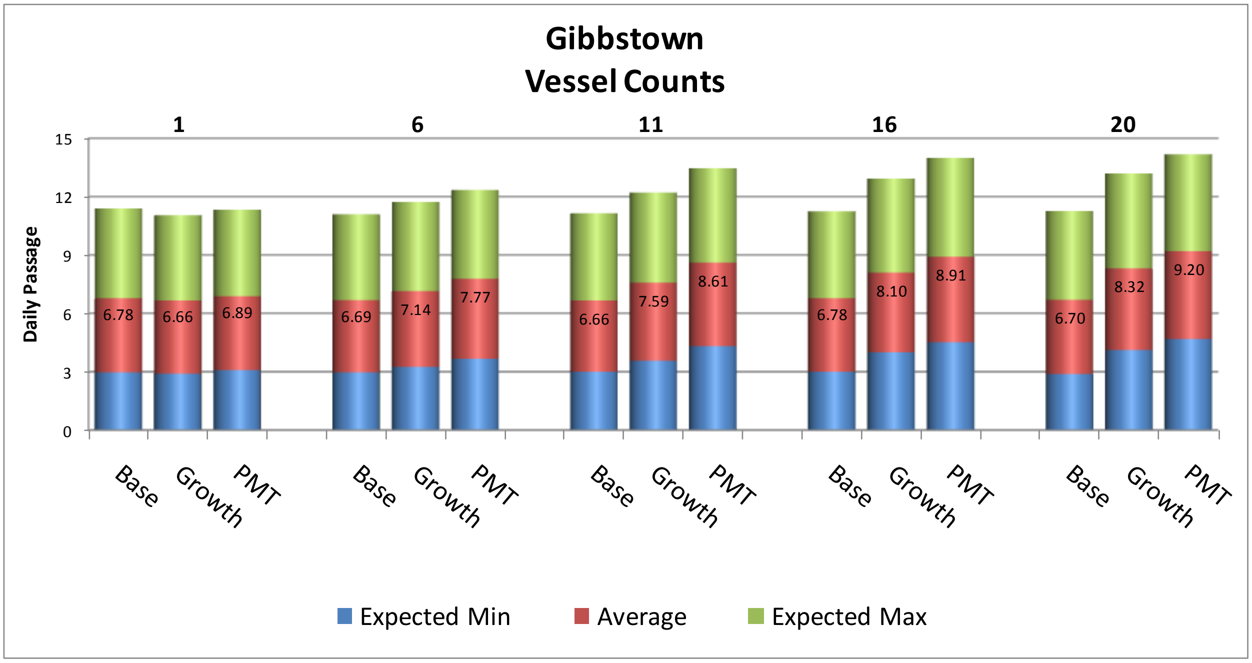


Figure 20 Daily vessel counts at Gibbstown

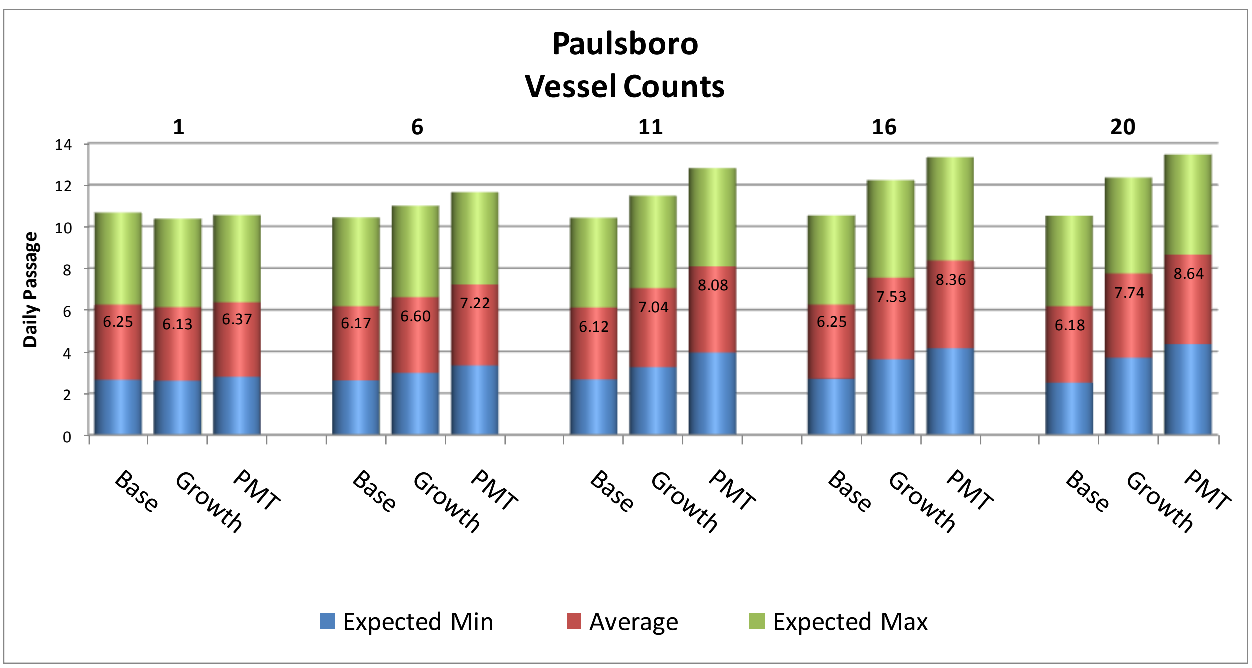


Figure 21 Daily vessel counts at Paulsboro

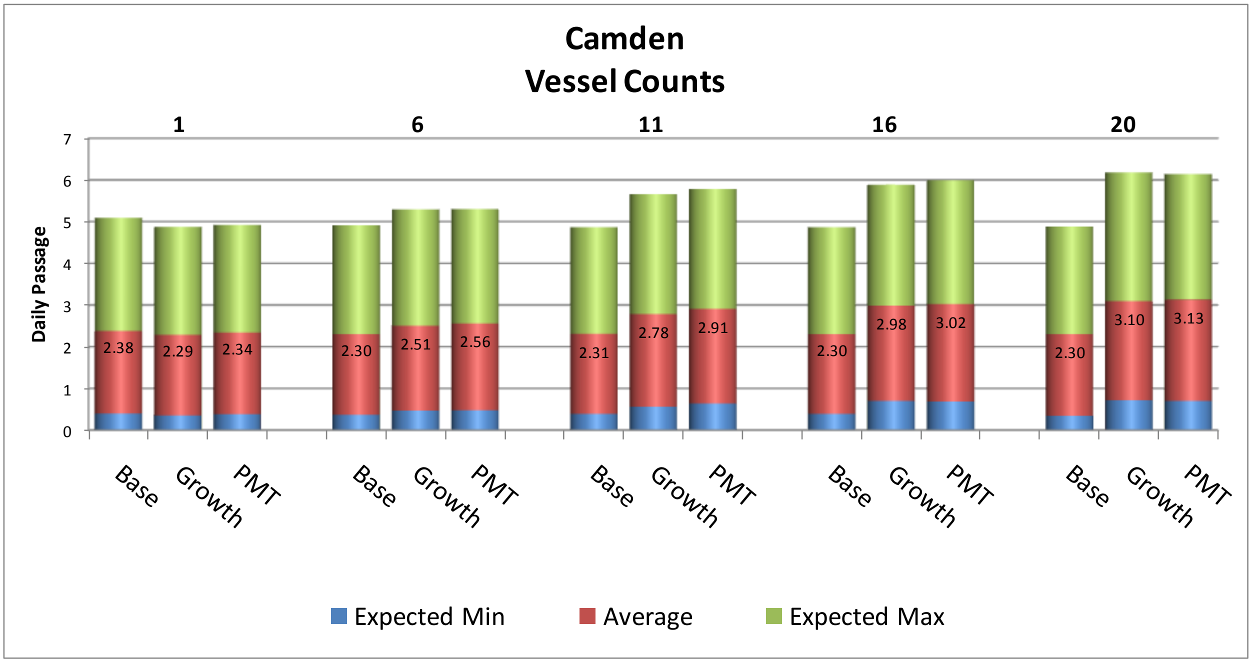


Figure 22 Daily vessel counts at Camden

In all these locations, observations from year 1 to year 20 increases in such a way that the Growth Case averages are greater than the Base Case averages and the PMT Scenario averages are greater than the Growth averages. The most significant increase in the PMT scenario appears to be in the 20th year. Therefore, we have carried out a statistical confidence interval analysis on the increases from the Growth Case to the PMT Scenario for each location in year 20. The results are shown in Figure 23.

Table 1. Increase in the daily number of vessels at each designated location and their 95% confidence intervals

| Location | PMT Mean | Growth Mean | Mean Difference | 95% Confidence Interval on Mean Difference |
|---|---|---|---|---|
| BW | 12.58 | 11.68 | 0.91 | (0.74 - 1.08) |
| CD | 15.13 | 14.21 | 0.92 | (0.74 - 1.10) |
| Wilmington | 12.93 | 12.06 | 0.88 | (0.71 - 1.04) |
| Marcus Hook | 11.51 | 10.65 | 0.86 | (0.71 - 1.01) |
| Gibbstown | 9.20 | 8.32 | 0.88 | (0.75 - 1.01) |
| Paulsboro | 8.64 | 7.74 | 0.90 | (0.77 - 1.04) |
| Camden | 3.13 | 3.10 | 0.03 | (-0.05 - 0.11) |

Note that increase in daily counts at any location is around 1 vessel a day and the 95% confidence intervals show that the increase is between 0.7 and 1 (average values). The lower value is a fraction since no vessels may pass in some days.

<u>We conclude that the marginal increase in the daily vessel counts along the River due to the PMT's integration is insignificant.</u>

SJPC-RU1824-2

# Paulsboro Marine Terminal

# Logistics Design Criteria to Support NJ Offshore Wind Power Initiative

Final Report

December, 2012

Submitted to

The South Jersey Port Corporation

Submitted by


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## DISCLAIMER STATEMENT

TECHNICAL REPORT STANDARD TITLE PAGE

| 1. Report No. SJPC-RU1824-2 | 2.Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| 4. Title and Subtitle<br>Paulsboro Marine Terminal Logistics Design Criteria to Support NJ Offshore Wind Power Initiative | | 5. Report Date<br>December 2012<br>6. Performing Organization Code<br>CAIT/Rutgers |
| 7. Author(s)<br>Birnur Ozbas, Ph.D.; Amir Ghafoori | | 8. Performing Organization Report No.<br>SJPC-RU1824-2 |
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16. Abstract


This study focuses on identifying both waterside and landside requirements for the Paulsboro Marine Terminal (PMT) to support the needs of New Jersey's offshore wind (OSW) power generation initiative. The study seeks to understand the capacity requirements of the Paulsboro Marine Terminal to accommodate the logistics associated with the projected power output.

The plan is to construct 10 wind power farms (each having 60 turbines) over a period of approximately 14 years. It is assumed that 30 turbines (half a farm) will be delivered by the end of the first year. 60 turbines are planned to be delivered in each of the 2nd and 3rd year. The 4th year yields 30 more turbines leading to 3 farms in total. This schedule is repeated 3 times to produce 9 farms in 12 years. In each of 13th and 14th year a half farm will be delivered so that the 10th farm finishes by the end of year 14.

The required resources for this project are planned based on the aforementioned schedule. The focus is more on the critical resources such as: berths and STS cranes at the terminal, barges to transport finished turbine components to offshore, jack-up crane at the offshore site. The study also looks at a number of other significant issues such as: schedule of raw material deliveries, inventory level for raw materials and finished turbine components, anchorage visits and delays for barges and raw material delivery vessels.

To provide a better overview for scheduling and resource allocation, 4 scenarios are considered to be modelled and the results of these scenarios are presented in the report and appendix.

In this study, it is assumed that it takes a week to manufacture each turbine component in the Paulsboro Terminal. Once specific time frames are confirmed by each component manufacturer, the model's input can be revised and the inventory related graphs should be modified accordingly.


| 17. Key Words<br>Offshore wind power, Logistics design, simulation modeling, vessel scheduling, SJPC | | 18. Distribution Statement | |
|---|---|---|---|
| 19. Security Classif. (of this report)<br>Unclassified | 20. Security Classif.(of this page)<br>Unclassified | 21. No of Pages<br>51 | 22. Price |

Form DOT F 1700.7 (8-69)

**ACKNOWLEDGEMENT**

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The required resources for this project are planned based on the aforementioned schedule. The focus is more on the critical resources such as: berths and STS cranes at the terminal, barges to transport finished turbine components to offshore, Jack-up crane at the offshore site. The study also looks at a number of other significant issues such as: schedule of raw material deliveries, inventory level for raw materials and finished turbine components, anchorage visits and delays for barges and raw material delivery vessels.

To provide a better overview for scheduling and resource allocation, 4 scenarios are considered to be modelled and the results of these scenarios are presented in the report and appendix. These scenarios are:

1. Having 1 operational berth while the crane works 12 hours a day (12h-1b).
2. Having 1 operational berth while the crane works 16 hours a day (16h-1b).
3. Having 2 operational berths while the crane works 12 hours a day (12h-2b).
4. Having 2 operational berths while the crane works 16 hours a day (16h-2b).

The results of running these scenarios can be summarized as follows:

One berth with an STS Crane seems to be enough for the OSW project operations. For the first 2 scenarios, an average of around 3 anchorage visits (each being a day and half long) exists per year. A precise schedule is required to avoid these visits especially during the busy months such as March and April (also July and August for full farm years) which can be completely resolved with 2 operating berths as seen in the last 2 scenarios. The 12 versus 16 hour shift length for operating STS Crane has a minimal effect on the utilization and schedule of other resources.

Two barges (turbine transport vessels) are required to provide the finished turbine parts in an effective time manner for the Jack-up crane. These barges seem to be quite utilized during the installation period. Since the Jack-up crane is a costly resource, the barges are planned such that the crane is never starving for finished parts while it is set up in the offshore site. Hence, its utilization is over 80% during the installation period.

The schedule of raw material delivery is sensitive to the manufacturing rate at the PMT. Currently it is assumed that it takes 7 days to produce each turbine part, but as this number changes the schedule of raw material delivery needs to be modified accordingly. Raw material delivery is scheduled considering:

1. Smoothness of the schedule within a year
2. It can be repeated in the same manner every year within the horizon of the project
3. The inventory level for raw materials and finished products are kept minimum

Based on such a schedule, the inventory level for various types of raw material and finished product does not change significantly among scenarios.

The availability of the berth and STS Crane allow 3 extra vessels to visit the PMT (each for 3 days) in every month for one berth and one crane scenario. However, these arrivals need to be scheduled accurately to minimize (or even remove) anchorage visits by the vessels visiting PMT. It is not feasible to add more extra vessels since the utilization of the berth exceeds 70%. Adding a berth increases the number of extra vessels to 5 in which STS Crane utilization reaches to 70% again.

In this study, it is assumed that it takes a week to manufacture each turbine component in the Paulsboro Terminal. Once specific time frames are confirmed by each component manufacturer, the model's input can be revised and the inventory related graphs should be modified accordingly.

## 1. Introduction

The objective of this study is to identify both waterside and landside requirements for the Paulsboro Marine Terminal to support the needs of New Jersey's offshore wind (OSW) power generation initiative. The study is to understand the capacity requirements of the Paulsboro Marine Terminal to accommodate the logistics associated with the projected power output. The plan is to construct 10 wind power farms over a period of approximately 14 years as shown in Figure 1. The years in which one half farm is built are called "half-farm" years and the years with two half farms built within are called "full-farm" years (note that the two half farms built in a full-farm year do not belong to the same farm). Installation of each farm is anticipated to take 2 years and it is desired to work on installation of 2 separate farms every year. However, this may not be possible due to potential permit issues and other unforeseen manufacturing or installation issues. As a result it is assumed that once every 4 years an issue may slowdown the development process. This leads to the planning horizon as showed in Figure 1. Each farm will consist of 60 turbines (with average capacity to produce 5 MW each) leading to 300 MW per farm and 3 GW in total as suggested in New Jersey's Energy Master Plan for 2011.

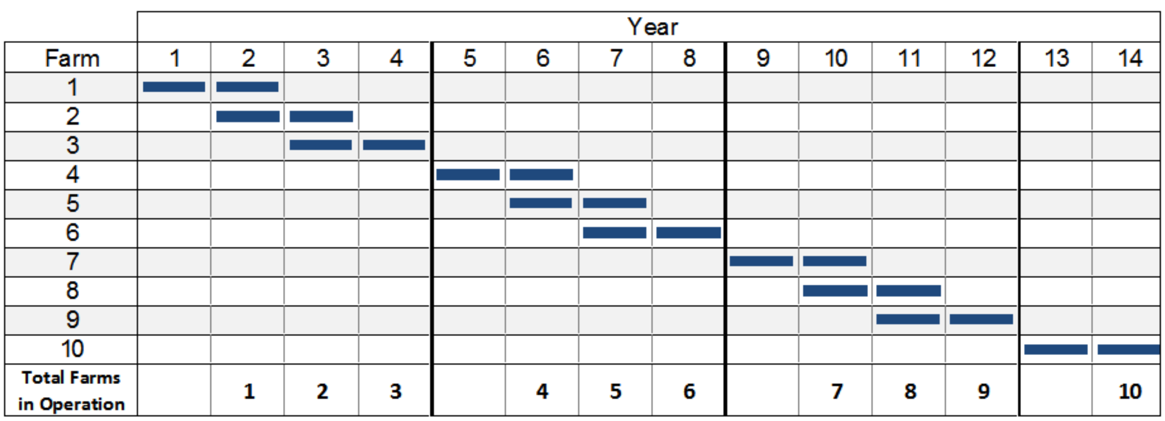


Figure 1. The master plan to build 10 wind farms

## 2. Offshore Turbine Parts

Typically each turbine is designed to have the followings:

Foundation: e.g. a cylinder (or a Jacket structure) of 700 tons, 300 ft in height and 17 ft in diameter.

Tower Sections: consisting of 3 pieces; e.g. 30 tons each, with length of 144 ft, 118 ft and 65 ft.

The lowest tower piece (65 ft.) is also referred to as the transition Piece, connecting foundation to other tower sections.

Nacelle: e.g. 250 tons, 65(l)×33(w)×33(h) cubic ft housing the turbine hub.

Nacelle contains all the electrical and mechanical components essential for the operation of the turbine. It is fitted at the top of the tower.

Blades: 3 pieces; e.g. 20 tons a piece, up to 210 ft long.

There are three composite rotor blades that are connected to the central hub, extracting the kinetic energy from the wind.

For the typical case mentioned above, total turbine weight is 700+90+250+60=1,100 tons. All parts are mostly made of steel and steel/concrete mixture, except blades which are built from composite materials.

For the purpose of this analysis, it is assumed that it takes a week to manufacture each turbine part in the Paulsboro Terminal facilities. This process is done in parallel, meaning that all required material for 1 turbine (1 foundation, 3 pieces of tower sections, 1 nacelle and 3 blades) are produced in a week.

## 3. Supply Side

The plan is to bring sufficient source/feed materials to Paulsboro to manufacture and pre-assemble the required turbine parts at the port for subsequent storage and loading in advance of transportation to the offshore wind farm.

Every year 62,400 tons of steel for manufacturing foundations, tower sections and nacelles is required to build 60 turbines as given in Table 1 in details. It is anticipated that 42,000 tons of steel which is required for foundation is going to be supplied from domestic sources, and is going to be shipped with rail cars. The capacity of each rail car is assumed to be 100 tons, and each train brings 40 of these cars. As a result each train shipment is 4,000 tons, which leads to 11 shipments during a year (approximately 1 per month). The remaining 20,400 tons of steel will be provided from international sources by vessels. Every year 3,600 tons of raw materials for manufacturing composite blades are going to be delivered by domestic providers with rail cars. However for the worst case analysis of the berth capacity requirements of Paulsboro terminal, all the raw materials will be considered to be delivered by vessels to the Paulsboro marine terminal. Typically each vessel can bring up to 5,000 tons of raw materials per shipment, but due to material sourcing issues, it is assumed that steel plates, steel coils and composite materials will arrive by different vessels. Each shipment is unloaded at the terminal using either ships gear (i.e. a crane that is permanently installed on the ship) (66%) or a ship-to-shore (STS) crane, which is permanently installed alongside the terminal berth (34%).

