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Analyses of Interactions between the Marine Terminal and Highway Operations

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16. Abstract
Changes in vessel sizes arriving at United States ports may influence the operating regimes and schedules at the port terminals However, the impacts to highway and rail operations outside of the port terminals because of changing port terminal operations are less clear. For example, anticipated changes in frequency and peak volume of the inbound marine cargo may translate into a corresponding change in highway demand as more trucks seek access to port terminals during peak hours, leading to increased traffic congestion disruptions in traffic operations. Therefore, the researchers seek to understand and quantify the effect of the increasing introduction of the mega-ships and related changes in port operations on a regional highway and rail system. Increased understanding will help planners and engineers identify and evaluate solutions to prevent the disruption of regional freight transportation systems. The research team developed a simulation model of a hypothetical port terminal to analyze "what-if" scenarios depicting changes in vessel size and arrival frequency. Researchers examined two policies commonly used to control the truck arrival patterns at the gate, extended gate hours and gate appointment systems, to assess the performance of the simulation model. Overall, four scenarios illustrate the performance of the combined terminal and highway system by comparing truck wait times, and truck queues at the terminal gate. The simulation model performs well in generating order of magnitude scenario results for comparison. Detailed model applications, and potential a combination of modeling software, may improve results.

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DESCRIPTION OF THE PROBLEM

Prior to expansion, the Panama Canal handled vessels hauling approximately 5,000 twenty-foot equivalent units (TEU[1]s). In an analysis of North American ports, Conway (2012) suggests that the expansion of the Panama Canal would enable passage of vessels capable of carrying around 12,500 containers. Rodrigue (2014) estimated that such an expansion could induce an additional 2,000 transits through the canal each year. According to the U.S. Army Corps of Engineers (2012), post-Panamax vessels may make up 62 percent of total container ship capacity by 2030. One can anticipate that these future changes in vessel size and shipment frequency resulting from the Panama Canal expansion will alter global trade routes, creating a need to understand the potential for port terminals to perform under changing operating conditions.

All major US Ports are already ready or will be ready to accommodate vessels capable of carrying around 12,500 containers by 2015 (Thuermer, 2013). The Port Authority of New York and New Jersey is spending $1.3billion to raise its Bayonne Bridge so that the post-Panamax vessels can make clearance. The Port Newark Container Terminal (PNCT) in undergoing a half-billion dollar investment to create a state-of-the-art container terminal while the maritime cargo center is undergoing $1.3 billion of improvements to provide access for post-Panamax ships to the Newark and Elizabeth terminals. Port of Savannah, Charleston and Miami are also investing into infrastructure and channel dredging to be able accommodate larger vessels.

The change in vessel size arriving at the port will not only impacts the operating regimes and schedules at the port terminals, but highway and rail operations outside of the ports as well. For example, changes in frequency and peak volume of the inbound marine cargo may translate to

[1] The twenty-foot equivalent unit is an inexact unit of cargo capacity often used to describe the capacity of container ships and container terminals

a corresponding change in highway demand as more trucks may be seeking access to ports and the cargo during the peak hours. This would lead to increased traffic congestion and over time serious disruptions in traffic operations. For this reason, it is necessary to understand and quantify the effect of the increasing introduction of the mega-ships and related changes in port operations on a regional highway system. A better understanding of these effects will help planners identify and evaluate solutions for preventing disruptions to local or regional freight transportation systems.

APPROACH

The objective of this study was to develop a model that will be capable of ascertaining the impact of the marine terminal operations on a highway system that provides access to the port. The model focuses on the specific relationships between the changes in terminal wharf operations caused by anticipated changes in vessel sizes and arrival schedules. Researchers measured the resulting peak truck demand on regional highways, along with the distribution of truck arrivals and departures at the terminal gates. Subsequently, researchers simulated a limited number of capital improvements and operating policies to analyze the effects of implementing alternative strategies to reduce congestion and demonstrate the efficacy of the simulation model.

The simulation model assumes the presence of a hypothetical intermodal (containerized) marine port terminal. The terminal components include the wharf operations, container storage, and truck and railway yards. Researchers defined a set of variables describing the terminal operations, such as vessel arrival times or distributions, the vessel size, the equipment productivity (e.g. moves per hour for cranes, straddle carriers, etc.), distribution of container storage times, truck arrivals for pick-up and/or delivery, train departure times and departure frequency. The simulation models allow users to analyze "what-if" scenarios evaluated different port development and growth scenarios with respect to the ship size and frequency of their arrivals at the port on a comparative basis.

LITERATURE REVIEW

Researchers reviewed both academic and professional literature to identify and catalog prior uses of simulation models to analyze interactions between marine ports and surface transportation systems. During the review, researchers also identified suitable port performance variables and operational characteristics to incorporate into model assumptions. The research team discovered three groups of applicable modeling literature: studies that focus solely on simulations of port operations, studies that model ports as a part of intermodal transportation and studies that measure the effects of policy or operational proposals on the performance of port infrastructure with respect to the adjacent surface transportation systems.

Researchers use computer simulation as part of the decision-making process for port terminal investments in order to mitigate the risk of the potential for unanticipated sensitivities in the performance of system designs. Carpenter and Ward (1990) used simulation modeling to integrate container flows with several sub-models to understand in-yard container handling operations. This multi-layered approach to simulation modeling for understanding performance of an overall system as the result of several subsystems is consistent with early simulation modeling methods. Yun and Choi (1999) proposed an object-oriented approach to simulation models for container terminal analysis in Pusan, Korea, that included additional sub-system simulations for container handling at the terminal, container transport between equipment, and equipment control. Kia et al. (2000) focused on developing an object-oriented modeling approach to compare a container terminal equipped with electronic devices to track containers against a terminal without such devices. Other studies extend simulation models beyond terminal boundaries to include the influence of terminal basin operations on terminal capacity, demonstrating the need for coordination of maritime systems within and outside of the terminal to most effectively utilize terminal capacity (Ng and wong, 2006; Cortes et al., 2007). Simulation provides a tool for researchers to understand the effects of changes in single mode operations both within and outside of the boundaries of a given marine terminal.

However, increasing system complexity and freight volumes require the multi-modal transport of goods to reduce cargo handling, improve security, reduce damage and loss, and allow freight to be transported faster multiple modes of transportation. Nagy (1975) performed an early simulation study to analyze the cost and performance of an intermodal dry bulk commodity-transshipping terminal. Others, such as Gambardella et al. (1998), later focused on using simulation to understand resource allocation problems at intermodal container terminals using various forecasting and optimization techniques based in operations research theory. Several researchers have used discrete event simulations to model the effects of modal shifts toward rail for container drayage and inland movements on port terminal operations, allowing decision makers to understand effects on capacity and inventory costs (Kia et al., 2002; Lee et al., 2006; Parola and Sciomachen, 2004). These simulations depend on models that reside within the same simulation tools, whereas other approaches require the integration of several modeling platforms.

Several researchers have been successful in integrating different simulation platforms to create comprehensive models. Ioannou et al. (2007) investigated the impact of various technologies and concepts on the terminal capacity and cost as well as on the traffic network outside the terminals, simultaneously modeling terminal performance measures that included gate, handling equipment and labor performance measures (e.g. utilization, productivity, turnaround time). Puglisi (2008) integrated an ARENA based port operations model with a VISSIM traffic simulation model to understand the effects of increases in container traffic at the Port of Savannah to address congestion concerns. Wall (2012) later improves and expands the model developed by Puglisi (2008) by automating the interaction among the VISSIM and Arena models to allow for the analysis of queue lengths, travel times, and other performance measures of concern. Moini (2010) develops a simulation model in ARENA that identifies six operational modules for terminal operations: truck arrivals, entrance gate (pre-gates and main gates), interchange area, yard, apron, and departure gates. Additional integrated macro and micro simulation modeling strategies have been used to study the interaction between container operations and truck operations to reduce congestion domestically at the Port of New York and New Jersey (Dougherty, 2010), and evaluate alternatives for emissions reductions internationally (Karafa, 2012; Tsitsamis and Vlachos, 2010). While the integration of different simulations models can allow for detailed analyses, it may also add a level of complexity and expense that will not be suitable for our exploratory purposes in this study.

METHODOLOGY

The research team chose to use a discrete event simulation model. Prior literature supports the choice of discrete event simulation because of the utility of the approach for modeling port systems in a variety of different contexts. Discrete event simulation approaches are commonly used in the analysis of complex systems with stochastic properties (e.g., processing sequences and times for ships, containers and trucks in a port terminal), and is effective in ascertaining the interactions between the components of a system.

