

**CALCULATION OF GMPH ORIENTED OPTIMUM STORAGE CAPACITY IN  
CONTAINER PORTS**

by

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**CALCULATION OF GMPH ORIENTED OPTIMUM STORAGE CAPACITY IN  
CONTAINER PORTS**

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## **ABSTRACT**

### **CALCULATION OF GMPH ORIENTED OPTIMUM STORAGE CAPACITY IN CONTAINER PORTS**

The increase in the world trade volume in terms of value and quantity and the increasing importance of the concept of economic globalization have increased the importance of the effective use of logistics modes. Since the ports are the transit point of the logistics modes, their performance, capacity and service quality are very important for the economies of the country and the region. For this reason, capacity and performance studies in ports have always attracted the attention of academics

In the study, definitions of capacity types and performance measurement types for container terminals were made and calculation methods were formulated. The definition of optimum storage capacity as a type of capacity was made, and the relationship between performance targets and service quality and storage capacity has been mentioned.

The motivation of the study is to calculate the optimum storage capacity in which the ports can use the yard equipment and operations most effectively at the focal point of the hourly performance (GMPH) which they aim to produce in vessel operations. Regression and Correlation analyzes were made using the data of a certain time period that belongs to a port operator operating in Turkey and the optimum storage capacity was calculated for the targeted hourly vessel operation performance.

## ÖZET

### KONTEYNER LİMANLARINDA GMPH ODAKLI OPTİMUM DEPOLAMA KAPASİTESİNİN HESAPLAMASI

Dünya ticaret hacminin değer ve miktar olarak artış göstermesi ve ekonomik küreselleşme kavramının gitgide önem kazanması lojistik modlarının etkin olarak kullanılmasının önemini arttırmıştır. Limanların lojistik modlarının geçiş noktası olması sebebi ile performansları, kapasiteleri ve hizmet kaliteleri ülke ve bölge ekonomileri için oldukça önem arz etmektedir. Bu sebeple limanlarda kapasite ve performans araştırmaları her zaman akademisyenlerin ilgisini çekmiştir.

Çalışma içerisinde konteyner terminalleri için kapasite türlerinin ve performans ölçüm çeşitlerinin tanımlamaları yapılmış ve hesaplama yöntemleri formüle edilmiştir. Bir kapasite türü olarak optimum depolama kapasitesinin tanımı yapılmış, performans hedefleri ve hizmet kalitesi ile depolama kapasitesinin ilişkisinden bahsedilmiştir.

Çalışmanın motivasyonu; işletmelerin gemi operasyonlarında üretmeyi hedefledikleri saatlik performansın (GMPH) odak noktasında, saha ekipmanlarını ve operasyonlarını en etkin kullanabilecekleri optimum depolama kapasitesinin hesaplanmasıdır. Türkiye’de faaliyet gösteren bir liman işletmesinin belirli bir zaman aralığındaki verileri kullanılarak Regresyon ve Korelasyon analizleri yapılmış ve hedeflenen saatlik gemi operasyon performansı için optimum depolama kapasitesi hesaplanmıştır.

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## LIST OF SYMBOLS

CCR	Container Code Recognition
CFS	Container Freight Station
DT	Dwell Time
E-RTG	Electrified Rubber Tired Gantry
GMPH	Gross Move Per Hour
Gs	Grand Slot
ILOSTAT	International Labour Organization Statistic
IMDG	International Maritime Dangerous Goods
ISO	International Standardization Organization
IT	Information Technologies
LCL	Less than Container Load
MPH	Move Per Hour
NFRP	National Cooperative Freight Research Program
NMPH	Net Move Per Hour
POD	Port Of Discharge
QC	Quay Crane
RMG	Rail Mounted Gantry
RTG	Rubber Tyred Gantry
SC	Straddle Carrier
Sf	Stacking Factor
SSC	Ship to Shore Crane
TT	Terminal Truck
TTT	Truck Turn Time
VGM	Verified Gross Mass
VTT	Vessel Turn Around Time
WO	Working Order

# 1. INTRODUCTION

The increase in the global trade volume in terms of both value and quantity, and the rising significance of economic globalization concept raised the importance of the effective use of logistics modes. As a result of economic globalization, the distance between the raw material and the producer, and between the producer and the consumer lost its importance and revealed the need of delivering the produced product to any end consumer anywhere in the world. Delivering raw materials and products to both producers and consumers at the right time is only possible with the effective use of logistics modes.

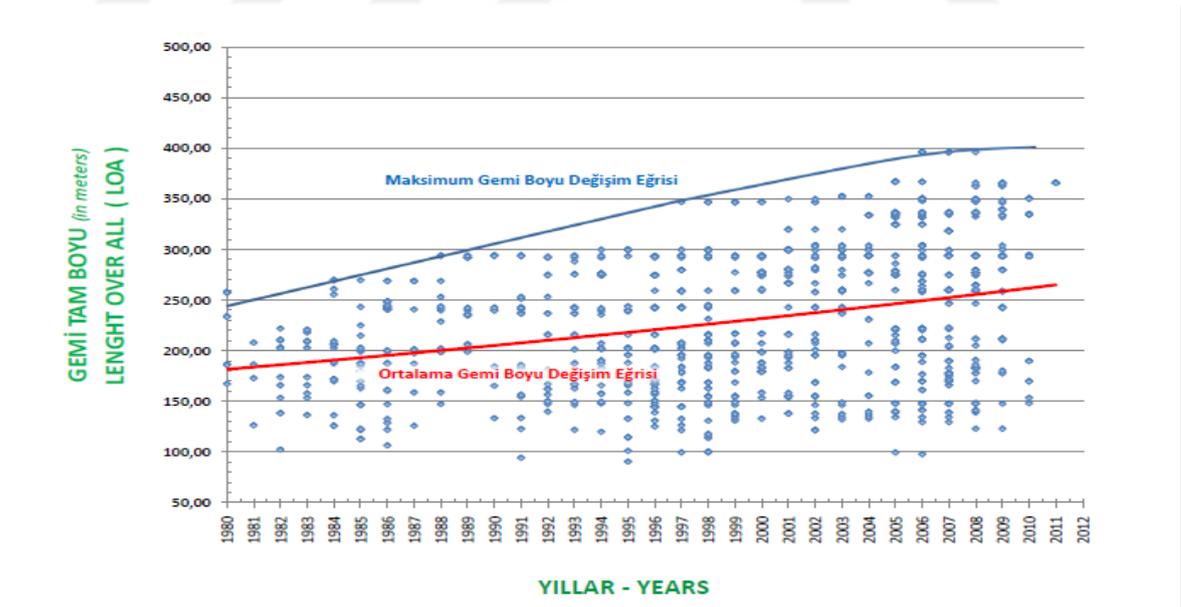
## 1.1 Motivation

It is thought that maritime transportation, which has the most important share among the logistics modes, has a share of around 90 percent in total transportation. The fact that most of the cargoes transported in global trade are carried out by maritime transport requires maritime transport to follow trade trends closely, keep up with changes and be open to continuous development.

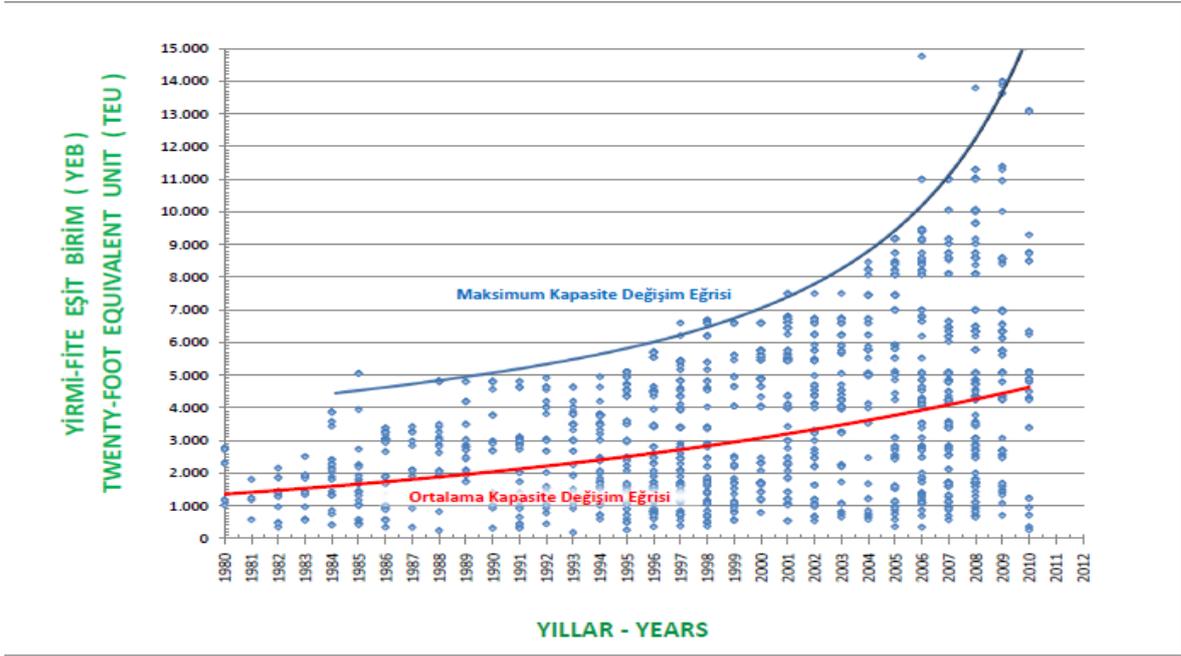
Maritime transport is in a rapid and continuous change depending on the strong competition that exists in its natural structure (Sekin & Gençer, 2019). The demand increase for maritime transport over the years caused the emergence of new routes. Shipowners, who want to increase their profitability and reduce their unit costs by transporting a large amount of cargo at once, built larger and higher capacity vessels. Increasing vessel sizes forced the ports to build docks and quays where large vessels can berth and be handled, and also forced them to buy new and large cranes.

The maritime transport volume, which has risen over the years, required to find some effective solutions such as containerization, since the rate of increase is very high, and made the transportation time important. Especially in the last 20 years, the increase in the variety of cargo and transporting semi-finished and finished goods as cargo has increased the share of container transportation. The container vessel fleet increased by 4.89% in 2019, increasing its share in the total fleet from 13.1% in 2018 to 13.4% (UNCTAD, Review of Maritime Transport, 2019).

The increase in demand for container transportation has led to new investments in this field. Shipowners have started to build new and high-capacity container vessels. SS Supanya, the first container vessel built in 1960, has a length of 152 meters and a capacity of 600 TEU, while MSC Gulsun, which was built in 2019 and is the largest vessel in this field, has a length of 400 meters and a capacity of 23,756 Teu. While container vessels had an average length of 180 m and a capacity of 1300 Teu in 1980, in 2010 their capacity is 4700 Teu with a length of 270 m. (Figure 1-1, Figure 1-2).



**Figure 1.1** Changes in Full Length of Container Ships According To The Years (Nas, 2010)  
(Red Line: Average Ship Length, Blue Line: Maximum Ship Length Change)



**Figure 1.2** Teu Capacity Changes of Container Ships By Years (Nas, 2010)  
(Red Line: Average Capacity Change, Blue Line: Maximum Capacity Change)

In 30 years, while the average vessel length has increased by 1.5 times, the capacity has increased by 3.6 times. These increases have forced the ports to evolve in this area and make the necessary infrastructure-superstructure investments accordingly.

Far beyond being a shelter to vessels affected by bad weather conditions, ports are now basically the logistics centers where cargo is transferred from one mode of transport to another, where cargo is stored in the terminal area and value-added services are provided (Soner, 2010). Changes in maritime transport and logistics in general have also caused radical changes in ports and increased the importance of ports in transportation.

Factors such as changes in the general structure of transportation, line mergers, mega-vessels have forced ports to structural and functional changes;

## **Changes in the Structure of Transport**

The rapid growth of the global economy and the emergence of large exporters such as China led to the emergence of new trade routes and an increase in the share of maritime transport in total transportation. Especially as a result of the cheap labor and high export policy of the Chinese state, even products with low value were gathered together and started to be transported with containers at very low costs, and the concept of LCL (less-than-container-load) was revealed. Thanks to LCL container transportation, loads of low volume and weight are collected and transported in one container. In this way, even small businesses and manufacturers can deliver their products to consumers in any part of the world.

Global brands that want to produce with cheap labor but do not want to move away from their markets have shifted their production facilities to countries with cheap labor, and consequently, they started to deliver these cost-effective products to all world markets by taking advantage of the cheap logistics costs of sea transportation as well. This situation has increased the demand for maritime transport and containerization. In line with these changing dynamics, ports are expected to integrate very quickly to the changes occurring in maritime transport.

### **Mega Vessels**

Container lines, which see the necessity of increasing the carrying capacity in order to meet the increasing demand, have found the solution in the transition to mega vessel in order to reduce the cost and to provide faster service to the customers (Sekin & Gençer, 2019). While vessel lengths have increased 1.5 times on average in 30 years, their capacities have increased 3.6 times. The vessels, which enable the transportation of more containers in one voyage, not only improved the customer portfolio of the lines, but also provided new

target audiences and economies of scale (Sekin & Gençer, 2019). However, mega vessels also create wide-ranging negative effects, as port infrastructure requires the adaptation of port equipment and causes significant cost increases in inventories related to economic order quantities in the supply chain (Çağlar, Esmer, & Bilgin, Mega Konteyner Gemilerinin Tedarik Zinciri ve Limanlar Üzerindeki Etkileri, 2015).

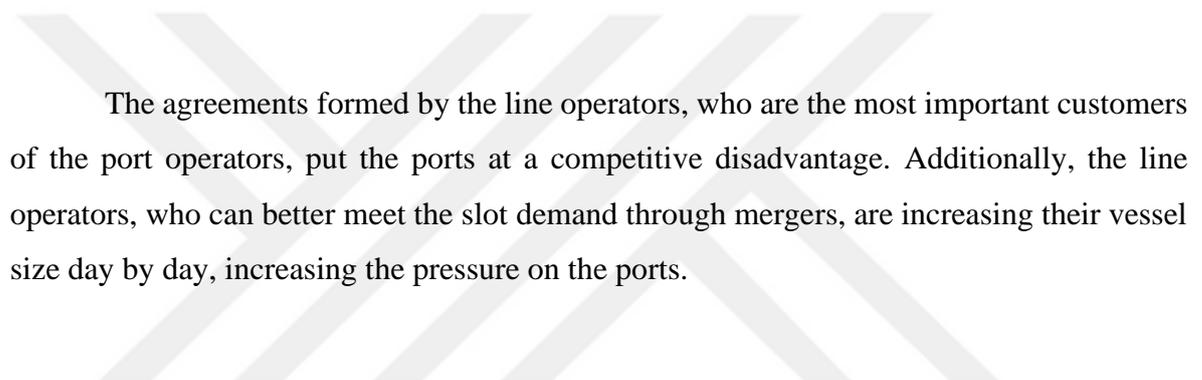
Vessel size increases require the existing ports to extend the berthing areas such as docks and quays and to increase their durability. Otherwise, the increasing size of the vessels forces ports to berth fewer vessels to the existing berths at the same time. These investments are high-cost and long-term investments. Especially the ports with small and natural borders could not keep up with these developments and this led to the emergence of new port investments. The increase of vessel sizes revealed the superstructure investment needs as well as infrastructure investments for port operators. The handling of the vessels which are stacking containers up to 22 rows side by side necessitated the emergence of new and larger ship to shore cranes. All these developments have brought structural and functional changes for port operators.