Table 1. Anticipated raw material deliveries

| Part | Material | Tonnage (per turbine) | Shipment | Total Tonnage for 60 turbines | Handling / Unloading Rate (tons per hour) | No. Of shipments (per full-farm year) | No. Of shipments (per half-farm year) |
|---|---|---|---|---|---|---|---|
| Foundation | Steel Plate | 700 | Rail Cars (Domestic) | 42,000 | 225 | 9 | 5 |
| Tower Sections | Steel Thin Plate | 90 | Vessel (imported) | 5,400[1] | 125 | 2 | 1 |
| Nacelle | Steel Coil | 250 | Vessel (imported) | 15,000 | 300 | 3 | 2 |
| Blades | Composite | 60 | Rail Cars (Domestic) | 3,600 | 150 | 1 | 1 |
| Total | - | 1,100 | - | 66,000 | - | 15 | 9 |

From a planning perspective, one wind farm will be built over a 2-year period. 60 turbines are required to be built for a full farm year (e.g. 30 turbines each for two separate wind farm locations) and 30 for a half farm year (e.g. 30 turbines for only one wind farm

[1] To meet annual installation plan, the last shipment which is in September is assumed to be tower sections. The total tonnage left for this shipment is not supposed to be more than required raw material to build 13 tower sections which is about 1000 tons.

location). Consequently the manufacturing process of turbines for a full farm year takes more than a year. In order to meet the installation plan requirements, the manufacturing process for full farm years must start at least 15 months in advance. As indicated in Figure 1, since two full farm years are planned to follow in consecutive years, (i.e. installation years 2 and 3) the production should start even earlier to be able to supply enough turbines for 2 full farm years and enough raw materials should be supplied as required by the production beforehand. These two full farm years are then followed by two half farm years. Production for half farm years can start just 8 months in advance and clearly fewer raw material shipments are required. This plan results in an unbalanced raw material delivery which requires more shipments in some years and fewer in other years. This may not be a desirable plan for a long term (14 year) period. Instead, it is possible to smooth out the shipment process throughout the scope of the project at the cost of keeping more inventories of products (approximately 10 to 15 of each turbine part on average).

Figure 2 shows a smooth or uniform raw material delivery plan for a 4 year period (starting from September of year 1 and finishing by August of year 5). Each “1” in rows 3 to 6 represents one raw material shipment for the corresponding part and in the corresponding month and year. This plan can be repeated 3 times to build 9 farms, while Figure 3 shows the delivery plan for the last farm (in year 12 and 13).

| Year | 1 | | | | 2 | | | | | | | | | | | | 3 | | | | | | | | | | | | 4 | | | | | | | | | | | | 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A |
| Foundation | | | 1 | 1 | 1 | | | 1 | 1 | | | 1 | 1 | | 1 | 1 | 1 | | | 1 | 1 | | | 1 | 1 | | 1 | 1 | 1 | | | 1 | 1 | | | 1 | 1 | | 1 | 1 | 1 | | | 1 | 1 | | | |
| Tower | | | | 1 | | | | | | | | | | | | 1 | | | | | | | | | | | | 1 | | | | | | | | | | | | 1 | | | | | | | | |
| Nacelle | | 1 | 1 | | | | | | | 1 | | | | 1 | | | | | | | | 1 | | | | 1 | | | | | | | | 1 | | | | 1 | | | | | | | | 1 | | |
| Blade | 1 | | | | | | | | | | | | | | 1 | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | |
| Total | 1 | 1 | 2 | 2 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| Total Annual | 6 | | | | 11 | | | | | | | | | | | | 11 | | | | | | | | | | | | 10 | | | | | | | | | | | | 4 | | | | | | | |

Figure 2. A 4-year schedule of raw material delivery (which will be repeated 3 times to build 9 farms)

As illustrated in Figure 2, the first shipment of raw material is delivered in September of the 1st year and the plan continues until August of the 5th year after which the plan repeats itself. As mentioned earlier the plan is smooth such that in every year either 10 or 11 shipments are delivered. The total number of shipments for 3 farms adds up to 42 which yield an average of 14 shipments per 60 turbine wind farm. These shipments are scheduled based on the manufacturing time of each part such that there are always enough finished pre-assembled parts to be transported to offshore for installation. It is also interesting to note that based on this plan the first offshore installation happens in mid-March of the 3rd year. It asserts that raw material delivery is required to start a year and half before the installation process begins.

| Year | 12 | | | | 13 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
| Foundation | | | 1 | 1 | 1 | | | 1 | 1 | | | 1 | 1 | 1 | | |
| Tower | | | | 1 | | | | | | | | | | | | |
| Nacelle | | 1 | 1 | | | | | | | 1 | | | | | | |
| Blade | 1 | | | | | | | | | | | | | | 1 | |
| Total | 1 | 1 | 2 | 2 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
| Total Annual | 6 | | | | 8 | | | | | | | | | | | |

Figure 3. Last farm schedule of raw material delivery

Manufacturing of turbine parts is typically a year round activity and for the first year it is assumed to start from September when the first shipment of raw material arrives. The amount of inventory of raw materials for manufacturing the parts is desired to be as low as possible but is ultimately dictated by the manufacturing process.

In addition to the turbine components detailed in Figures 1 – 3, a contractor must manufacture the array cables (i.e. connect each of the wind turbine within a single farm) and export cables that will facilitate transmission of electricity from the wind farm to the onshore substation location. For each farm (60 turbines) a cable wheel of 2000 tons is required in the second year of installation of each farm. It takes 5 days to load the cable wheel on a vessel in berth.

## 4. Paulsboro Marine Terminal Facilities

In anticipation of the Paulsboro marine terminal's serving as the support port for the New Jersey OSW initiative, a set of assumptions are made to satisfy the needs of the initiative. For instance, the terminal facilities involved in this project will include open (i.e. outside) storage and enclosed (i.e. environmentally protected) storage facilities, port staging area and the berth(s). Clearly, larger turbines or more turbine units will require more storage space. Pre-assembly is assumed feasible from February to November in New Jersey due to weather conditions. It is critical to have sufficient space to efficiently store and preassemble turbine or foundation components. This is not only for the regular flow of components to the installation site but also to have buffer storage in case installation is halted due to permit approvals, financing issues, inclement weather conditions and / or equipment or vessel failures. Furthermore, electrical components such as offshore transformers, switch gear and converters, to be used in the farm for connection of turbines and transmission to the grid, need to be stored and loaded on vessels at the port. Foundation (monopole or Jacket structure), transition piece and tower sections are all made of steel plates that need to be fabricated (i.e. rolled, welded, sanded and coated) to assemble the finished product and ultimately stored for pre-assemble.

Linear berth space or wharf length is a critical parameter. Considering the port calls of different types of transport and installation vessels as well as import vessels, single or multiple berths or longer wharf length may become a necessity to minimize delays at the port. The berth may also be used for other product lines being handled. For instance, the study done for the OSW development in Massachusetts ports indicated a minimum of 500 ft berth length to serve the vessels for a 30-60 turbine farm. It suggested a minimum berth depth of 24 ft at low tide for installation vessels. The study also indicated the need for 2 crawler cranes, a truck mounted crane, a cherry picker, a terrain moving transport vehicle, a triple axel trailer and a low loader for offloading, assembling and loading turbine parts on the installation/feeder vessels in the wharf.

In this study the scenarios of opening 1 berth or 2 berths are going to be examined against each other to determine the timeframe for when a 2$^{nd}$ berth is required. It is assumed that the berths are available 24 hours a day and 7 days a week. One STS Crane is considered to be working in berth(s) which may not be operated due to weather conditions 3% of the time and also may experience mechanical failures 1% of its operation time. This crane is assumed to be operated 12 hours or 16 hours a day. These 2 scenarios are also contrasted against each other to see if it is required to operate it for 4 additional hours. These 2 situations together with the possibility of having 1 berth or 2 berths generate 4 scenarios as follows:

1. Having 1 operational berth while the crane works 12 hours a day (12h-1b).
2. Having 1 operational berth while the crane works 16 hours a day (16h-1b).

3. Having 2 operational berths while the crane works 12 hours a day (12h-2b).
4. Having 2 operational berths while the crane works 16 hours a day (16h-2b).

These scenarios are then compared to see which one can meet the operational requirements better. The scenario results are presented in Appendix.

Paulsboro marine terminal can also be used to support operation & maintenance functions at the offshore farms to support major failures (which are expected to be as low as 1% of the operation at the terminal). For smaller, routine operation and maintenance activities, dedicated service vessels, which are located in marinas along the Atlantic Ocean shoreline, can be used for daily missions throughout the majority of an offshore wind farm's service life.

## 5. Vessels for Transportation and Installation

Transportation to Offshore

Currently in U.S., typical transport vessels are barges moved by tugboats, even though feeder vessels are targeted for future purposes. A barge is typically 150×400 square ft. to carry five foundations per trip. The same barge can also carry the other parts of the turbine in a subsequent trip. Three towers (nine tower sections), three nacelles and three sets of blades are all transported in each trip of the barge. In both cases barge loading time is assumed to be two days and barge speed is 5 knots per hour. It is approximately 90 miles to sail down the river and 30 miles to get to offshore farm location (as considered for modelling purposes). More than one barge may be needed depending on the installation schedule. For modelling purposes the loading process of these barges takes 2 days; 1 day for loading the parts using the STS Crane and 1 day for tying and securing the parts without requiring the crane. This process may reduce to 1 day in the following years. The STS Crane available at berth(s) is used for loading the barge(s). It is also assumed that in case inventories of turbine parts are not enough to load the barge, the vessel goes to anchorage and waits there until the parts are ready for loading. This way the berth is available for other operations while the barge is waiting.

Installation Vessels

For this modelling effort, installation is carried out using Jack-up vessels that come with a crane to unload turbine components from barges and install them in water. These vessels are supported by four legs and they can stand moored on the ocean floor which assists the heavy lifting necessary for turbine components. These vessels are either moved by tugboats or are self-propelled. Their size depends on the project and may vary between 150-600 feet (l), 100-150 feet (b), 10-15 feet (d).

Import Vessels

As mentioned earlier, it is likely that certain raw materials for the turbines to be used in the East Coast offshore farms will be imported and the support port will be visited by vessels bringing these parts. These vessels are likely to be general cargo vessels, and their sizes may vary based on what and how much they carry. Their length may vary between 300-900 feet with beams from 75 to 150 feet and with typical drafts of 20-40 feet.

## 6. Installation Process

The way the turbines will be installed in New Jersey's OSW project will provide important information and impact decisions regarding the choices of vessels and characteristics of the port to support the project. In this study we will use approximate times and simplified processes for installation details to be able to develop a preliminary model.

Due to winter weather concerns, installation processes can take place from mid-March through November in offshore sites in New Jersey. Installation rate for foundations is one per day (6am-8pm) and the installation process continues 7 days a week. After the installation of the last foundation is finished the barge (feeder) can get back to the port to bring more supplies. As mentioned above multiple barges are likely to be used.

Installing the tower sections, nacelles and blades for each turbine takes one day each. It takes 9 days to unload the barge since it carries parts for 3 turbines in each trip. The barge will go back to the port after unloading the last piece. A 75% utilization rate due to weather conditions is already considered in installation rates.

After installation, the tower sections will be bolted (without using crane) in 3 days by an installation crew. Turbine related cabling (systems) work will be done by a systems crew in five days (a week). This work can be done in parallel with bolting. Systems (cabling) can take place from mid-March to November in the installation sites in New Jersey.

After installing tower sections, the nacelle will be installed on top of the tower in a day by the installation crew. Then, it takes three weeks to do the systems work for the nacelle by the systems crew. The blades will be installed in one day once the installation of the nacelle is complete. Figure 4 gives an idea about the sequence of operations and rough installation times in the case of a single turbine.

Due to the fact that internal cabling or turbine wiring takes 3 weeks, it is not feasible to install turbines one at a time (such as one complete installation after another). From the project planning perspective, a feasible approach would be to place a batch (say 30) of foundations over a period of a month, followed by the installation of the tower section for all the turbines and let installation crews work on bolting them as well as installing nacelles and blades on them. Thus, various operations can be done in parallel as shown in Table 2 and demonstrated in Figure 5. Building of 60 turbines is expected to take 8-9 months.

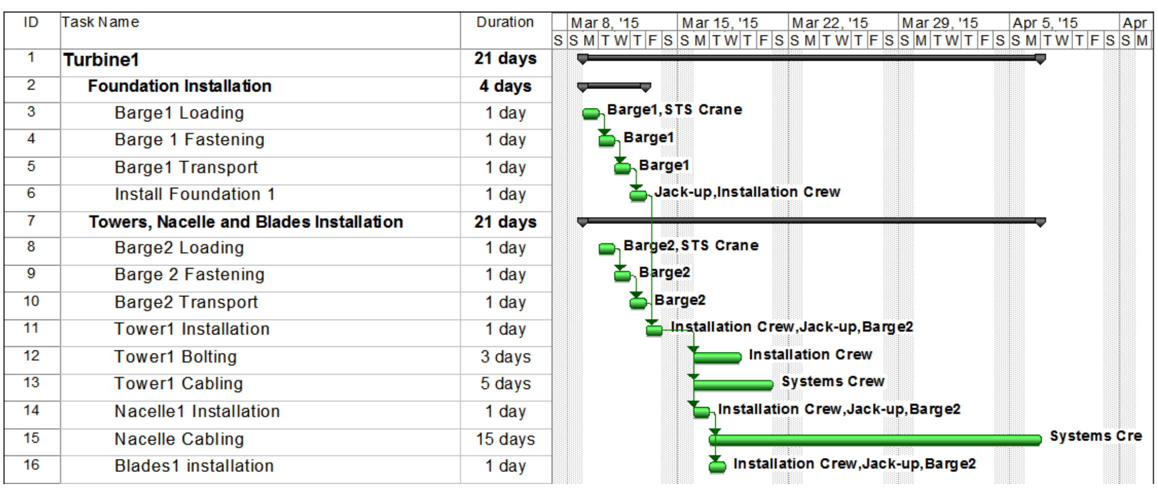


Figure 4. An approximate project plan for the installation of a single turbine

The annual installation plan is also given below. Table 2 provides an approximate plan for installation of foundations and other parts (tower sections, nacelles and blades). In this table the numbers of installed parts per month are rounded based on the capacity of barges (barge capacity for foundations is 5 and for other parts is 3 sets). Table 3 gives the exact number of installed parts without rounding off.

Table 2. Annual installation[2] plan (Planned)

| Month | Mid-Mar. | Apr. | May | June | July | | Aug. | Sep. | Oct. | Nov. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Farm | 1 | | | | | 2 | | | | | |
| Foundations installed | 15 | 15 | - | - | - | 20 | 10 | - | - | - | 60 |
| Balance of turbine components | - | 6 | 9 | 9 | 6 | - | 6 | 9 | 9 | 6 | 60 |

Table 3. Annual Installation Plan (Modelled)

| Month | Mid-Mar. | Apr. | May | June | July | | Aug. | Sep. | Oct. | Nov. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Farm | 1 | | | | | 2 | | | | | |
| Foundations installed | 17 | 13 | - | - | - | 19 | 11 | - | - | - | 60 |
| Balance of turbine components | - | 5 | 11 | 10 | 4 | - | 7 | 10 | 10 | 3 | 60 |

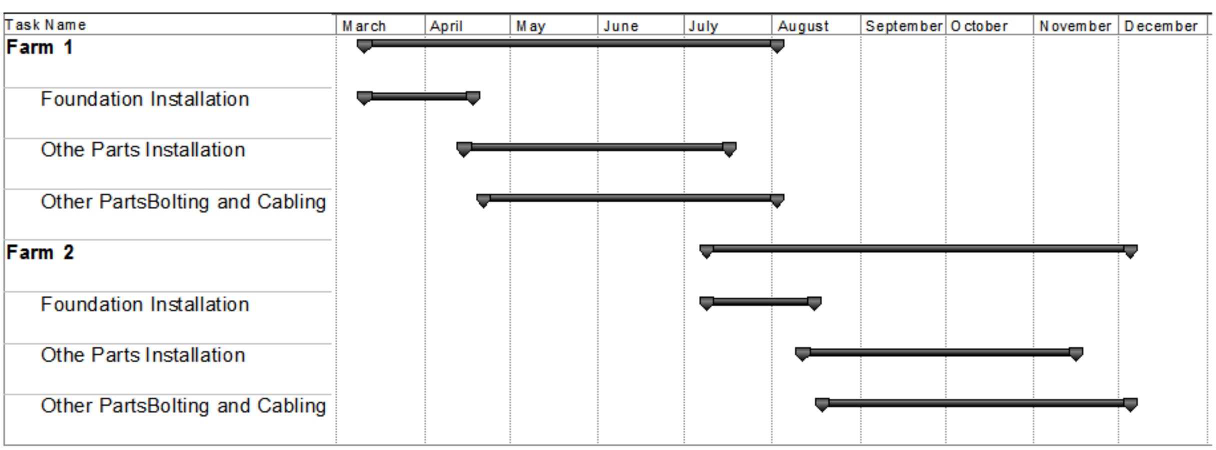


Figure 5. An example project plan for installation of 60 turbines in 9 months

[2] The timing in these tables just represents the installation process. The time to finish the rest of operations is shown in Figure 5.

Another consideration is to use lift vessels as recommended by turbine manufacturers. They are concerned with vessel heave damaging nacelles during critical lifts. The reason Turbine Installation Vessels (TIVs) have become prevalent in Europe is because Original Equipment Manufacturers (OEMs) may also prohibit offshore transfer of sensitive components, especially nacelles and blades. The towers are less susceptible to this type of damage. A stable crane doesn't completely prevent issues of heave associated with transport vessels. Certain parties within the industry have experimented with the idea of using floating crane equipment stabilized by the foundation, rather than investing in a full Jack-up platform. Clearly this issue is related to equipment selection and is expected to have minimal impact on the modelling effort.

## 7. The Simulation Model

The current Delaware River Vessel Traffic simulation model developed by Rutgers University will be modified to incorporate the storing, preassembly, staging and loading in PMT, transporting turbine parts to offshore location and the installation process details. The logic and the animation component of the model will be revised to accommodate the necessary details of the port activity and offshore wind effort. The model generates results on capacity and performance issues regarding:

- Berths (to import raw material and transport parts)
- Vessels, types and specifics
- Equipment utilization (barges, cranes, Jack-up crane, etc.)
- Installation timeline

It is also possible to measure the performance of storage areas, preassembly, cabling or installation crews if adequate data is provided.

Two snapshots of the simulation model are shown in Figure 6 and Figure 7.