The research team developed the simulation model using the Arena[2] simulation modeling software. The team chose this alternative based on researchers' experience with the software and a desire to limit cost and complexity through the use of a single modeling suite. Arena models entities through a process that is defined by a flowchart of blocks. Entities are the units of analysis for the study that the model processes and analyzes to record statistics (e.g. vessel

[2] http://www.arenasimulation.com

and trucks in this study). The entities travel through processes that consist of process blocks or modules. Blocks represent logical principles used to control entities, and sometimes require elements as inputs to define the actions performed by the block. Elements are resources used to describe the model components. The resources implemented in this model are berths, gantry cranes, gate (number of lanes), straddle carriers and truck parking slots.

Researchers determined candidate performance measures available from the literature and supplement those measures with site visits to marine container terminals in the Port of New York/New Jersey to enable the research team to observe and implement the processes that occur within typical container terminal. The system components such as the gate operation, wharf operations, container storage, and truck parking slots were implemented within the model, along with variables that represent vessel arrival times, vessel size, equipment productivity (e.g. moves per hour for cranes, straddle carriers, etc.), container storage times, and arrival times for truck and rail conveyances. The extensive literature review ensured the appropriate definition and selection of system variables to make sure that the model realistically approximates port terminal operations, which one can implement with data that are generally available to public transportation planning agencies.

The research team developed the simulation model for a hypothetical intermodal (containerized) marine port terminal. The model validation focuses primarily on the logical structure of the model and the sensitivity of model outputs and performance parameters with respect to changes in input parameters. The simulation model is applied in analyzing a series of “what-if” scenarios involving different combinations and iterations of the growth in freight demand, increase in vessel size and different operating policies. For each scenario, a set of operating policies is formulated and simulated in order to determine their effectiveness in responding to the changes in freight (container) demand.

The simulation of scenarios yields a set of performance measures such as truck and container processing and waiting times and port terminal resource utilization. The research team analyzed and compared these performance measures to ascertain the effects of changes in vessel arrival schedule and size on operating policies.

DEVELOPING A CONCEPTUAL MODEL

The operation within the container terminal can be divided into three major categories:

- **Berth Operation.** The activities consist of allocation of berth(s) and crane(s) to vessels based on their capacity.
- **Yard Operation**. The processes consist of allocating container handling equipment (i.e. straddle carriers) between:
    - The yard and berths. The straddle carriers are transferring cranes from (to) berths, and
    - The yard and truck slots. The available straddle carriers perform unloading and loading of containers to (from) trucks located in parking slots.
- **Gate Operation**. The processes simulate the truck related activities usually performed at the terminal gates (the scanning of containers, checking the paperwork, additional inspection, etc.)

The processes within the container terminal use basic process modules, advanced process modules and advanced transfer modules that are part of the Arena simulation software. The model does not simulate the movement of containers between the yard and rail. The research team assumed that 5% of inbound container are moved by rail.

The following sections explain the logic, assumptions and parameters based on which the container terminal is designed and simulated. The terminal characteristics (such as number of berths, cranes, number of gates, yard capacity, and number of parking slots for trucks) and operational parameters (vessel capacities, allocation of cranes to vessels, truck processing times, etc.) were obtained from the literature review and by field visits to terminal operations.

BERTH OPERATION

VESSEL CHARACTERISTICS

The research team assumed that the container terminal handles approximately 2,000,000 TEU's per year. The classification of vessel types and their capacities as implemented in the model are shown in Table 1.

Table 1. Vessel Traffic by Ship Capacity

Capacity (TEU)	Name
14,501 and higher	Ultra Large Container Vessel (ULCV)
10,000 –14,500	New Panamax
5,101–10,000	Post Panamax
3,001 – 5,100	Panamax
2,001 – 3,000	Feedermax

MODELING CARGO DATA

Arriving vessels are classified into three categories. Each vessel type is differentiated by the number of containers unloaded (loaded) from (to) vessel. The vessel classification by type and corresponding capacity is presented in Table 2. The ratio of inbound[3] versus outbound container traffic implemented in the model is approximately 80:20.

Table 2. Vessel Classification by Type and Capacity

Vessel Type	Inbound Containers	Outbound Containers
50%	Uniform (900,1100)	Uniform (200,300)
30%	Uniform (1100,1300)	Uniform (300,400)
20%	Uniform (1300,1500)	Uniform (400,500)

[3] Containers unloaded from the vessel

VESSEL ARRIVALS

The vessel arrival is modeled based on the premises the vessel inter-arrival times are not correlated. Each vessel has a time window (i.e. laytime) designated for container loading and unloading operations. Based on vessel arrival observations, the research team selected the mean length of 20 hours for laytime. The distribution of the vessel arrival times was estimated based on a literature review is obtained through a literature review of previous port operations models. The mean vessel inter-arrival time is 10 hours and the distribution of the vessel arrival time is described by a triangular distribution (Triangular (0, 20, 40).

RESOURCES

The model assigns necessary resources to each vessel upon their arrival. There are two types of resources assigned to each vessel:

- The berth and
- The cranes

There are total of eight berths that vessels can have assigned. Five out eight berths has an ability of accommodating post-Panamax and ultra large container vessels. The model tracks berth availability and assigns the appropriate vessel to a berth based on a vessel size. As soon as a vessel arrives at the berth, the model allocates the necessary number of cranes needed to unload the vessel. There are 16 cranes within the model, 9 of which are capable of handling the height and width of Post-Panamax vessels. Crane productivity in the model is 30 lifts per hour and cranes are assigned to a vessel based on a number of container-moves[4] that have to be performed per vessel. There are two possible cases based on which the cranes are allocated to a vessel:

- The model allocates 2 cranes if the number of container-moves per vessel is below 1300

[4] The number of containers to be unloaded/loaded from/to a vessel.

- The model allocates 3 cranes if the number of container-moves per vessel are over 1300

Figure 1 below shows the logic based on the berth operation is implemented within the model. Upon vessel arrival the model checks if there is available berth based on the vessel type. If there is an available berth, the model assigns vessel to a berth. If the berth is not available, the vessel is waiting until the adequate berth becomes available. The model keeps track of number of available berths, cranes, records their utilization and vessel turnaround time as well.

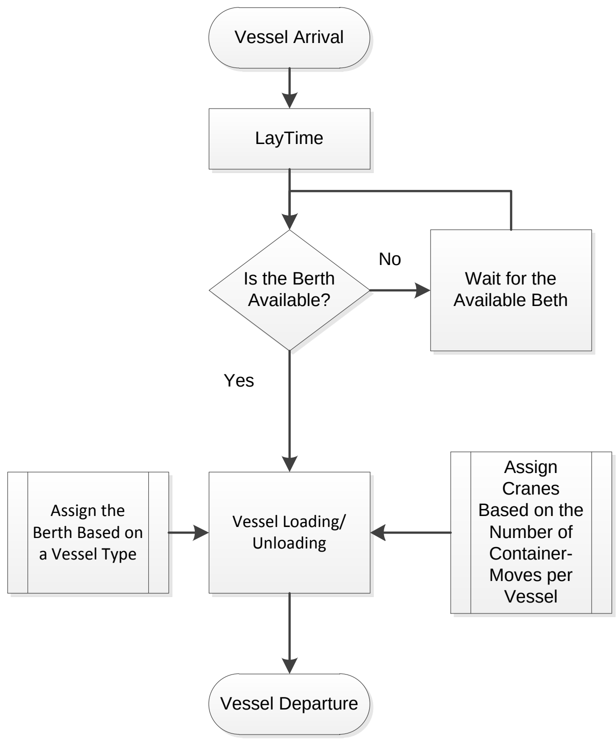

Figure 1. Vessel Arrival and Berth Allocation

THE YARD OPERATION

Typical operations in the yard include storage and retrieval of containers. The Straddle carrier operation can be classified into processes:

- The transfer of containers between the cranes and storage area, and
- The transfer of containers between the trucks and the storage area

The storage capacity at the terminal is estimated based on the aerial observation of a single container terminal. Researchers assumed that the storage capacity is from 25,000 to 27,000 containers. The model further classifies the storage yard area designated for inbound containers (maximum of 20,000 containers) and the storage area for outbound containers that has a capacity of 5,000 containers. The maximum number of straddle carriers that can be operational at any given point of time is 100.