Mega vessels have caused Hub ports to become an important location, especially on the Asia-Europe line. Ports used by line operators such as Malta Freeport and Asya Port as the main transfer hubs are equipped with infrastructure and superstructure to meet these mega vessels. Containers to be transported from the Far East to Europe are left at the main transshipment ports and transferred to other ports by smaller vessels or by vessels calling at destination ports. Thus, it was ensured that mega-vessels visited fewer ports, reducing operational risks and operating costs.

### **Shipping Line Merger (Alliance)**

Before the 2008 global crisis, increasing freight rates and maritime transportation demands pushed line operators and shipowners into serious competition. However, with the

2008 global crisis, the crash in freight rates caused an excess of vessel tonnage supply. The line operators, who suffered serious losses in the face of this situation, found the solution with line mergers. Mergers have become an operational solution for line operators who also want to share the high operating cost risks that mega vessels bring with them. Operational cooperation between container shipping companies comes in many forms, ranging from slot - chartering and vessel - sharing agreements to strategic alliances (Talley, The Blackwell Companion to Maritime Economics, 2012). Although the basis of line mergers and agreements dates back to the mid-1990s; 2M, Ocean Alliance, and THE Alliance alliances, which play a decisive role in the East-West line today, were established after 2010.



The agreements formed by the line operators, who are the most important customers of the port operators, put the ports at a competitive disadvantage. Additionally, the line operators, who can better meet the slot demand through mergers, are increasing their vessel size day by day, increasing the pressure on the ports.

Increasing competitiveness of port operators is directly proportional to the answers they give to the needs of their customers. The most important service that the line operators, who are their most important customers, expect from the ports is the reduction of turnaround time by spending less time at the quays. This study aims to enable port operators to better measure the service they produce in order to increase the quality of service they provide to line operators and to calculate the yard utilization they need more accurately. The motivation of the study is to calculate the optimum storage capacity where the ports can use their area equipment and operations most effectively at the focal point of the hourly performance, they aim to produce in vessel operations. In the following sections of the study, storage capacity types and calculations, performance types and calculations will be mentioned. By using the realized performances, yard density and yard operation data, the required occupancy rate for the targeted performance will be calculated with the regression analysis method.

Calculations made during the study were made in the light of general practices in the port industry, Drewry and UNCTAD industry reports, existing studies in the literature and the author's experience in the port industry.

## **1.2 Literature Review**

### **1.2.1 Container Terminals**

The increasing share of maritime and container transportation in world trade has led academics to work in this field. There are many studies on container transportation and ports in the literature. Detailed information on port and terminal management are available in the studies of (Steenken, Voss, & Stahlbock, 2004; Böse, 2011; Esmer, 2019). Since each country and economic region has different dynamics in terms of ports, regional port features have also been mentioned in some studies made on ports. Ports directly affect the country's economy as they are the trade connection points of countries in the global economy in a sense. Therefore, in the literature, there are studies that examine the country and regional ports in depth. Çağlar (2012) focused on Turkish ports in his study examining the efficiency and productivity analyzes of ports. Elferjani (2015) deepened his study on Libyan ports, focusing on the importance of port performance in developing economies.

Statistical information about the previous year's maritime transport, container transport and ports can be accessed from the Review of Maritime Transport reports published by UNCTAD every year. The *Review of Maritime Transport* is a recurrent publication prepared by the UNCTAD secretariat since 1968 with the aim of fostering the transparency of maritime markets and analyzing relevant developments (UNCTAD, Review of Maritime Transport, 2019). In addition, Drewry Maritime Research's Container Terminal Capacity and Performance Benchmarks reports can be examined for capacity and performance comparisons of container terminals within a given sample.

### **1.2.2 Capacity**

Capacity problems in ports have always attracted the attention of researchers. Studies on the capacity of container ports in the literature started in the 1980s (Sekin & Gençer, 2019). The changing trends in port and container transportation over the years have brought capacity and accurate capacity measurements to a very important point for ports. Salminen (2013) made one of the most detailed studies on capacity measurements and capacity types in ports. The author examined the capacity as Static & Dynamic Capacity and Theoretical & Actual Capacity in his study and made a case study specific to Southeast Asian Port. Çağlar (2012) defined the importance of capacity in his study where he conducted data envelopment analysis and efficiency and productivity analysis of Turkish Private Ports as “A comprehensive capacity analysis is required for an accurate efficiency and productivity measurement”.

There have been serious changes and developments in port handling equipment over the years. The high cost of these equipment requires detailed research and examination at the stage of choosing the right equipment of the investment. There are studies in the literature that can shed light on this issue. Chu & Huang, 2014 focused on the definition of capacity according to the type of equipment used in their studies. Kalmar (No Date) mentioned the effect of yard capacity of handling equipment and equipment matching on productivity in the knowhow they published.

Undoubtedly, one of the factors that most affect the capacity is dwell time. Raballand, Refas, Beuran, & Isik (2012) also touched upon the country and region commercial relations of dwell time in their study where they talked about the effects of dwell time on port performances and capacity. Soberón (2012) determined in their study that a decrease in dwell time from 11 days to 10 days will cause an increase of 10% in annual yard capacity.

### **1.2.3 Performance**

Elferjani (2015) compared the performance efficiencies of Libyan ports with the Data Envelopment Analysis method. The increasing popularity of container transportation and global economic developments have increased the importance of liner transportation day by day. In the face of increasing demand; the efficiency and performance of port operators has become an important indicator for all parties. Gülmez & Esmer (2019), in their literature study on capacity measurements at ports, found that there is an increase in studies focusing on performance as of 2000. In addition, in their analysis, the authors determined that the studies on container terminals mostly focused on capacity planning and performance.

Increasing port performance and efficiency is possible by keeping up with developments in all fields. In recent years, IT applications, auto gate projects, port automation projects in ports have become increasingly common. Lee, Tongzon, & Kim (2012) focused on customer connections and terminal management-oriented E-transformation in ports. The authors provide a useful conclusion based on empirical studies, that Planning tools or e-Transformation can help ports in retaining competitiveness while ensuring customer satisfaction (Kulkarni, Lau, Wang, Sivabalasingam, & Tran, 2018).

Most of the studies examining port performance in the literature have focused on vessel operating speed. (Jo & Kim (2019) investigated the effects of ship to shore cranes on performance indicators and vessel performance. In the study, the authors examined in detail the effect of technical features of SSCs such as hoist, trolley, gantry, and boom on their performance. Schwientek, Lange, & Jahn (2020) used the simulation method in their studies where they examined the effects of terminal size, yard block assignment and dispatching methods on port performance. Talley (2007) in his study examining port performance from an economic perspective, tried to find an answer to following question: 'Should a port's performance be evaluated relative to its performance over time (a single-port approach) or relative to the Performance of other ports (a multi-port approach)?'

As will be explained in the following sections of the study, there are many factors which affect the performance of vessel operations. There are also some studies in the

literature that deal with and examine these factors separately. While Zhang & Kim (2009) talked about the effect of dual cycle rate in vessel operation on vessel performance and ways to maximize it, Cordeau, Legato, Mazza, & Trunfio (2015) focused on the effect of housekeeping rate in transshipment ports.

#### **1.2.4 Optimum Capacity**

Most of the studies on optimization and optimum area/region have been cost-oriented. Optimization is defined as a technology which enables reaching goals by using the resources existing in a system (such as labor, time, capital, processes, raw materials, capacity, equipment) in the most efficient way, to achieve certain goals (such as reducing cost, maximizing profit, maximizing capacity utilization and maximizing efficiency) (Gass, 2000). Optimization, which has an important place in business science, generally focuses on costs.

Although there are studies on optimum capacity and capacity optimization in the literature, most of the studies are cost or throughput focused. A port's economic optimum throughput is that throughput that satisfies an economic objective of the port (Talley, 2007). Focusing on port yard capacity, Jurjevic (2011), Chang, Tongzon, Luo, & Lee (2012), Zenzerovic, Vilke, & Antonini (2015) examined the optimum yard capacity in their study, but they considered cost as the focus.

Çağlar (2012) stated in his study that the optimum capacity is under the current and theoretical capacity without difficulty and where the total costs are the lowest. Oral & Kişi (2011) defined optimum capacity in the port capacity review report as; “The optimum capacity in ports is a capacity in which port economy (income, expenses and profitability, etc.) is taken into account as well as the cargo volume, according to the other two capacity calculations (theoretical and current capacities).”

In the literature, studies focusing on the optimization of the berthing capacities of port docks and quays and the waiting times of vessels for berthing have also been found. Gürhan (2000) focused mainly on the quay capacity in his research on the optimum port capacity of İzmir Alsancak Port. Soner (2010) mentioned the optimal number of berths in the port in a part of his detailed study in which he developed a simulation on the optimization of logistics processes in container terminals.

Mappangara, Samang, Adisasmita, & Sitepu (013) who has made one of the most comprehensive studies on yard capacity in container ports and terminals, focused on cost-oriented optimum yard capacity. However, this study is a study specific to the Pantolon port, and it is open to discussion in terms of seeing the general effect in other ports.

In the literature, no study has been found on the optimum storage capacity focused on vessel performance in container ports. During this study, studies on capacity, performance, container terminals and optimization in the literature, the author's industry experience, sectoral reports/statistics and general port practices were used.

## **2. STORAGE CAPACITY CALCULATIONS IN CONTAINER TERMINALS**

In terms of services provided to vessels and cargo, ports need a certain capacity. Capacity measurements in ports have strategic importance in many aspects such as the continuity of the services provided, the necessity of new investments and shifting these new investments to the right area and performance measurements. Ports can only produce services as much as their capacity (Esmer, Liman ve Terminal Yönetimi, 2019).

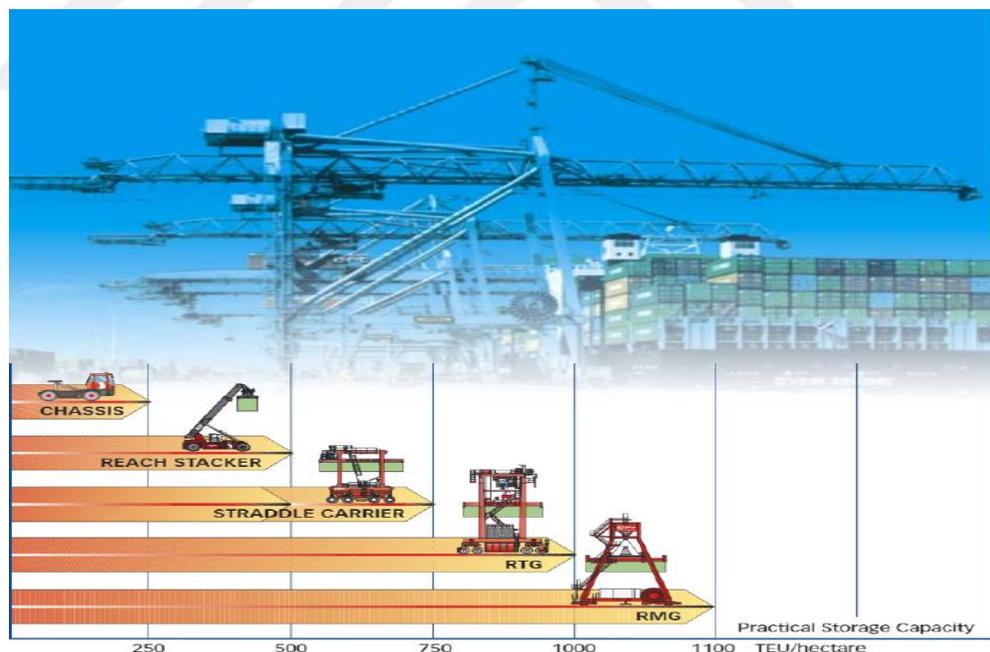
Capacity for ports refers to the service that the ports can produce, which is calculated by taking into account the values such as equipment, storage area, vessel maneuvering areas, workforce and hinterland.

Considering the services provided at the ports; capacity types such as storage capacity, handling capacity, door capacity, CFS capacity, vessel berthing capacity can be mentioned. Each capacity type has different calculation methods as well as different dynamics.

One of the biggest advantages that container storage brings to maritime transport is standardization. The standard sizes of circulating containers allow them to be stacked on top of each other in ports and vessels. The way the containers are stacked and the maximum floor heights they can be stacked directly affect the storage capacity. The determining factor of the stacking shape and the maximum floor height is the superstructure equipment to be used in storage.

One of the most important decisions in container terminal installation is the determination of the superstructure equipment to be used. Different equipment such as RTG, RMG, Straddle Carrier, Reach Stacker can be used in yard operations. As can be seen in Table xx, each equipment has different advantages, disadvantages, and an effect on storage capacity.

**Straddle Carrier;** Due to their high mobility, their mobility rate is high. The SCs are independent from any other equipment and are able to perform all the different handling operations (Böse, 2011). They do not need transportation equipment such as yard trucks and shuttle trucks, as they can carry containers in addition to handling. This saves operation and investment costs. However, the storage capacity per hectare of Straddle Carriers, which can stack 3 times at most, is quite low compared to RTG and RMG. ( Figurexx)



**Figure 2.1:** Practical Storage Capacity  
Source: Kalmar.com

**Reach Stacker;** While their investment costs are lower than other equipment and their high mobility is one of their advantages, high maintenance costs, risks in

terms of occupational health and safety and transfer costs in full container stacks are among their disadvantages.

**Rubber Tyred Gantry;** RTG, which is the most used superstructure equipment in ports today, provides high energy savings and low carbon emissions thanks to its electric motors. The most important advantages of RTGs, which generally work over a certain area, are that they have a certain amount of mobility thanks to their rubber wheels. RTG crane system gives very high stacking density because of high stacking capability and block stacking (Kalmar, No Date). However, storing a large amount of containers in a certain area can create a disadvantage in terms of vessel performance, especially for ports operating at high capacity, and may result in high planning costs.

