The Impact of Vessel Bunching: Managing Roll-on-Roll-off Terminal Operations

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Abstract

The operations at port terminals are under consent examination, consistently investigating the various operational challenges effecting efficiency and performance. In a study to identify the consequences of vessel bunching, vessels that arrive within a short amount of time between each vessel, this paper presents an approach to forecast Ro-Ro terminal capacity while referencing the various input factors: vessel arrival schedule, inbound cargo volume, and rail or truck out-gate volume. Using a quantitative analysis derived using actual historical data from a Ro-Ro terminal at the Port of Long Beach, California, the proposed approach applied an additional probability factor that vessel bunching would occur. The analysis highlights the effectiveness of using actual historical data when examining a Ro-Ro terminal's capacity and how the resulting information could be communicated inclusively with all stakeholders involved in port operations as means of performance improvement.

Keywords: vessel bunching, ro-ro, terminal, forecast, capacity, risk assessment

The Impact of Vessel Bunching

Seaports remain the most common way to transfer goods from one form of transportation to another. Global ports are responsible for handling over 80 per cent of global merchandise trade in volume and more than two thirds of its value (UNCTAD, 2017). As key nodes in the supply chain, ports are under continual pressure to implement efficiency improvements and cost saving measures. Terminals must increase competitiveness thru different forms of optimization to accommodate larger ships with increased cargo volumes and the unpredictability associated with arrival schedules causing vessel bunching.

Vessels that arrive back to back or within a short amount of time between each vessel, is known as vessel bunching. Vessel bunching is associated with port congestion, often causing delays, extra time of voyage, ship and cargo dwell, and severely disrupts the supply chain. Considering the negative impact vessel bunching has on port operations, this paper aims to investigate and assess the various causative factors and metrics used to define vessel bunching, how it relates to congestion and the impact vessel bunching has on terminal capacity. Due to the increase in competition and demand, along with the absence of current research, there is a need for an analytical approach to evaluate whether a Ro-Ro terminal can meet the demand required from vessel bunching. An examination of actual historical data on a Ro-Ro terminal from the Port of Long Beach, California, will present various methods when analyzing data to forecast a terminal's ability to meet the incoming demand. The effectiveness of the analysis is highlighted in the results, along with a recommended strategy to use the information learned to improve the communication between stakeholders involved in port operations as a means to drive performance initiatives.

Literature Review

When evaluating the impact of vessel arrival schedules (vessel bunching) on terminal capacity, most current research is comprised of information regarding container shipping or container terminal operations such as Meng et al (2016). Although specific research on Ro-Ro terminals is scarce despite its importance, relevant research conducted by Xu et al (2017); exists to derive a useful understanding into the degree of congestion caused from vessel bunching. Within this section, it is important to provide a review into the current state of the shipping industry, an introduction of port terminals and the types of terminals to be examined; then, more specifically, an investigation into vessel bunching and the metrics used to define and measure the impact of vessel bunching on port congestion will be analyzed. The different causes associated with vessel bunching and the relation to congestion will then be addressed.

On the subject of congestion, it is hypothetical to assume that if a port terminal did not have a restricted capacity or processing limitations then vessel bunching would have less of an impact on terminal operations. However, due to a realistic viewpoint and increasing demand, it is important for terminal managers to take a tactical level of approach, typically involving berth and yard planning over a month period of time, when evaluating if the terminal's capacity can meet the demand. Based on the literature from ÖZKAN et al (2016) and Maksimavièius (2004), it became clear that analyzing effects of vessel bunching on terminal capacity is one of the primary reasons for this study. Following the lit review from the items referenced above, this section will also provide the reader with an understanding into the effects of vessel bunching on container and Ro-Ro terminal capacity.

Shipping Industry

The development of seaports is a result of their multi-functionality providing access to different markets, linking customers and producers and are the key nodes for distribution of import or export products. Port terminals have been recently affected from new emerging developments, in particular, the growing size of ships and cargo volume places greater demand on port performance. Fluctuations in the economy, changes in the institutional, regulatory and operating landscapes is constantly pressuring seaports to emphasize optimization of operations and time efficiencies (UNCTAD, 2017).

As maritime freight transportation increases year after year there is growing competition, adding more stress to the current port facilities. Sharp increases in cargo volume from larger container ships create greater demand and more local congestion. Guan et al., (2017) found,

> a one per cent growth in ship size and its auxiliary industry operations increases time in port by nearly 2.9 per cent and creates diseconomies of scale at ports, indicating that economies of scale that are gained at sea are lost at ports.

Simply put, larger vessel may be financially efficient while operating at sea, however, there is an extra burden placed on ports often requiring additional cost, labor and equipment. Although larger vessels handle high peak volume with lower arrival frequency, terminal capacity is over utilized on some days and underutilized on others (UNCTAD, 2017). As a result, the strain from the spike in cargo volume often requires ships to spend extra time at berth. Figure 1 highlights the total volume of international seaborne trade from 1980 thru 2016. The largest is a grouping of the dry cargo segments (ie. container, other dry cargo, and five major bulks) accounting for 70.2 per cent of the total volume. In addition, seaborne trade expanded by 8.17 per cent from 2013 for all dry cargo segments. The increase in volume and competition from the different cargo segments requires port terminals to continually implement efficiency improvements and cost saving measures in order to remain competitive. For the reasons mentioned above, competition among port terminals has become more and more complex. It is apparent that port terminals are having to increase competitiveness though different forms of optimization to accommodate larger ships along with the increase cargo volume.

In determining the justification to review the impact of vessel bunching on container terminal capacity, it should be referenced from Figure 2 that container ships account for more than fourteen per cent of the total vessel arrivals and it clearly demonstrates that container ships dominate the world fleet by accounting for twenty-four per cent of the total seaborne vessels. Furthermore, most research such as Meng et al (2016) and Mongelluzzo (2016) is comprised of information regarding container shipping or container terminal operations. From that understanding, it is relevant to evaluate the consequences of vessel bunching and the impact on container terminal capacity.

It is apparent that in comparison to container shipping, Ro-Ro vessels make up a rather small fleet and are therefore grouped with general or dry cargo ships when used in the review of maritime transportation (UNCTAD, 2017). Figure 3 illustrates a steady decline in market share, (-0.2 per cent) for the general cargo segment and is currently four per cent, down from seventeen per cent in 1980 (UNCTAD, 2017). Ro-Ro carriers and terminals are highly susceptible to global vehicle sales, however, remain as the most cost-effective way to ship vehicles. As the global market segment slows, Ro-Ro carriers and terminals are having to expand to new markets, increase stowage capacities and implement efficiency improvements in order to maximize profits. These facts prove that competition has become more dynamic and requires Ro-Ro carriers and terminals to drive performance improvement initiatives in order to remain competitive.

Terminal capacity can be affected by various reasons such as inadequate number of terminal gates, inefficient operations, volume of cargo arriving to the facility and ship arrival patterns. It was observed that Ro-Ro terminal capacity is substantially susceptible to congestion over any other type of marine terminal since Ro-Ro cargo cannot be stacked (Maksimavicius, 2004). It was also found within the literature review that most current research is comprised of information regarding container shipping or container terminal operations such as Meng et al (2016) or Mongelluzzo (2016). Due to the increasing demand and competition, along with the susceptibility to congestion and the minimal research available, the author found it equally important to evaluate the impact of vessel bunching on Ro-Ro terminal capacity.