Figure 2 below shows the logic applied to transfer a container from the moment it is unloaded from the vessel to the storage yard. When the container is unloaded from the vessel the model first checks the availability of the straddle carriers. If the straddle carrier is available it is assigned to a container, the total transfer time to the storage is recorded and the model releases the straddle carrier for the next assignment. The model records the number of containers in the storage, and at the decision point checks if any straddle carrier is available. Figure 3 shows the logic applied to a process of transferring a container from the yard to the berth.

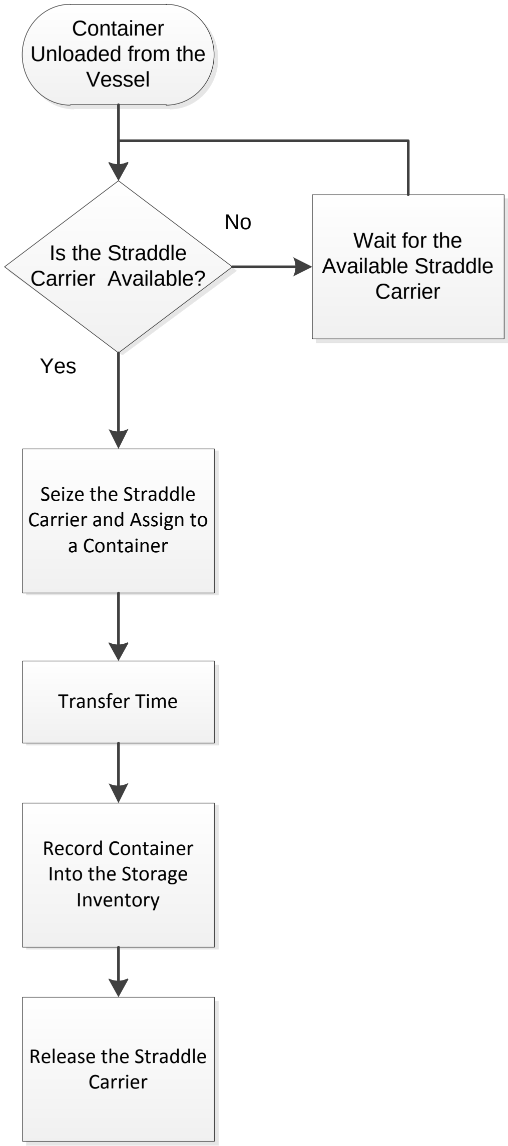

Figure 2. Container Transfer Logic From the Berth to the Yard

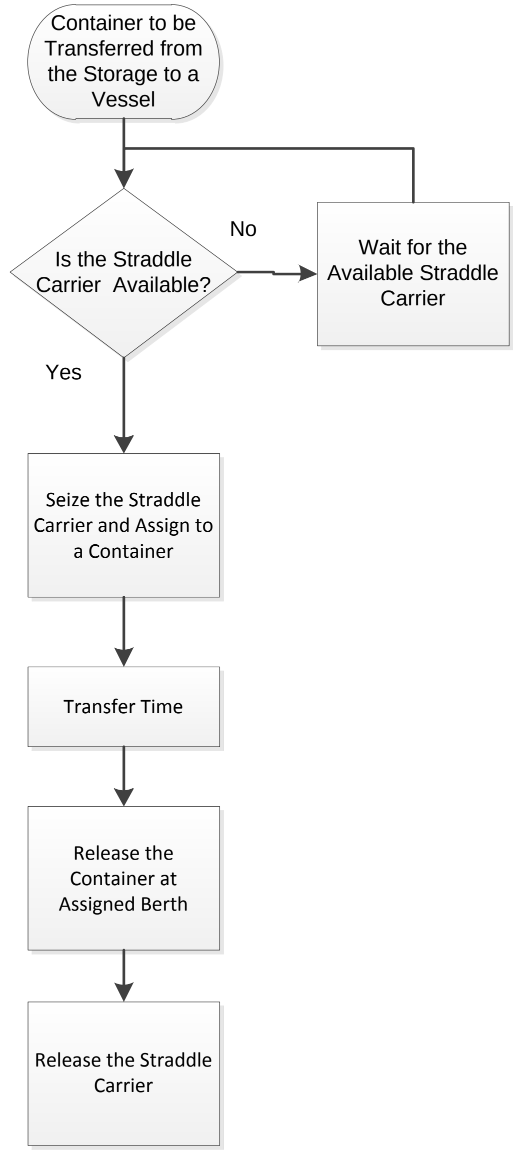

Figure 3. Container Transfer Logic From the Yard to the Berth

Figure 4 shows the logic implemented for the container transfer between the storage area and truck waiting in the slots. There are three distinctive cases that can occur:

- Container is dropped-off by the truck and truck leaves the slot
- Container is picked-up by the truck and truck leaves the slot, and
- Transshipment of container (truck drops-off the container and picks-up the container and then leaves the slot)

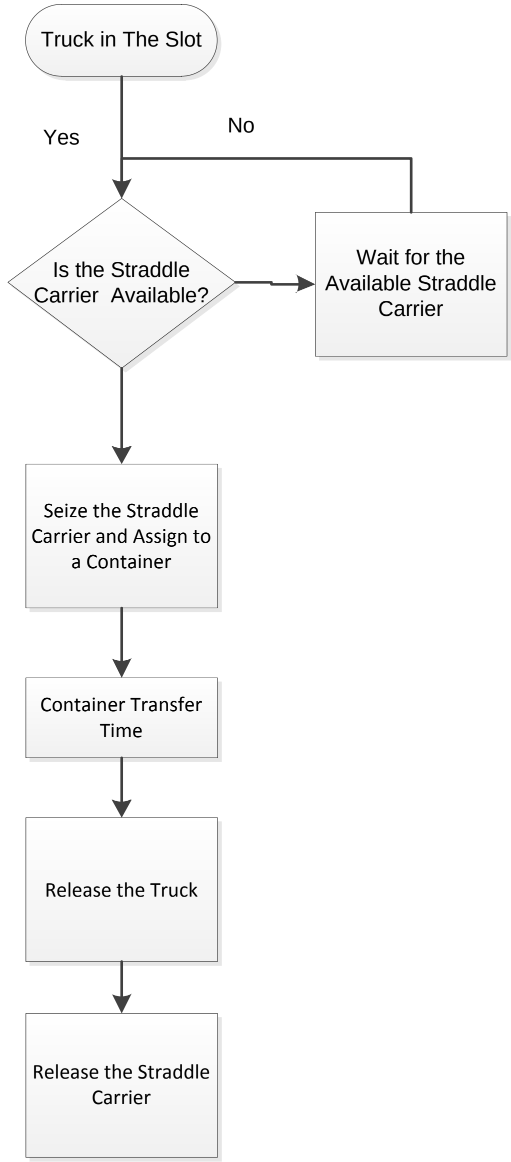

Figure 4. The Logic Applied to a Truck in the Slot

The container transfer logic in Figure 4 applies in all three cases. The difference is the transfer time taken for container to be unloaded, loaded or both. The transfer times are obtained from the sample data that terminal operator provided. The data provided contains the transfer times for all three cases recorded during three random days. Table 3 shows the truck processing times consistent with the logic depicted in Figure 4.

Table 3. Truck processing times in the slot

	Minimum	Average	Maximum
Truck Drops-off the Container	4	20	38
Truck Picks-up the Container	6	17	22
Container Transshipment	15	31	48

TERMINAL GATE OPERATION

Terminal entrance gates have two standard configurations; one-stage and two-stage. At one-stage entrance gates, all processing transactions are handled at one gate by an employee in a booth. At two-stage entrance gates, drivers complete a portion of paperwork transactions electronically before arriving at a manned entrance gate to complete the entrance process. The simulation model is based on the assumption that entrance gate is a one-stage gate.

To replicate the terminal gate operation effectively, it is important to identify and implement a variety of events associated with the truck from the moment it arrives at the gate until it enters the terminal yard area. The gate lanes are imposing a delay to trucks either due to queues that are often forming at the gates or when the documents and container is inspected prior to truck entrance at the yard. Besides the terminal gate operational characteristics, the truck arrival distribution during the day is also an important piece of information that is needed to estimate and evaluate the gate operation.