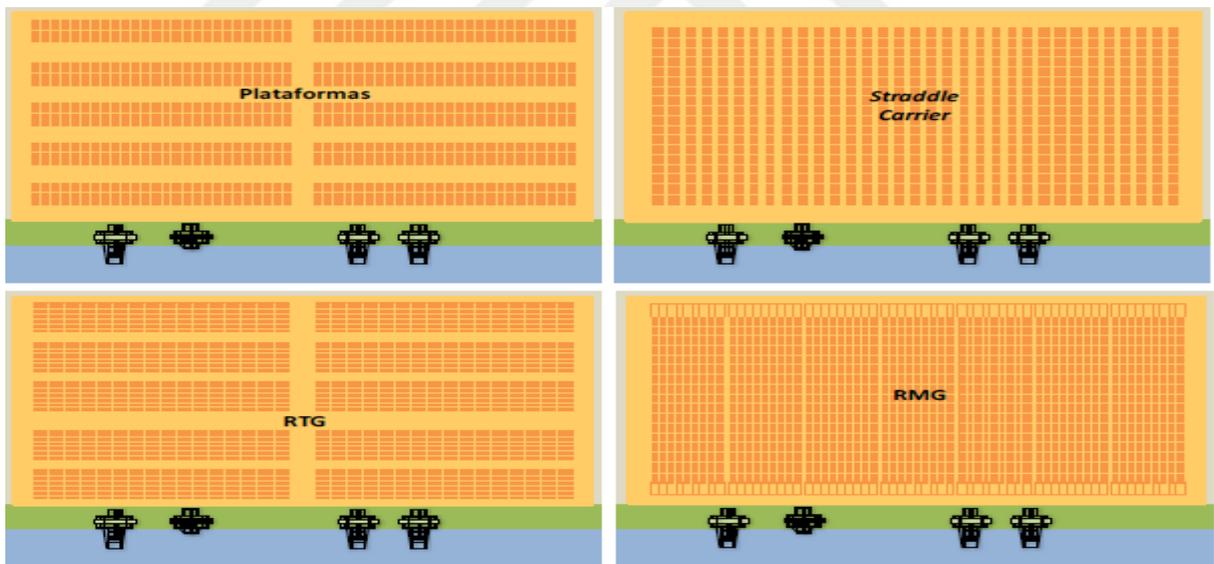
**Rail Mounted Gantry;** Besides having high stacking capacity and high energy savings like RTG, RMGs have operational advantages such as stability. However, moving on the rail causes restrictions on their mobility and high investment costs.

The quality of the stacking operations and storage-area utilisation is indicated by the yard density, which gives the number of TEU per hectare of the container storage yard (Kemme, 2013). As can be seen in Table 2-1, the yard capacity due to yard density (occupancy) varies according to the equipment used in storage. Capacity calculations in this study are performed assuming that RTG is used in storage.

	<b>Advantages</b>	<b>Disadvantages</b>
<b>SC</b>	Flexibility and mobility, low labour cost, low stacking height (performance), no need extra equipment for STS operation	Traffic jam, low stacking height (Yard), high energy cost, slower for travel than TT

<b>RS</b>	Low investment cost, low operation cost, Flexibility and mobility	Low automation, high maintenance cost, risks arising from mobility (Accident etc.),
<b>RTG</b>	Low energy and maintenance cost (E-RTG), high automation, High stacking height (Yard),	High stacking height (Performance), mixed traffic, planning cost. High investment cost due to equipment cost
<b>RMG</b>	Low energy and maintenance cost, high automation, High stacking height (Yard), operational advantage (stability)	High investment cost due to equipment and construction costs, low mobility, High stacking height (Performance), mixed traffic, planning cost

**Table 2-1:** Comparison of Handling Equipment



**Source:** Monfort et al. (2011)

**Figure 2.2:** Storage System of Equipment Types

In this section, the storage capacities and types for ports will be examined. Storage capacity represents the number of containers that can be stored at the same time. However, capacity calculations in container terminals differs from the classical storage capacity

calculation due to the existence of variables such as stacking height, waiting time of containers at the port, stacking factor, ground slot according to the equipment used;

**Ground Slot;** It shows the areas where containers can be stacked in the storage yard. Each block on top of each other in the stacking areas represents a Ground slot (Figure 2.3). Therefore, the maximum number of containers that can be stored in a yard is found by multiplying the floor height of the Ground slot (Sekin & Gençer, 2019).

**Maximum Stack Height:** The maximum stack height is the maximum number of floors that can be stacked in a Ground slot (UNCTAD, 1985). The number of floors varies according to the type of superstructure equipment (Table 2-2). While RTG (Rubber Tyred Gantry) can stack up to 6 floors high, SC (Straddle Carrier) can stack up to 3 floors. Ports with narrow area but high business volume prefer equipment with a maximum stacking height in order to increase their storage capacity. While the maximum stack height creates an advantage in terms of capacity, it requires high planning costs. Productivity decreases in parallel with the increasing density (occupancy) rate in equipment with more stack height. Depending on the density rate, the current stack height increases. As the stack height

increases, the intra terminal transfer rate increases. Wide blocks typically imply slower cranes, while high blocks imply more reshuffles (Carlo, Vis, & Roodbergen, 2014).

Equipment (wide; nominal stacking height)	Area density (ground slots ha)	Operational average stacking height (h)	System density or static capacity ( $C_s$ ) (TEU/ha)
Chasis	150 - 250	1,00	150 - 200
Forklift (-; 3)	130 - 190	1,80	234 - 300
Reachstacker (-; 3)	200 - 260	1,80	360 - 450
SC (-; 3+1)	265 - 330	1,80	475 - 500
RTG (6; 4+1)	260 - 300	2,40	650 - 670
RTG (7; 5+1)	290 - 310	2,75	800 - 850
RTG (8; 5+1)	300 - 350	2,75	825 - 965
RMG (9; 4+1)	340 - 430	2,80	1.100 - 1.200

Source: Monfort et al. (2011)

Table 2-2: Equipment Storage Capacity

**Stacking Factor;** For maximum storage capacity, containers are stacked on a ground slot at the maximum floor (Sekin & Gençer, 2019). However, overhead cranes used for stacking containers need some free space in order to move the containers in the stack in the area where they are located, and the number of containers corresponding to this empty area is expressed by the stacking factor (Soberón, 2012). For example; If the g1h1 container in the RTG stack in Figure 2.3 is wanted to be loaded onto the vehicle, the 5 containers on it will have to be transferred to another place within the same stacking area. Therefore, in order to ensure the continuity of the operation in this stowage area, there is a need for 5 containers of free space in the same bay.

The stacking factor calculation for RTGs that can stack 7 ground slots in the same bay is as follows;

$$Sf = (G_s * H_m) - (H_m - 1) / (G_s * H_m) \quad Sf = (7*6) - 5 / (7*6) = 0,88$$

**Sf** = Stacking Faktör

**Gs** = Ground Slot

**H<sub>m</sub>** = Maksimum Height

The 0.88 number calculated for the standard RTG (7 ground slot 6 height) stack means that approximately  $6 \cdot 0.88 = 5.28$  containers can be stacked in each ground slot. Stacking factor, which is an important factor in instant storage capacity calculations, is an important point that separates port capacity calculations from standard capacity calculations.

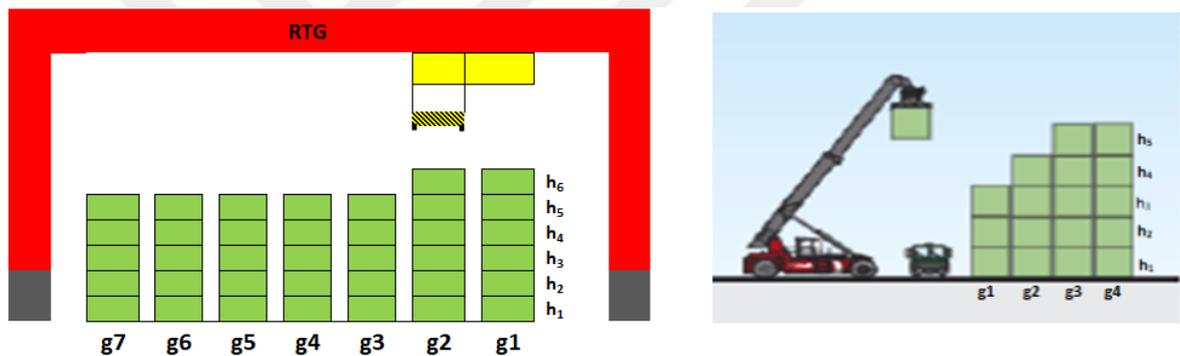


Figure 2.4: Stacking Factor

Dwell Time; The average of the time that the containers wait is called the dwell time (UNCTAD, 1985). Containers may wait in the port area for a certain period of time for various reasons (such as customs procedures, storage needs, commercial factors). The time that the containers spend in the port storage area is called dwell time.

Dwell time is an important criterion in annual storage capacity calculations. By taking the average of the waiting times of the containers in the yard, the average dwell time to be used in the calculation is determined. Between 2014 and 2018, the average dwell time per TEU in ports is calculated as 6 days (UNCTAD, Review of Maritime Transport, 2019).

When calculating the annual processing capacity, a Dwell Time Rate is obtained by dividing the number of days the port is operating by the average dwell time. The number of cycles is multiplied by the total instant storage capacity to calculate the capacity-oriented maximum throughput for the year.

The lower the average dwell time means the greater container cycle and thus the annual throughput capacity within the terminal. In this sense, for example, if average dwell time is reduced from 11 to 10 days, annual yard capacity increases by 10% (Soberón, 2012). For this reason container terminal operators want the average dwell time to be low. However, because high dwell times are often driven by a minority of problematic shipments, it is difficult to decrease the average/ mean dwell time in the short and medium term (Raballand, Refas, Beuran, & Isik, 2012).

When all factors are brought together, the following formulas emerge for the annual storage volume:

<p><b>Stacking Factor (For RTG 7+1, 6+1 standard)</b></p>	$SF = \frac{(Gs \cdot H_m)^{-5}}{(Gs \cdot H_m)}$ $SF = \frac{(7 \cdot 6)^{-5}}{(7 \cdot 6)} = 0,88$ <ul style="list-style-type: none"> <li>• <b>SF</b> = Stacking Factor</li> <li>• <b>Gs</b> = Ground Slot</li> <li>• <b>H<sub>m</sub></b> = Maximum Height</li> </ul>
<p><b>Dwell Time Rate (average number of turnovers per year)</b></p>	$DT_r = \frac{Wd}{Dw}$ <ul style="list-style-type: none"> <li>• <b>DT<sub>r</sub></b> = Dwell Time Rate</li> <li>• <b>Wd</b> = Port Working Days</li> <li>• <b>Dw</b> = Average Dwell Time</li> </ul>

<b>Storage Capacity (Instant)</b>	$C_s = G_s * H_m * SF$ <ul style="list-style-type: none"> <li>• <b>C<sub>s</sub></b> = Storage Capacity</li> <li>• <b>G<sub>s</sub></b> = Ground Slot</li> <li>• <b>H<sub>m</sub></b> = Maximum Height</li> <li>• <b>SF</b> = Stacking Factor</li> </ul>
<b>Annual Storage Capacity</b>	$C_a = G_s * H_m * SF * DT_r$ <ul style="list-style-type: none"> <li>• <b>C<sub>a</sub></b> = Annual Storage Capacity</li> <li>• <b>G<sub>s</sub></b> = Ground Slot</li> <li>• <b>H<sub>m</sub></b> = Maximum Height</li> <li>• <b>SF</b> = Stacking Factor</li> <li>• <b>DT<sub>r</sub></b> = Dwell Time Rate</li> </ul>

**Table 2-3:** Annual Storage Volume Formulas

### Sampling of Capacity Calculations

In Figure 5, a port storage area is simulated as an example. On this area the application of formulas will be demonstrated. The storage area consists of standard RTG blocks and the yard features are as follows;

- 6 RTG blocks
- Each yard has 7 rows and 1 truck line.
- Maximum 6 layers of containers can be stacked on each row.
- Each block consists of 10 bays

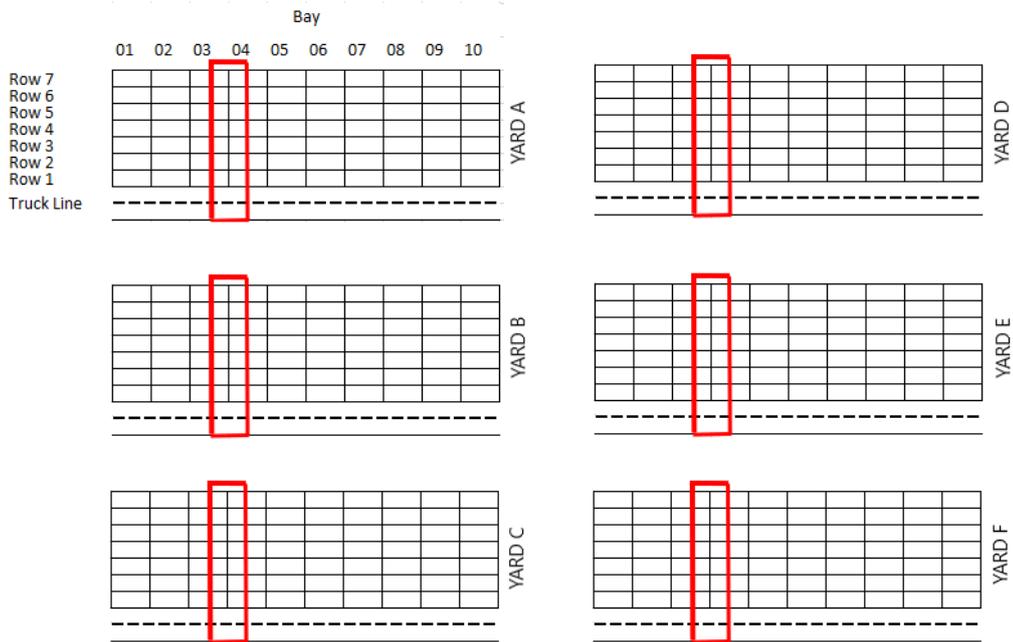


Figure 2.5: Yard Design

### Ground Slot

The areas where containers can be stacked on top of each other in a yard are called ground slots. In our example yard, each RTG block has 10 bays and each bay has 7 rows. In other words, 6 layers of containers can be stacked on each row in each bay. The first floor of the rows in each bay represents the ground slot. Therefore, in each RTG block in our sample area;

$$Gs = 10 * 7$$

= There are 70 ground slots. Since our yard consists of 6 RTG blocks in total, the total ground slot;

$$\sum(Gs) = 70 * 6$$

$$= 420$$

### **Maximum Stack Height**

Due to the standard RTG equipment, a maximum of 6 layers of containers can be stacked on each row.

$$H_m = 6$$

### **Stacking Factor**

As explained in detail in the previous section, a certain amount of space must be left in each bay due to operational requirements. The stacking factor for standard RTG blocks was calculated as 0.88. In our example site, the stacking factor will be taken into account as 0.88 in capacity calculations.

$$Sf = (Gs * H_m) - (H_m - 1) / (Gs * H_m)$$

$$Sf = (7 * 6) - 5 / (7 * 6) = 0,88$$

### **Dwell Time Rate**

As we mentioned in the previous section, the dwell time rate is obtained by dividing the average dwell time by the number of days the port is actively working. In our sample yard, it is taken into account that our port will work 365 days. The 6 days specified in the UNCTAD 2019 reports will be used as the average dwell time.