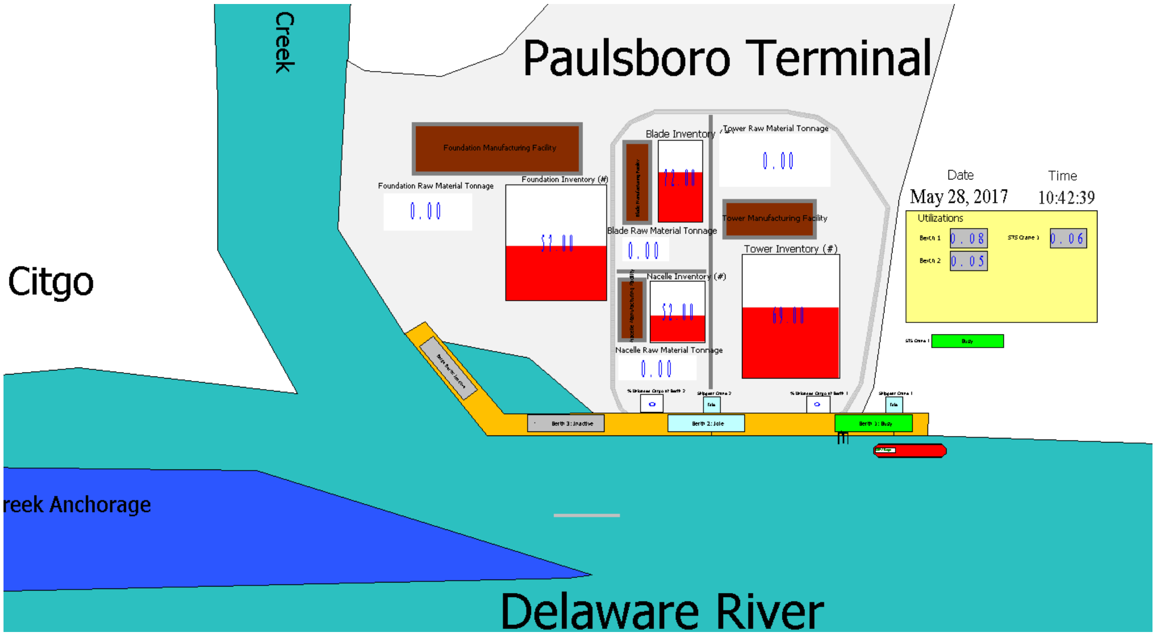


Figure 6. General view of the Paulsboro terminal in the simulation model

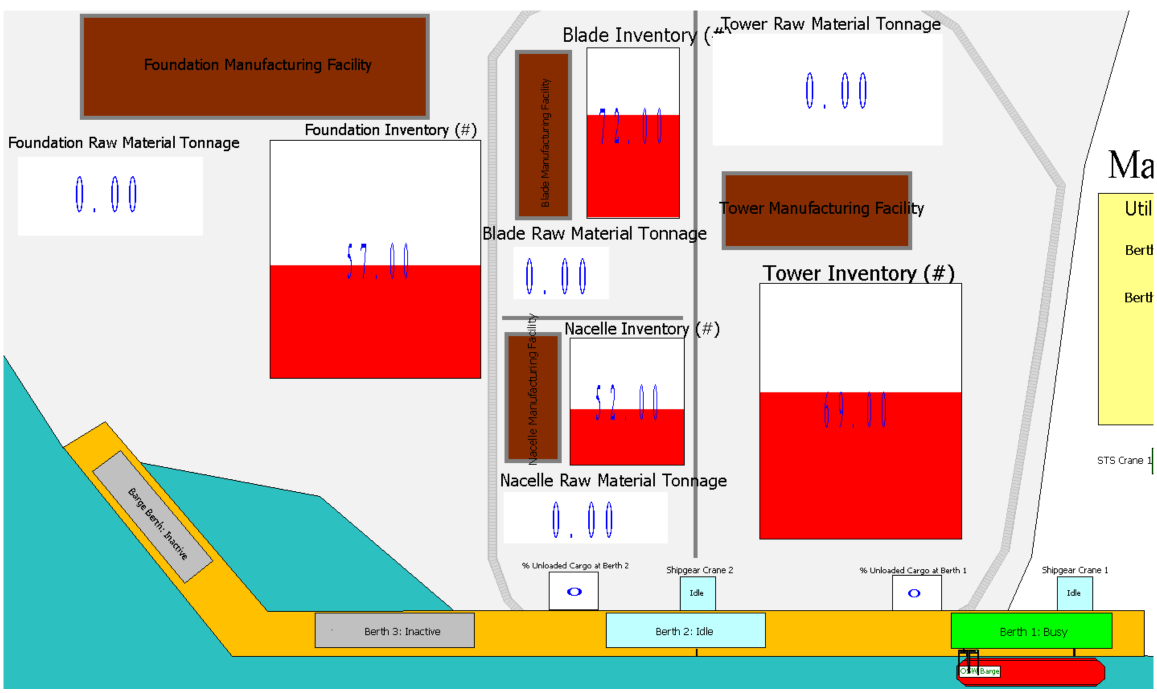


Figure 7.  A closer view of the Paulsboro terminal in the simulation model

## 8. Capacity Analysis of Terminal Resources for Additional Berth Operations in PMT

The projected scope of work to support OSW related manufacturing and logistics within the Paulsboro Marine Terminal (PMT) leaves some extra time for the terminal resources to be utilized for additional operation in the berth(s). Scenario analyses (e.g. **Error! Reference source not found.** through **Error! Reference source not found.**) show that berth and STS Crane utilization in the 16 year time horizon for the OSW project are under-utilized.

A part of this study includes the capacity analysis for the PMT resources to check whether it is possible to use the Terminal for additional berth operations or not. If so, how many extra vessels can visit the terminal per month and also to specify which resource limits this number. This study is done for scenarios 12h-1b and 12h-2b among all scenarios as requested by the project planners. For this study, it is assumed that the terminal time for each extra vessel is approximately 3 (consecutive) days. The acceptable level for utilizations is considered to be 70%.

Figure 8 and Figure 9 illustrate the berth and STS Crane utilization for the 1st Scenario (i.e. having 1 operational berth while the crane works 12 hours a day). It is possible to add 3 extra shipments (each dwells 3 days) in this Scenario until the berth utilization maximum reaches 70%. It means that the berth acts as a bottleneck here, and it limits the number of extra shipments to 3. Otherwise, the utilization for STS Crane allows bringing 2 additional shipments on top of the three adding up to 5 additional shipments per month before reaching the proposed 70% utilization threshold.

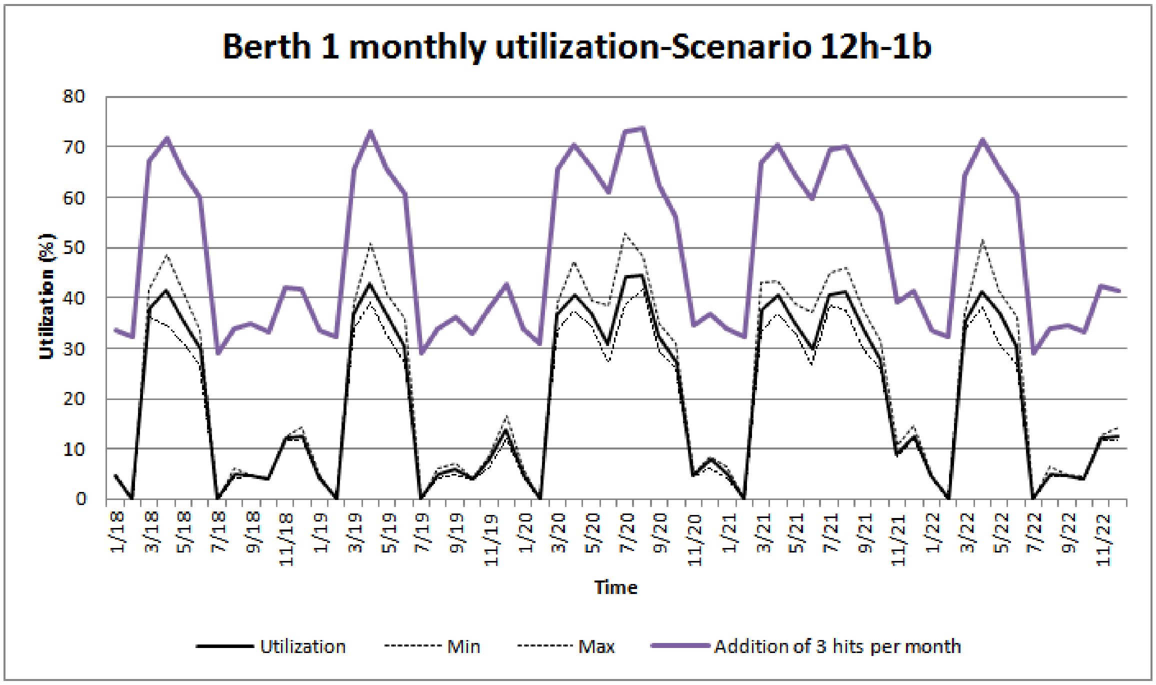


Figure 8. Berth 1 monthly utilization including 3 extra shipments for Scenario 1

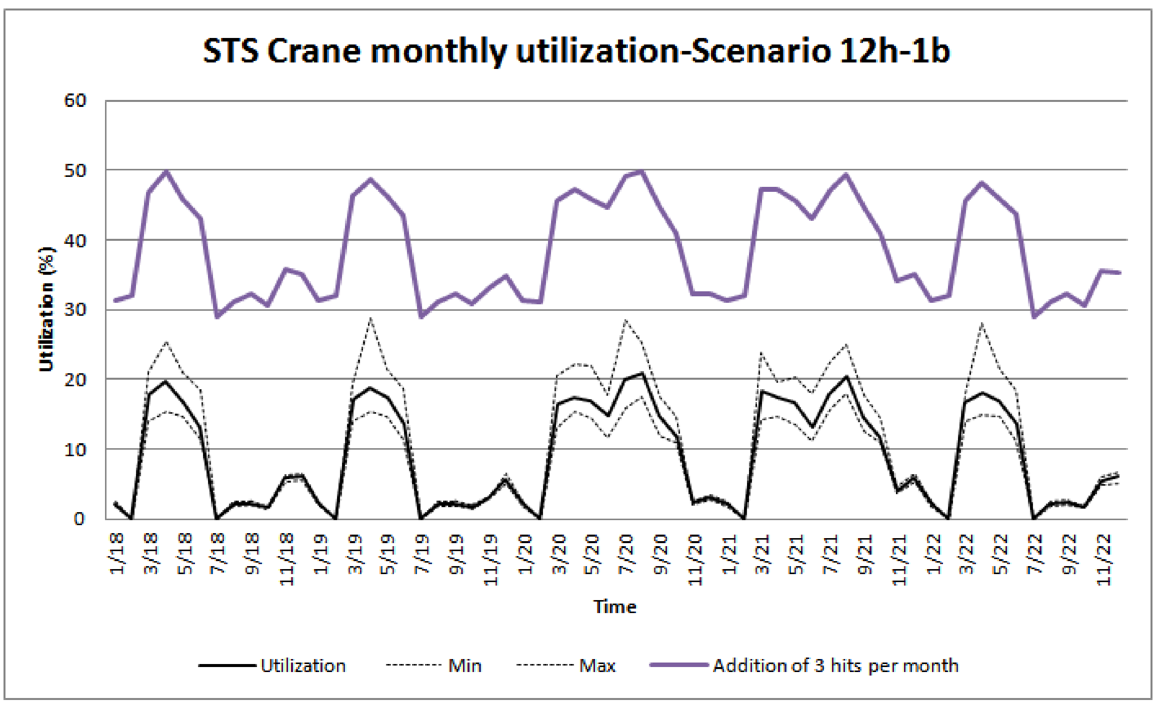


Figure 9. STS Crane monthly utilization including 3 extra shipments for Scenario 1

In order to be able to bring more than 3 extra shipments to the terminal per month, one can increase the number of berths to 2. In Figure 10 and Figure 11 the results for the scenario of having 2 berths are presented. In this case 5 extra shipments are brought to the terminal and the STS Crane becomes the bottleneck. When the number of extra shipments increases to 5, the utilization of the crane reaches 70% in the busiest months. In this Scenario the berth utilization falls below 50%.

The result of this analysis can be summarized as:

It is possible to add 3 extra shipments for the 12h-1b Scenario and 5 extra shipments for the 12h-2b Scenario before reaching the 70% utilization for the terminal resources (berth and crane).

It is also important to note that in this part of the study the outputs of the simulation model were analysed to find the cases where the berth and crane were available for 3 consecutive days, so that it is possible to fit an extra shipment in between. It means that an extra shipment is allowed in a month only if the resources are available for 3 consecutive days in that month.

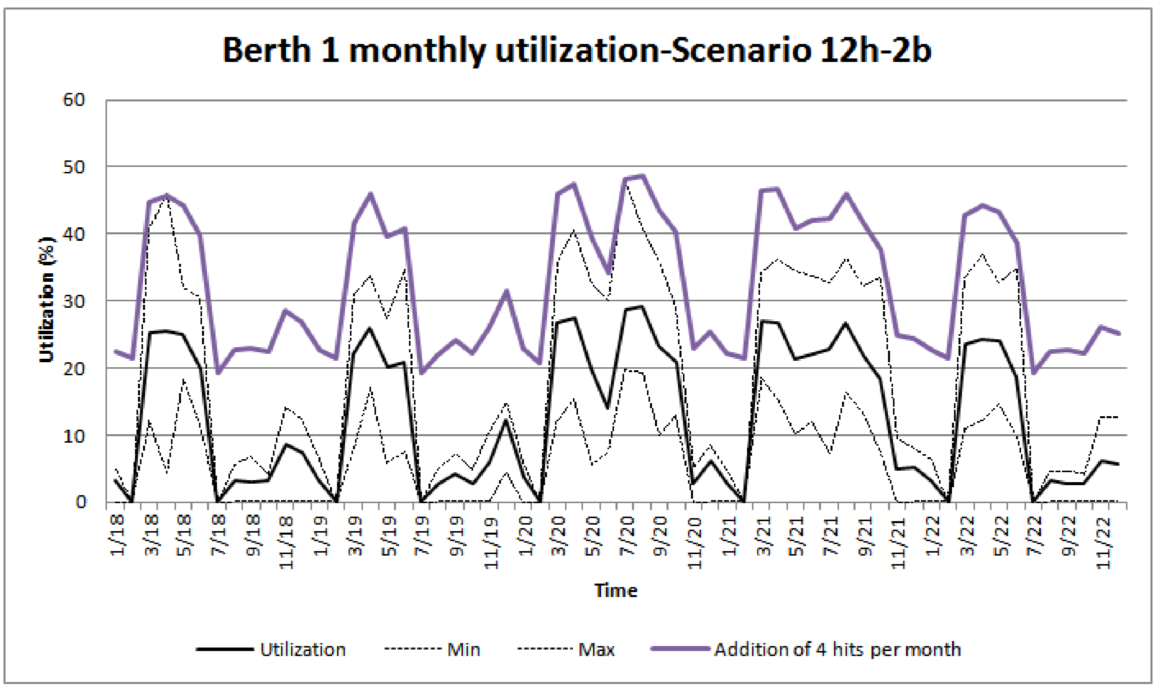


Figure 10. Berth 1 monthly utilization including 5 extra shipments for Scenario 3

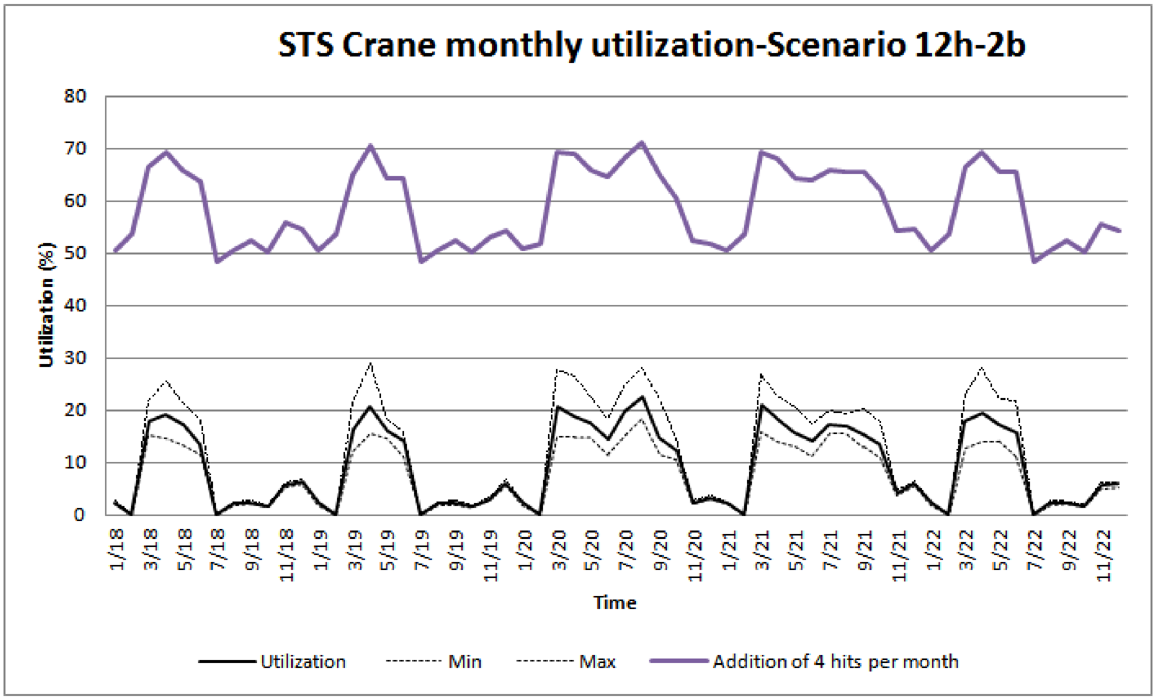


Figure 11. STS Crane monthly utilization including 5 extra shipments for Scenario 3

## APPENDIX

Since the production of each turbine component takes a week, the manufacturing process needs to start more than a year before shipping turbine parts to the offshore site.

This plan starts in September 2013 when the first shipment of raw material is delivered to the terminal. The first transport of manufactured turbine components to the offshore installation site happens a year and a half later in March 2015 and the plan repeats itself every four years. This repetition can be seen in most of the graphs that are presented below. This plan finishes in 2028. The results for 4 scenarios follow:

### Scenario 1: 1 berth, 12 hour crane

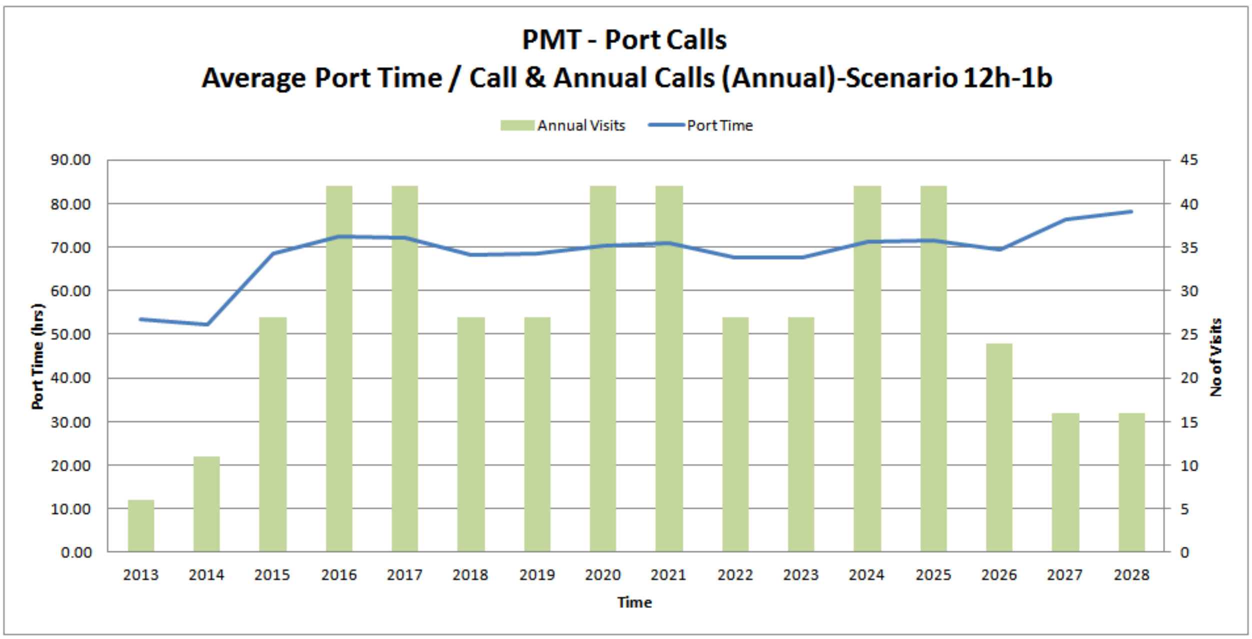


Figure A. 1. PMT annual port visits and average port times in Scenario 1

Port time means the time that a vessel spends from entering the Delaware River at Breakwater (i.e. Mile Post 0) until it departs the Delaware River again at breakwater. Figure A. 1 shows the annual average port time for all the vessels (raw material vessels and OSW vessels or barges) that visit the Paulsboro Terminal with the line on the left vertical axis. The bars represent the annual number of vessels that go to Paulsboro and they should be read from the right vertical axis.