There are three primary logical processes that are implemented within the gate model:

- Incoming trucks processing logic (i.e., truck entering the container terminal)
- Route and Assign trucks to loading/unloading position logic.
- Process outgoing trucks logic(i.e., trucks exiting the container terminal),

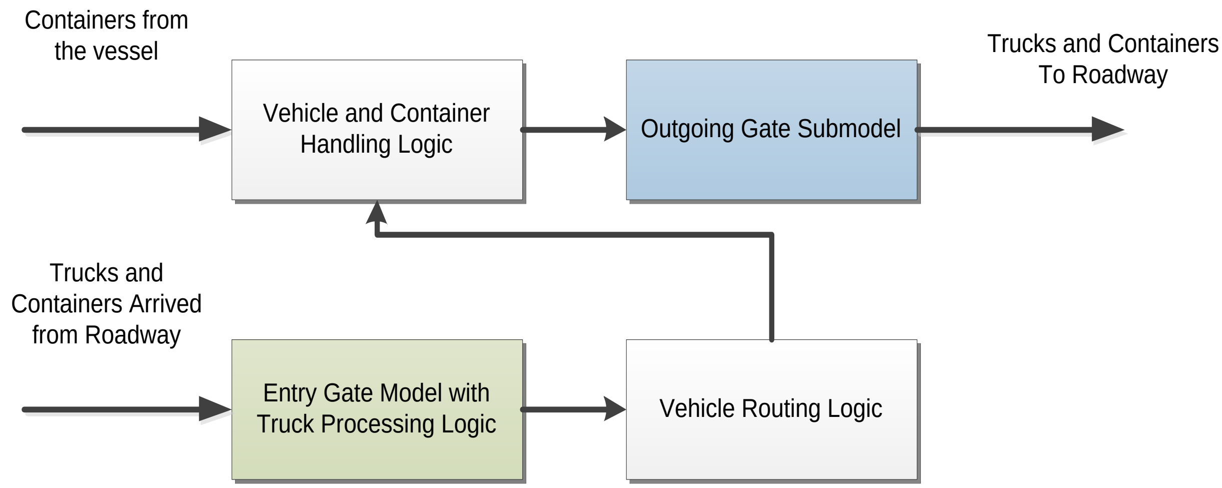

Figure 5. Processes within the Gate Model

Figure 5 above shows the relationship between gate model processes. The elements shown in green and blue represent the logic developed for the incoming and outgoing trucks respectively. The logic is designed to assign a truck to appropriate lane with predefined processing time. The trucks are differentiated based on if they are hauling a container (empty or full) or arriving with a chassis or as a bobtail. Upon entrance, “vehicle routing logic” emulates the process of trucks travelling to the available slot where it is handled by a straddle carrier. The delay is added to each truck that represents travel time from the gate to a parking slot. The vehicle routing logic monitors the number of available slots and holds a truck in the queue if the slot is not available. The process “vehicle and container handling logic” assigns straddle carrier to a truck waiting in a slot. It measures the truck time in the slot and its processing time.

GATE DESCRIPTION

In contrast to vessel operations, which can arrive at any day and hour, a container terminal gate is usually open during the workweek (Monday thru Friday) for a fixed time interval. In this model the gate is designed to process trucks from 6:00 A.M. to 9:00 P.M. Monday through Friday. The entrance and exit gate consist of 20 lanes. Based on the field observations and literature review the first 6 lanes are assigned to process chassis and bobtail trucks with uniform distribution among lanes. The container truck demand is handled by remaining 14 lanes with equal demand assigned to each lane.

AVAILABLE DEMAND DATA

To simulate the realistic demand the data from New Jersey Department of Transportation "The Portway Extensions Study Area[5] was able to provide a basis for truck arrival pattern development. The study provides truck counts for the area around the container terminals during the day. The site visit enabled research team to closely observe the truck arrival pattern and movements around the entrance gate. The data is further adjusted to meet the demand requirement from the berth side. Figure 6 below shows the truck hourly distribution entering the gate on a typical weekday.

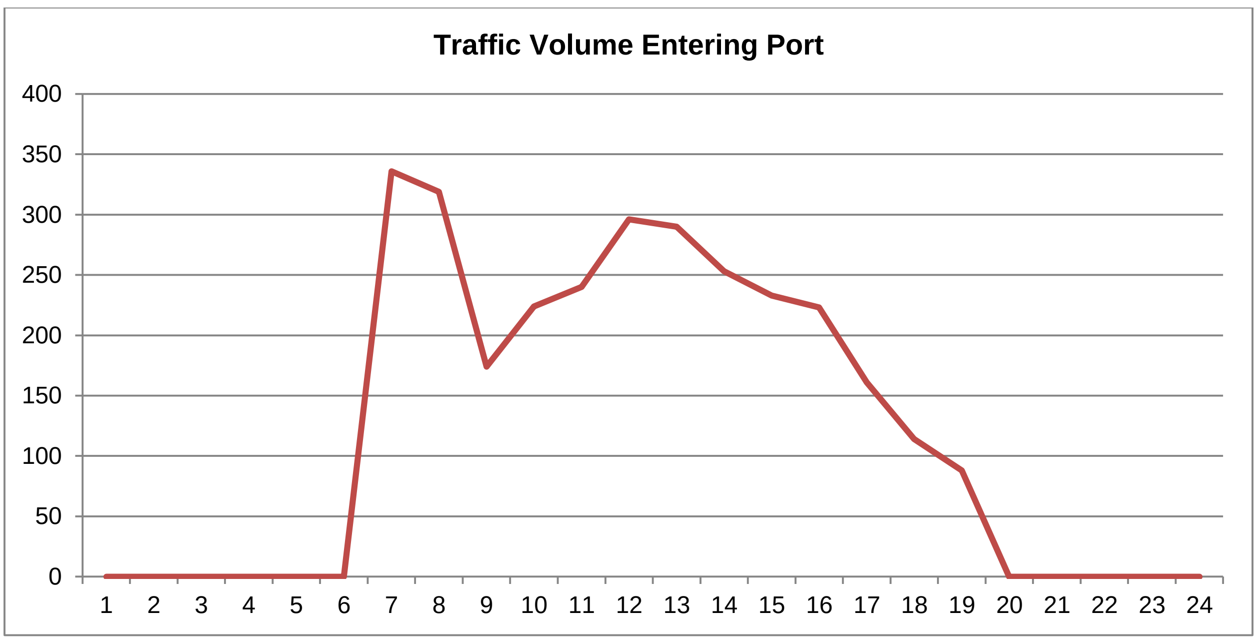

Figure 6. Hourly Truck Volume Entering Port (Weekday)

[5] "Portway Extensions Concept Development Study"", NJDOT, 2003

The literature review suggests that a weekly cyclical truck arrival pattern repeats over a monthly period when accounting for all types of transactions. In this model three vehicle types are defined that represent trucks arrival at the terminals; trucks hauling a container (from now on referred to as container trucks), trucks hauling a bare chassis (chassis trucks), and bobtail trucks. Container trucks are further disseminated into a truck hauling a full container or an empty container. The Port Authority of New York and New Jersey[6] annual trade reports are used to determine the ratio of full versus empty containers handled by the port. The ration of truck with a full versus empty container is 78 to 22 percent of total demand at the gate.

MODELING DELAYS AT THE GATE

Delays at terminal gates result from delays to in-gate processing. As discussed this process typically includes verifying driver identity, in case the driver is picking up the container operator is determining availability of the specified container, delivering instructions to drayage operators for container pick-up and dispatching yard equipment. If the driver is dropping off a container, container related paperwork and possible container inspection has to be conducted before the truck is assigned and dispatched to a specific slot. At exit gates, in-gate delays typically consist of verifying that the correct container has been picked up. Reduction in the amount of processing needed at exit gates corresponds with lower delays for these gates.

The mean delay for an entrance gate on a lane which serviced container was represented by a normal distribution with a mean of 4 minutes. Entrance gates that serviced chassis trucks are approximated with a normal distribution with a mean delay of 2 minutes. The literature review suggests that the delay for exit gates would be half of a delay for entrance gates, as the operation for trucks exiting the terminal is tend to be simpler.

[6] http://www.panynj.gov/

SCENARIOS AND RESULTS

The researchers hypothesize that the greater frequency of vessel arrivals, combined with the increasing variability of the size of the vessel s will generate new challenges for port terminal managers. Researchers developed scenarios based on recent studies completed to inform the raising of the Bayonne Bridge. As part of this exercise, research developed scenarios to simulate the potential growth of the New York and New Jersey truck traffic as result of attracted Post-Panamax vessel due to rising of the Bayonne Bridge. While the research team is not modeling a particular terminal facility, we are using the knowledge of the terminal operations and configurations to develop a baseline scenario of the terminal operation to understand the potential impacts on a given hypothetical port terminal. The baseline scenario operational assumptions are utilized to portray the potential policy impacts of Post-Panamax ships on traffic and consequently highway infrastructure around the port.