Port Terminals

Ports are transition points attached to a sea, ocean, river, or connecting waterway that is equipped with infrastructure to move cargo between water and land (Roa et al. 2013). The specific technical facilities within allow them to manage product in which they are specialized. The primary function is to provide the transfer of goods from one form of transportation to another, most of which serve as the link between land and sea.

Port classifications are based on the technical facilities within each terminal. Although Roa et al. (2013) studied and defined eight types of port classifications, this paper will refer specifically to a "Port Terminal". Also known as "dedicated terminals", it is simply a terminal whose product is uploaded or downloaded, is consistently the same and their facilities are accessible only to the types of goods in which they manage (Roa et al, 2013). The vast majority of dedicated port terminals move coal and other minerals but may include containers, Roll-on

Roll-off cargo, passenger, or liquid bulk (ie.oils, gas etc.). Terminals can be defined by the vessel type in which they can provide service, this study will introduce and focus solely on container and Ro-Ro terminals.

Container Terminals

Generally speaking, a container terminal is a dynamic transit point for handling containerized goods where a variety of operations are carried out by moving containers arriving and leaving the terminal by different modes of transportation, e.g. by ship, truck or train (Gamal Abd & El – Horbaty, 2015). As mentioned previously, terminals can be defined by the vessel type in which they can provide service. When defining the type, container ships are usually expressed in their capacity of TEUs (twenty-foot equivalent units), ie. 9,000 TEUs (UNCTAD, 2017). A container terminal can be divided into three sub areas, seaside where cargo is unloaded from container ships by cranes, yard area where internal trucks transport containers to yard storage to be stacked in an allocated position and the landside area where trucks and trains are loaded or unloaded with containers waiting for distribution (Gamal Abd & El – Horbaty, 2015). As is clear from the above description, container terminal operations need to be executed efficiently; any cause of congestion can dramatically impact operations, thus reducing terminal productivity.

Roll-On / Roll-Off Terminals

Unlike container terminals, Ro-Ro terminals enable the loading and unloading of ships through ramps instead of gantry cranes and is a more flexible alternative for carrying wheeled cargo. Using the same logic referenced above, a Ro-Ro terminal can be defined by the type of cargo in which they provide service. Ro-Ro ships can transport a wide variety of cargo but usually consist of car and trucks, the most common being PCC (Pure Car Carrier), built exclusively for passenger cars, and PCTC (Pure Car and Truck Carrier), built to transport normal style passenger cars, SUVs and trucks (Danish Ship Finance, 2017). Although there are additional types of Ro-Ro ships and terminals with various abilities it will be assumed that all Ro-Ro terminals further described in this paper shall distribute product solely from a PCC or PCTC.

Vessel Bunching

In the literature, it was observed that authors had slight differences when defining vessel bunching. Bill Mongelluzzo (2016) referred to vessel bunching as the number of port calls by large vessels on certain days of the week or as described by Xu et al (2017), as the number of vessels required to wait due to the accumulated vessel arrivals exceeding the port capacity. Simply put, vessels that arrive back to back or within a short amount of time between each vessel, is known as vessel bunching.

Metrics for Vessel Bunching

When evaluating whether a terminals capacity can meet the demand it is important to understand the metrics that define vessel bunching**.** A review of one study by Aguilar and Obrer (2009) defined the variable to characterize vessel bunching as the, "the time interval between consecutive arrivals of vessels", measured in hours. From that context, based on a terminal's ability to receive the vessel, this paper will use the time interval between vessels as the metric to define vessel bunching.

Metrics for Port Congestion

It is further important for the reader's understanding, to define the metrics to measure port terminal congestion. Mongelluzzo (2016) and UNCTAD (2017) both indicated that measuring the impact of vessel bunching on port congestion can be inherently complicated. Cargo surges are spread over different periods of time and vessel rotation can vary between different port terminals. Vessel size along with the terminal's willingness to pay for overtime work to expedite loading are all potential factors (Mongelluzzo, 2016). It should be recognized that the differences in the types of port terminals make it difficult to compare productivity and therefore is difficult to measure congestion.

With an understanding of the apparent limitations of such a metric, quantifying the impact of port congestion has been measured from two alternative perspectives. A known measure used from the ports has been Berth on Arrival (BoA) rate, the percentage of vessels berthed within a certain time window since arrival, represents port berthing performance after a certain period of time (Dai et al. 2004). However, Xu et al. (2017) describes BoA as limited as it cannot provide timely information to the terminal and does not include the perspective of the vessel owners and operators, ie., the cargo volume from the vessel is not included.

The second perspective is from the customers, i.e., shipping companies and operators. UNCTAD (2017) measured overall port congestion using total ship time in port as the means to calculate the average time a ship spends in port before departure. Figure 2 illustrates the average time in port from different carrier segments. Using this logic, container ships can boast the best time at 0.87 days in port. However, when including the number of seaborne vessels and the total number of port arrivals, along with various other reasons, container terminals are highly susceptible to congestion related to vessel bunching. Taking into account these consideration, average time a ship spends in port does not account for the differences between time at berth, working and idle time or wait time, it is simply an overall estimation of time in port (UNCTAD, 2017). Bearing all this in mind, it appears at the moment there are inaccuracies and unaccounted factors when quantifying the severity vessel bunching has on terminal congestion.

An indicator easier for ocean carriers to understand is total dwelling (or turnaround) time of a vessel while in port as this is a primary contributor in transportation economic performance (Morales-Fusco, 2014). It should be compared between two variables, service time plus waiting time. Service time is related to terminal performance during discharge while waiting time will be defined as the total time spent delayed from vessel arrival patterns (vessel bunching) and the over demand on the terminals capacity. Additionally, UNCTAD (2017), Morales-Fusco (2014) and Xu et al (2017) reference the importance of waiting time as an indicator when evaluating terminal performance. With an understanding into complexity required, the measure of vessel bunching on port terminal congestion will be defined as the amount of time spent waiting to berth.

Factors that Cause Vessel Bunching

Even within normal operations, port terminal's usually have an ebb-and-flow to their workload. While at berth, cargo tends to accumulate within the yard at a higher rate than cargo being distributed thru the out gates, but when the vessel leaves the berth the terminal has the ability to catch up with yard work. Vessel schedules are meticulously managed to ensure the correct labor amount, equipment resources and capacity available are properly distributed to flow cargo through the facility without undue disruptions (Federal Maritime Commission Bureau of Trade Analysis, 2015). However, as the vessel arrival patterns become uncertain and vessels begin to arrive out of sequence with a smaller time interval between each arrival; vessel bunching requires the allocation of excess resources which then become scarce and places an enormous strain on port operations.