$$DTr = Wd/Dw$$

$$= 365/6$$

$$= 60,8$$

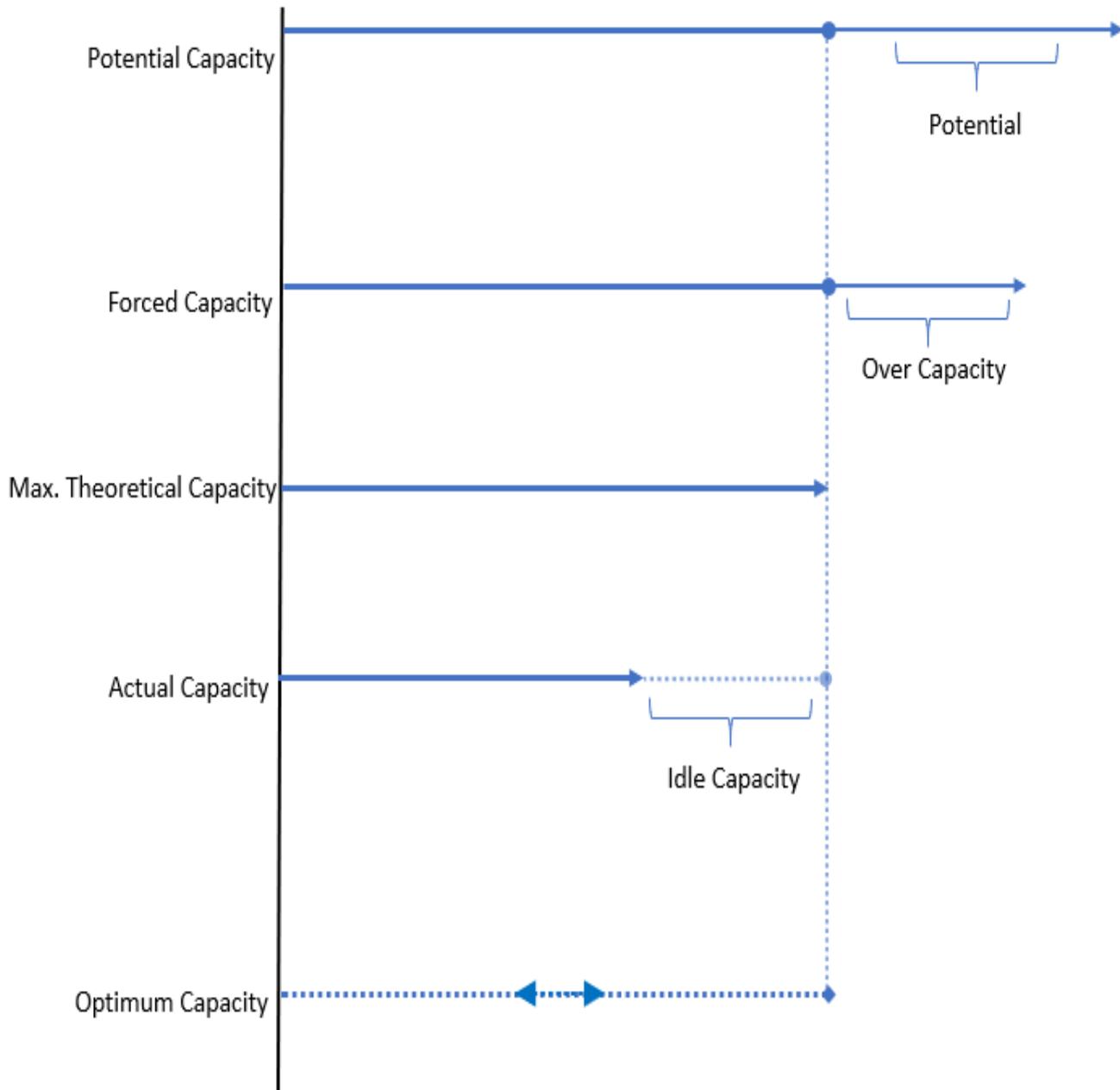
<p><b>Stacking Factor (For RTG 7+1, 6+1 standard)</b></p>	$SF = \frac{(Gs*Hm)-(Hm-1)}{(Gs*Hm)}$ $SF = \frac{(7*6)-5}{(7*6)}$ $=$ <p style="text-align: right;"><b>0,88</b></p>
<p><b>Dwell Time Rate (average number of turnovers per year)</b></p>	$DT_r = \frac{Wd}{Dw}$ $= \frac{365}{6}$ $= 60,8$
<p><b>Storage Capacity (Instant)</b></p>	$C_s = Gs * H_m * SF$ $= 420 * 6 * 0,88$ $= 2.217 \text{ TEU}$
<p><b>Annual Storage Capacity</b></p>	$C_a = Gs * H_m * SF * DT_r$ $= 420 * 6 * 0,88 * 60,8$ $= 134.830 \text{ TEU}$

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When we apply the formulas in our sample port yard, it is seen that the instant maximum storage capacity is 2,217 TEU, and the annual storage capacity is 134,830 TEU. Calculations are made over teu and each ground slot represents a 20' container. In order to be able to calculate on the number of containers, the teu factor of the port operator should be calculated and added to the formula.

In the next parts of the study, the capacity types will be discussed. In the study, the types of capacity will be examined under 6 main headings as follows, the optimum storage capacity will be examined in detail in section 5;

- Potential Capacity
- Forced Capacity
- Maximum (Theoretical) Capacity
- Idle Capacity
- Actual Capacity
- Optimum Capacity



**Table 2-4:** Capacity Types

## 2.1 Maximum (Theoretical) Capacity

Theoretical capacity refers to the maximum annual business volume that the port operator can perform with its infrastructure and superstructure equipment. Theoretical capacity is the maximum capacity that the storage yard, in which all the functions specified

in the port information forms, are used actively in operational suitability, and that the equipment can produce when it operates at full capacity.

Theoretical capacity is a production power that takes into account acceptable delays, does not allow forcing, and can be maintained continuously (Çağlar, Türk Özel Limanlarının Etkinlik ve Verimlilik Analizi, 2012). The capacity calculated in the examples above is the theoretical capacity. In theoretical capacity, there are no extreme cases as in forced capacity, it is the capacity that the port operator can produce if it uses all of its capabilities. It is the type of capacity that port operators generally use as a way to express their size and volume. There are some factors that directly affect the theoretical capacity, such as equipment type (Table 2-2), yard area width, dwell time. In order to increase the theoretical capacity and reach the potential capacity, certain infrastructure and superstructure investments must be made. However, reductions in dwell time without investing in infrastructure and superstructure will also increase the theoretical capacity. Likewise, increases in dwell time will cause a decrease in theoretical capacity. In this sense, for example, if average dwell time is reduced from 11 to 10 days, annual yard capacity increases by 10% (Soberón, 2012). In our sample storage capacity calculation (Section 3), the average dwell time was taken into account as 6 days and the dwell time rate was calculated as 60.8. The effect of changes in average dwell time on capacity is shown in the table xx, with other variables remaining constant.

<b>Average Dwell Time</b>	<b>Dwell Time Rate</b>	<b>Annual Storage Capacity (Theoretical) (TEU)</b>	<b>Difference (From Reference)</b>
4	91,25	202.356	+%50
5	73	161.884	+%20
6 (Reference)	60,8	134.830	
7	52	115.315	-%14,3
8	45,6	101.122	-%25

**Table 2-5:** Dwell Time Case Study

It is the lowest cost capacity increase alternative for port terminals due to the impact of average dwell time on Annual Storage Capacity. However, ports do not have much effect on dwell time. In general, environmental factors, exchange rates for developing countries, economic crises and external factors such as the Covid 19 epidemic in 2020 are effective on dwell time changes. It is a dangerous situation for port operators as the decreases in average dwell time have an effect on the capacity increase without any cost, and on the contrary, increases will cause decreases in Annual Storage Capacity. As can be seen in Table 2-5, an increase of approximately 33% in average dwell time (if the reference average dwell time is 6), causes a 25% decrease in Annual Storage Capacity. Likewise, a decrease of approximately 33% in average dwell time (if the reference average dwell time is taken into account 6) causes an increase of 50% in Annual Storage Capacity.

Although the calculations and definitions made in this study are made on the storage capacity, the maximum equipment capacity is also mentioned in addition to the maximum storage capacity in the theoretical capacity definition. However, the focus of the study will be on storage capacity.

## 2.2 Forced Capacity

As we mentioned in the previous sections, the capacities of the ports represent the annual business volumes they can produce. This capacity is calculated with the infrastructure and superstructure equipment they have. However, in some periods, ports may take urgent measures and create a forced capacity that does not actually exist within the theoretical capacity (Çağlar, 2012). Ports take certain urgent actions and measures in order to exceed the theoretical capacity in emergency situations. To expand the theoretical equipment capacity, ports;

1. Can temporarily rent equipment
2. Can postpone the periodic maintenance of the equipment,
3. Can delay staff trainings
4. Can ignore cost calculations in the use of equipment (such as the use of E-RTG outside its area)

besides similar measures and emergency actions can also be applied. Likewise, to increase the theoretical storage capacity, ports;

- Can rent a warehouse, etc., near the port,
- Can use the parts (roads, waste areas, parking lot, etc.) that are not visible in the business plan as storage areas,
- Can expand the business plan urgently, if possible
- Can change storage dynamics (like putting import/export containers in the same space)
- Can ignore stacking factor in storage areas
- Can make short-term changes in the tariffs to reduce the Dwell time,

and can consult to similar measures and emergency actions. The measures and actions to be taken may vary depending on the dynamics of the port operator.

Since the forced capacity is a capacity outside the limits specified in the theoretical capacity, a calculation method has not been determined, but some port operators determine a certain peak factor (security factor) in their calculated theoretical capacity and include the part that they can work above the theoretical capacity into the capacity by deducting it from the theoretical capacity calculation. Thus, the port operation does not exceed its capacity even at peak times (times when the transaction flow is above average).

The urgent actions taken by the port operator to operate within the enforced capacity limits require concessions in different areas. E.g; Renting temporary equipment is usually more costly than purchasing equipment, or the use of areas that are not visible as storage areas in the operation plan as storage areas may disrupt the traffic order in the port and adversely affect truck turn time and therefore the performance of the vessel. Likewise, ignoring the stacking factor will cause serious decreases in operation speed. Operation of the port operator with forced capacity may cause;

- Additional costs
- Work accidents,
- Machine damages,
- Shortening the life of the machines,
- Low service quality
- Decreases in vessel and yard operation performance
- Revenue loss
- Delays in some services (such as CFS, Weighbridge, gate) and thus customer complaints.
- Transactions below business standards

and similar situations. Therefore, working for a long time with forced capacity is not sustainable for port operators.

The port operator may exceed the maximum theoretical capacity in some periods, and may also operate below the maximum theoretical capacity from time to time. The port

operator should always be prepared for such situations and distributions. Especially near future plans and budgets should be made very well. As illustrated in Figure 2.5, monthly capacity distributions may fluctuate due to regional and global economic fluctuations, political events, exchange rates, national holidays, political fluctuations, etc. In Figure 2.5 sampling, the movement of the monthly realized capacity distribution relative to the monthly average maximum theoretical capacity is shown. While the capacity realized in certain periods is lower than the maximum theoretical capacity, that is, in the idle capacity area, it is seen that the realized capacity in some periods is above the maximum theoretical capacity, that is, in the excess capacity region.

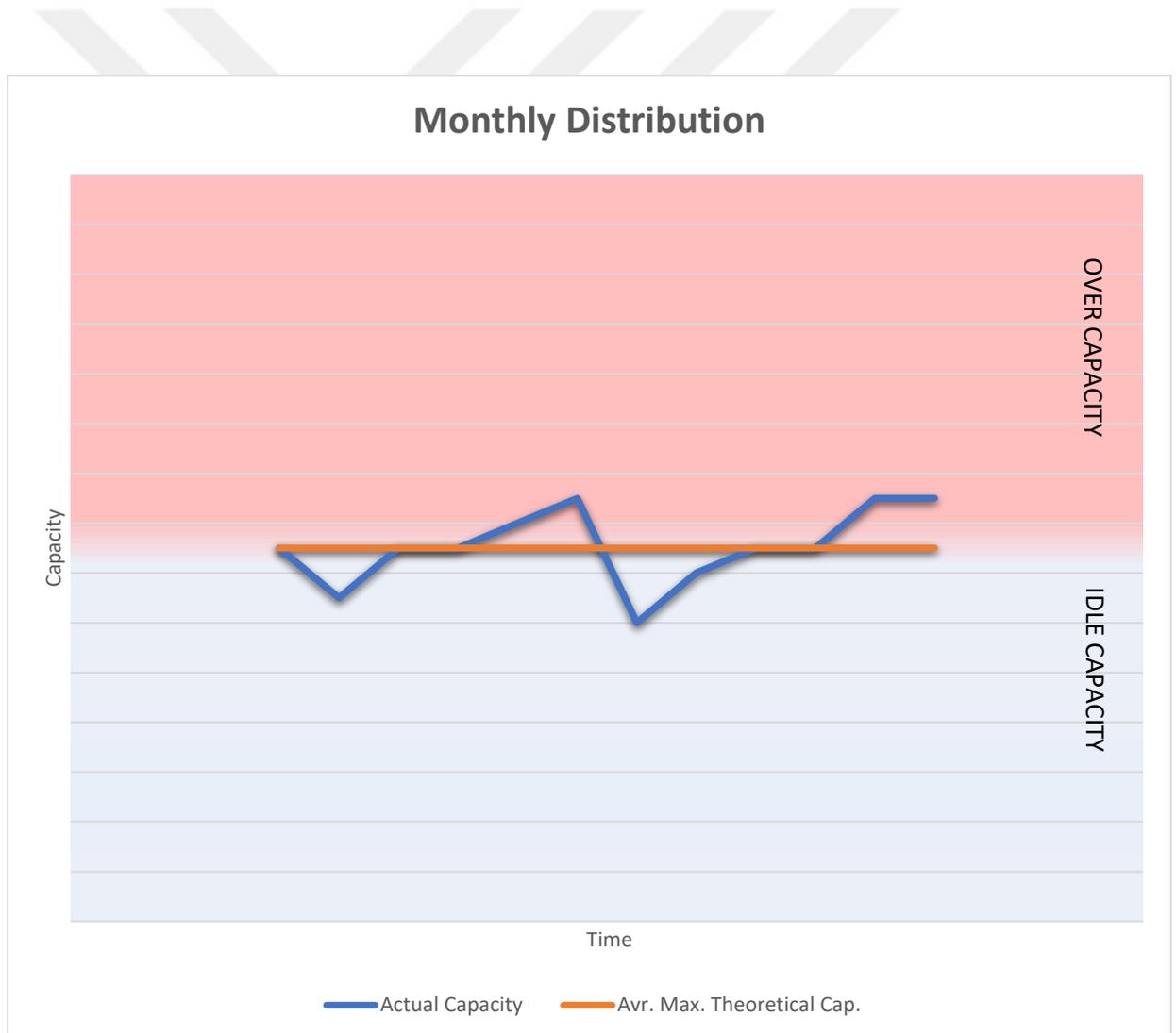
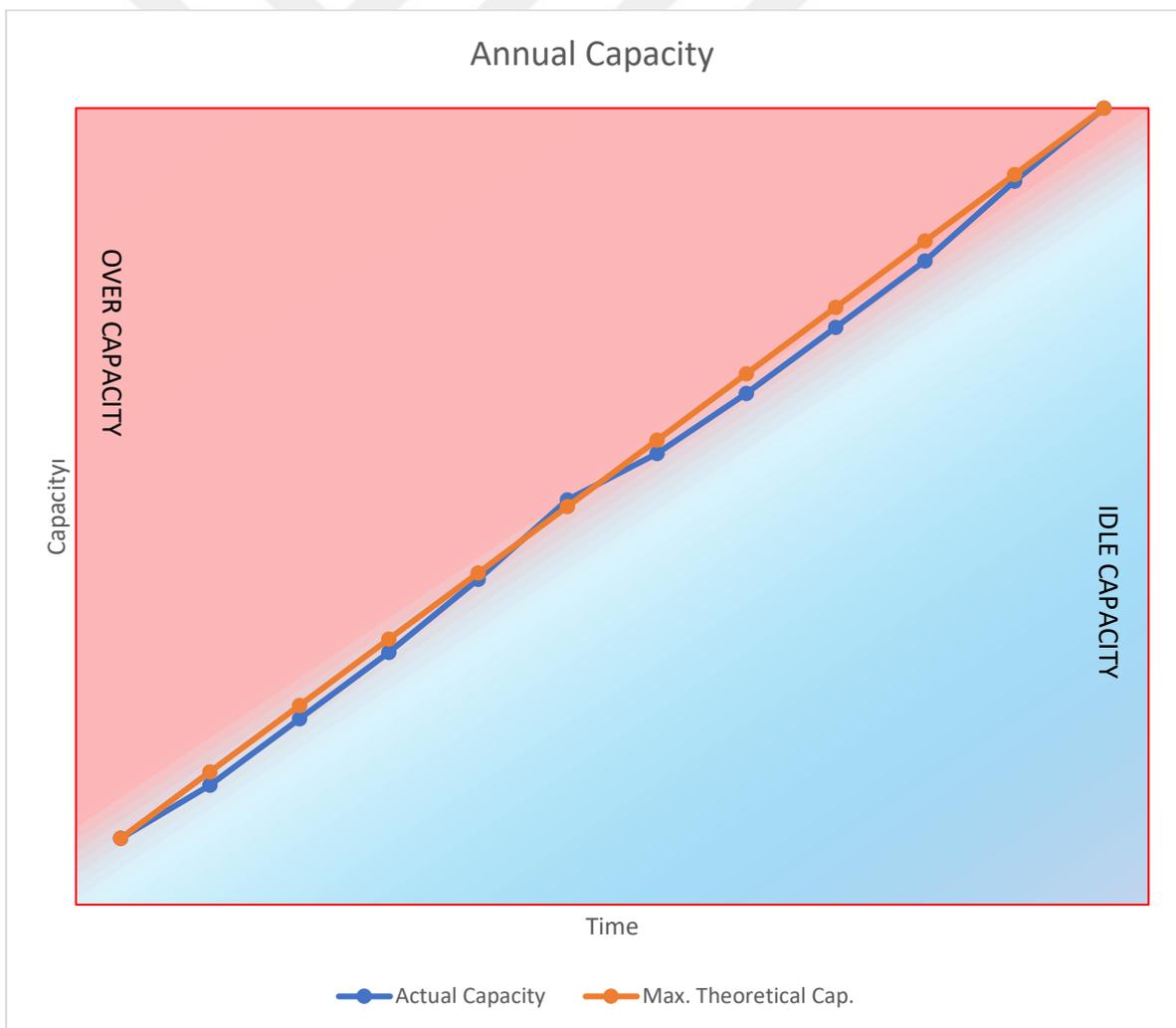