The increasing truck waiting time at the gate might defer shippers of using terminal services and cause them to redirect their cargo to other terminals that can provide faster service. To provide the same level of service, terminal operators can either increase the throughput of the gate by adding more entry and exit lanes or change the gate operating hours or reduce the gate processing times by implementing new technologies. Often the limited land availability restricts the expansion of the gate lanes leaving the change in gate operating policy and new gate technologies as the only viable strategy that can increase the gate throughput. In this study two policies, commonly used to control the truck arrival patterns at the gate, were examined to address the gate operation:

- Extended gate hours, and
- Gate appointment system

The goal of extended gate hours strategy is to divert a percentage of demand from peak hours to off-peak hours. The gate appointments strategy goal is also the reduction of the congestion at peak hour periods and thus controlling the demand at the gate side. At the same time terminal operator can efficiently plan the yard side operations. The strategies can be especially successful if the terminal operator decides to provide incentives to the drayage operators for using the gates at off peak.

THE MODELING SCENARIOS

Table 4 illustrates the characteristics of each of the four scenarios analyzed in this study:

- **Scenario I** is design evaluate the operation of the terminal under the assumption that one Post-Panamax ship is arriving per month. The gate operating hours remain identical to baseline scenario.
- **Scenario II** emulates the extended gate hours strategy. The gate operating hours during the day are extended for 3 hours per day (to 16 hours per day).
- **Scenario III** emulates the gate appointment strategy. Compared to Scenario 2, the gate remains open for an additional day during the week. The gate remains open for 13 hours during the day.
- **Scenario IV** is based on the Scenario 1. It has the same vessel arrival frequency and gate operating hours. The difference is that the chassis lanes are allowed process container trucks as well.

Table 4. Analyzed Scenarios

Scenario	Post-Panamax Vessel Arrival Frequency	Gate Operating Hours
I	1 per month	13 hrs/day and 5 day week
II	1 per month	16 hrs/day and 5 days/week
III	1 per month	13 hrs/day and 6 days/week
IV	1 per month	13 hrs/day and 6 days/week

Based on the literature review, the research team assumed that a single Post-Panamax vessel will induce demand of 3,000 trucks at the port gates. The truck arrival distribution in each scenario is modified to reflect additional demand.

The terminal performance indicators chosen to depict the gate performance are:

- The Truck Turnaround Time; The time elapsed from truck the moment that truck generated in the model until it leaves the model

- The Truck In Terminal Time; The time elapsed from the moment truck passed the gate until it processed by straddle carrier
- Average Truck Waiting Time at the Gate; The time elapsed from the moment truck is generate in the model until the moment is being started processed by the gate
- Truck Queue Size at the Gate; The number of truck waiting at the gate

FINDINGS

This section presents the results of modeling scenarios and their comparison to the baseline scenario. The scenarios are evaluated and compared by capturing change in performance indicators as a result of a Post-Panamax vessel arrival.

SCENARIO I RESULTS

The Scenario 1 is designed with the premises to estimate the impact of Post-Panamax ship arrival on gate performance indicators. Table 5 presents the performance indicators for the Baseline and Scenario 1 and their comparison. In can be observed that the average truck turnaround time increased by 18%[7] while the maximum truck turnaround time increase by 27%[8].

Table 5. The Performance Indicators

	Truck Turnaround Time (min)		**Truck In Terminal Time (min)**		**Truck Wait Time (min)**	
	Average	**Max**	**Average**	**Max**	**Average**	**Max**
Baseline	107	275	41	75	60	221
Scenario I	130	376	41	76	83	328
Change (%)[9]	18	27	0	1	28	33

The processing time of the truck within the terminal remained the same, which indicates that there is adequate number of resources that can handle the increased demand. The increase in truck waiting time implies that the gate capacity is not sufficient to handle the increased truck

[7] (130-107)/130
[8] (376-275)/376
[9] (Scenario I-Baseline)/Scenario I

demand, thus the truck are waiting longer (on average 28%[10]). The consequence of increased truck turnaround time is that it limits the number of trips that a truck driver can make during the day, limiting the potential revenues of contracted drayage truck drivers.

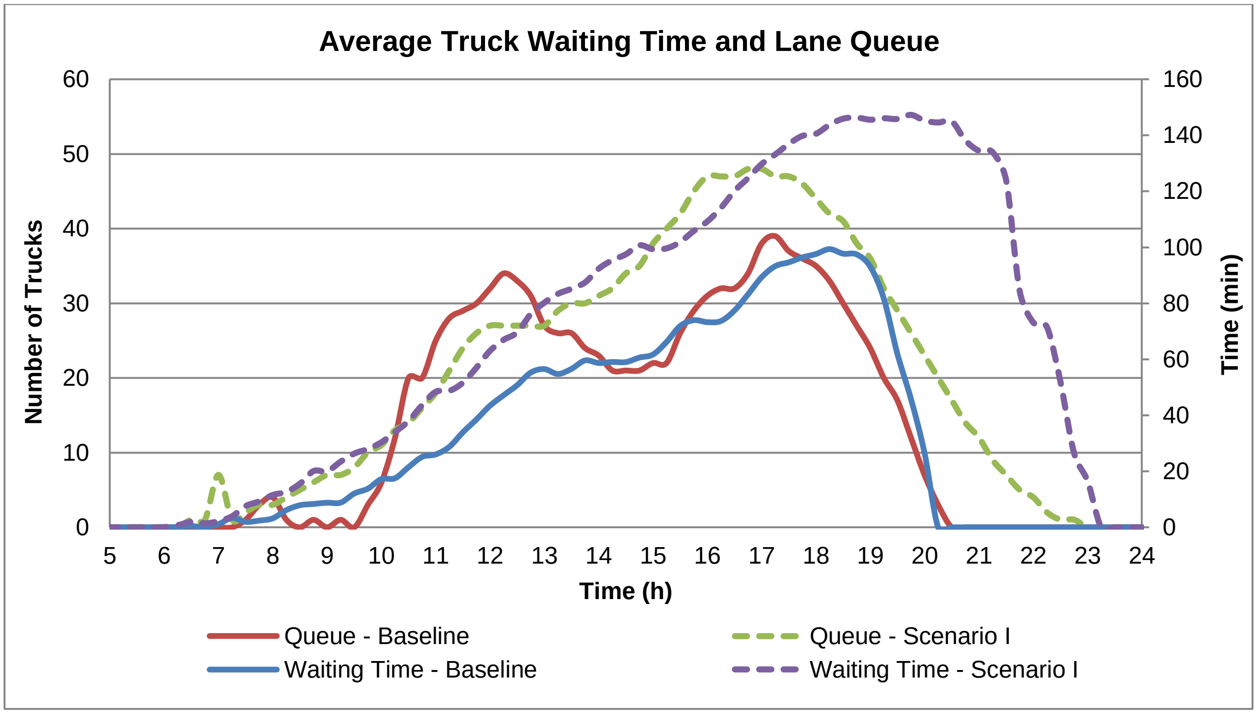

Figure 7. Average Truck Waiting Time and Lane Queue

Figure 7 shows the change in average truck waiting time and average truck queue at each gate lane during the day. The average queue in the Baseline scenario has two peaks that follow the truck arrival pattern. In Scenario 1, the truck queue is constantly increasing reaching its peak around 5 pm. One can observe that in Scenario 1 it would take additional 2.5 hours to process all truck remaining in queue.

SCENARIO II RESULTS

The implemented extended gate hours policy reduced the average truck turnaround time and waiting time is reduced by 14 % and by 24% respectively (Table 6) compared to Scenario I.

[10] (83-60)/83

Compared to the Baseline Scenario, the average truck turnaround time and waiting time still remains higher (by 6% and 10 % respectively).

Table 6. The Performance Indicators

	Truck Turnaround Time (min)		Truck Wait Time (min)	
	Average	**Max**	**Average**	**Max**
Baseline	107	275	60	221
Scenario I	130	376	83	328
Scenario II	114	336	67	278
Change (%)[11]	-14	-12	-24	-18
Change (%)[12]	6	18	10	21

One can conclude that the gate extended hours strategy alleviates a portion of the congestion at the gate, but it never completely provides the service levels from prior to Post-Panamax vessel arrival. Figure 8 shows the progression of the truck waiting time and number of trucks in the queue during the day for Scenarios I and II. The truck queue has been reduced and it peaks earlier in the day. The time required to process all truck remains similar to Scenario I.