Participants from the Federal Maritime Commission (FMC) port forum regarded vessel schedule reliability as being “one of the worst and most miserable” later stressed was the consensus that vessel bunching placing a heavy degree of strain on port terminals (FMCBTA, 2015). It can be argued that, at Ro-Ro terminals, there is a high degree of unpredictability when scheduling the amount of time between vessel arrivals. Aguilar and Obrer (2009) found Ro-Ro vessels, at higher rate, would alternate random arrival dates and scheduled arrival dates. It was difficult to define the specific cause, but in recent years slow steaming practices have become more widely applied. Because of the cost saving measure, ocean carriers are reluctant to speed up when they fall behind in their schedule (FMCBTA, 2015). Missing the scheduled arrival date or berth window can place undue strain and disrupts the terminal’s work plan. It was also found in the literature that the west coast ports reported an average vessel delay ranging from 1.5 day to 1.7(FMCBTA, 2015). The report further attributed the delays to the various types of port congestion. Therefore, when examining the causes that affect vessel arrival schedules, any one of the causes of port congestion referenced below could cause changes in the time interval between vessels and lead to vessel schedules being uncertain or bunching of port calls.

Factors that Cause Port Congestion

Referring to wait time as the amount of time a vessel has to wait for berth, port congestion is one of the various components that cause vessel bunching, often requiring vessels to wait. In December of 2014, the average wait time exploded to 5.2 days following longshoreman labor disputes and terminal operational issues that limited port performance

(FMCBTA, 2015). Many of the various factors that cause port congestion have resulted from the actions of the maritime industry that have developed over a considerable period of time, rather than the results from short term unanticipated spikes in volume. (FMCBTA, 2015). As a result, the standard practices of today are quite different from the methods a decade ago. Regardless of this viewpoint, it is critical for terminals to resolve the causes of port congestion. Within this section the six major types and causes of port congestion will be reviewed.

Although the literature had differences in the major types of congestion such as (FMCBTA, 2015), the author found Gidado (2015) gave simple descriptions the easiest for the readers to understand which include:

- **Berth congestion**, caused by bunching of ships waiting to berth as a result of other ships waiting at the port entry.
- **Vessel work congestion**, mainly caused by delays attributable to the loading and / or unloading of the ship, which extends the time a ship remains at berth
- **Terminal capacity congestions**, resulting from the aging cargo above the maximum capacity of the area.
- **Terminal performance congestion,** emanating from additional cargo movement necessary within the terminal's area, the lack of available equipment or inefficiencies.
- **Vehicle out gate congestion**, mainly resulting from landward access to the port via truck or rail. Limited terminal processing may cause delays in vessel discharge.
- **Ship routing congestion**, caused from some form of blockade on the entry and exit routes.

Considering the many different variables that might trigger port congestion, there is significant research into the possible factors and the associated impact. Typical causes that might affect port congestion include amongst others (Gidado, 2015):

- Congestion from heavy weather delays
- Work stoppage from a labor related event or the limitation of stevedoring services
- Seasonal peak demands
- Terminal receiving or distribution limitations
- Congestion on the entry and exit routes
- Congestion from lack of equipment resources or services
- Congestion resulting from any documentation process
- Congestion from motor carriers with the terminal
- Congestion of cargo capacities
- Congestion of the landside access to the port
- Congestion associated with connectivity of the port
- Congestion resulting from holidays etc.

Terminal Capacity

As mentioned previously, it is hypothetical to assume that if the port terminal did not have a restricted capacity or processing limitations then vessel bunching would have less of an impact on terminal operations. A terminal's ability to meet the demand can be measured, as described by Xu et al (2017), as the number of vessels required to wait due to the accumulated vessel arrivals exceeding the port capacity. Following the research, it became apparent to review the effect vessel bunching has on container and Ro-Ro terminal capacity.

As described in the introduction, container terminals are a dynamic transit point for handling containerized goods where a variety of operations are carried out. Thus, the impact from vessel bunching produces high peak demand on terminal capacity along with other terminal activities that all have highly interconnected characteristics. This means that a multitude of decisions and variables need to be taken into account. Vessel bunching plays a decisive role in terminal organization (Pani, 2013) managing container storage and yard stacking on the tactical and operational level. Often times areas of the yard are organized to a specific ship and typically containers are moved to a defined area prior to loading of a vessel (Pani, 2013). Stacking containers efficiently was referenced as one of the most important factors for a container terminal (Gamal Abd & El – Horbaty, 2015). Any disruptions from changes in the vessel arrival schedule can have a cascading effect on these processes and therefore affect the terminal capacity. From the above considerations, to know in advance an accurate vessel schedule would allow terminal managers to assign the necessary labor and equipment resources required for handling operations efficiently, thus avoiding an increase in terminal capacity.

Within RoRo terminals, capacity is a primary constraint and is one of the most important factors causing vessel wait time. This is largely due to being substantially susceptible to congestion over any other type of marine terminal since Ro-Ro cargo cannot be stacked (Maksimavicius, 2004). Bearing this in mind, the primary variables affecting Ro-Ro terminal capacity is vessel bunching and discharge volume. When discussing possible actions, port managers should make an analysis of their current terminal capacity to determine if it can support the inbound discharge volume. Engin Özkan (2016), presented a capacity analysis using different simulated methods to present terminal operators and port planners with a complete analysis of current conditions. In the aforementioned study, the effect of three variables were investigated including: inbound vessel capacity, distance between ports and number of truck available. The results showed that that the outbound truck volume most affected terminal capacity. It can then be assumed that terminal performance related to their distribution volume is an important factor in determining whether the terminal capacity can support inbound vessels even if there is apparent vessel bunching.

It is worthwhile to mention, the prevailing attitude exercised by most terminals believe once a terminal is not in the position to handle the matter, the Ro-Ro ship should increase wait time (Maksimavièius, 2004). For clarity, if terminals have processing limitations and are restricted in size, it has less impact on the facility to delay discharge or extend wait time when their yard congestion increased to a capacity it could no longer support. Although the potential cost from a vessel awaiting discharge does not necessarily impact the Ro-Ro terminal, the cost is realized along the supply chain either with the ocean carrier or at a cost to the sales company.

Creative Portion: Analysis

A successful Ro-Ro terminal capacity forecast is highly dependent on accuracy, relevance and availability of the information. This study analyzed actual historical data in conjunction with expected vessel arrival schedules to predict if a Ro-Ro terminal's capacity can consistently meet the incoming demand. After reviewing various input factors from a Ro-Ro terminal in Long Beach, California; an opportunity was recognized to utilize actual historical data from vessel schedules, inbound cargo volumes, and truck and rail out gate volumes to predict spikes in demand for various times of the year. During the analysis it was evident that if the inventory remained above the efficient operating limit during peak demand periods there was a direct correlation to the risk of vessel bunching. The following section will examine the primary dynamics of the terminal operations used in the analysis. The analysis will highlight the different input factors, a number of variables, the methods used in the forecast. A strategy to use inclusive communication between port stakeholders to collaborate on forecasted events will be presented to highlight the effectiveness of making proactive decisions to prevent future constraints or disruptions.

Input Factors

A Ro-Ro terminal can most simply be described as a parking lot; the total number of parking spaces within that parking lot is the terminal capacity. For example, if a Ro-Ro terminal capacity is 5,000 then the terminal has 5,000-parking spaces. For the fact that Ro-Ro cargo cannot be stacked, a terminal's inventory is the primary indicator in their current performance. As a terminal's inventory raises to higher levels, the operations within the terminal become increasingly inefficient. As terminal inventory increases (a direct correlation to quantity of available spaces) the available paths from offload to onsite destination become more limited which forces inefficiencies. Inefficiencies in offloading and stowage of new inventory has a compounding effect which can extend inventory levels having an additional impact on vessel bunching probability.