Figure 2.6: Monthly Capacity Distribution

However, when we analyze the same sample on the basis of annual collected data, a result is obtained as in Figure 2.6. As can be seen in Figure 2.6, the forced capacity on the basis of the total volume was not worked much, only 1 point exceeded the maximum theoretical capacity. As it can be understood from here, capacity managements in port operators can give misleading results when viewed from certain projections. The instant effects of the capacity on the operation can be very different from the general projections. When we evaluate the issue over the vessel operation performance, the most challenging times for the port operator in terms of performance are the times when it works with forced capacity. The shorter the time intervals performed, the better the capacity effect of the port operator, which affects the vessel operation performance, can be revealed.



**Figure 2.7:** Annual Capacity Distribution

## 2.3 Actual Capacity

The container handling volume realized in a certain period of time in the port operation is called the realized capacity. The specific time period is usually taken as 1 year, and the annual capacity is mostly used as output in efficiency analyzes, and efficiency and productivity analyzes of the port are made over certain inputs (equipment number, number of employees, port area). At the end of the year, the revenue per Teu calculations, which are of great importance for port operators, are based on the realized capacity; it is calculated by dividing the revenue generated during the year by the annual realized capacity. As in many port calculations, TEU (Twenty foot Equivalent Unit) is used as a unit of measurement.

Just like all other areas, in realized capacity calculations too, port capacity calculations differentiate from general capacity calculations. Realized capacity does not indicate an actual potential output (Çağlar, 2012). The realized capacity represents the finalized data that has already been realized and is used in many areas such as future plans, budget calculations, personnel needs calculations, new investment decisions for port operators. It is expected to increase/decrease in line with the general economic trend of the country and the region, but the general trend is in the direction of increase since there is a flow towards containers in world trade and new trade routes are constantly opened.

The annual container throughputs and annual changes of some countries are shown in Table 2-6. The countries in the table were chosen randomly and the data of the last 5 years were examined. The unit of measurement is calculated as TEU (Twenty-foot Equivalent Unit). As can be seen from the table, there have been positive changes in the ports of many countries in recent years, parallel to the changes in the world. However, there is a slowdown in the rate of increase worldwide in 2019, and the increase in the amount of cargo handled at world ports is 1.9 percent compared to 2018. The change in 2020 is expected to be negative

due to the Covid 19 pandemic, which affects all world economies and therefore maritime transport in 2020.

ECONOMY	2015	2016	2016 Growth	2017	2017 Growth	2018	2018 Growth	2019	2019 Growth
World	692.432.934	703.518.114	2%	757.122.385	8%	795.735.911	5%	811.215.378	1,9%
Belgium	11.237.600	11.459.909	2%	11.967.553	4%	12.686.187	6%	13.570.787	7,0%
France	5.381.800	5.454.600	1%	5.861.000	7%	5.963.100	2%	5.871.100	-1,5%
Greece	3.679.000	4.026.000	9%	4.546.200	13%	5.332.000	17%	6.098.800	14,4%
Italy	9.436.316	9.774.316	4%	9.894.845	1%	9.922.512	0%	10.014.212	0,9%
Japan	20.138.396	20.319.000	1%	21.962.500	8%	22.610.460	3%	21.708.860	-4,0%
Korea,	25.477.000	26.373.000	4%	27.415.800	4%	28.867.900	5%	28.955.300	0,3%
Norway	786.500	739.633	6%	763.100	3%	800.802	5%	836.102	4,4%
Portugal	2.702.500	2.919.300	8%	3.177.500	9%	3.191.600	0%	2.920.700	-8,5%
Turkey	8.297.985	8.851.485	7%	10.094.700	14%	10.887.700	8%	11.679.100	7,3%
United Arab Emirates	21.233.200	20.413.200	4%	19.128.300	-6%	19.054.000	0%	19.171.000	0,6%
United Kingdom	9.772.000	10.200.000	4%	10.240.000	0%	10.313.000	1%	10.276.500	-0,4%
United States of America	47.886.446	48.436.473	1%	52.132.844	8%	54.776.341	5%	55.518.878	1,4%

**Table 2-6:** Annual container throughputs  
**Source:** unctad.org/statistics

## 2.4 Idle Capacity

As we mentioned in the previous sections, the theoretical capacity refers to the maximum transaction volume that the port operator can meet annually, and the realized capacity refers to the volume realized within a year. Idle capacity, on the other hand, refers to the unused capacity between the theoretical capacity and the actual capacity, where the realized capacity is below the theoretical capacity. As mentioned in Section 3.2, the fact that the realized capacity is higher than the theoretical capacity indicates the forced capacity.

Idle capacity means that although the port operator has the necessary infrastructure and superstructure, there is a capacity that it does not use. Idle capacity has advantages and disadvantages for port operation in the long run. In the long run of idle capacity can have advantages such as;

- The port operator can focus on increasing its income without the need for new investments,
- Decrease in housekeeping costs as it can better distribute containers in the yard,
- Positive effect of low housekeeping rate on vessel performance,
- Attractiveness for the new line and customers,
- High customer satisfaction in terms of service received by local customers (such as CFS, Weighting),

However, all businesses work for high profitability, working below the maximum capacity for a long time means not benefiting from a potential income for the company. Idle capacity means that the capital is not used efficiently (Esmer, Liman ve Terminal Yönetimi, 2019). The fact that the idle capacity is high and it continues in the long term shows that the company continues its life with a lower business volume and therefore a lower income, while it can generate higher income. Long-term and high-volume idle capacity conditions mean continuous loss of the port due to the investment made in terms of time value of money (Çağlar, 2012). In addition, working at maximum capacity for a long time will also have major disadvantages such as additional costs, customer dissatisfaction, low performance in terms of business. Therefore, the best way for ports is to work at optimum capacity, which will be explained in detail later.

## **2.5 Potential (Increasable) Capacity**

Potential capacity is the capacity that the port operator can create by making new infrastructure and superstructure investments and adding additional capacity to the

theoretical capacity. It is not an existing capacity and is generally found in the future projections of port operators. The potential capacity is higher than the theoretical capacity, but to reach this capacity, new investments such as expanding the storage area, new quay/dock construction, purchasing new equipment, increasing the number of personnel are required.

The potential capacity type is important in terms of showing the maximum cargo volume and vessel traffic that the port can reach in the future (Esmer, Liman ve Terminal Yönetimi, 2019). Port operators make expansion plans in certain periods depending on the ongoing increase trend in maritime transport and the expected increase in cargo volume. However, the infrastructure and superstructure investments required for the realization of these plans require a certain period of time as well as high costs. It takes a long time for the newly ordered equipment to be produced and transported to the port. For example, it takes about 2 years for RTG orders from manufacturers in the Asian region to be used in port operations to be used in a port in the European region. Likewise, yard expansion or construction of new quays/docks and opening the areas to operational use take a long time. Therefore, while making potential capacity calculations, it is important for the sustainability of port operations to make a certain projection and plan the investments that need to be made to reach the potential capacity. While port operators are making potential capacity calculations and planning, in the medium and long term, they should consider various factors such as;

- Situations of competitor companies and medium and long term investment plans,
- New and potential competitor businesses
- Legal changes and government incentives
- Global and regional developments
- Regional investments
- Changes and developments in the hinterland
- Trends and investments in the industry
- Status and trends of global and local customers and industries such as line businesses
- Emerging technologies in the main and parallel sectors

## 2.6 Optimum Capacity

Optimum capacity is generally defined as the capacity where maximum capacity is combined with maximum benefit. Oral and Kişi defined the optimum capacity for port operations as; optimum capacity in ports is a capacity in which port economy (income, expenses and profitability, etc.) is considered as well as the cargo volume according to the other two capacity calculations (theoretical and current capacities) (Oral & Kişi, 2011). It is assumed that the port operates at the most efficient point within the optimum capacity. As can be seen in Table 2-4 and Figure 2.7, the optimum capacity can be at any point up to the maximum theoretical capacity, it cannot be above the maximum theoretical capacity, and is often closer to the actual capacity.

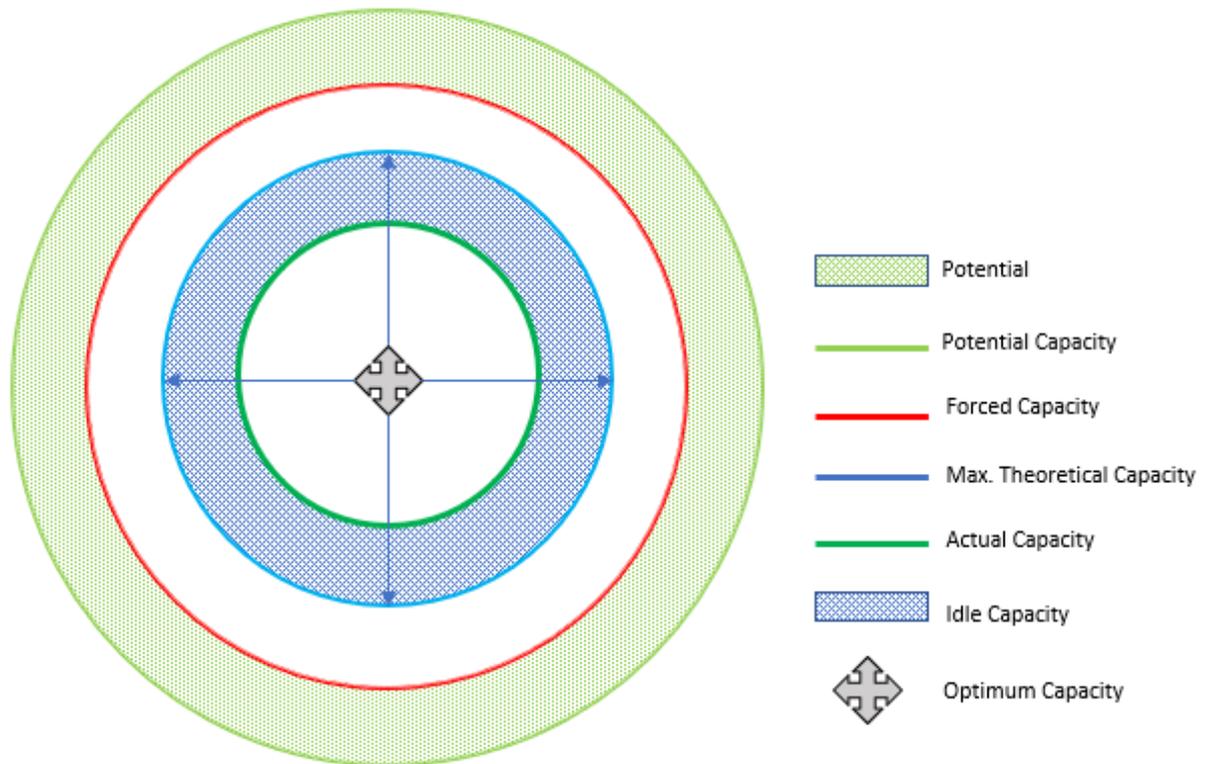


Figure 2.8: Capacity Types

While determining the optimum points in the general business logic, cost is usually taken as the focal point and the capacity with the lowest unit cost is called the optimum capacity. However, in this study, while determining the optimum storage capacity, the focus will be on the gross move per hour produced for the vessel. Gross move hour focused optimum capacity will be examined in detail in Chapter 4 of the study.



### **3. PERFORMANCE CALCULATIONS IN CONTAINER TERMINALS**

Performance, in general, is the set of indicators that show how well the business works in accordance with its establishment goals and objectives, the level of service production quality, and whether the continuity of sustainability is provided. Performance is a multidimensional concept and only more than one indicator can evaluate it as a whole (Bayyurt, 2011).