The terminal time is defined as the time that a vessel spends at a berth. The average terminal time for the raw material vessel is about 36 hours. This number increases to 60 hours for the OSW vessels.

Figure A. 2 illustrates the average annual anchorage visits and average waiting times per visit. In order to provide more details, the number of anchorage visits is presented monthly in Figure A. 3. The anchorage visits in Figure A. 3 are shown for just 5 years (years 2018 to 2022). The reason is that the plan repeats itself every 4 years and a time span of 5 years can reveal more details compared to a 16 year time horizon.

As seen in Figure A. 2, three vessels per year go to the Mantua Creek Anchorage (MCA) each for approximately a day and half. Looking at Figure A. 4 and Figure A. 5 one can see that the berth utilization does not exceed 55% even in the worst case. It means that the berth has enough availability to avoid vessels from going to anchorage. Hence to reduce or eliminate anchorage visits, the raw material vessel arrivals must be planned in such a way that they do not interfere with OSW vessel arrivals.

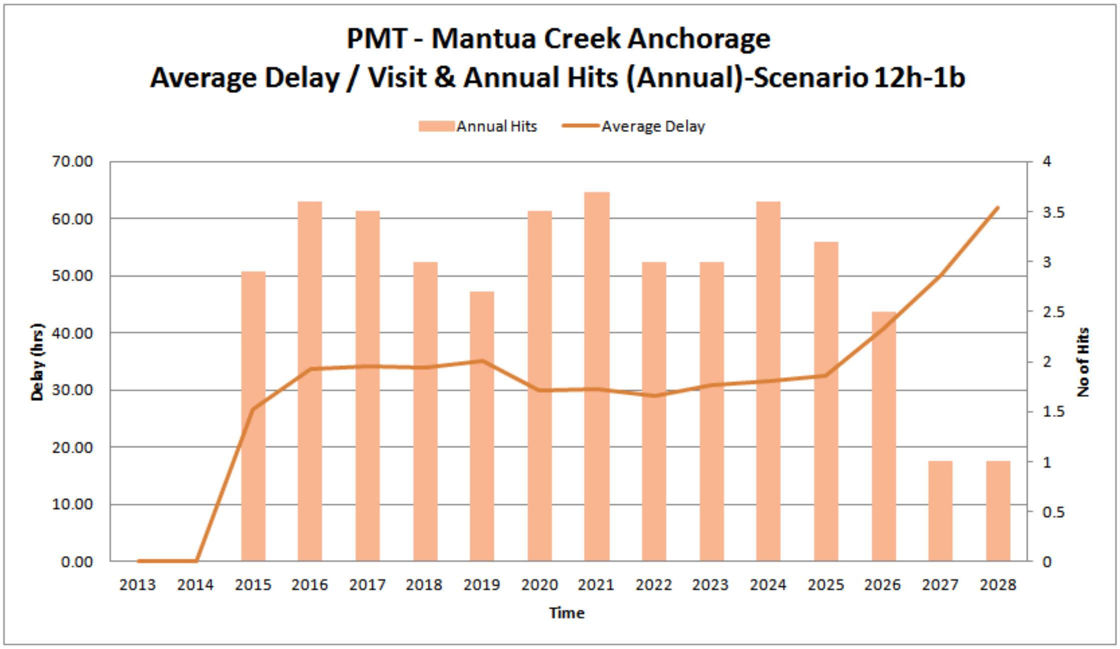


Figure A. 2. Annual Mantua Creek Anchorage (MCA) visits and average delays for OSW vessels in Scenario 1

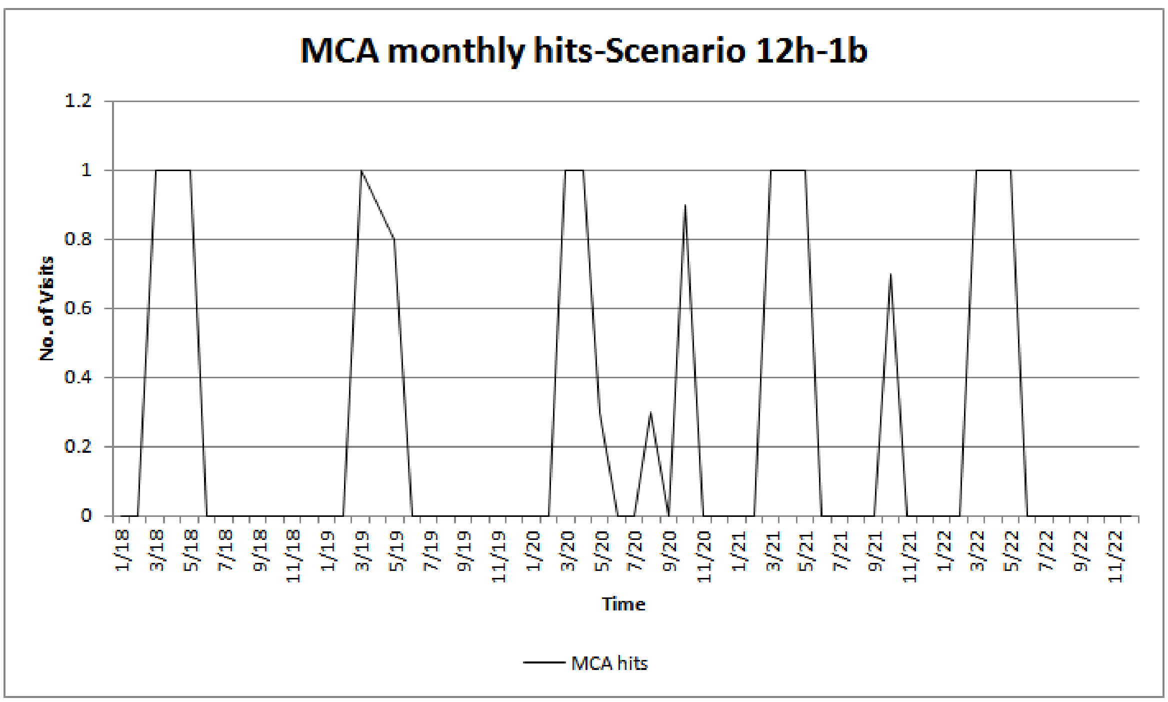


Figure A. 3. Monthly Mantua Creek Anchorage (MCA) visits for OSW vessels in Scenario 1

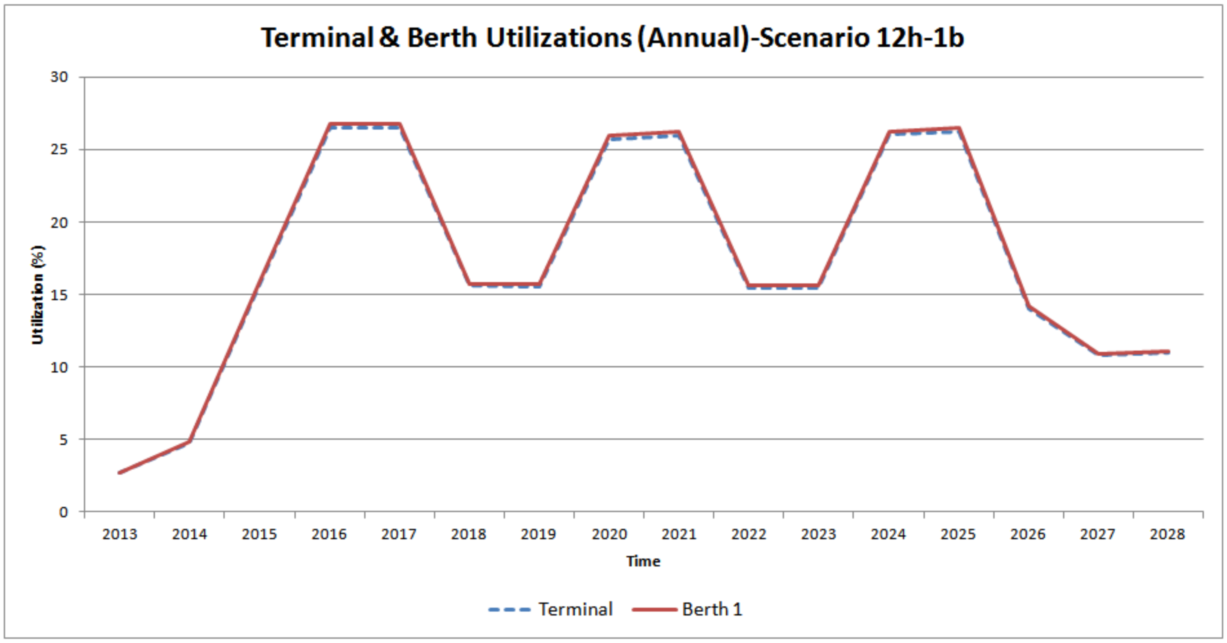


Figure A. 4. Annual berth utilization for Scenario 1

Both Figure A. 4 and Figure A. 5 show berth utilization, while the first one shows it annually and the second provides it monthly.

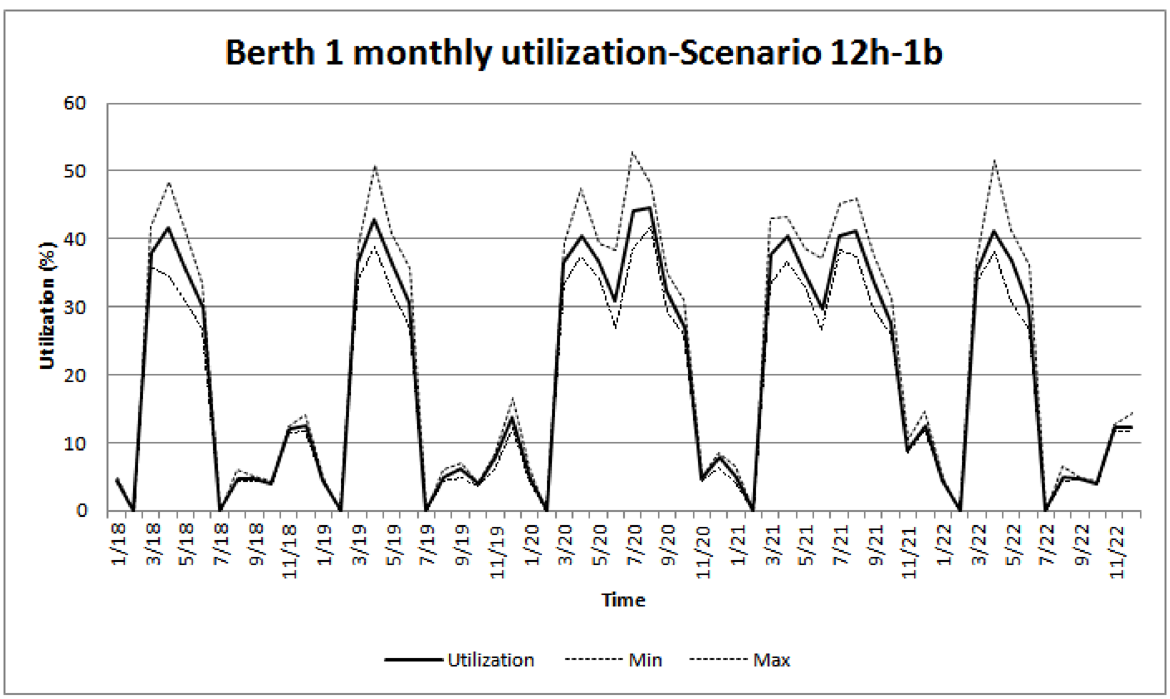


Figure A. 5. Monthly berth utilization for Scenario 1

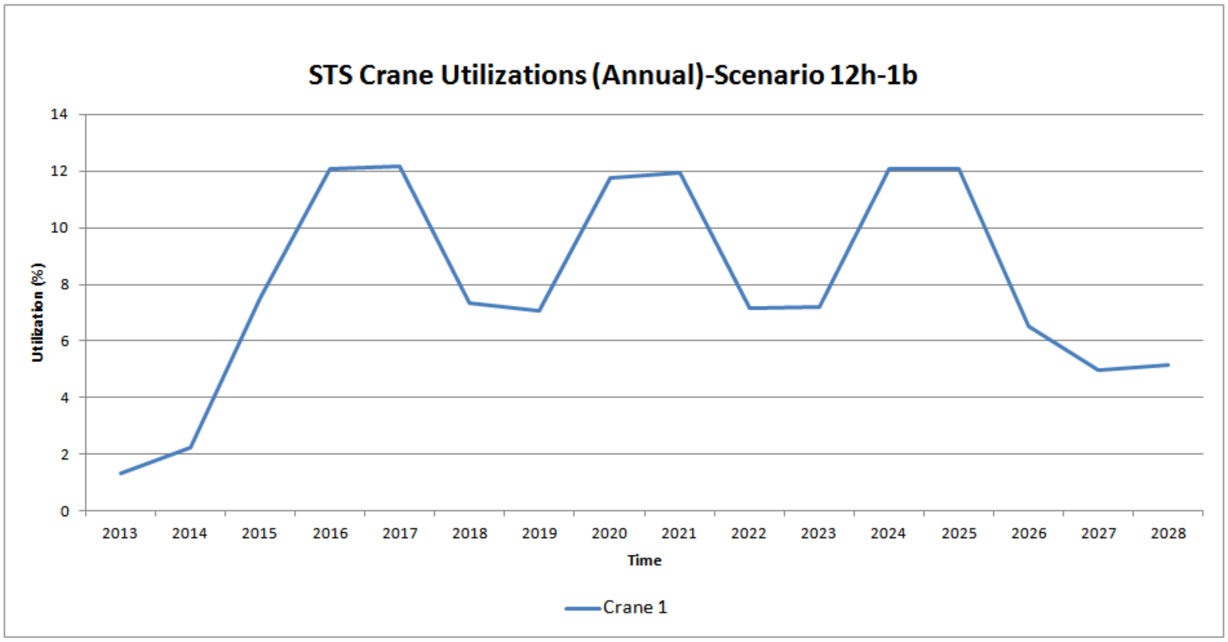


Figure A. 6. Annual STS Crane Utilization for Scenario 1

Figure A. 6 and Figure A. 7 provide the STS Crane utilization annually and monthly for 5 years, respectively.

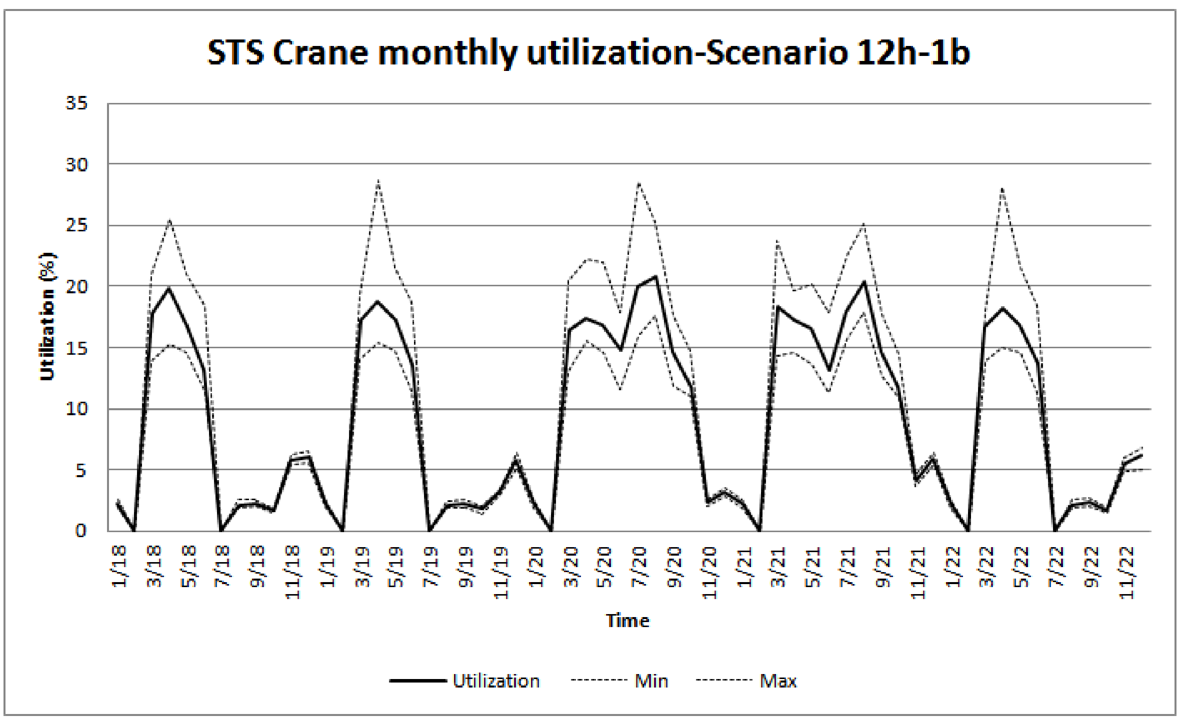


Figure A. 7. Monthly STS Crane Utilization for Scenario 1

Figure A. 8 illustrates the utilization for Jack-up crane. The average utilization for the Jack-up crane for the busy period (from mid-March to July for half-farm years and from mid-March to November for full-farm years) is about 83%. This number can be broken down to 78% for half farm years and 87% for full farm years. The Jack-up crane is quite utilized in the busy periods and it is never starving for turbine parts. This pattern is similar in all the scenarios and consequently the aforementioned utilization factor remains approximately the same among all scenarios.

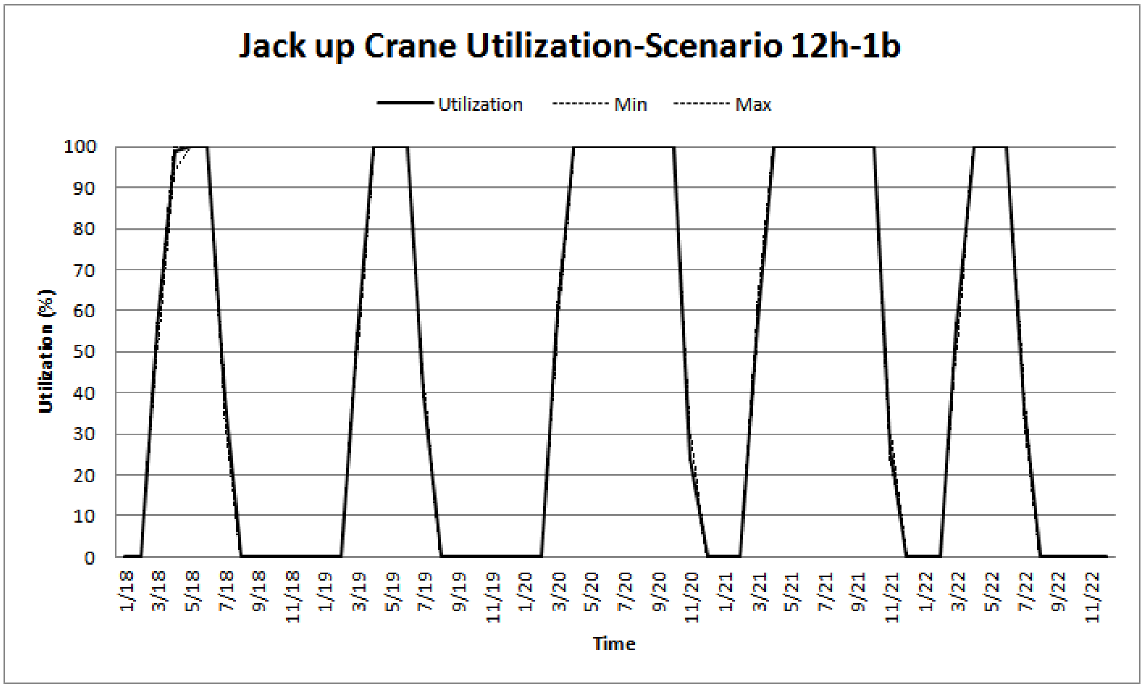


Figure A. 8. Monthly Jack-up Crane utilization for Scenario 1

The following figures provide information about the inventory of turbine parts that are manufactured at the terminal. Figure A. 9 through Figure A. 12 show the inventory for each type of turbine component (foundation, tower sections, nacelle and blades) separetely in 5 year blocks of time.