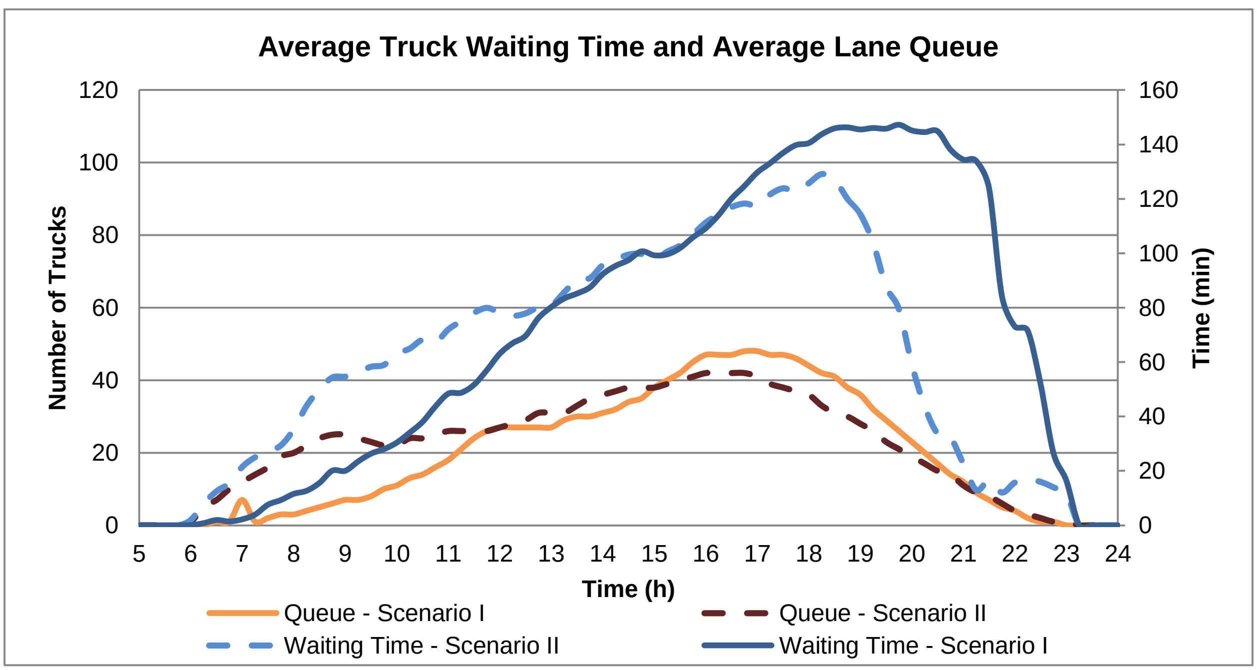

Figure 8. Average Truck Waiting Time and Lane Queue (Scenarios I and II)

[11] (Scenario 2 – Scenario 1)/Scenario 2

[12] (Scenario 2 – Baseline)/Scenario 2

SCENARIO III RESULTS

As stated, Scenario 3 is designed to portray an appointment system that provides truckers with an additional day during the week to pick-up/deliver containers at the port. The additional day provides flexibility for truckers to plan their pick-up and delivery within two weeks when ship is scheduled to arrive. Table 7 shows the Scenario III results and comparison to previous scenarios.

Table 7. Scenario III Performance Indicators and Comparison to Other Scenarios

	Turnaround Time (min)		**Truck Wait Time (min)**	
	Average	**Max**	**Average**	**Max**
Baseline	107	275	60	221
Scenario I	130	376	83	328
Scenario II	114	336	67	278
Scenario II	112	294	65	233
Change (%)[13]	-2%	-14%	-4%	-19%
Change (%)[14]	-16%	-28%	-28%	-41%
Change (%)[15]	4%	6%	8%	5%

The flexibility of scheduling an arrival to the terminal reduces the average truck turnaround time and waiting time by 2 % and 4% respectively compared to Scenario II. The indicators still remain higher compared to baseline scenario (by 5% and 7%). Figure 9 shows the progression of the average truck waiting time and lane queue during the day. One can observe that the shape of the queue line for Scenario III closely follows the Baseline Scenario line shape, which is not the case in Scenarios I and II.

[13] (Scenario III – Scenario II)/Scenario III
[14] (Scenario III – Scenario I)/Scenario III
[15] (Scenario III – Baseline)/Scenario III

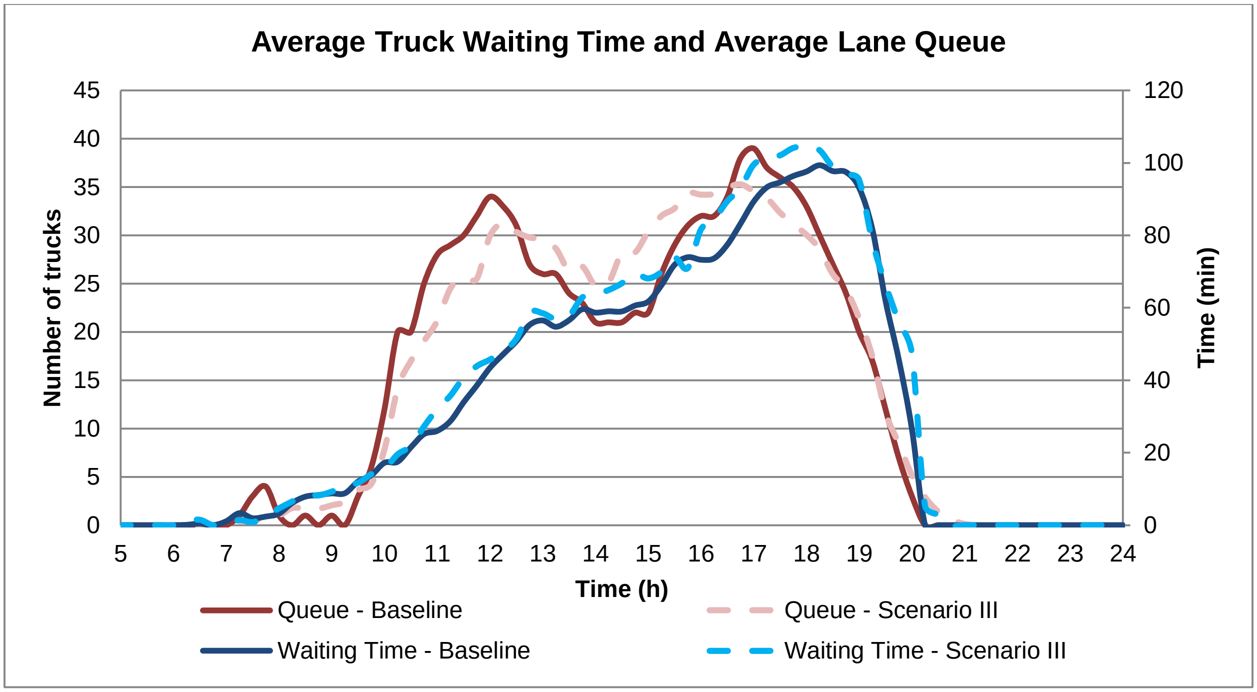

Figure 9. Average Truck Waiting Time and Lane Queue (Scenario III and Baseline)

SCENARIO IV RESULTS

During the field visit to the container terminal, the terminal operator presented a possibility of displacing the portion of the chassis service outside of the terminal. In this case the gate lanes can accommodate the portion of trucks demand. The Scenario IV is designed to emulate possibility of container truck traffic using chassis lanes. In Scenario IV, 10 % of container related truck volume is allowed to utilize the chassis gates during the period when Post-Panamax ship is scheduled to arrive. Table 8 shows the results of Scenario IV.