All ports need performance metrics to measure and evaluate their profitability and productivity. The performance outputs of the port support the decision-making mechanism of decision makers in many areas such as future planning, detection of deficiencies and malfunctions, directing investments, human resources training. However, measurement systems and analyzes are as important as performance outputs. Although there are popular performance measurement systems for every business line, standardizing performance measurement systems may not always give accurate results. Even for enterprises with the same measurement systems, the evaluation criteria may vary, because performance is the set of systems that measure whether the enterprise works in accordance with the purpose of its establishment. Performance measurement and evaluation systems are based on the field of activity of the port, its close and distant environment, competition conditions, customer requests and demands, physical conditions, infrastructure and superstructure characteristics, financial conditions, political relations, human resources, etc. It can vary based on many different factors.

The performance of ports has a direct impact on the economic factors of regions and countries, since maritime transport has the largest share in global trade and ports are the starting and ending point of maritime transport. In addition, the increase in the share of container transportation in general transportation and the fact that ports are the only places where vessels stop and lose time in liner transportation make port performance very

important for line operators, who are the biggest customers of port operators. Driven by constantly increasing handling volumes and ever larger ships, seaport container terminals face the challenge to handle containers as quickly and efficiently as possible (Schwientek, Lange, & Jahn, 2020). Especially vessel operation performances have become the most important service output for ports. In particular, container terminals focus on performance outputs while making infrastructure and superstructure investments, equipment investments, IT investments. There are many different types of performance for ports, such as yard performance, berth performance, workforce performance, occupational safety performance, gate performance, but generally the most important is the vessel performance, which determines the time the vessels spend in the port. As a matter of fact, this study aimed to calculate the optimum point in storage capacity by focusing on vessel performance.

From time to time, port performances are confused with the port capacity/business volume described in Chapter 2, and the actual volume of the port is evaluated as the port performance. However, as explained before container throughput shows the operations carried out by the port operator within a certain period of time and does not provide information about the performance of the port operator. Likewise, some studies use port performances together with productivity concepts, and sometimes the concept of productivity is used instead of the concept of performance. The concepts of performance and productivity are very close to each other and can be used together, but they cannot be used interchangeably. Productivity is concerned with the effective use of resources, while performance is a system of measuring the results obtained from the use of resources. For example, the operation of a quay crane at 30 mph (move per hour) is a measure of performance, while the analysis of the inputs (yard truck, yard crane, quay crane, manwork etc.) used to produce 30 movements per hour is a measure of productivity.

Ports are areas where many processes interact as complex dynamic logistics systems (Soner, 2010). Therefore, performance indicators are versatile and different dynamics may outweigh for each port. While teu/working hour is an important performance criterion in regions where labor force is high for the enterprise, teu handling per square meter of berth

may be a more important performance indicator in regions where infrastructure costs are high. Likewise, while external trucks truck turn times are a very important performance indicator in very busy and congested ports, this indicator may not be very important in terms of management in ports that are not busy, that is, not congested. However, the common and most important performance indicator for many container terminals today is Gross move per hour. As port operators act as a transition between transport modes, their performance affects more than one area. Each port stakeholder assesses port performance from different angles, based on the stakeholder's interests and the nature of their business ( Elferjani, 2015). While line operators expect port operators to perform vessel operations and yard operations at high performance, local customers expect high performance in yard storage services such as cfs, and shipping companies expect high performance in gate and yard operations. As a matter of fact, researchers have examined different performance criteria in the literature. In this study, the types of performance will be examined under 3 main headings and then will be divided into subheadings as indicated in Table 3-1;

- Vessel Performance
- Quay Performance
- Yard Performance
- Gate Performance

Gate Performance	<ul style="list-style-type: none"> <li>• Gate Move Per Hour</li> <li>•</li> </ul>
Yard Performance	<ul style="list-style-type: none"> <li>• Housekeeping Rate</li> <li>• Average Truck Turn Time</li> <li>• Man Hour Rate</li> <li>•</li> </ul>
Quay Performance	<ul style="list-style-type: none"> <li>•</li> </ul>
Vessel Performance	<ul style="list-style-type: none"> <li>• Gross Move Per Hour</li> <li>• Net Move Per Hour</li> <li>• Dual Cycle Rate</li> </ul>

**Table 3-1:** Performance Types

Before moving on to performance types in container terminals, it is necessary to examine the points and terms that are taken into account in performance calculations;

**Gross Move;** refers to the total movement of a vessel in a certain period of time, in general, gross move per hour is used. Except for force majeure, all stops such as lid movement, crane failure, meal breaks are included in the specified time. However, some port operators do not deduct the time spent for the vessel cover from the gross move time, but add it to the total movement as a movement and include it in the performance calculation. Contracts between line operators and ports are generally made on gross move.

**Net Move;** refers to the total movement in a vessel's operation in a certain time period, when the times not spent on the operation (such as lid movement, downtime, meal breaks) and force majeure situations are subtracted. It is generally used as net move per hour and actually refers to the movement produced by the crane when it works without hesitation.

**Crane Intensity;** Since the number of movements per crane during the operation will not be evenly distributed to each crane, the concept of crane density emerges in the performance calculation (Sekin & Gençer, 2019). Crane density is the density value obtained by dividing the total working times of the cranes operating in vessel operation by the working time of the longest working crane. To explain on the example, the operation times in a vessel operation that starts with 4 cranes are as follows;

		Total Operation Time
<b>Crane 1</b>	Discharge 02:00:00	4:30:00
	Load 02:30:00	
<b>Crane 2</b>	Discharge 03:00:00	4:15:00
	Load 01:15:00	

<b>Crane 3</b>	Discharge	03:00:00	5:20:00
	Load	02:20:00	
<b>Crane 4</b>	Discharge	01:05:00	4:40:00
	Load	03:35:00	

The total operation time of 4 cranes is 1125 minutes. The longest working crane is crane 3 with 320 minutes. By dividing the total working time of the cranes by the working time of the longest working crane;

$$\sum_{k=1}^n Cw_k / Cw_x$$

$C_w$  = Crane Working Time

$C_{wx}$  = Crane Longest Working Time

$1125/32 = 3,51$  crane intensity is detected.

The closer the Crane intensity is to the total number of cranes working, the more successful it is. The fact that the Crane intensity is close to the total number of working cranes indicates that the loads are evenly distributed on the vessel, so the operation time will be shortened as all cranes will be loaded close to each other or with equal workloads. Otherwise, some cranes will have more workload and will prolong the operation time.

**Truck Turn Times (TTT)**; shows the time elapsed between two transfers performed by vehicles in the port. It is the time elapsed between a yard truck working in a vessel loading

operation picking up the container from the yard and leaving it to the quay cranes to be loaded onto the vessel. Likewise, it shows the time elapsed between the gate in of the external truck coming to receive the import container from the outside through the port entrance gate (ingate) and taking delivery of the import container and gating out from the port exit gate (outgate).

Truck Turn Times is an important indicator for calculating the optimum number of yard trucks to be used in vessel operations. Determining the optimum number of vehicles is very important for carbon emission, cost and preventing traffic congestion in the port.

**Dual Cycle;** refers to the dual use of equipment to increase productivity in operations. Considering the cranes working in vessel operations, in one-way operations, the crane goes to the vessel's hold and takes the discharging container and loads it to the yard truck waiting on the quay, then repeats the same movement and finishes the discharging containers in the hold. However, in a dual cycle operation, if the operation is to be carried out to discharge first and then to load to the same hold, the crane takes the discharging container from the vessel's hold and loads it to the yard truck, then takes the export container waiting on the quay and loads it into the same hold. In this way, the rotation movement of the crane is also utilized. Likewise, the empty tour of the yard truck is utilized too, as it will load the next discharge container from the vessel to the yard truck on which it is loaded. This is very important in terms of reducing fuel costs and reducing carbon emissions.

**Operation Time;** refers to the total time between the start and end of a vessel's operation. The operation period also includes port management-related problems such as malfunctions, waiting for containers from the yard, waiting for yard trucks, technical problems. After the vessel berths to the port quay, they need a certain amount of time for operations such as customs controls, solving the cargo lashings, getting the vessel's ladder ready until the operation starts. These times should not be evaluated within the operation period. The time, which includes these times, is called the quay time, which shows the time from the time the vessel berths to the quay/dock to the moment it takes off. The operation

period starts from the moment the first cargo is taken from the vessel and covers the period until the last cargo is loaded.

**Number of Crane;** refers to the number of cranes that will work in vessel operation. It is a very important criterion in terms of performance measurement. The number of cranes that will work in the vessel operation directly affects the operation time of the vessel and therefore the vessel's operational performance. The fact that the loads are evenly distributed on the vessel and working with the maximum number of cranes is a factor that increases the vessel's operation performance. However, in cases such as insufficient number of yard trucks, high yard density, insufficient yard equipment, port operators may want to reduce the number of cranes working on the vessel in order to keep crane head performance high. Generally, the number of cranes to work on the vessels is specified in the contracts made between port operators and line operators.

**Number of Moves;** refers to the total number of containers to be handled in the vessel operation. In container transportation, TEU (twenty-foot equivalent unit) is generally used as a unit of measurement, but the number of containers is generally used for performance calculations in vessel operations. Using the number of movements provides advantages in terms of performance in containers handled as twin or tendem. Some port operators include hatch cover or gear box movements in the total number of movements in their performance calculations.

**Housekeeping;** Yard arrangement movements for vessel loading and discharging operations in yard operations are called housekeeping. A housekeeping operation consists in transferring a container from one storage location to another with the aim of speeding up discharge/loading operations and avoiding congestion (Cordeau, Legato, Mazza, & Trunfio, 2015). Housekeeping is the replacement of containers in the yard. Export containers that will be loaded on the vessel may be loaded with other containers that will not be loaded on the vessel, or POD (Port of Discharge) or containers with a changed vessel may be stuck on the containers that will be loaded on the vessel that will start the operation first. In this case, in

order not to waste time with the transfer of these containers during the vessel operation, the containers are transferred in the yard before the operation and they are made suitable for loading on the vessel.

Although the rate of housekeeping is very high in busy and congested ports, the high rate of this rate reveals the result that the first site planning cannot be done as it should be. The high rate of housekeeping directly increases the operating costs.

**Rollover;** Under normal conditions, when containers enter the port area, it is clear which vessel they will be loaded on, their discharge ports and tonnage. Containers are placed on the yard by taking these criteria into consideration while planning the yard. In the yard, the containers of the nearest vessel are stacked on the containers to be loaded on the next vessels, the heavy ones on the upper floors and the light ones on the lower floors. Even if this planning cannot be done at the gate in stage, these adjustments are made by housekeeping later in the yard. However, in some cases, POD (port of Discharge) or the vessel to be loaded can be changed before the container is loaded on the vessel, these changes are called rollover.

**Operation Delays;** in vessel operation, as cranes work, they produce movement to the vessel. It is an important indicator as it directly affects the operation time. Most of the operation delays are caused by the vehicle waits for discharging operations or yard loading container waiting for vessel loading operations.

**Yard Utilization Rate;** is used to show the impact of vessel operation on yard capacity. The yard utilization rates before and after the operation are taken and compared, and the effect of the vessel operation on the yard operations is observed. If the average effects of each line on the yard can be calculated, how much housekeeping will be done in the yard for the next vessels or the gross move per hour calculations can be made more accurately. Yard utilization rate is an important indicator in terms of showing the impact and workload of the vessel /line on the yard.

### 3.1 Gate Performance

Port gates are connection points of ports (which are the transition points between the transportation modes) with land transportation. Gate operations are one of the important stages of port operations. Especially in ports where there is no railway connection, the gate in and gate out of all containers and LCL (Less than Container Load) loads, except transshipment containers, through the port gate brings the performance of the gate to an important position.

In port gates some controls are carried out such as ;

- Document checks of containers and vehicles
- Customs controls
- Condition checks of export containers before delivery
- Booking controls of vehicles that will receive import containers
- Condition checks of empty containers
- Compliance checks of vehicles
- International compliance (such as ADR) controls of vehicles that will carry dangerous goods
- IMDG tag control
- Seal control

In addition, some ports weight the containers at the port gates in accordance with the Solas VGM regulation. While the weights of the vehicles are recorded together with the container during the gate in procedures, the empty weights are taken at the gate out and the weighing process is completed, thus preventing the vehicles from making additional tours for weighing in the port and creating traffic. However, the weighing process takes a certain amount of time. These transactions are important in terms of the operation and reliability of the port operators, as well as the guarantees given by the port operators to the line operators and customers. In terms of insurance transactions and customs, the condition checks of the container, the seal checks, the conformity checks of the vehicles are very important.

Port operators need a certain amount of time for the controls made during the gate operations. The long duration of this period causes waiting at the port gate and thus causing queue. Port congestion at the gate of a container port occurs when the waiting times for trucks to enter the gate increase beyond normal waiting times due to the increase in the number of trucks seeking entrance (Talley, 2012). Waiting at the port gates puts ports in trouble with their immediate surroundings and local governments. One critical aspect of traffic management is gate operations management, ensuring a good customer experience to logistic carriers and considering the impact of congestion in and around the port (Cordeau, Legato, Mazza, & Trunfio, 2015). Freight forwarders complain about long queues and waiting times, while local customers complain about not being able to pick up or deliver their cargo on time. At the same time, the traffic caused by the vehicles waiting in the gate-out queue at the ports with short gate-out lines affects the inner operations of the port management, extends the external truck turn time times and even affects the truck turn times of the yard trucks by causing traffic congestions in the yard from time to time.

Control times are not the only reason for vehicle queues and waiting at port gates. The accumulation of vehicles at the gates as a result of increasing demand also causes vehicle queues and traffic congestion. One of the most important reasons for the increase in the demand for export container entries is the free time allowed for the registration of containers to the vessel. Line operators or port operators offer a certain amount of time (free time) to shippers who want to send export containers, where they can keep their containers in the port area without paying a storage fee. This time period is usually 1-2 days before the vessel where the container will be loaded, 1-2 days before the dock. The shippers who do not want to pay the storage fee and want to bring their cargo to the port in this time period cause an increase in demand and vehicle queues at the port gate. Some of the reasons for waiting at the port gates are as follows;

- Long control times
- Not using a gate automation system/too many manual operations

- System malfunctions/outages
- Customs rules
- Free times are tight
- Too many traffic intersections on port gate-in/gate-out lines
- Insufficient parking space
- Unexpected changes in Vessel Schedules

Some port operators use an appointment system to prevent congestion at the port gate. Thus, the port operator determines a certain capacity for each time zone and the shipping company makes an appointment for the appropriate time zone and sends its vehicle to the port gate at the appointment time. Thus, since the number of vehicles suitable for the port gate capacity arrives at the gate, vehicle accumulation at the port gate is prevented. Although the Appointment system is an effective solution for the vehicle queue, it is not a suitable solution for every port operator due to some application-related problems.