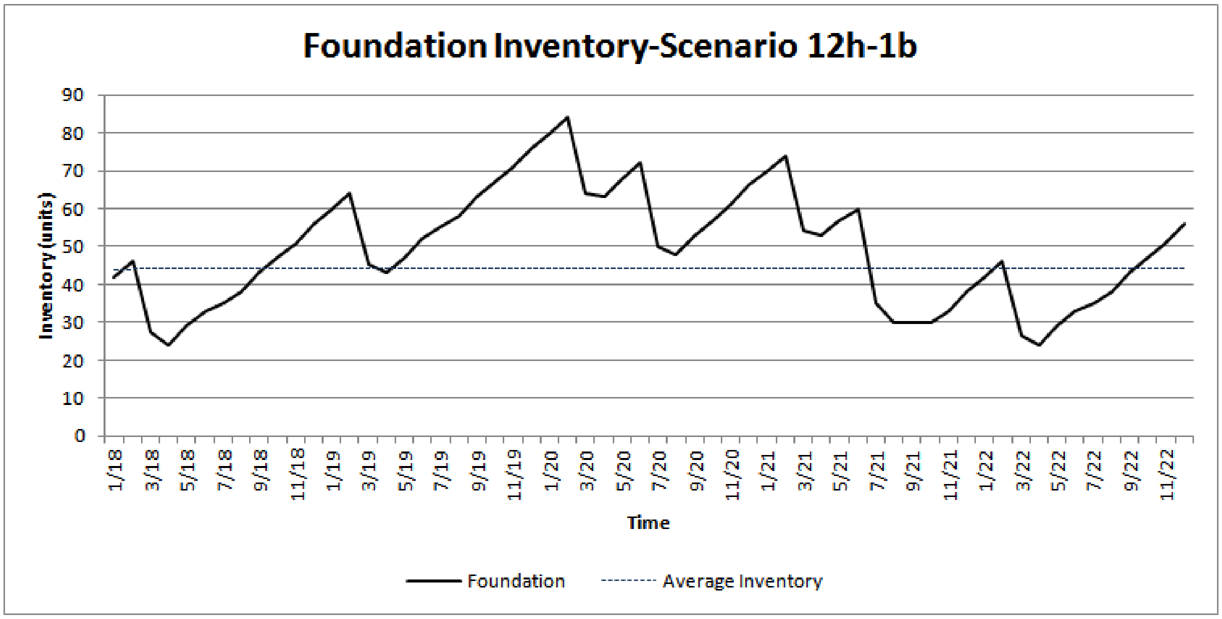


Figure A. 9. Foundation Inventory for Scenario 1

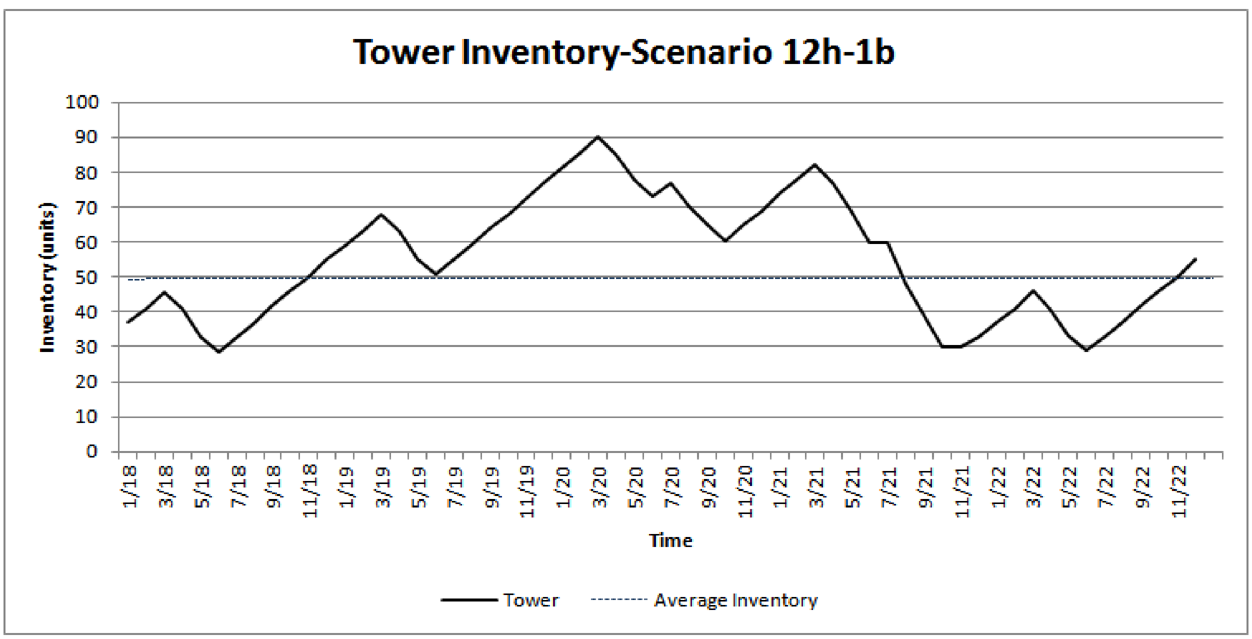


Figure A. 10. Tower sections Inventory for Scenario 1

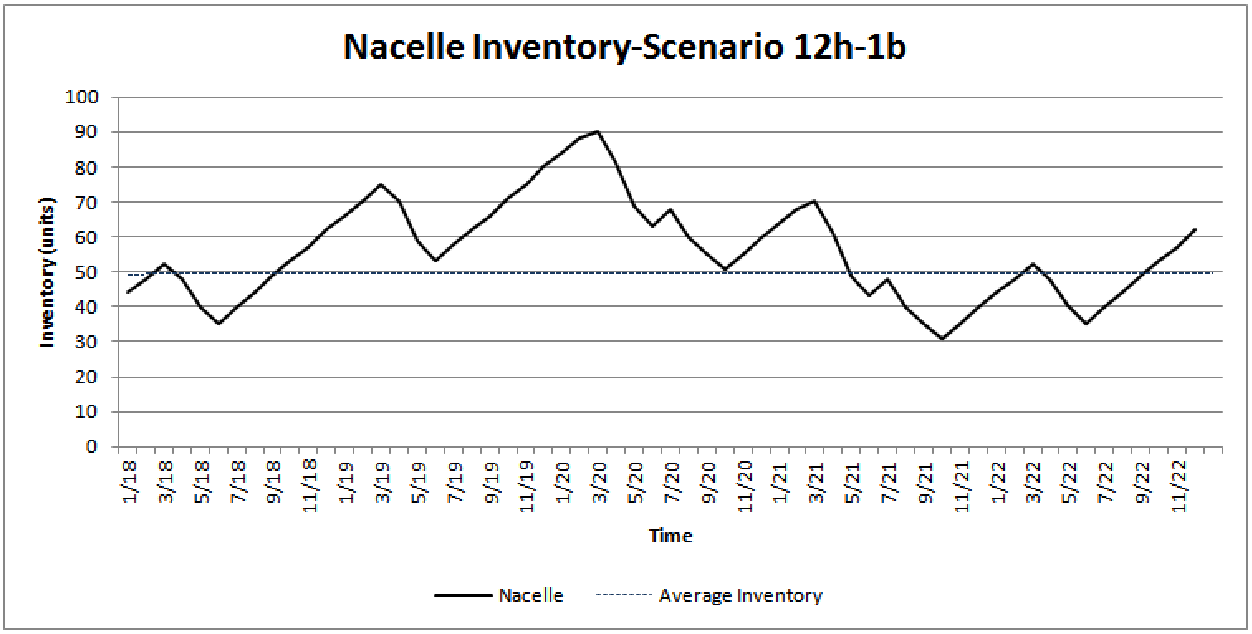


Figure A. 11. Nacelle Inventory for Scenario 1

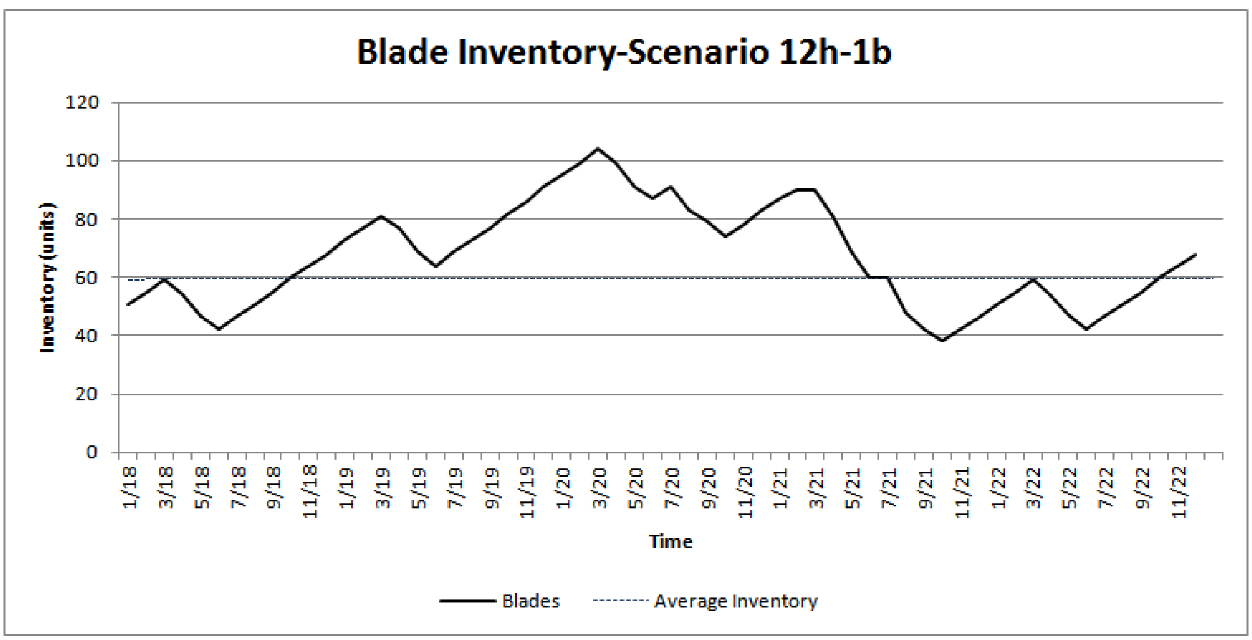


Figure A. 12. Blade Inventory for Scenario 1

Figure A. 13 through Figure A. 16 show the raw material inventory for producing turbine components in the same manner as it was presented for the finished products.

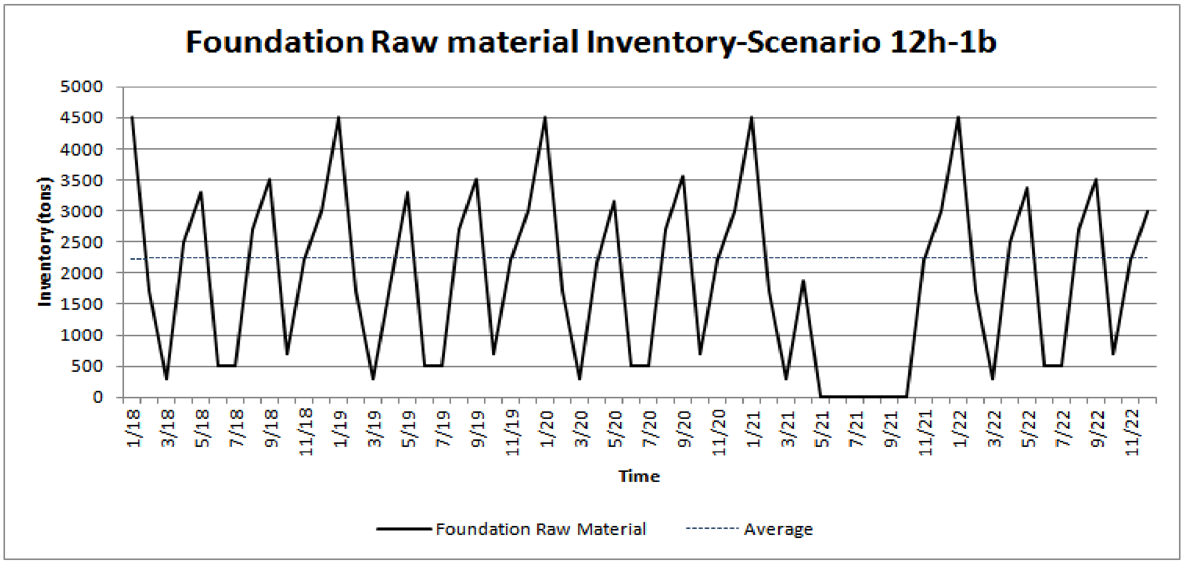


Figure A. 13. Foundation raw material Inventory for Scenario 1

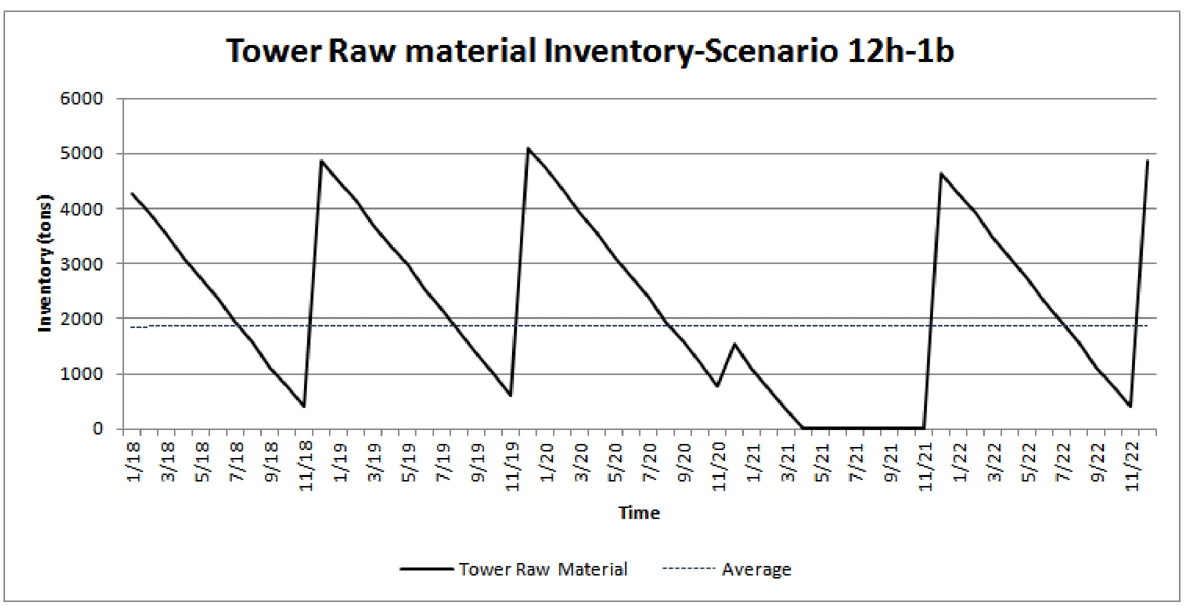


Figure A. 14. Tower sections raw material Inventory for Scenario 1

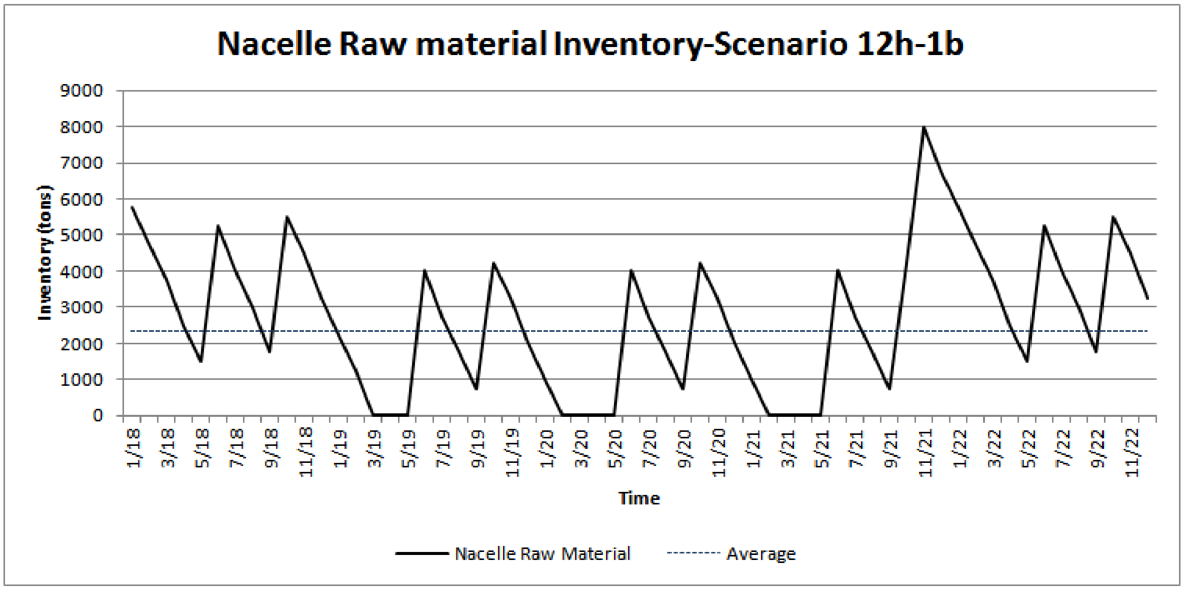


Figure A. 15. Nacelle raw material Inventory for Scenario 1

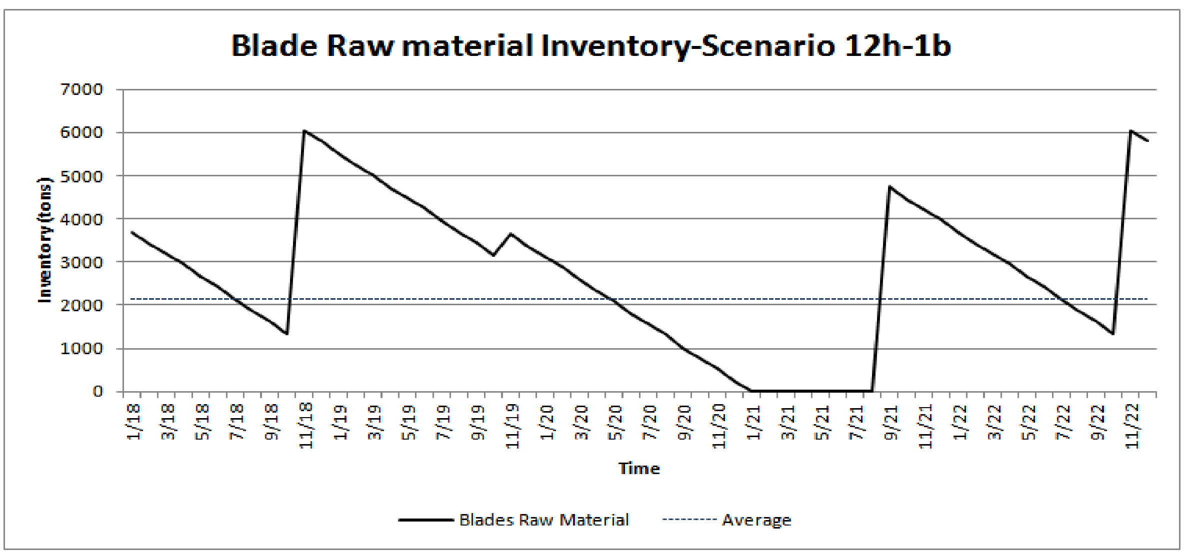


Figure A. 16. Blade raw material Inventory for Scenario 1

The inventory-related graphs (Figure A. 9 through Figure A. 16) remain quite similar among all the scenarios and are not presented in this report but they can be generated separately for each scenario. At the beginning of this analysis, it is assumed that it takes a week to manufacture each turbine component in the Paulsboro Terminal. Once specific time frames are confirmed by each component manufacturer, the model's input can be revised and the inventory related graphs should be modified accordingly.