The dynamics of the terminal operations for which the forecast was made are shown in Figure 4 as a process flowchart to visually clarify the relationships between each variable. The Ro-Ro terminal's process is as follows: vessels arrive at the terminal based on their arrival schedule; if the terminal's capacity cannot meet the inbound vessel cargo volume then the vessel will have to wait until the inventory levels lower. If the terminal can meet the incoming demand the vessel will unload cargo onto the terminal which will increase the terminal's inventory levels; as referenced in Figure 5 and shown as target lines, the terminal's capacity can be viewed at three levels.

1. Normal operating inventory (Green Line at 6,000k vehicles located within the terminal) is the most efficient capacity for terminal operations.
2. Efficient operating limit (Yellow Line at 9,000k) is the highest point in the terminal capacity where operations remain normal. Any further increase to inventory requires vehicle movement to inefficient locations within the terminal, limits the routes available forcing congestion and negatively effects performance requiring additional labor and equipment.
3. Maximum operating capacity (Red Line at 12,500k) is the highest amount of cargo volume the terminal can hold. If an inbound vessel's cargo discharge volume is higher than the max capacity of the terminal, the vessel will have to wait until the capacity lowers to an acceptable level.

Once cargo is available for distribution, the terminal's daily operations involve loading cargo onto rail or truck, where they will be out-gated and removed from the terminal's inventory, thus increasing the available capacity. This can be seen in Figure 5; as cargo is unloaded, the terminal's capacity will spike in inventory; however conversely, the loading of truck and rail to out-gate is lowering the inventory on a daily level producing an ebb and flow of cargo throughout the week, month and year.

The forecasting described here, heavily relies on pattern recognition and pattern changes for: vessel arrival schedule, inbound cargo volume, and landside out-gate volume. For this instance, the importance of accurate information cannot be stressed more. All data presented was collected through a Terminal Processing System (TPS). TPS is a Ro-Ro specific terminal processing system designed to calculate, schedule, record and analyze all of the terminals daily processing operations therefore, ensuring the validity and accuracy of the system. The data was obtained between 2013 and 2017, consisting of historical data that includes: daily terminal capacity, vessel arrival schedules and cargo volume as well as daily throughput measured by truck / rail out-gate volume.

Variables

Using the actual historical data, the terminals daily inventory was examined to view peak months where the terminals increased inventory is above the efficient operating limit. This can be seen in Figure 5 showing the five years of overlaid daily inventory to identify yearly trends. As a result, it clearly demonstrates consistent ebb and flow of demand year after year, specifically showing high demand on capacity for the months of January, April, May, August, November and December. The majority of the variation in the series of data can be assumed to be caused from seasonal peaks and spikes in volume. However, further investigation was needed to determine if vessel bunching had related to higher demands in capacity.

In order to understand the potential impact of vessel bunching on available terminal capacity, a correlation analysis was completed to understand if the impacted months were strictly due to an increase in the number of vessels arriving to the terminal or whether vessel arrival intervals were more closely related. The Pearson Correlation Coefficient (a method to investigate the relationship between two quantitative variables (University of the West of England, 2018) was performed to determine the relationship each had on the number of times the terminals inventory was above the efficient operating limit. The results are shown on Figure 6 and 7.

The correlation analysis between the total number of vessels arriving resulted in ($r = 0$) demonstrating that the total number of vessel arrivals is not correlated to the number of times the terminal capacity was higher than the efficient operating limit. For example, a terminal could receive two or eight vessels within a month and it would not affect terminal performance as long as they were evenly spaced throughout the month. However, as clearly shown in Figure 7, there is negative and high inverse correlation, (r= -0.739) or (-74%), for the average time interval between vessels. According to the results, as the time interval between vessels decreases the total number of days above the efficient operating limit increases. This can be interpreted, as for example, a terminal could have two or ten vessels discharge in a month but if either scenario resulted in bunching of vessel arrivals within an estimated (2 to 2.5) days then the terminal capacity is at risk of performance inefficiencies.

Knowing the relationship between vessel bunching and terminal capacity is a key factor when developing a forecasting method. Due to the resulting high inverse correlation for the time interval between average vessel arrivals and number of days the inventory was above the terminals efficient operating limit, along with the consistent pattern in the seasonal demand, it was determined useful to review the probability of reoccurrence and risk associated with each month of the year. Reoccurrence interval is a rather straight forward calculation when using historical data, however, because the inverse correlation resulted in a high value, the reoccurrence interval should include a level of impact that will provide a more accurate probability of business disruption. Figure 8 reflects the ranking of impact based on the average time interval between vessel arrivals over the five-year period. A low rank of one represents a high average time between vessels, where as a rank of five is a low average time.

From this, the reoccurrence interval can be defined by $T = (n+1)/m$, where (T) is the reoccurrence interval, (n) is the number of working days in the month and (m) is the magnitude ranking (Baer, 2018). Taking into account the different variables, the probability of vessel bunching occurring during any given month can be then calculated by $P = 1/T$ where (P) is the probability index. Referencing Figure 9, each month has been calculated to examine which months are most potentially impacted from vessel bunching.

The results shown further support the conclusion that Ro-Ro terminal capacity is highly susceptible to vessel bunching. As mentioned, a Ro-Ro terminal is continually under pressure to increase performance, drive cost savings initiatives and remain flexible to different forms of congestion. Planning and forecasting are potentially more important within a Ro-Ro terminal than any other terminal type, when speaking to capacity limitations. In this case, terminal operators should use different methods and strategies to help improve communication and outlook between terminal operations, business agents, vessel, truck and rail carriers.

Most terminals are aware of the inbound vessel arrival schedule and cargo volume more than three months in advance. Terminal operators however, are responsible for planning and forecasting performance within their own operations. One opportunity identified during this study was the ability to compare five years of historical data showing clear patterns in seasonal peak demand. It became obvious to use this data for other parts of the terminal operations to include rail and truck out gate daily volume. Thus, each day of the year was compared to the five years prior. It should be noted, there were no reports of any significant process changes or disruptions that could have affected major changes in out-gate volume. The daily out-gate volume per day of the year was forecasted using a linear equation where:

- $y = a + bx$
- $a = \bar{y} - b\bar{x}$
- $b = \dfrac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2}$

The (x) and (y) values were the weighted average from the daily out-gate volume by day was taken into account with the most recent year's data scoring higher (UWE, 2018). Referencing

Figure 10, a week forecast was created to show the linear trend of the daily distribution volume. It is important to explain, with most forecasting methods or programs (i.e. Microsoft Excel) the forecast could be simply extended to view long term trends more than the week shown such as three, six or even a twelve-month outlook. The results reference a slight linear decrease in daily distribution volume. Taking this into account, the forecasted data shown in Figure 10, along with the expected forecasted vessel arrival schedule and cargo volume, can be used to show an accurate picture of the ebb and flow within a Ro-Ro terminal.