Table 8. Scenario IV Results

	Turnaround Time (min)		Truck Wait Time (min)	
	Average	**Max**	**Average**	**Max**
Baseline	107	275	60	221
Scenario IV	101	228	53	179
Change (%)[16]	-6%	-21%	-13%	-24%

[16] (Scenario IV - Baseline)/Scenario IV

Allowing 10 % of container traffic to utilize chassis lanes improves the truck turnaround time by 6% compared to the Baseline scenario. The added gate capacity reduced the truck waiting time on average 13%. The observed underutilization of the chassis gates indicates that they can be an additional resource for terminal operator to service trucks during high demand. The partial or full displacement of chassis service adds the needed capacity for container trucks and thus improves the gate throughput. Figure 10 illustrates the change in average truck waiting time and lane queue during the day. One observes that the waiting time and queue is below levels observed in the Baseline Scenario.

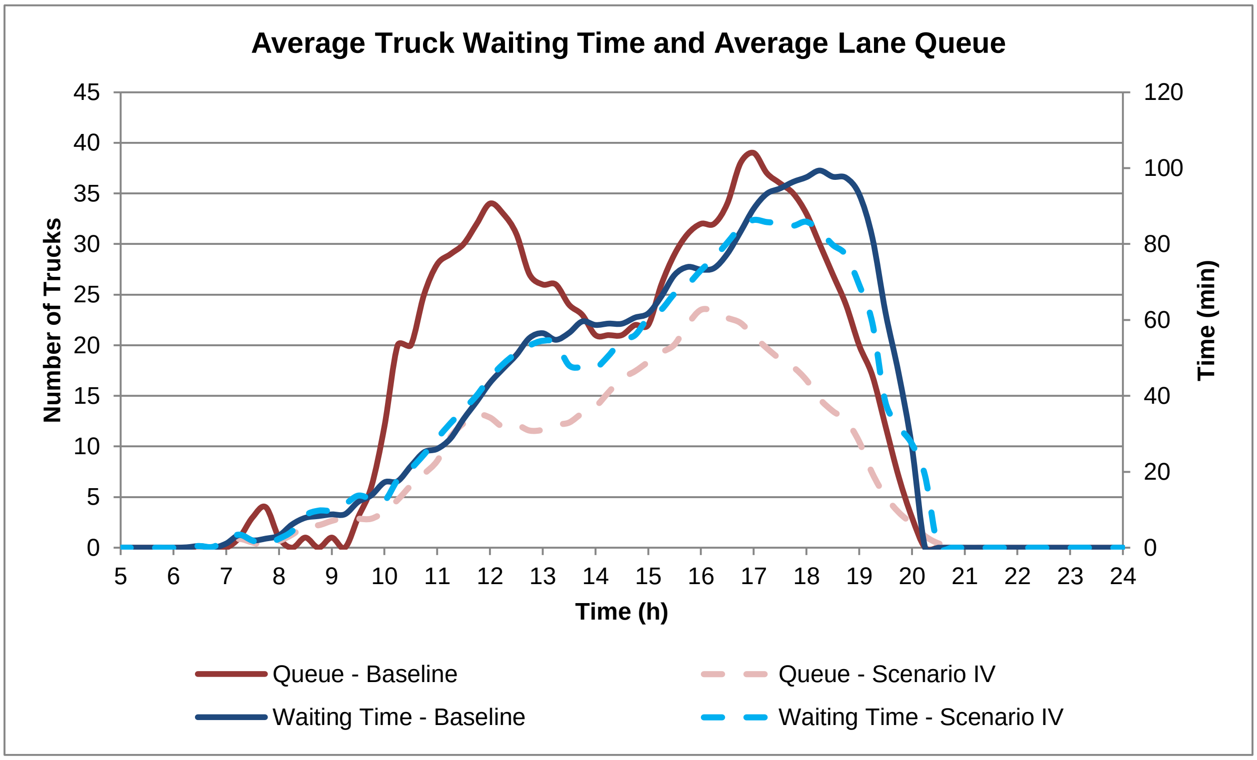

Figure 10. Average Truck Waiting Time and Lane Queue (Scenario IV and Baseline)

The researchers modeled captured the number of trucks waiting at the gate in each simulated scenario. Considering average truck length with a 20 foot container, the number of trucks waiting can be translated into the queue length expressed in feet. Figure 11 shows the truck queue length (in miles) progression during the day. The queue length outside of the gate in Scenario 1 has the maximum length of 1.6 miles. The Scenarios II and III alleviate the maximum queue length to 1.3 and 1.03 miles respectively. The Scenario IV significantly reduces the queue during the morning compared to Baseline Scenario while the afternoon queue is at same level or below.

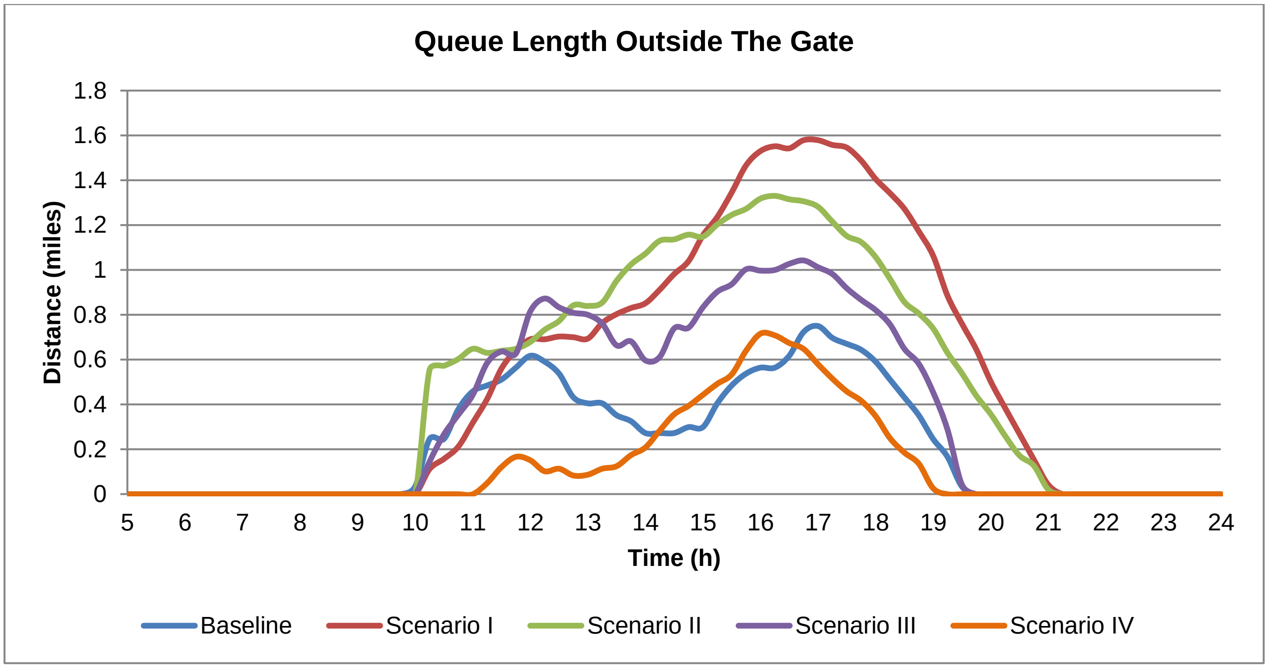

Figure 11. Queue Length Outside of the Gate

CONCLUSIONS

The objective of this research was to investigate the hypothesis that the greater frequency of vessel arrivals, combined with the increasing variability of the size of the vessel will generate new challenges for a port terminal. The research was partially motivated by the results and recommendations of recent studies of the rising of Bayonne Bridge in New Jersey. As part of this exercise developed scenarios simulate the potential growth of the New York and New Jersey truck traffic as result of attracted Post-Panamax vessel due to rising of the Bayonne Bridge.

The research team used the knowledge of the terminal operation and configuration to develop a baseline scenario of the hypothetical terminal operation. The four developed scenarios are used understand the potential impacts on a given hypothetical port terminal. Two scenarios are based on policies commonly used to control the truck arrival patterns at the gate:

- Extended gate hours, and
- Gate appointment system

Scenario I evaluates the operation of the container terminal under Baseline scenario operational assumptions with a premise that one Post-Panamax vessel is arriving during the month. The results show that the truck turnaround time and truck waiting time increased by 18% and 28% respectively. The in terminal processing time remained the same which implies that the gate capacity is insufficient to handle the increase in truck volume. The result shows it would take additional 2.5 hours to process all trucks remaining in the queue within the terminal.