The same Figures that are presented for Scenario 1 are given for each of Scenarios 2, 3 and 4 in the following pages.

## Scenario2: 1 berth, 16 hour crane

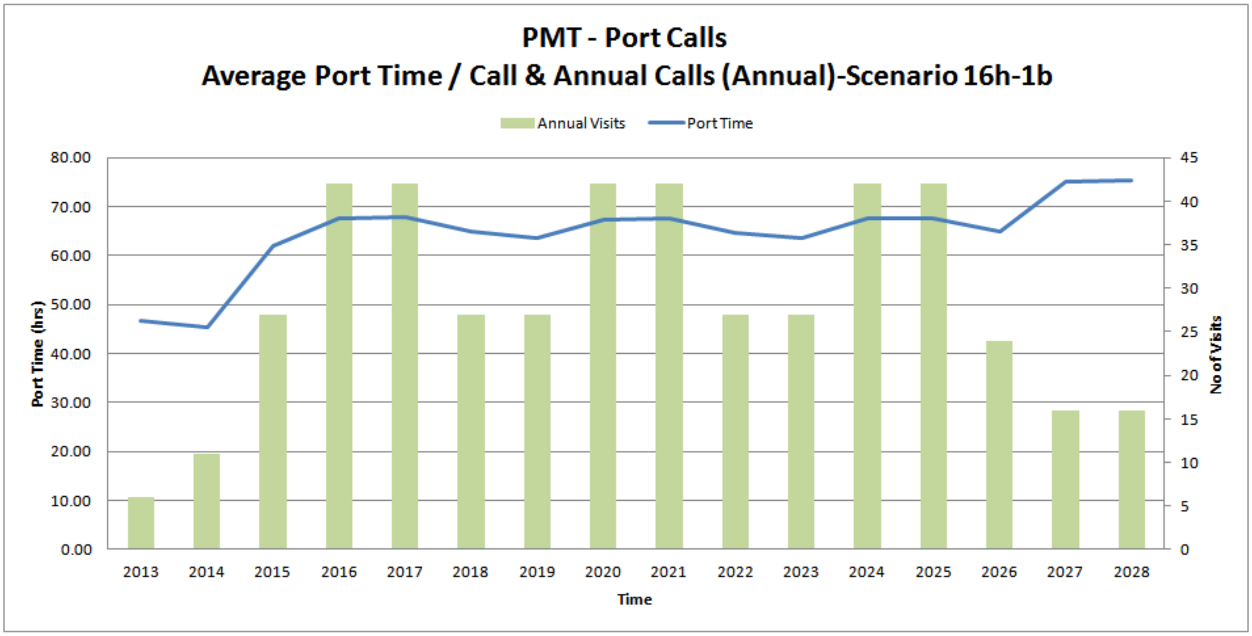


Figure A. 17. PMT annual port visits and average port times in Scenario 2

The average terminal time for the raw material vessels is about 29 hours. This number increases to 57 hours for the OSW barges.

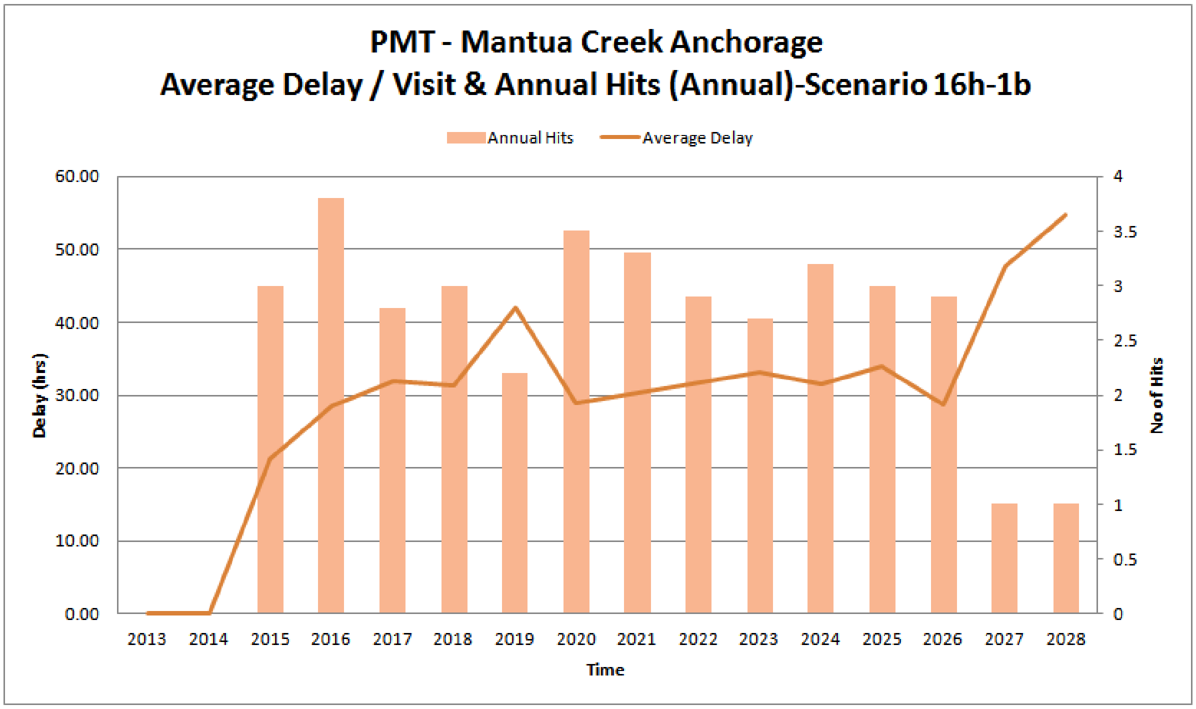


Figure A. 18. Annual Mantua Creek Anchorage (MCA) visits and average delays for OSW vessels in Scenario 2

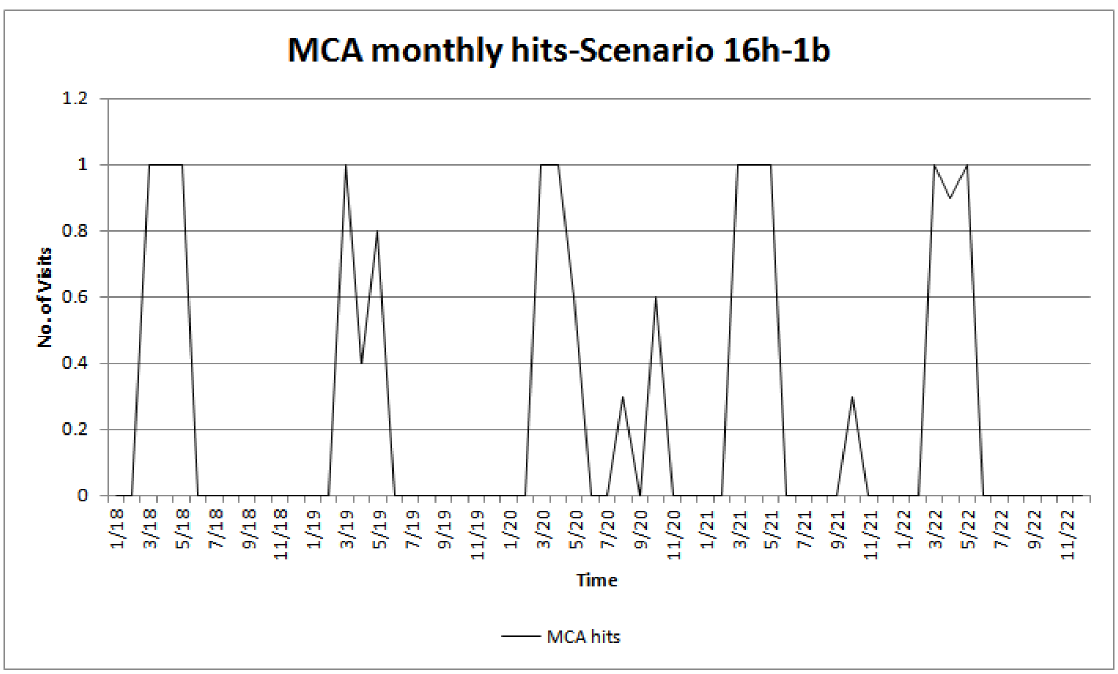


Figure A. 19. Monthly Mantua Creek Anchorage (MCA) visits for OSW vessels in Scenario 2

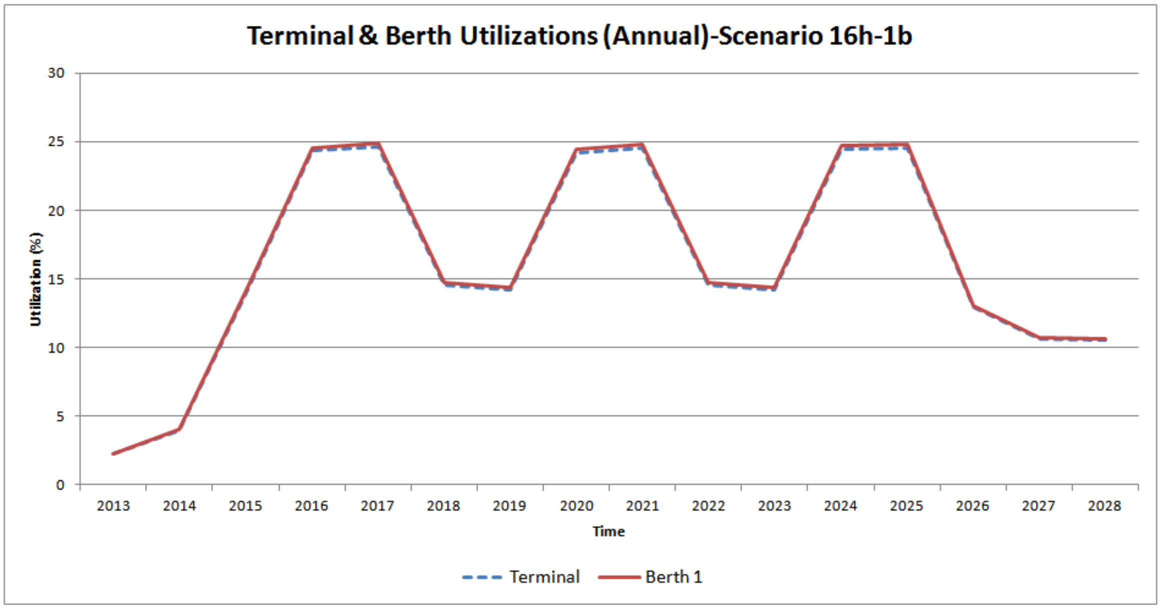


**Figure A. 20. Annual berth utilization for Scenario 2**

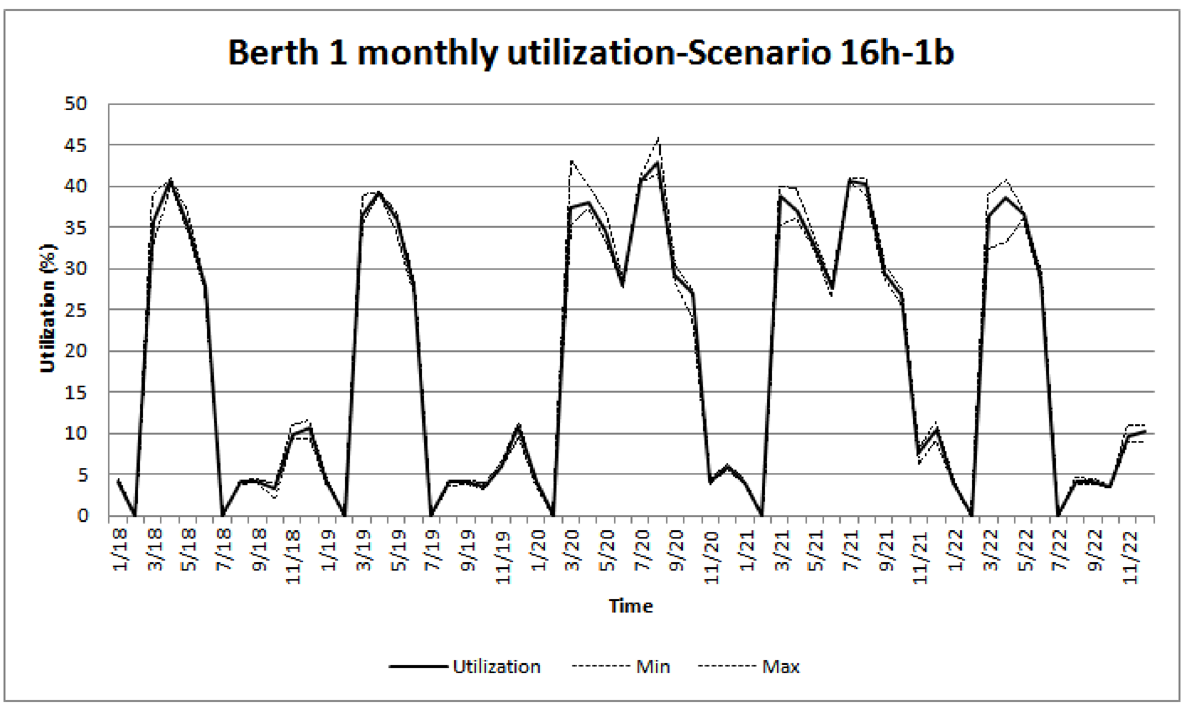


Figure A. 21. Monthly berth utilization for Scenario 2

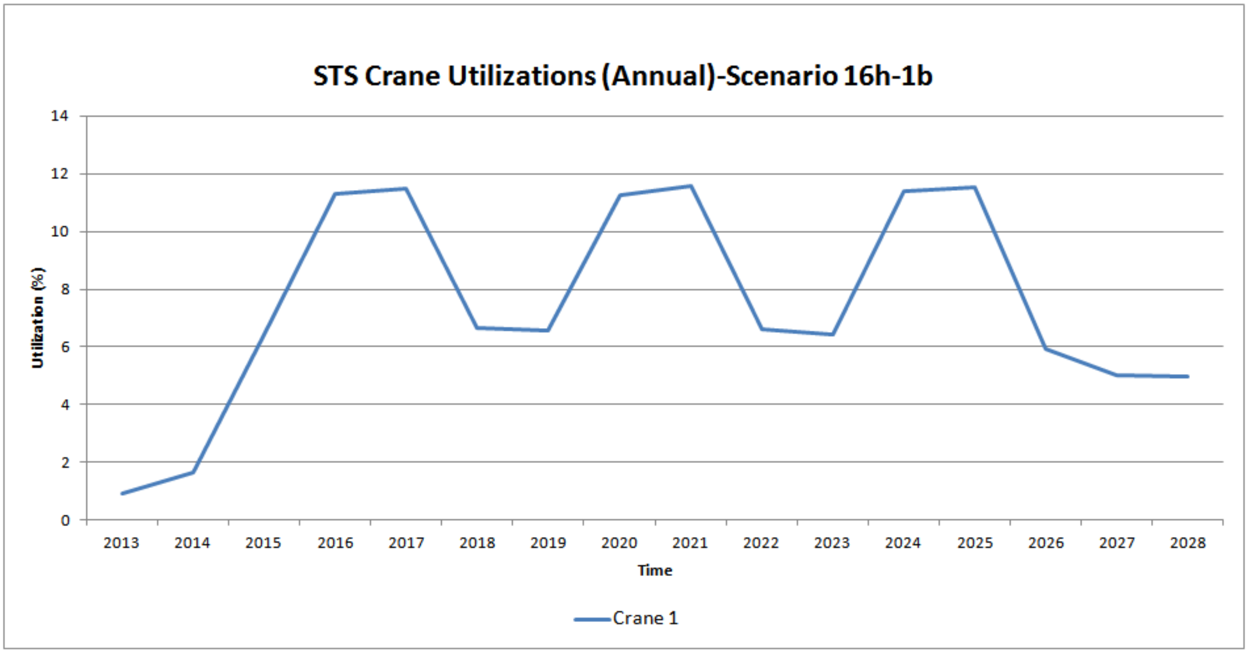


Figure A. 22. Annual STS Crane Utilization for Scenario 2

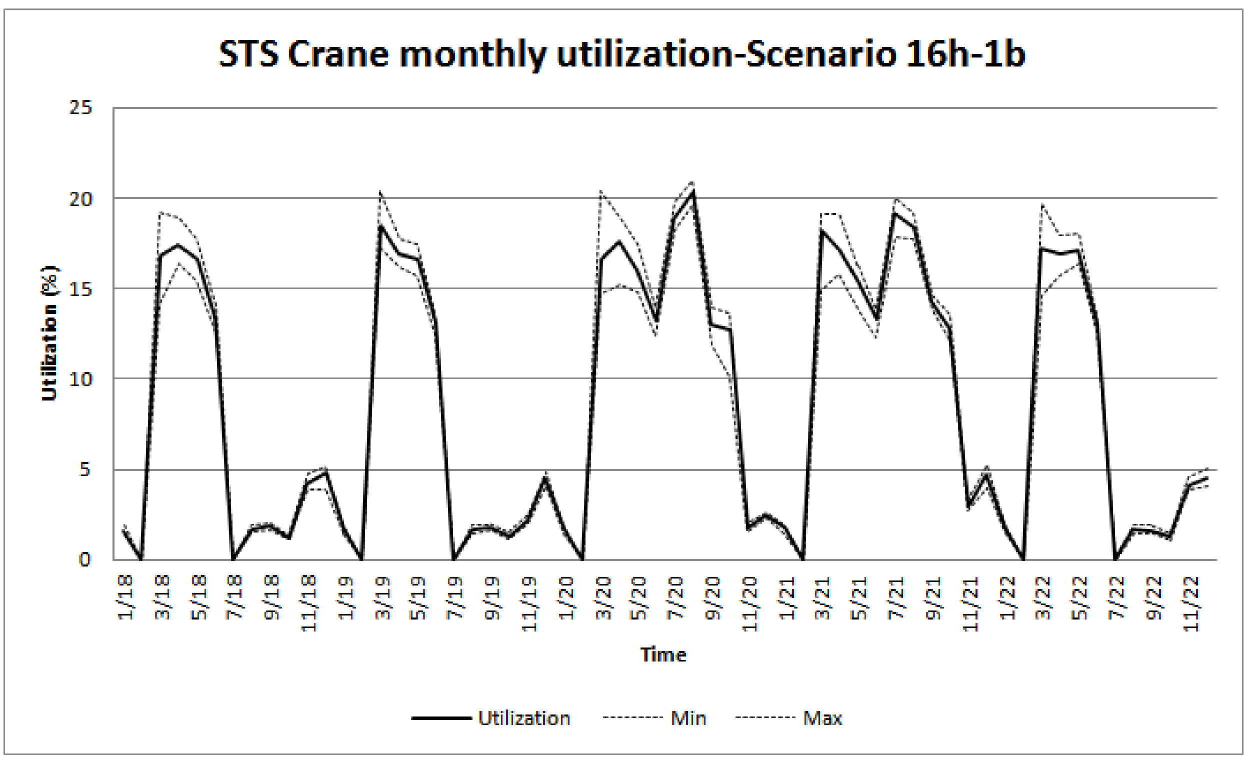


Figure A. 23. Monthly STS Crane Utilization for Scenario 2

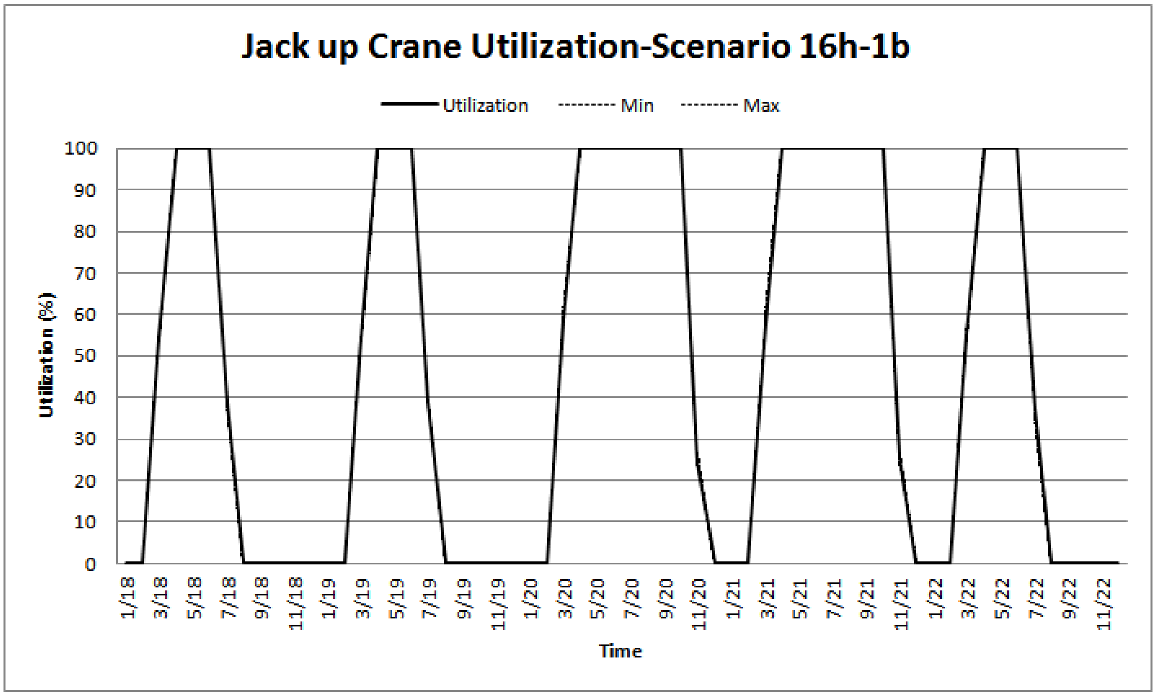


Figure A. 24. Monthly Jack-up Crane utilization for Scenario 2

The average utilization for the Jack-up crane for the busy period is about 83%. This number can be broken down to 78% for half farm years and 87% for full farm years.