The historical data has proven to be a unique opportunity to review the forecast with an additional input factor from the information quantified earlier, the probability of vessel bunching by month. Figure 11 is an example of a simple forecast model to reference the cargo movement through the terminal and the impact it has on capacity. Using this as a reference, along with the probability factor, can accurately predict potential disruptions to capacity and will improve the terminal's ability to plan and forecast. For example, the data described in Figure 11 is from the month of January; according to the probability factor there is a (35%) chance of vessel bunching and has an already low average time interval between vessels; however, February has very low probability factor (4%) and as shown on Figure 5 is rarely impacted from seasonal peak demand. This information could then be used to make tactical planning decisions. For example, the month of February is calculated as a low chance of disruption. A terminal operator may choose to enter the month with a higher capacity than normal or plan to use the time to repair equipment and facilities. Conversely, if entering a month with a high probability of disruption then operational decisions could be managed to increase rail and truck out-gate volume and lower capacity.

The method best determined to analyze the data previously mentioned is a risk assessment based on the times of year that potential risk has been identified. This approach will evaluate risk in terms of two variables: the probability of vessel bunching and the disruption caused from a terminals inefficient operating capacity (Blanchard, 2008). The risk factor can be calculated by:

- (RF) = (P) + (C) – (P)(C)

Where (P) is the probability percentage of vessel bunching occurring and (C) is the impact from the inefficient operating inventory as shown in Figure 12. Figure 12 references a weight magnitude scale to determine the least and highest potential risk of impact. Each month was then quantified based on probability and the risk assessment to identify and rank potential months most at risk.

The results from to risk factor calculation are shown on Figure 13. Figure 13 used the magnitude ranking from Figure 12 and the probability percentage found on Figure 9 and highlights the results as a complete risk assessment. High risk items require frequent report outs and direct management supervision, whereas low-risk can be managed on the normal operating level (Blanchard, 2008). The results show that April, May, July, August, November and December are all susceptible to high risk associated with vessel arrival schedules on terminal capacity. This can be used in conjunction with Figure 11 to assist terminal operators with a reference forecast to accurately predict whether the terminal's capacity can meet the incoming demand, along with highlighting what times of the year require additional operational planning to manage the potential constraints.

Strategies

In this part it will be understood that although information derived from data analytics has shown to be useful as an early warning indicator to potential disruption, it is the responsibility of the terminal operators to use this type of information when developing operational planning strategies. There are a number of potential uses, but relevant readings found in Hvolby (2017), FMC (2015) and UNCTAD, (2017) all reflect on the key primary opportunity is with information sharing and collaborative communication of a terminal's operational performance and forecasts to proactive report out challenges to port stakeholders, rather than a reactive approach.

In reviewing the flow of communicable information between responsible stakeholders, it is apparent that in an effort to improve port performance, the communication of reliable data and other information is needed in a timely, transparent and collaborative manner. Port performance improvement initiatives through collaborative communication have already undergone trials by different ports such as the Port of New York/New Jersey (PONYNJ), which created a Port Performance Task Force aimed in reducing the impact of congestion and improve port efficiencies (FMC, 2015). The PONYNJ recognized earlier on that one single entity could not fix the problem but rather the entire port community, which includes: ocean carriers, port terminals, rail roads, motor carriers and organized labor, such as the International Longshore and Warehouse Union's (ILWU) (FMC, 2015). With this in regards, leveraging current forecasting tools and emerging technologies by sharing this information to port stakeholders is likely to improve performance and may help level out peak demands often associated with port operations.

The ability for all stakeholders to come together and openly discuss and formulate solutions has been proven to be an effective means of increasing performance and reducing congestion. It has been reported by PONYNJ, "the collaborated initiatives accomplished by the task force have been unprecedented and the port community is eager to further the inclusive process" (FMC, 2015). The use of the forecasting method mentioned during the analysis of this study, is just one example of information that could be useful to multiple stakeholders involved in terminal operations. Other forms of emerging technologies may also be integrated to create real time channels of communication. One example is the Freight Advanced Traveler Information Systems (FRATIS), which aims to improve truckers routing around congestion (FMC, 2015). These communication improvement initiatives are key factors when determining what is found useful and what processes can be improved upon based on the shared information.

According to this suggestion, inclusive collaboration and communication of information will facilitate different forms of performance improvement for all areas of port operations. Using historical data and various methods to analyze and forecast conditions, as previously discussed, can provide the ability to examine short and long-term volume spikes, terminal capacity constraints and dwell times, and the maximum rail and truck out-gate volumes, but it not limited to sharing any relevant information that will impact stakeholders involved in terminal performance. Having established clear measures and metrics to track and communicate forecasted information can provide various opportunities to create and improve performance.

Many opportunities can be identified in the sharing of accurate and consistent information. When accurate and informative information is shared with rail or motor carriers, for example, they can provide more ability to maximize the out-gate distribution volume. Land based carriers can now proactively improve labor and equipment allocation to match identified seasonal demands as shown on Figure 5 & 11, as well as decrease much of the excess financial burden associated to spikes in demand causing unproductive trips and congestion.

Furthermore, early communication to ocean carriers of potential wait time due to terminal capacity constraints can allow the ocean carriers additional latitude to adjust their estimated arrival time. As shown in Figure 7 & 11, Ro-Ro terminals are significantly impacted from vessel bunching. Any bunching of vessel arrival schedules, will disproportionately require additional allocated resources to handle the vessels, thus resulting in cargo being accumulated within the terminal (FMC, 2015). Eventually, the terminal will run out of available capacity, requiring the inbound vessel to wait, often creating enormous financial burden. It can be easily understood; ocean carriers and terminals will benefit from early communication of potential capacity constraints and wait time. Most ocean carriers share their ETA when leaving the previous port. As a terminal operator, the ETA and cargo volume could then be added to a reference model, as shown in Figure 11, to visualize forecasted inbound and outbound distributions. This information can then be shared with the ocean carriers identifying any potential concerns to capacity. If concerns are identified, early communication can provide the ocean carriers the opportunity to either speed up or slow down and adjust to a new ETA that may reduce the probability of the ocean carrier having to wait once arrived at the port.

Summary

There will always be various forms of congestion worldwide; requiring port terminals to implement efficiency improvements and effective planning measures often related to vessel bunching. The inevitable bunching of vessel arrivals requires ensuring adequate availability of terminal capacity. Ro-Ro terminal capacity is particularly susceptible to vessel bunching since wheeled ro-ro cargo cannot be stacked upon one another unlike containers; this necessitates terminal operators to forecast early on to determine if there is adequate capacity or how much improvement would be needed in order to meet the demand.

It is known that vessel bunching is a form of congestion and can dramatically impact port terminal efficiencies. With this in mind, this study aimed to share an approach that analyzed historical data to measure the volume of inbound and outbound distributions, to calculate the different potential correlations and the probability of vessel bunching occurring during each month of the year. It was found that, as the vessel arrival interval decreased the number of days the capacity was negatively impacted increased, thus proving an inverse correlation.

From this, terminal operators can make proactive decisions in forecast planning which can be further used in collaboration with port stakeholders. This type of analytical information if shared can help with different means of performance improvement by acting as early warning system to potential capacity disruptions. It is expected the input factors used will be found useful when determining which historical data is relevant when forecasting and why sharing this information between port stakeholders could increase performance.