As it is known, most of the vessels calling at the container terminals carry out liner transportation. All parties such as port operator, line operator and shipper follow this plan by creating a specific vessel program. However, sometimes due to weather conditions, malfunctions, waiting times at other ports on the line, and natural events, the vessel schedule is interrupted and the container volume accumulates. This situation causes accumulation at the door and above-average transaction volume, especially in the delivery of import containers.

Gate performance is an important performance indicator for the port operation as it affects all stakeholders. Important gate performance indicators for ports will be examined as follows;

- Gate Move Per Hour

### 3.1.1 Gate Move Per Hour

The waiting and queues at the port gates and their effects were explained in detail in section 3.1. In order to avoid queues at the port gate, the number of vehicles arriving at the port in a certain time period (Demand) and the transaction capacity of the port gate (Supply) must be close to each other. Increases in demand, especially at certain hour intervals, increase the waiting time and queue length.

Gate move per hour is an important performance indicator for determining gate performance and making planning. It represents the number of vehicles operating at the port gate for an hour. There are some factors that affect this performance indicator. Import-export balance is one of the important factors. At the gate, the check-in times of the vehicles that bring export containers are much longer than the vehicles that come to the port empty just for taking import units as export units have various control points such as damage check, booking check, seal check, container number check, container weighing.

The most important indicator of the gate performance is the gate move per hour. Port operators are making various infrastructure and superstructure investments in order to increase the number of vehicles passing through the gate in the unit of time (Supply) by shortening the time the vehicles spend at the gate and increasing the number of gate lines. Port operators use automation systems as follow below to increase gate performance and customer satisfaction;

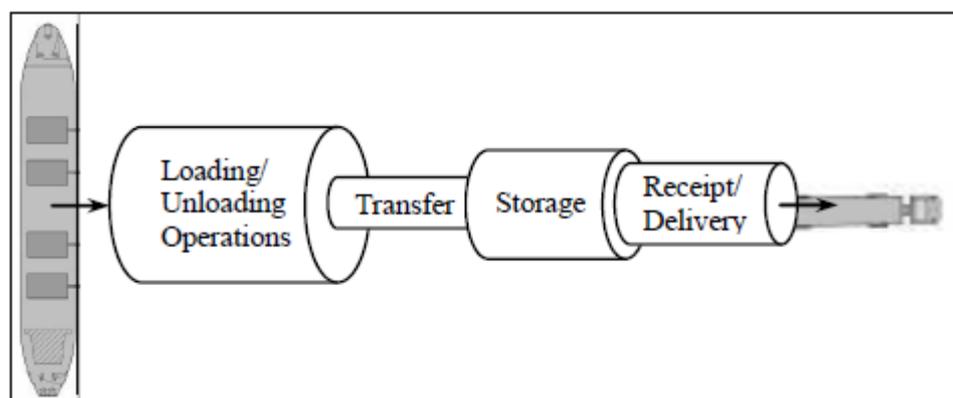
- **Automatic Damage Detection;** is a system in which cameras are used to detect the damaged area and damage dimensions of the container, process them on the determined system, archive it visually and inform the users.
- **Gate Container Code Recognition (CCR/OCR);** Gate CCR system enables users to automatically identify ISO containers as they are transported by truck through a controlled access point (Orbitaports, No Date). The CCR system is a system created by cameras that determine and record specific features such as

container number, ISO type, without using manpower. Thanks to CCR/OCR systems, the accuracy of container numbers and types is systematically checked and visually recorded.

- **License Plate Recognition:** is a system that allows the plates of vehicles carrying containers to be read automatically. In this way, container plates are read by cameras and processed into the system, gate operations are started and plate control is provided.
- **Gate Kiosk;** kiosks are the devices used by the drivers to initiate the transactions over the system at the entrance and exit of the port. This system includes work orders, communication between the driver and terminal staff, document printing and other functions involved in the admission and exit process for controlled premises (Orbitaports, No Date).

### 3.2 Yard Performance

Yard performance is the area where the most energy and time is spent in port operations. Every movement made in vessel operations has at least one counterpart movement in yard operations. Containers unloaded from the vessel are stored in the yard until the customs procedures are completed and loaded onto the transport vehicle or train wagons authorized by the cargo owner. The import cargo passes from the ship at berth to the hinterland via the ship cargo handling system, the dominant part of the berth system (İbrahimi, 2009). (Figure 3.1)



**Figure 3.1:** Operations Process  
**Source:** (İbrahimi, 2009)

Likewise, export containers are stored in the port area until they are discharged and loaded at the port area for a certain period of time before the vessel to be loaded arrives at the port. Cut off is the time that the export containers need to be brought to the port area before the vessel to which they will be loaded arrives.

The waiting time of containers at the port is called dwell time. According to the report published by UNCTAD in 2019, the average dwell time per TEU in ports between 2014 and 2018 is 6 days (UNCTAD, 2019). Some services are provided to containers during storage such as;

- Inspection
- Weighing
- Seal change
- Labeling
- Cleaning
- Stripping
- Stuffing
- PTI
- Repair
- Classification
- Lashing

In order to provide these services, the container moves within the area.

As explained in detail in Section xx, the containers stored in the port area can perform housekeeping movements for effective yard planning and arrangements. All these movements made in the area are considered as a part of the area performance and directly affect the vessel performance and area operations take the biggest share in the total

movements of the ports. The fact that it directly affects the general performance outputs of the ports and is very important for optimization makes area operations and area performance an important performance indicator. In this section, area performance will be examined under 3 sub-headings;

- Housekeeping Rate
- Avr. Truck Turn Time
- Man Hour Rate

### 3.2.1 Housekeeping Rate

In yard operations, yard arrangement movements for vessel loading and discharging operations and other services provided to the cargo (such as CFS, reefer, weighing) are called housekeeping. Housekeeping movements can be done in the same yard as the transfer of the container from one row to another (yard shift) or as a yard move between the yards. As the yard occupancy rate increases, the number of housekeeping will also increase as the desired planning cannot be made in the placement of the containers that are discharged on the yard after the gate in and vessel discharging. There is an inverse relationship between housekeeping rate and operational productivity. It can produce a certain amount of movement with the equipments of the port operator. Especially since the housekeeping movements made during the vessel operation will spend a share from the total movement, it directly affects the operation speed. To explain through an example, the port information and time range to be used in the example are as follows;

Equipment	RTG	QC
	21	4

- An 8-hour shift is taken into account as the time interval.
- Produced movements;
  - CFS
  - Vessel Moves (discharge, load)
  - Gate Moves (gate in, gate out)

- Realized movements;
  - All movements made by RTG
  - Produced movements
  - Housekeeping movements

The number of movements made by RTGs in 8-hour time intervals are as follows.

<b>RTG TOTAL MOVES</b>									
<b>Hour</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>TOTAL</b>
<b>RTG01</b>	5	13	6	7	-	18	14	5	68
<b>RTG02</b>	5	15	5	16	2	5	14	7	69
<b>RTG03</b>	5	4	5	17	8	17	12	5	73
<b>RTG04</b>	-	15	16	16	7	11	11	12	88
<b>RTG05</b>	16	14	19	13	4	13	19	18	116
<b>RTG06</b>	5	19	11	17	1	13	20	20	106
<b>RTG07</b>	6	7	13	18	5	7	15	9	80
<b>RTG08</b>	10	6	11	16	7	15	12	8	85
<b>RTG09</b>	8	19	8	24	7	20	20	14	120
<b>RTG10</b>	2	11	4	9	5	16	11	3	61
<b>RTG11</b>	4	7	18	15	4	16	2	7	73
<b>RTG12</b>	5	12	7	7	3	6	6	8	54
<b>RTG13</b>	-	1	6	22	12	24	10	12	87
<b>RTG14</b>	2	5	3	15	3	6	9	4	47
<b>RTG15</b>	4	5	10	6	6	17	9	12	69
<b>RTG16</b>	8	12	13	13	6	12	7	12	83
<b>RTG17</b>	3	3	14	8	10	17	10	15	80
<b>RTG18</b>	2	9	4	9	8	17	14	3	66
<b>RTG19</b>	6	4	19	12	-	23	16	15	95
<b>RTG20</b>	-	6	6	12	3	6	18	10	61
<b>RTG21</b>	6	20	13	18	6	13	20	13	109
<b>TOTAL</b>	110	216	221	301	119	305	283	227	<b>1690</b>

Table 3-2: RTG Moves

RTGs made a total of 1690 movements during 8 hours between 08-16 in the port operation. These movements show the number of each container moved, not the movements produced by the RTGs. For example, a container loaded from RTG to be loaded on the vessel represents 1 movement, but if there is another container on the container to be loaded, the number of movements made is 2 movements because that container has been transferred. During the 8-hour period, the highest number of movements was 305 between 13:00 and 14:00. The average movement per RTG is 14.5 movements at the hour of the most movement, while the average movement per hour for 8 hours is 10 movements per RTG. However, these data do not mean that the RTGs work continuously in the specified time interval, they can only be considered as a sample.

The number of movements produced by RTGs for 8 hours are given below;

<b>RTG</b>	<b>PRODUCED</b>
<b>MOVES</b>	
<b>CFS</b>	13
<b>DISCHARGE</b>	302
<b>LOAD</b>	294
<b>GATE IN</b>	311
<b>GATE OUT</b>	197
<b>TOTAL</b>	<b>1117</b>

The total movement produced as a result of the movements of the RTGs during 8 hours was 1117. The highest number of movements produced is Gate In movements with 311. The total number of movements made for the vessel operation is 596. The hourly average of all movements is 139.6. The ratio of gate out, load and CFS movements, which are generally produced movements that require housekeeping movements, in the total produced movements is 45.5%. As mentioned before, the generated movements show the movements that yield (chargeable) as a result of all the movements made by the RTGs.

Movement and housekeeping shares produced in the total movement are given below;

RTG MOVES				
	TOTAL MOVES	PRD. MOVES	HOUSEKEEPING	PER.
<b>08/16</b>	1690	1117	573	34%

As a result; during an 8-hour shift (8:00-16:00), RTGs at the port operated a total of 1690 container movements, resulting in 1117 efficient (chargeable) movements. The remaining 573 show the in-yard transfers made to achieve results. In other words, the port operator made an additional 573 movements in order to produce 1117 movements in 8 hours. All of these movements, which have a share of 34% in the total movement, can be considered as movements that waste the performance and energy of the port operator. In any case, even if they do not directly affect the performance of the vessel, they should be considered as expenses that do not correspond to financial performance.

From all the above, we can characterize the housekeeping rate as a performance criterion that shows the rate of housekeeping movements that need to be done in order to produce efficient movements. To reach the housekeeping rate the formula is as follows;

$$HK_R = \frac{\sum HK_m}{\sum PM}$$

- $HK_R$  = Housekeeping Rate
- $HK_m$  = Housekeeping Moves
- $PM$  = Produced Moves

Based on the formula above, the housekeeping rate in the date and time range determined for our sample study is as follows;

$$\begin{aligned}
 HK_R &= \frac{\sum HK_m}{\sum PM} \\
 &= \frac{573}{1117}
 \end{aligned}$$

**= 0,512**

There is an inverse correlation between housekeeping rate and operations productivity. We can say that the lower the housekeeping rate, the more efficiently the port works in yard operations. At the same time, the housekeeping rate directly affects other performances. The fact that the housekeeping movements to be carried out in the yard for the containers to be loaded on the vessel or for the containers that will gate out directly affect the Truck Turn Time and therefore the performance of the vessel.

### **3.2.2 Average Truck Turn Time (TTT<sub>A</sub>)**

Truck turn times shows the time elapsed between two transfers performed by vehicles in the port. The average of these times taken during a certain time interval, such as during the day or during the vessel operation, represents Average Truck Turn Time (TTTA). It is an important indicator that affects vessel operation and gate operation performance. Average yard truck turn time is directly proportional to quay crane idle time. The faster the vehicle cycle of the yard trucks operating in the vessel operation, the lower the idle time of the quay cranes will be. Likewise, the turn time times of external trucks entering through the gate will directly affect the traffic in the port and the gate move per hour, which is the gate performance indicator.

Truck turn time shows the time elapsed between the start and end times of the work orders received by vehicles working in the port (yard truck or external truck). In order to examine the subject in detail, yard truck and external truck turn time should be mentioned separately.

### 3.2.2.1 External Trucks Turn Times

It shows the time spent by the transport vehicles coming to the port to deliver export containers or to pick up import containers. Those turn times are, however, customer specific and location specific, and influenced by distance, highway conditions, business practices, drayage strategies, etc. (NFRP, 2011).

For external trucks, turn time shows the time elapsed between two gates (gate to gate). Although ingate to outgate is usually taken as the reference in the measurement of time, it can be diversified such as pregate to ingate, pregate to outgate. Ingate to outgate turn time periods do not include waiting times at port gates. As a matter of fact, modern port designs have considerably reduced the processing time at the gates thanks to the automation they use at the gate in and gate out.

Truck Turn Time can be found for External Trucks with below formula;

$$TT_E = TT_I - TT_O$$

$TT_E$  = External Truck Turn Time

$TT_I$  = Truck Time In

$TT_O$  = Truck Time Out

Although external truck turn time expresses the time spent by the transport vehicle in the port, it does not express the time the transport vehicle completes the work received from its customer. In some ports, there may be long waits in the parking areas at the port gates. In order to measure their own performance, some shipping companies may also measure the time between the delivery of the container from the exporter customer to the port, or the time between the delivery of the import container to the company after picking up it from the port. This time is generally called the overall turn time and includes the time

spent in the port as well as the time spent on the port access road, port gates, port waiting areas and highways.

Average external trucks turn time is an important indicator for the port operator to manage the traffic in the terminal, to make effective planning and improvement, and to reduce carbon emissions from transportation vehicles. It should also be taken into account in calculating the optimum number of yard equipment.

### **3.2.2.2 Yard Trucks Turn Times**

It refers to the time elapsed between two work orders received by the vehicles (yard trucks, terminal trucks, shuttle trucks etc.) used for terminal services belonging to the port operator. For a yard truck working in vessel operations, this period refers to the time when it picks up the discharge container from the quay, leaves it on the yard and arrives back at the quay to pick up a new discharge container. However, in an operation that works as a dual cycle in vessel operation, the yard truck picks up the discharge container from the vessel and leaves it on the yard, and then picks up the loading container from the yard and goes to the quay to deliver it. In this case, the yard truck will have made two moves in one turn. In dual cycle movements, the turn time of the yard truck does not end when it arrives at the quay; it only ends when the yard truck leaves the container it took from the vessel on the yard and picks up the loading container from the yard.