## Scenario 3: 2 berths, 12 hour crane

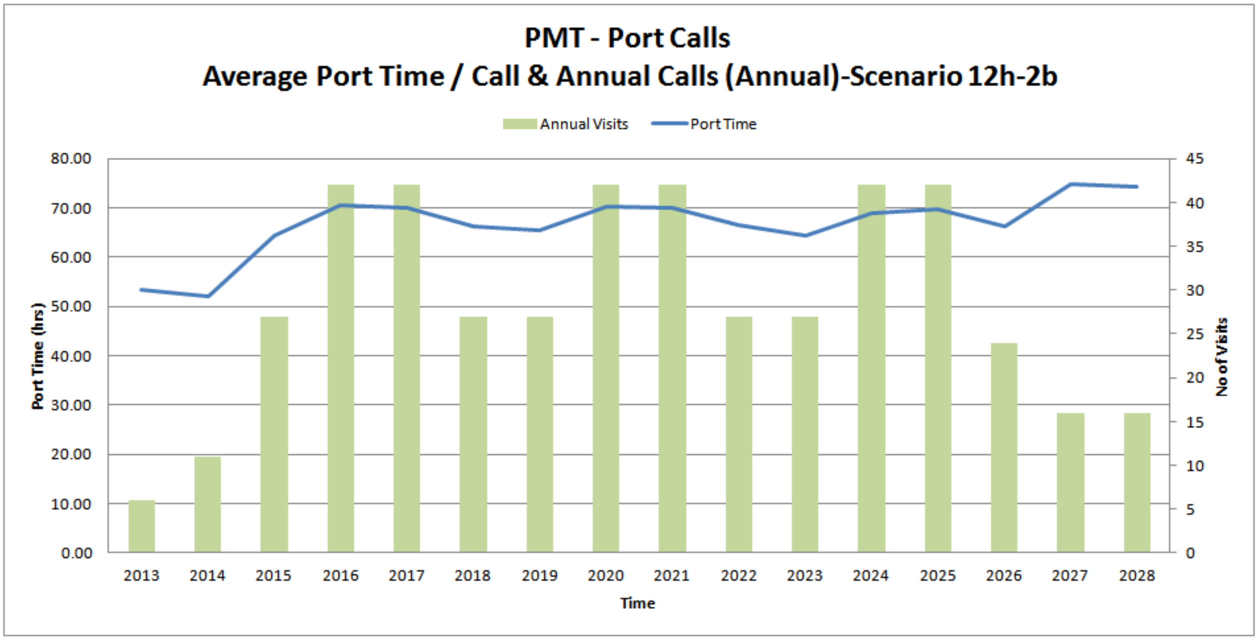


Figure A. 25. PMT annual port visits and average port times in Scenario 3

The average terminal time for the raw material vessels is about 35 hours. This number increases to 61 hours for the OSW barges.

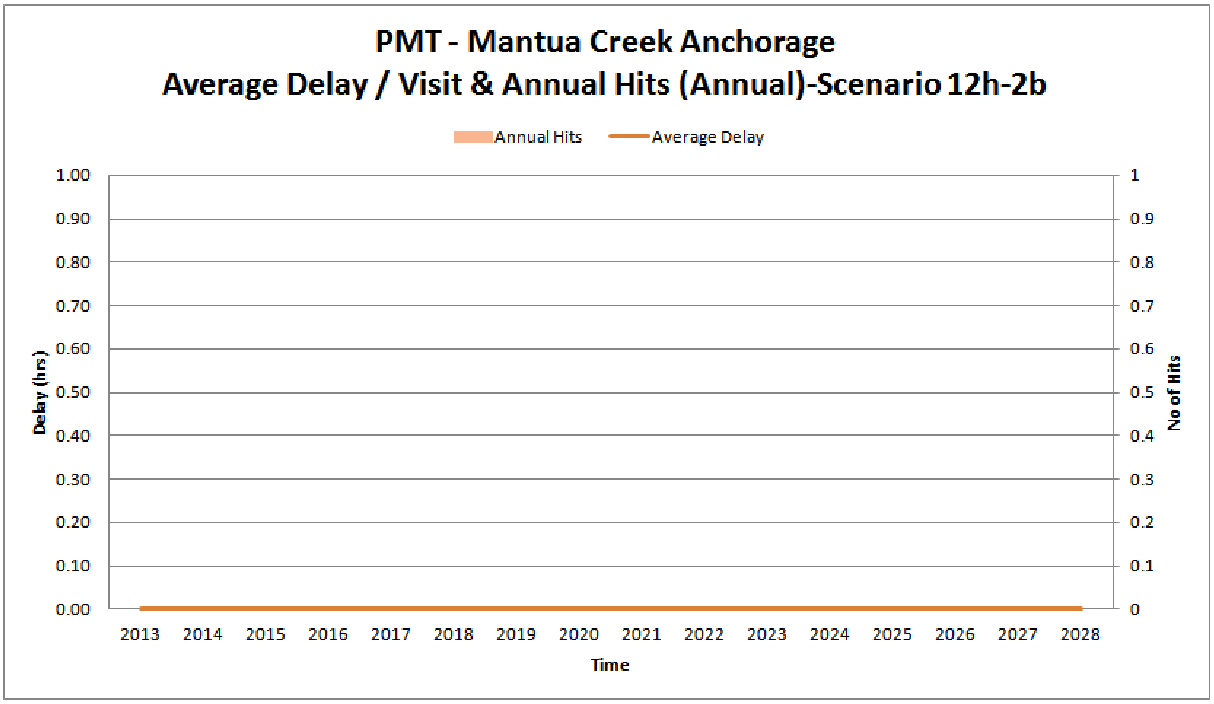


Figure A. 26. Annual Mantua Creek Anchorage (MCA) visits and average delays for OSW vessels in Scenario 3

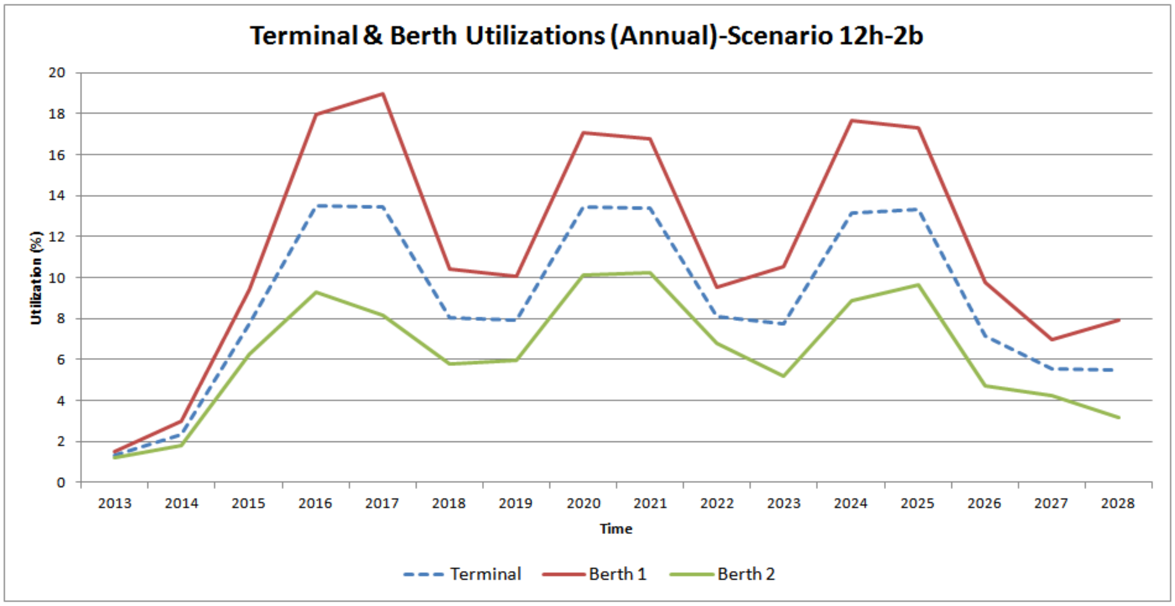


Figure A. 27. Annual berths utilization for Scenario 3

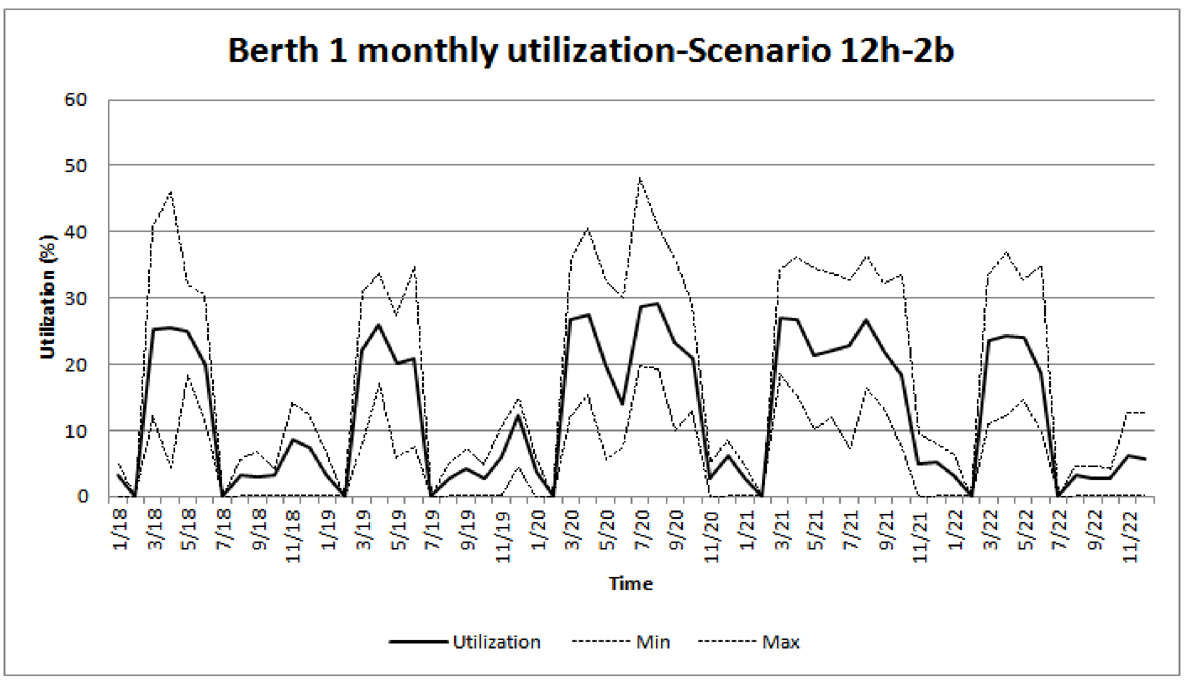


Figure A. 28. Monthly berths utilization for Scenario 3

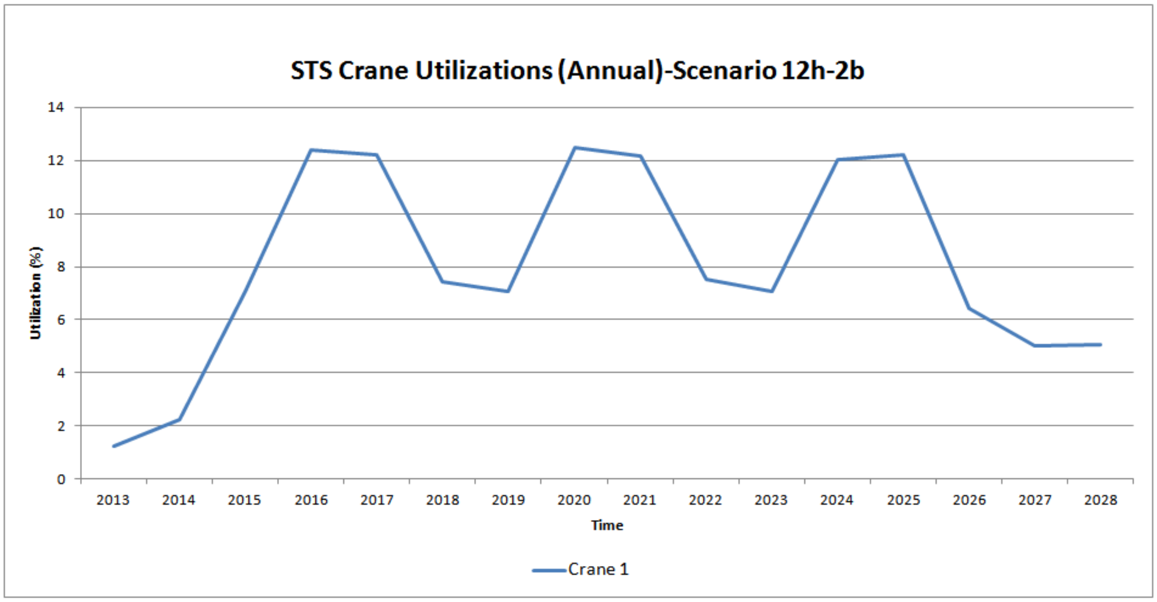


Figure A. 29. Annual STS Crane Utilization for Scenario 3

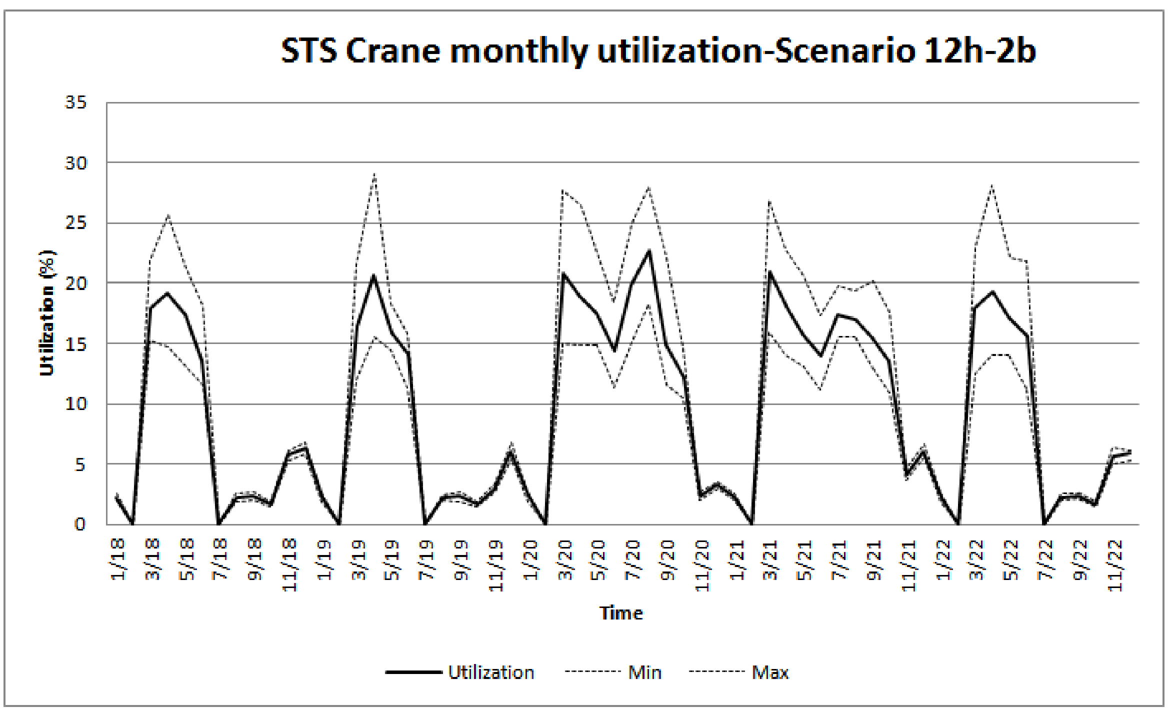


Figure A. 30. Monthly STS Crane Utilization for Scenario 3

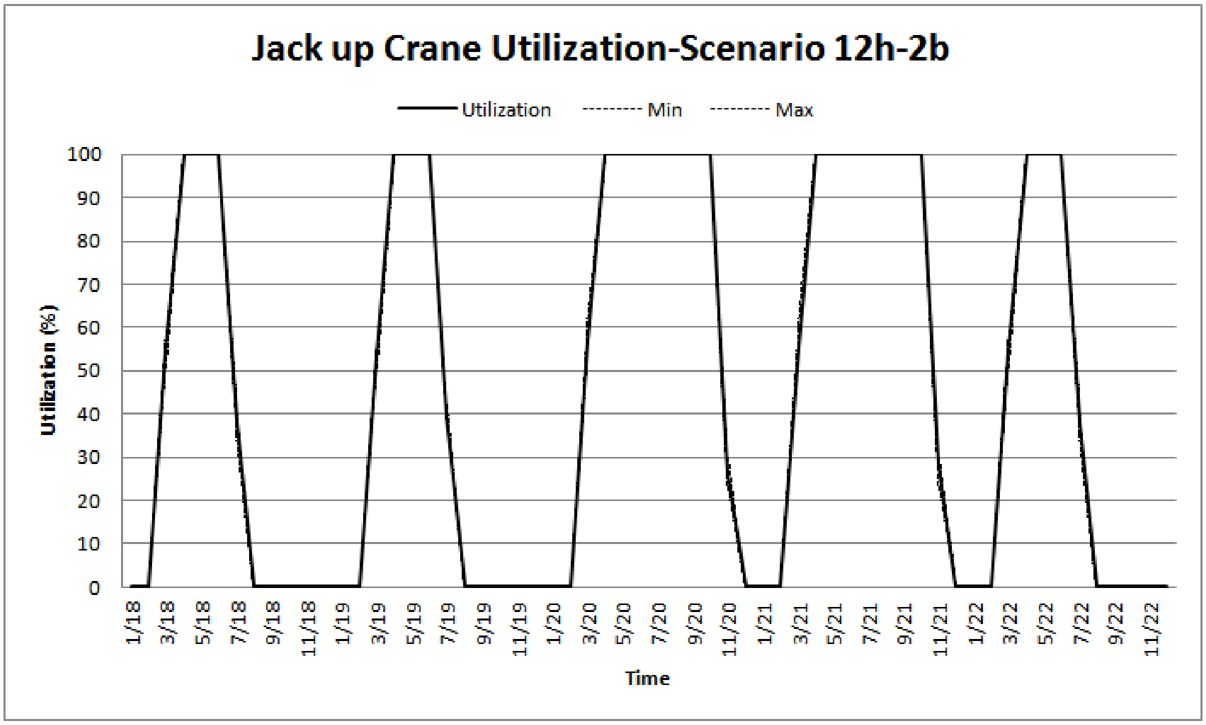


Figure A. 31. Monthly Jack-up Crane utilization for Scenario 3

The average utilization for the Jack-up crane for the busy period is about 83%. This number can be broken down to 78% for half farm years and 87% for full farm years.