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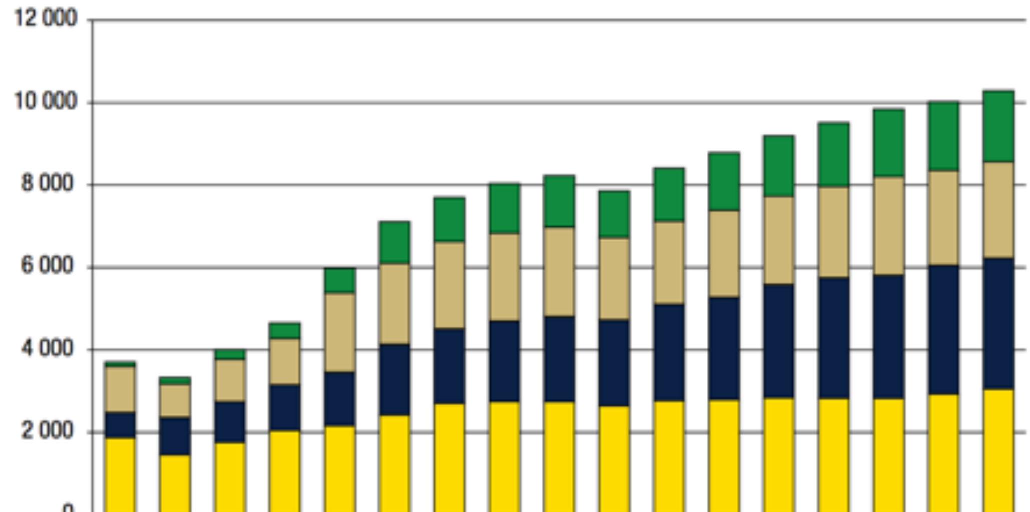
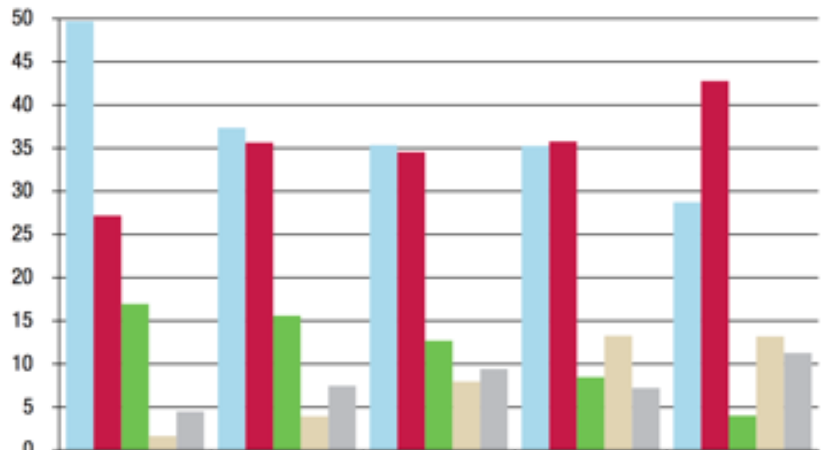


	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Container	102	152	234	371	598	1 001	1 076	1 193	1 249	1 127	1 280	1 393	1 464	1 544	1 640	1 661	1 720
Other dry cargo	1 123	819	1 031	1 125	1 928	1 975	2 112	2 141	2 173	2 004	2 022	2 112	2 150	2 218	2 393	2 310	2 339
Five major bulks	608	900	988	1 105	1 295	1 711	1 814	1 953	2 065	2 085	2 335	2 486	2 742	2 923	2 985	3 121	3 172
Oil and gas	1 871	1 459	1 755	2 050	2 163	2 422	2 698	2 747	2 742	2 642	2 772	2 794	2 841	2 829	2 825	2 932	3 055

Figure 1: International seaborne trade (Millions of tons loaded) by cargo type Source: UNCTAD (2017)

Vessel type	Days in port	Total arrivals	Total vessels	Total dead-weight tonnage (thousands of tons)
Container ships	0.87	445 990	288 148	18 288 135
Tankers	1.36	309 994	205 034	8 504 418
Gas carriers	1.05	59 183	32 404	765 328
Bulk carriers	2.72	213 497	169 851	12 150 088
Dry cargo and passenger ships	1.10	2 065 505	474 982	6 372 305
Grand total	**1.37**	**3 094 169**	**1 170 419**	**46 080 274**

Figure 2: Average time in port by vessel type Source: UNCTAD (2017)



	1980	1990	2000	2010	2017
Oil tankers	49.7	37.4	35.4	35.3	28.7
Dry bulk carriers	27.2	35.6	34.6	35.8	42.8
General cargo ships	17.0	15.6	12.7	8.5	4.0
Container ships	1.6	3.9	8.0	13.3	13.2
Other	4.5	7.5	9.4	7.2	11.3

Figure 3: Five segments of the world fleet by vessel type, 1980–2017 (Percentage of Market)

Source. UNCTAD (2017)