Two scenarios (Scenario II and Scenario III) represent policies commonly used to control the truck arrival patterns. Both scenarios reduced the truck turnaround time and truck waiting time compared to Scenario I. The Scenario II reduced the truck turnaround time and truck waiting time by 14 % and 24% respectively. The Scenario III reduced the truck turnaround time and truck waiting time by 16 % and 28% respectively. However, the truck turnaround time and waiting time still remains higher compared to the baseline scenario. Scenario IV allows 10% of container related truck volume to utilize the chassis gates reduced the truck turnaround time and waiting time below levels observed in the Baseline Scenario. Table 9 summarizes the change in these two performance measures compared to the Baseline scenario.

Table 9. The Average Truck Turnaround Time and Waiting Time Comparison

	Percent Change Compared to Baseline Scenario	
	Truck Turnaround Time	**Truck Wait Time**
Scenario I	18	28
Scenario II	6	10
Scenario III	4	8
Scenario IV	-6	-13

RECOMMENDATIONS

The arrival of larger vessels at current container terminal operations may have detrimental effects on terminal performance rising from issues with gate capacity. The recorded truck turnaround times in this study, across scenarios, range from a minimum of approximately 10 minutes to a maximum of 8 hours in some cases. The discrete event simulation modeled within ARENA software served to allow researchers to make initial comparative conclusions related to the effects of post-Panamax vessel arrivals at a container terminal. Further improvements in the model for future research can add to transportation planners' capabilities to understand the effects of vessel size and arrival distribution on multimodal networks:

- Researchers can expand the model logic to incorporate more detailed process models that use specific terminal data and performance measures. In particular, more detailed logic and observations regarding the behavior of trucks within and outside of the terminal would improve the findings of the simulation model.
- One could choose to integrate additional macro or micro simulation software that are able to more closely model the behavior of land transportation through standard process logic, such as VISSIM.
- Researcher can improve the logic models that define the behavior of different terminal yard handling equipment and processes including modified behaviors for straddle carriers, container cranes, and other processing resources.
- Gate operations scenarios can include the simulation of several different policies available for appointment systems, including 24 hour prior appointment scheduling.
- One could choose to model the interaction between neighboring container terminals to develop a more comprehensive analysis of total burden on the highway system from container processing at neighboring terminals, consistent with port terminal areas in New York, Virginia, Los Angeles / Long Beach and elsewhere.

REFERENCES

Abadi, Afshin, Mithun Baphana, and Petros Ioannou. "Simulation Models for Evaluation of Terminal Operations and Traffic Flow on Adjacent Road Network." In *Proceedings of 12th IFAC Symposium on Transportation Systems*, Redondo Beach, CA, USA, September 2-4, 2009.

American Transportation Research Institute (ATRI). Compendium of Idling Regulations. 2005. Available at: http://www.atri-online.org/research/results/idling_chart.pdf

Carpenter, Beth C., and Thomas Ward. "The use of computer simulation for marine terminal planning." In *Proceedings of Winter Simulation Conference,* pp. 802-804, 1990.

Christensen Associates. National Cooperative Freight Research Program (NCFRP) 16: “Preserving and Protecting Freight Infrastructure and Routes”. Transportation Research Board. Washington, DC. 2012 Available at: http://onlinepubs.trb.org/onlinepubs/ncfrp/ncfrp_rpt_016.pdf

Cortés, Pablo, Jesús Muñuzuri, J. Nicolás Ibáñez, and José Guadix. "Simulation of freight traffic in the Seville inland port." *Simulation Modelling Practice and Theory* 15, no. 3 (2007): 256-271.

Conway, K.C.,“North American Port Analysis preparing for the first post-Panamax Decade”, 2012, Colliers international.

Dougherty, Patrick Shane. "Evaluating the impact of gate strategies on a container terminal's roadside network using microsimulation: the Port Newark/Elizabeth case study." Ph.D. dissertation, Rutgers University-Graduate School-New Brunswick, 2010.

Gambardella, Luca Maria, Andrea E. Rizzoli, and Marco Zaffalon. "Simulation and planning of an intermodal container terminal." *Simulation* 71, no. 2 (1998): 107-116.

Giuliano, Genevieve, and Thomas O'Brien. Evaluation of Extended Gate Operations at the Ports of Los Angeles and Long Beach. No. METRANS Project 05-12. 2008.

Huynh, Nathan N., and C. Michael Walton. “Methodologies for reducing truck turn time at marine container terminals”. No. SWUTC/05/167830-1. 2005.

ICF International. National Cooperative Freight Research Program (NCFRP) 6: Impacts of Public Policy on the Freight Transportation System (Revised). Transportation Research Board. Washington, DC. 2010 Available at: http://onlinepubs.trb.org/onlinepubs/ncfrp/ncfrp_rpt_006.pdf

Ioannou, Petros, Anastasios Chassiakos, G. Valencia, and C. Hwan. “Simulation test-bed and evaluation of truck movement concepts on terminal efficiency and traffic flow”. METRANS, 2007.

Karafa, Jeffery. "Simulating gate strategies at intermodal marine container terminals." *Ph.D. dissertation*, The University of Memphis, 2012.

Kia, M., E. Shayan, and F. Ghotb. "The importance of information technology in port terminal operations." *International Journal of Physical Distribution & Logistics Management* 30, no. 3/4 (2000): 331-344.

Kia, M., E. Shayan, and F. Ghotb. "Investigation of port capacity under a new approach by computer simulation." *Computers & Industrial Engineering* 42, no. 2 (2002): 533-540.

Klodzinski, Jack, and Haitham M. Al-Deek. "Methodology for modeling a road network with high truck volumes generated by vessel freight activity from an intermodal facility." *Transportation Research Record: Journal of the Transportation Research Board* 1873, no. 1 (2004): 35-44.

Lee, Byung Kwon, Bong Joo Jung, Kap Hwan Kim, Soon Oh Park, and Jeong Hoon Seo. "A simulation study for designing a rail terminal in a container port." In *Proceedings of Winter Simulation Conference*, pp. 1388-1397, 2006.

Moini, Nadereh. "Modelling the interrelationship between vessel and truck traffic at marine container terminals." *Ph.D. Dissertation*, Rutgers University-Graduate School-New Brunswick, 2010.

Nagy, Ellen A. "Intermodal Transshipment Facility Simulation: A Case Study." In *Proceedings of Winter Computer Simulation Conference, Sacramento*, pp. 217-23, 1975.

Ng, Wing-Cheong, and Ching-Sze Wong. "Evaluating the impact of vessel-traffic interference on container terminal capacity." *Journal of Waterway, Port, Coastal, and Ocean Engineering* 132, no. 2 (2006): 76-82.

Parola, Francesco, and Anna Sciomachen. "Intermodal container flows in a port system network: Analysis of possible growths via simulation models." *International Journal of Production Economics* 97, no. 1 (2005): 75-88.

Puglisi, Christopher Michael. "Issues and challenges of federating between different transportation simulators." *Master's Thesis*, School of Civil and Environmental Engineering, Georgia Institute of Technology, 2008.

Rizzoli, Andrea E., Nicoletta Fornara, and Luca Maria Gambardella. "A simulation tool for combined rail/road transport in intermodal terminals." *Mathematics and Computers in Simulation,* 59, no. 1 (2002): 57-71.

Rodrigue, Jean-Paul "Comparative Characteristics of the Panama Canal Expansion", Hofstra University, http://people.hofstra.edu/geotrans/eng/ch1en/appl1en/table_panama_new.html, Accessed January 2014.

Strauss-Wieder, A. "NCHRP 320: Integrating Freight Facilities and Operations with Community Goals". Transportation Research Board. Washington, DC. 2003. Available at: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_320.pdf

Thuermer, K., "Bigger, wider, deeper: US ports prepare for post-Panamax ships", http://www.fdiintelligence.com/Locations/Americas/USA/Bigger-wider-deeper-US-ports-prepare-for-post-Panamax-ships?ct=true, Accessed December 2013.

Tsitsamis, D. and D. Vlachos. "Truck operations planning at a container terminal." In *Proceedings of 1st Olympus International Conference on Supply Chains,* 1-2 October, Katerini, Greece, 2010.

U.S. Army Corps of Engineers, "U.S. Port and Inland Waterways Modernization: Preparing for Post-Panamax Vessels", 2012

Wall, Thomas Aubrey. "A federated simulation approach to modeling port and roadway operations." *Master's Thesis*, School of Civil and Environmental Engineering, Georgia Institute of Technology, 2010.

Yun, Won Young, and Yong Seok Choi. "A simulation model for container-terminal operation analysis using an object-oriented approach." International Journal of Production Economics 59, no. 1 (1999): 221-230.