## Scenario 4: 2 berths, 16 hour crane

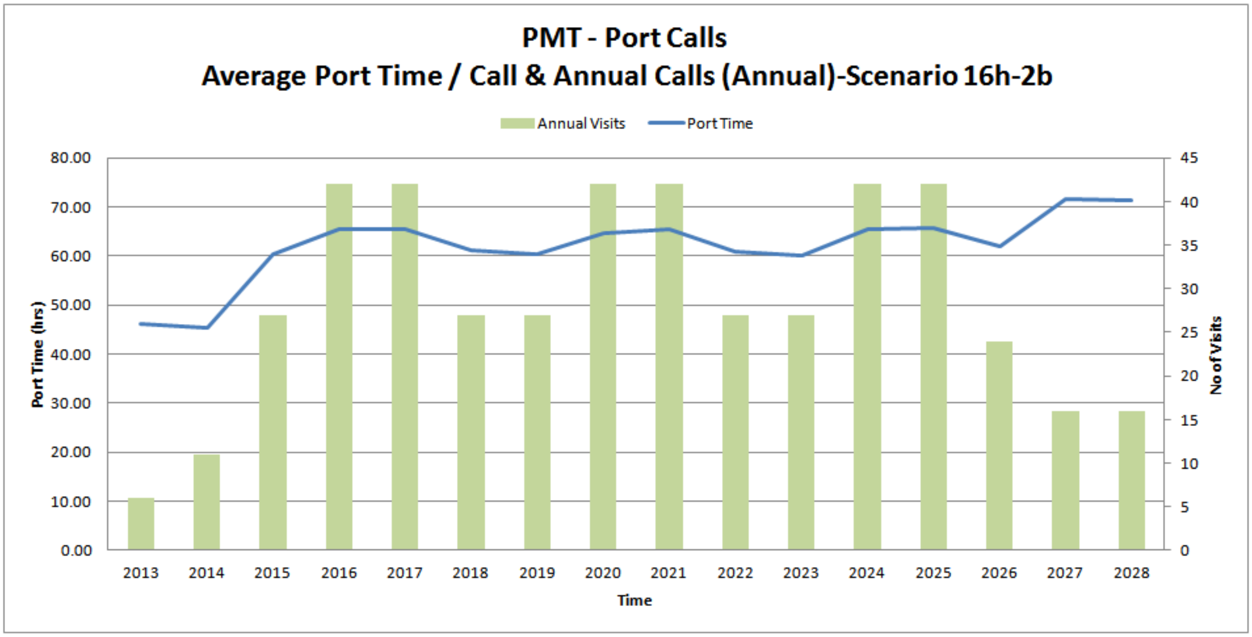


Figure A. 32. PMT annual port visits and average port times in Scenario 4

The average terminal time for the raw material vessels is about 29 hours. This number increases to 57 hours for the OSW barges.

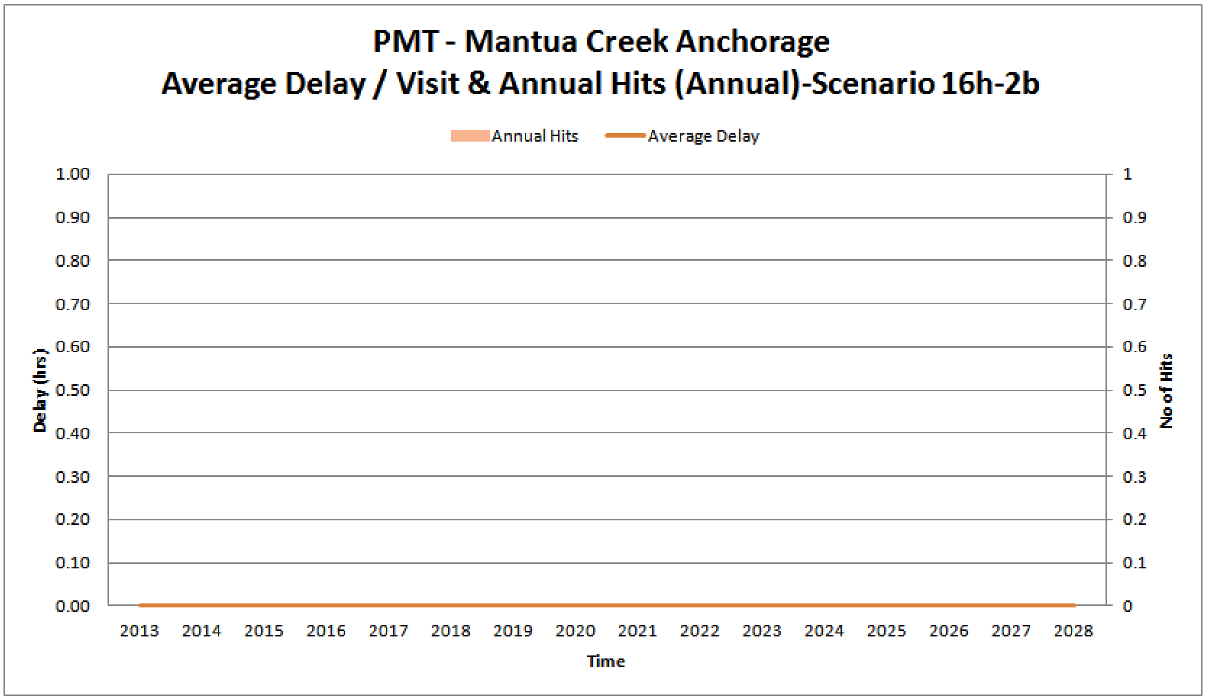


Figure A. 33. Annual Mantua Creek Anchorage (MCA) visits and average delays for OSW vessels in Scenario 4

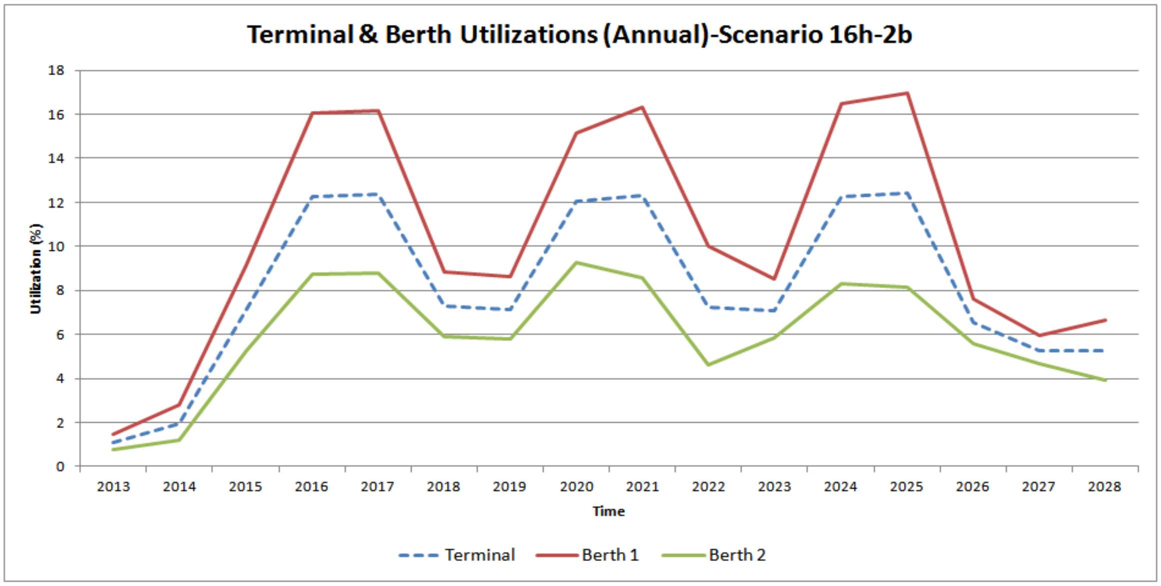


Figure A. 34. Annual berths utilization for Scenario 4

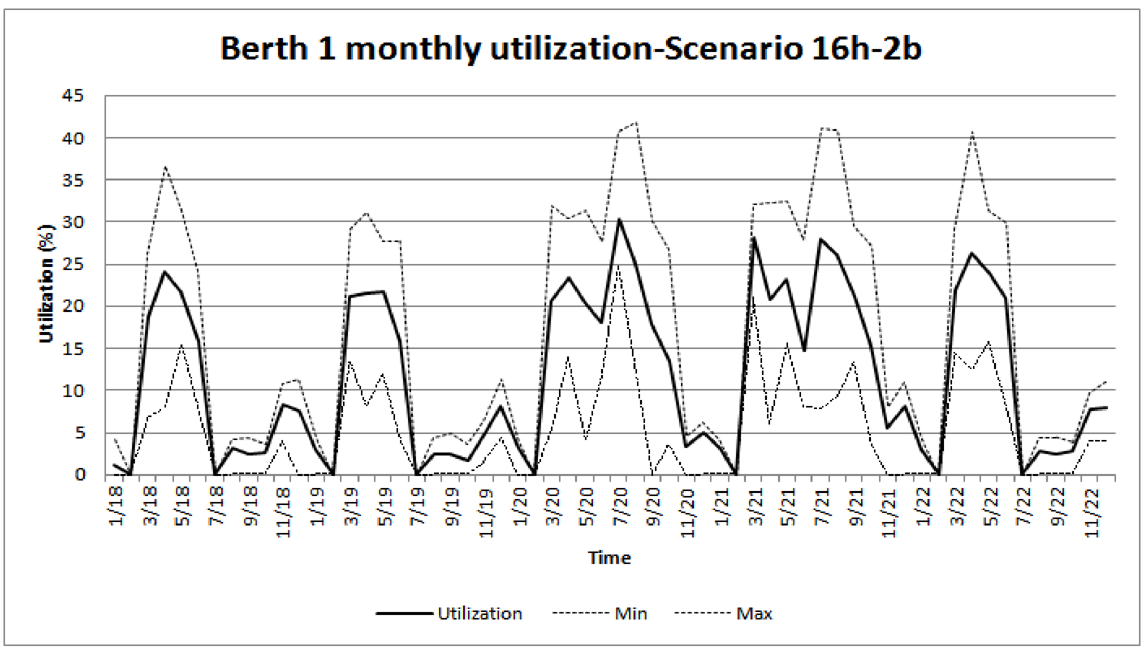


Figure A. 35. Monthly berths utilization for Scenario 4

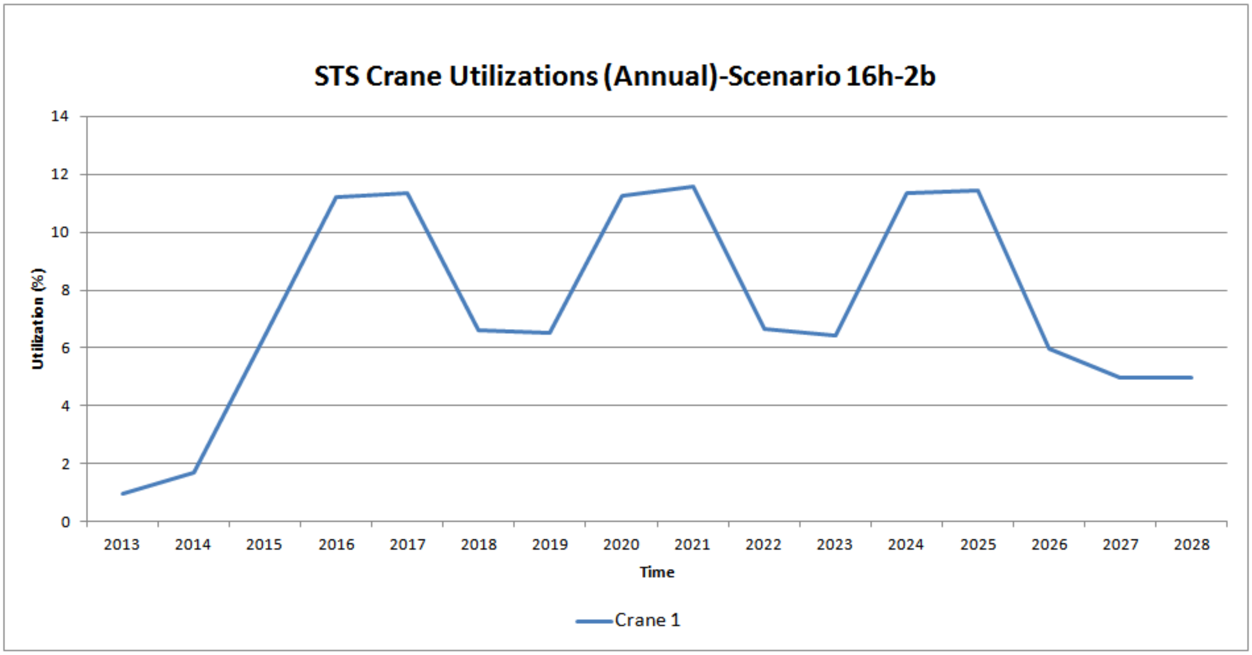


Figure A. 36. Annual STS Crane Utilization for Scenario 4

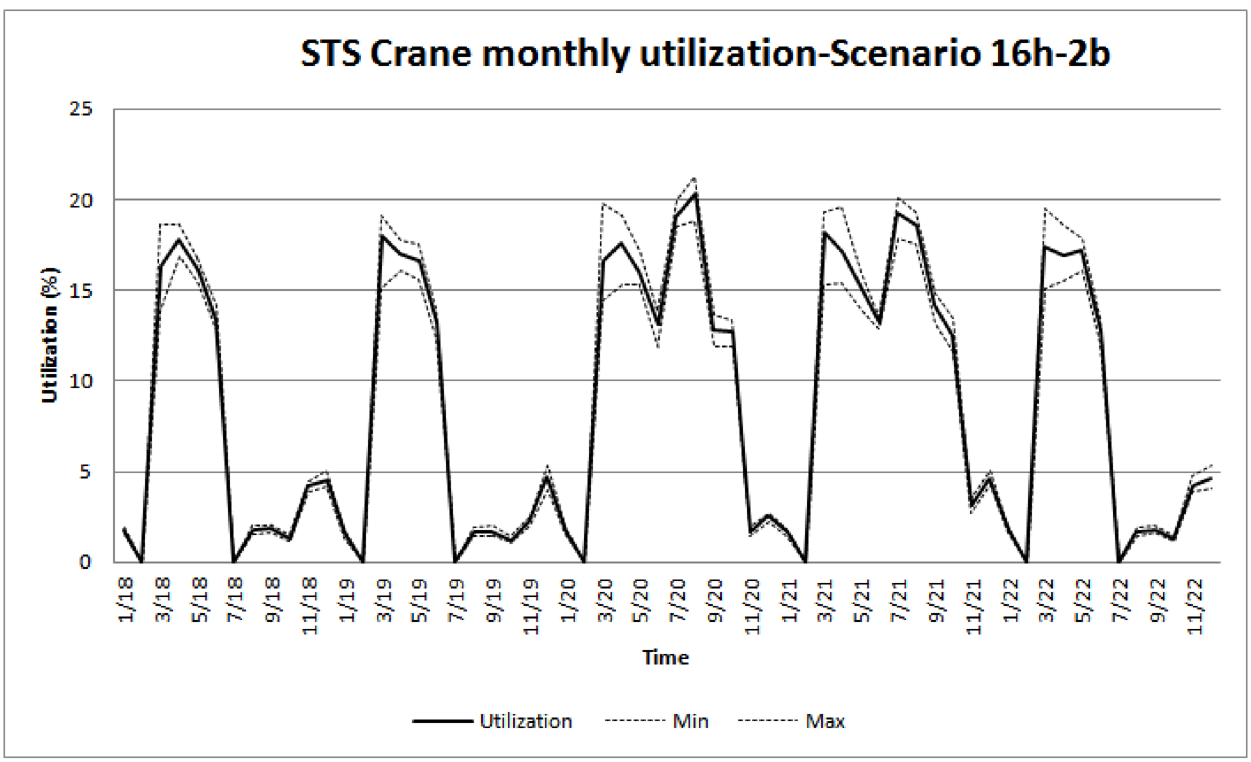


Figure A. 37. Annual STS Crane Utilization for Scenario 4

The average utilization for the Jack-up crane for the busy period is about 83%. This number can be broken down to 78% for half farm years and 87% for full farm years.

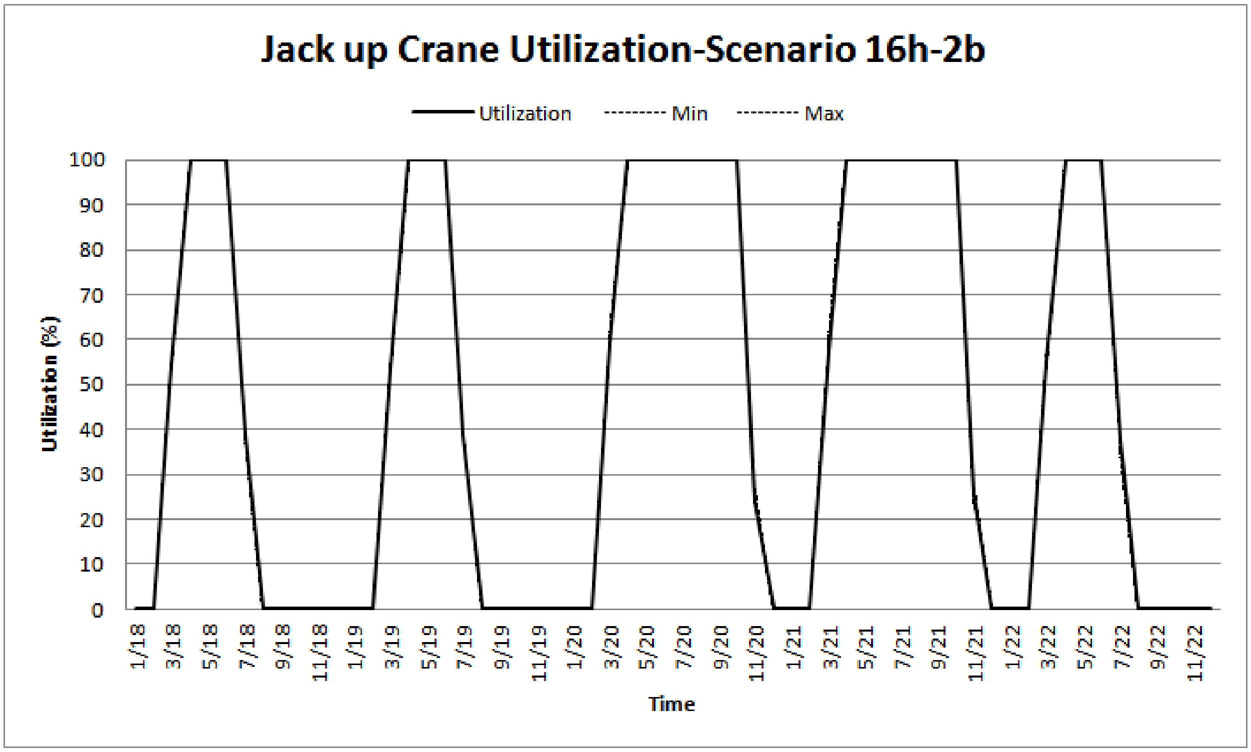


Figure A. 38. Monthly Jack-up Crane utilization for Scenario 4