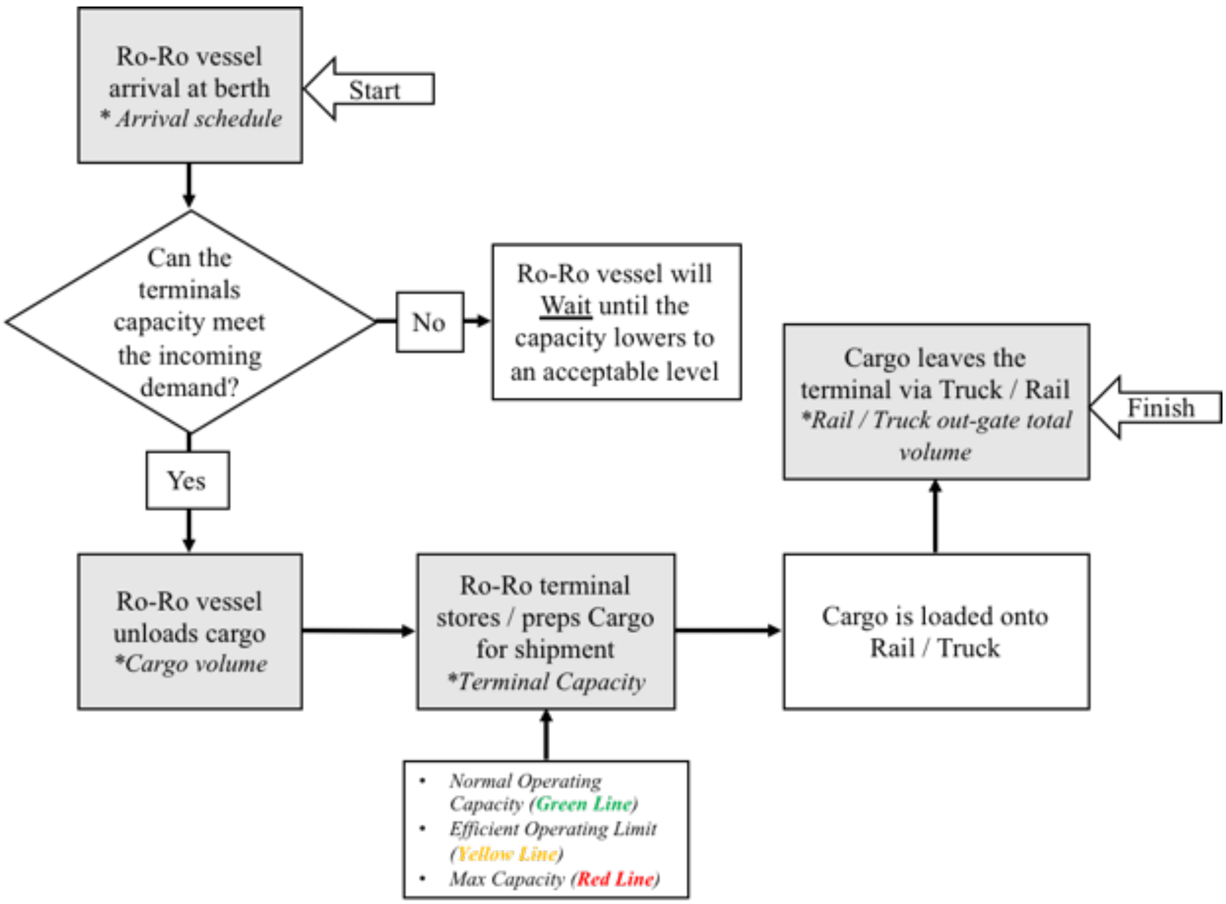


Figure 4: Flow chart Ro-Ro terminal operations (Author created)

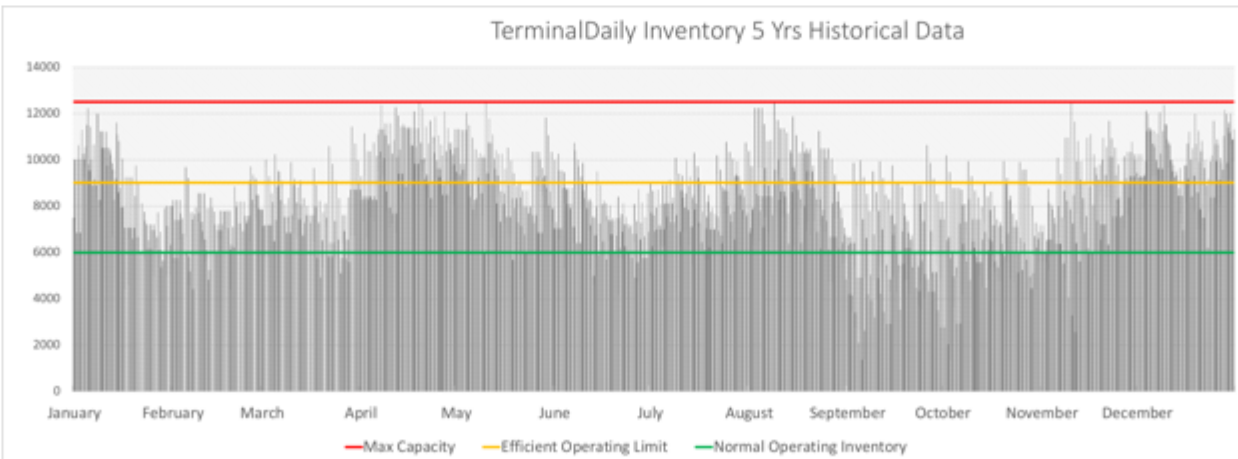


Figure 5: Daily terminal inventory from historical five years (Author created)

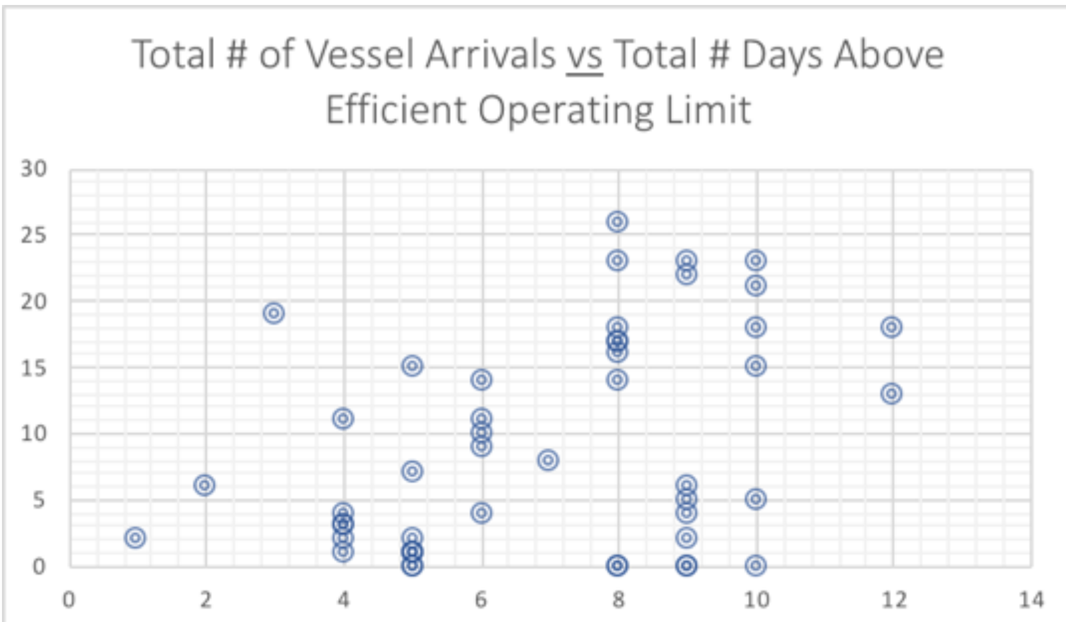


Figure 6: Total number of vessel arrivals (X) compared to the total number of days above efficient operating limit (Y) (Author created)

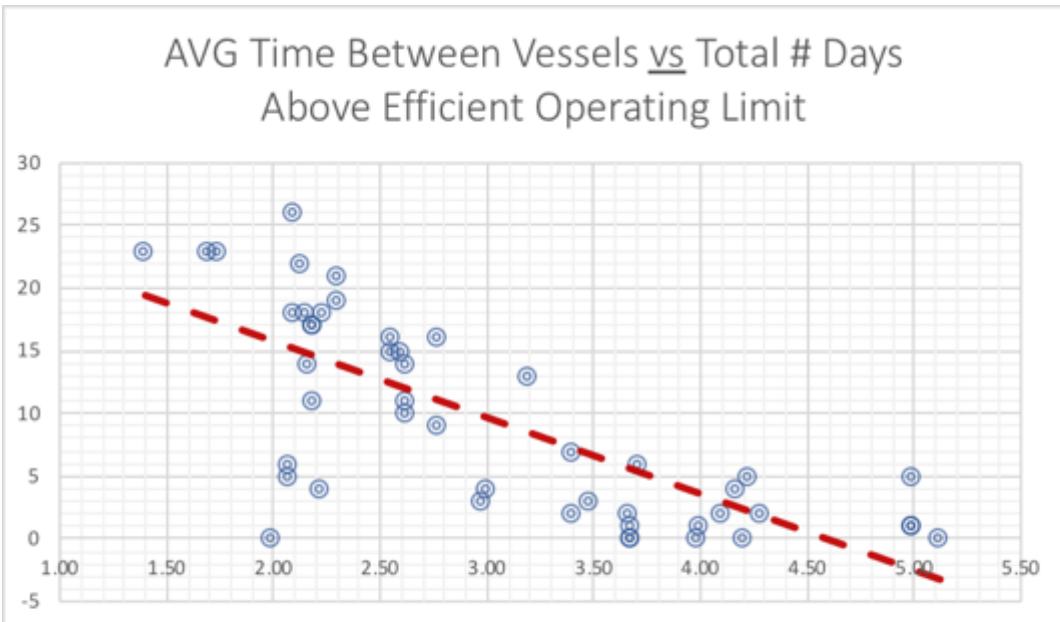


Figure 7: Average time (in days) between vessel arrivals (X) compared to the total number of days above efficient operating limit (Y) (Author created)

Magnitude Ranking	
rank (m)	AVG Time Interval Between Vessels
5	1.4 to 2
4	2.1 to 2.7
3	2.8 to 3.6
2	3.7 to 4.1
1	4.1 to 5.12

Figure 8: Magnitude ranking of the average time interval between vessels (Author created)

Month	AVG Time Interval Between Vessels	Reoccurance Interval	Probability of Vessel Bunching
J	2.6	2.9	35%
F	4.0	23.0	4%
M	2.6	2.9	35%
A	2.1	2.6	39%
M	2.2	2.6	39%
J	4.2	5.8	17%
J	2.1	2.6	39%
A	2.0	2.3	43%
S	3.7	4.6	22%
O	4.2	5.8	17%
N	2.2	2.6	39%
D	1.7	2.3	43%

Figure 9: Probability of vessel bunching (Author created)

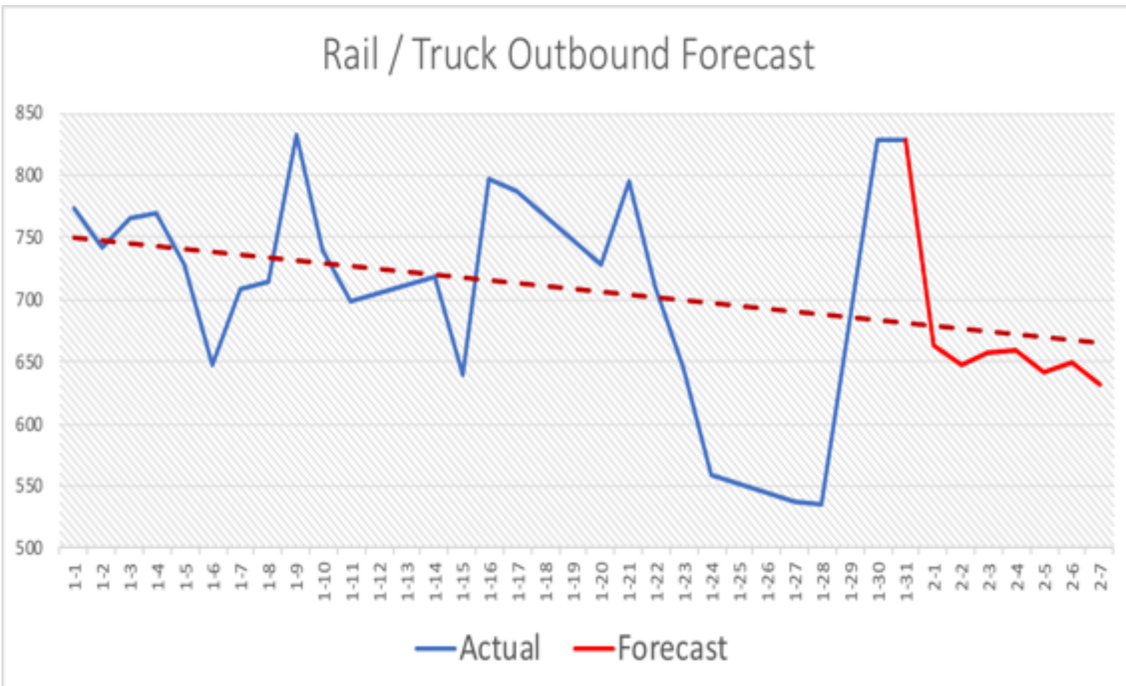


Figure10: Rail and truck total daily volume out-gated (Y) Day of the year with the terminal forecasted RED (X) (Author created)

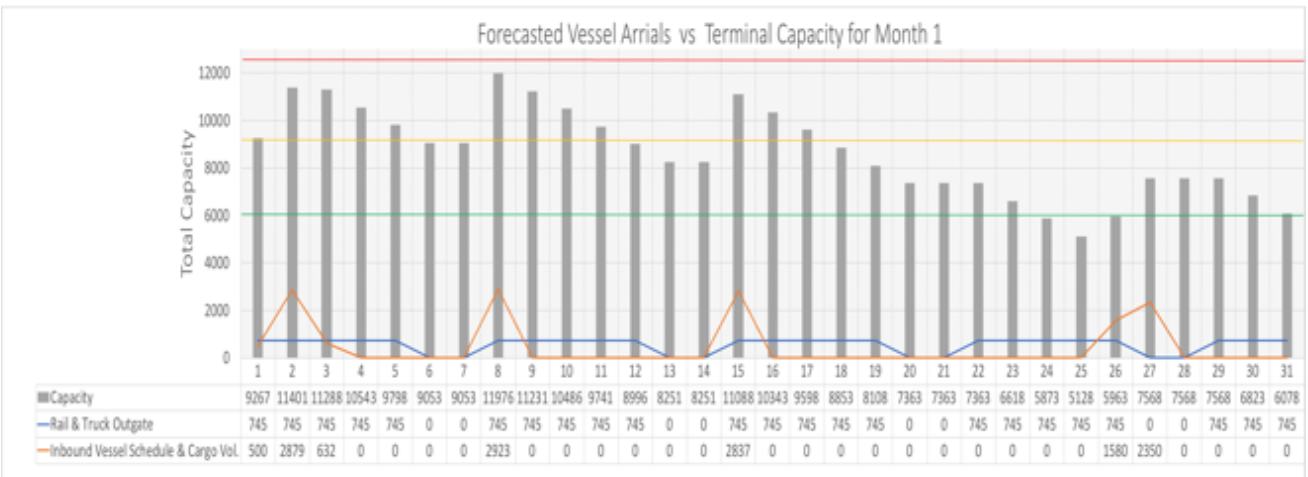


Figure 11: Ebb and flow terminal inventory example (Author created)

Magnutude Rank	Inefficent Operating Capacity
0.1	Negligible impact on process, slight operational changes, compensated by available schuedle slack
0.3	Minor inefficient times, additional scheduling required
0.5	Small delay realized
0.7	Delays increase, additionalovertime scheduling begins
0.9	Large delays in cargo distribution, vessel discharge delayed

Figure12: Magnitude rating scale for risk assessment (Author created)

Month	Risk Assessment	Ranking
January	0.67	Medium Risk
February	0.14	Low Risk
March	0.67	Medium Risk
April	0.82	**High Risk**
May	0.82	**High Risk**
June	0.26	Low Risk
July	0.82	**High Risk**
August	0.83	**High Risk**
September	0.30	Medium Risk
October	0.26	Low Risk
November	0.82	**High Risk**
December	0.94	**High Risk**

Figure 13: Results from the Risk Factor, formatted as a risk assessment by month (Author created)