Yard Trucks Turn Time can be calculated as follows;

$$\mathbf{TTT}_Y = \mathbf{WO}_n - \mathbf{WO}_{n-1}$$

$\mathbf{TTT}_Y$  = Yard Truck Turn Time

$\mathbf{WO}$  = Work Order

Yard truck turn time is important for port operators in terms of optimum vehicle calculation. As mentioned in the previous section, the lower the Average Truck Turn Time, the lower the idle time of the cranes working in vessel operation. At the same time, it is important to achieve the optimum in the number of yard trucks for fuel savings, carbon emissions and keeping the traffic in the port under control. One of the important data in calculating the optimum number of yard trucks is the average yard truck turn time. Optimum yard truck calculation for vessel operation can be exemplified as follows;

$$\frac{TTT_A / TT_C}{TW_F} \times QC_N$$

$$TT_C = \frac{60 \text{ Min}}{QC_p}$$

- **TTT<sub>A</sub>**= Average Truck Turn Time
- **TT<sub>C</sub>**= Turn Time Cycle
- **TW<sub>F</sub>**= Twin Factor (Twin Factor; the ratio which is calculated in case every 2 x 20' containers are handled as twins)
- **QC<sub>N</sub>**= Number of QC
- **QC<sub>p</sub>**= QC Performance Goal (Hour)

We can explain yard truck optimization through an example. The average truck turn time, which has 8 cranes and aims to make 28 movements per hour with each crane, is 15 min. The optimum number of yard trucks and the need for vessel operations of a port operator calculated as in the sample port, the data is as follows;

- **TTT<sub>A</sub>**= 15 min.
- **QC<sub>N</sub>**= 8 QC
- **QC<sub>p</sub>**= 28 Gross Move Per Hour

- $TT_C = \frac{60 \text{ Min}}{QC_p} = 2,1$  (For 28 move performance, every 2,1 min. each crane needs one TT)
- $TW_F = 1,22$  (The ratio which is calculated in case every 2 x 20' containers are handled as twins) (We use the twin factor because when the containers are discharged or loaded as twins from the vessel, the yard truck carries 2 containers in one transport, so it makes two movements.)

$$\frac{TT_A/TT_C}{TW_F} \times QC_N$$

$$= \frac{15/2,1}{1,22} \times 8$$

$$= \frac{7,1}{1,22} \times 8$$

$$= 46 \text{ YT}$$

The optimum number of yard trucks calculated according to the data of the sample port is 46. This number shows the number of yard trucks needed to achieve an average of 28 movements per hour for each crane when 8 cranes of the port are operating at the same time. In the calculation, the yard density (occupancy), the position of the containers on the yard, malfunctions, etc. are not taken into account, and it shows the number of yard trucks required to achieve the targeted performance when all conditions are suitable. In addition to the specified calculation, many ports add 1 yard truck per day to the optimum number calculated for failure maintenance etc., considering that it is out of use.

### 3.2.3 Man Hour Rate

Even with a high level of mechanization, labor costs still form a large part of total terminal costs and it is important to monitor labor well and know what the productivity per man-hour is over a measured period (Esmer, 2008). Labor costs have a large share in the

expenses of port operators and vary greatly between countries. The fact that labor costs are an important expense item for port operators makes it important to measure and evaluate labor performance. This reveals labor productivity as a performance criterion. Labor productivity represents the total volume of output produced per unit of labor during a given time reference period (ILOSTAT, 2021).

Labor productivity in ports is generally calculated as man hour per ton for ports with general cargo weight, and man hour per teu for container ports. Many port operators also calculate the working time per Teu among their performance criteria and consider it as a performance target. Another advantage of automation systems such as gate automation, crane ocr, RTG/RMG remote control, autonomous trucks, autonomous straddle carriers, which have been widely used in ports in recent years, is that they reduce the total man hour time.

The reduction of man hour per Teu is important in terms of occupational safety measures as well as operating costs. Ports are defined as very dangerous workplaces. As the number of people decreases in port areas where heavy loads are handled, where dangerous cranes with high mobility such as reach steacker and straddle carrier are actively located, and where external truck traffic is constantly experienced, deaths and injuries due to occupational accidents also decrease.

The man hour rate is calculated as follows;

$$\mathbf{MHR} = \frac{\mathbf{MHT}}{\mathbf{CTt}}$$

**MHR**= Man Hour Rate

**MHT**= Total Man Hour

**CTT**= Container Throughput

### 3.3 Quay Performance

Quay performance is the stage where data about the berthing and waiting of the vessel are measured before the vessel operation starts. Productivity at this stage is mostly related to the infrastructure and superstructure investments of the port operator, such as the length and number of quays, the draft, the number of quay cranes. Factors such as the time spent for the maintenance of the quay and cranes, the distance to the waiting area, the customs controls after the vessel dock, the time taken for the control of the operation plans are the factors affecting the quay performance.

Especially in container transportation, vessels waitings cause major disruptions in the supply chain and increases the costs of shipowners with increasing vessel lengths. Therefore, quay performances are as important as vessel operation performance. Berthing on arrival or berth availability is an important competitive advantage that influences port choice decisions ( Elferjani, 2015). In this section, quay performance will be examined under 3 headings;

- Berth Utilization Rate
- Vessel Turnaround Time
- Container Throughput Per Meter

#### 3.3.1 Berth Utilization Rate

Berth availability can be considered as the efficient utilization rate of the quays owned by the port operator. Port operators cannot use their quays actively, and there are certain idle times even if there are vessels waiting to berth. These idle times are generally;

- Vessel berthing/departure maneuvers
- Lashing/unlashing time
- Time taken for customs controls
- Crane maintenance/breakdowns

- Time taken for berth/quay maintenance and repair
- Time taken for port authority applications

Berth availability refers to the ratio of the time intervals when the quays owned by the port operator are not in use, that is, it is the ratio of the time intervals (that the operator cannot benefit from the quays) to the total time. As stated above, the time periods such as the berthing/departure maneuvers of the vessels, customs controls, quay maintenance and repair periods are the times when the quays are not in use and the quay cannot be utilized even if there is a vessel waiting to berth.

Berth availability is an important performance indicator for port operators' future planning and especially for capacity calculations. Berth availability should be taken into account when calculating the quay/dock capacity of the port operator, and the times when the quay is not in use should be taken into account.

When calculating Bert availability, the ratio of the time the port operator is open throughout the year to the time period when the quays are not in use is taken into account. The times during which the quays are active within the total working period can be calculated as a percentage with the following formula;

$$\mathbf{BA} = \frac{WT-CT}{WT} X100$$

**BA** = Berth Availability

**WT** = Total Working Time

**CT** = Closed Time

### 3.3.2 Vessel Turnaround Time

Vessels also spend time outside their operational time at the port quays where they are berthed. Some of the reasons why vessels spend time out of operation times (service times) are as below;

- Port authority controls
- Customs controls
- Lashing/unlashing operations
- Operation preparations
- Crane malfunctions
- Regional factors (sea pollution, power outage, etc.)
- Pilot, mooring and tugboat waiting times are also spent at the quays.
- Installation of transportation vehicles such as vessel ladders, safety nets, etc.

The times mentioned above are some of the times that the vessels spend at the quay, apart from the loading-discharging operations. Vessel turn around time covers the entire period from the vessel's berthing to the departure. The ratio of the total time the vessels stayed in the port to the total number of vessels can be defined as vessel turnaround time.

The time, especially the one that container vessels spend in ports, is very valuable, which makes vessel turnaround time an important port performance indicator for shipowners. In terms of ports, the time spent by vessels in ports is an important indicator in terms of quay capacity and berth planning. However, some factors such as customs controls, regional factors, pilot times, port authority controls, ladder installation of this performance indicator may occur outside the control of the port operator. Vessel Turn Around Time is calculated as follows;

$$\mathbf{VTT} = \frac{\mathbf{TTv}}{\mathbf{TNv}}$$

**VTT** = Vessel Turn Around Time

**TTv** = Total Vessel Time

TN<sub>v</sub> = Total Number of Vessel

### 3.3.3 Container Throughput Per Meter

Port operators are high-cost enterprises in terms of infrastructure and superstructure investments. Docks and quays are the most valuable areas in terms of vessel sheltering and operations, which are the primary duties of port operators. While calculating the capacity of port operators, the quay/dock capacity is also calculated and this indicator is very important. Especially in busy ports, it is very important to plan the quay correctly in terms of vessel berthings and queues, and to use quays/docks effectively.

Container throughput per meter is calculated by dividing the number of containers handled within a certain period of time in the port operation by the usable quay/dock length. It can be calculated separately for each quay owned by the port, or it can be calculated over the total quay length without exception. Container output per meter is quite high, especially since Asian ports are busy ports. Of course, this rate may change with factors such as the number of vessels arriving at the port, container density, and the existing equipment of the port. The World average quay-line performance was around 1,000 teu per meter of quay in 2011, rising to nearer 1,100 teu by 2013: a 6% increase (Drewry, 2014).

Container throughput per meter is calculated as follows;

$$CT_m = \frac{CT_t}{BL}$$

CT<sub>m</sub> = Container throughput per meter

CT<sub>t</sub> = Total amount of container throughput

BL = Berth Length (meter)

### 3.4 Vessel Performance

The most important service output for container ports is vessel operation speed (Sekin & Gençer, 2019). Factors such as the continuous increase in the share of liner transportation in container transportation, the increase in container freights in recent years, the demand increase after the Covid 19 pandemic period have made turn time more important for container vessels, and many shipowners have run their vessels at full speed since there is no load problem. In such periods, shipowners put pressure on port operators in order for their vessels to spend less time in ports and to make more voyages. Even though vessels lose time in ports outside of the operation time, most of the time they spend in ports is vessel operation, that is, container handling. This makes vessel operation performance the most important performance indicators for port operators and line operators/shipowners. Line operators want to guarantee the service they receive from ports by adding vessel performance requirements to their agreements with port operators.

As in many performance indicators, the most important factors for the port operation in vessel performance are its infrastructure and superstructure equipment. The type of vessel crane owned by the port operator is an important factor as it directly affects the performance of the vessel with the movement it can produce hourly. With the increase in the share of container transportation in total transportation over the years, changes and developments have occurred in cranes working in this area over the years. Operations that were previously carried out with cranes on the vessel were replaced by mobile harbor cranes (MHC) and later ship to shore (STS) cranes. Today, STS cranes are used in modern container ports and, together with technological developments, they also allow autonomous uses. As can be seen from Table xx, STS cranes are quite advantageous compared to MHCs in terms of operation speed. However, for some congested ports and quays, MHC may be a more convenient option for mobility.

Crane	Average gross productivity
Ship-to-shore gantry crane	Low 20 - 25 moves/hour
	Medium 25 - 30 moves/hour
	High 30 - 35 moves/hour
Mobile harbour crane	15 - 20 moves/hour

*Source: PLANC (2014b)*

**Table 3-3:** Average Gross Productivity

Many indicators that affect the vessel's operational performance can be examined under different headings, but in this part of the research, they will be examined under 4 headings that are considered to be important;

- Gross Move Per Hour
- Net Move Per Hour
- Dual Cycle Rate
- Crane Availability

### **3.4.1 Gross Move Per Hour (GMPH)**

The importance of speed in vessel operations and the expectations of line operators from port operators were explained in previous sections. Gross move per hour is one of the most important indicators that are given importance by port operators and line operators, they usually add this item to contract terms. Gross move per hour (GMPH) refers to the number of movements produced by each crane operating in vessel operations in one hour. GMPH is the average moves per hour measured in the total time between the chosen start and finish

of crane operations (Drewry, 2014). Average gross move per hour values according to the KPI reports in Drewry 2014 are shown in Table 3-4.

Ship Size (teu)	Size of Exchange Per Call (no. of Boxes)	Average Crane Intensity (no. of Cranes)	Average Moves Per Hour Per Crane	Time in Port (Hours)
18,000	4,500	7	26	24.7
18,000	4,500	5	37	24.3

Source: Drewry Maritime Research

**Table 3-4:** Key Performance Indicator

Hourly movements on vessels may vary depending on equipment type, operation type, number of cranes working on the vessel, yard occupancy rate, and number of yard equipment working on the vessel. The main purpose of the port operator's operations is to demonstrate a measurable and standard performance. With terminals becoming part of larger organizations and shipping lines changing and using new terminals, there is a need to standardize the measurement for more accurate comparison (Drewry, 2014).

In GMPH, measurements are made on unit based. The purpose of the terminal operators and line operators is for the cranes to operate continuously and produce movement during vessel operation, but there may be some downtime during operation. These delays may be due to terminal, line operator, shipowner or weather conditions. While calculating the GMPH, the waiting times in a time zone are not taken into account, but the movement produced in the hour is taken into account. All movements such as loading, discharging, shifting, cover movement that the crane performs within the vessel operation are included in the movement produced. GMPH calculation in the simplest way is the sum of the movements (loading, discharging, shifting, cover) made by 1 crane in vessel operation within 1 hour.

### **3.4.2 Net Move Per Hour (NMPH)**

In vessel operations, it is aimed to continuously operate the cranes and produce movement, but in some cases, operational delays may occur. General operation waits are shown in the table below (Table 3-5). The waitings may differ depending on the terminals and the type of operation. Net Move Per Hour also shows the movements of a crane working in vessel operation in one hour, as in the GMPH. However, unlike GMPH, the waiting times are NMPH can be defined as the movements produced by cranes working in vessel operations while they are actively working. NMPH; is the average moves per hour when the crane is actually in operation, deducting time when the crane is idle (Drewry, 2014).

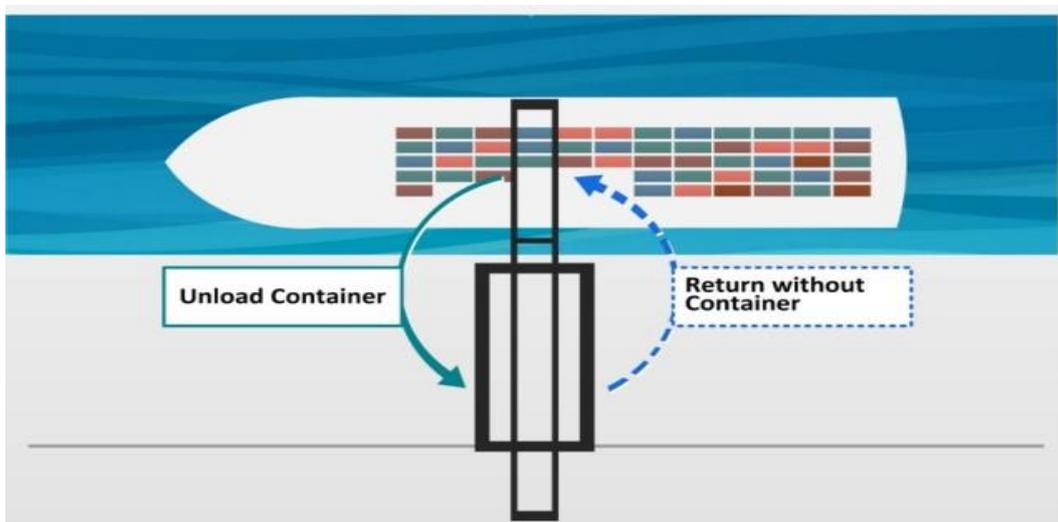
Although line operators are generally interested in GMPH, NMPH is an important indicator in terms of showing the potential of the port operation. At the same time, the difference between GMPH and NMPH shows the performance losses caused by waiting during operation. Typical GMPH is in the region of 20-30 MPH while typical NMPH figures are from 25 to as high as 40 MPH (Drewry, 2014). The fact that the difference is high can be considered as an indication that the port operator loses a lot of time in waiting and works ineffectively. Generally, port operators create a delay report by recording the waits they faced during vessel operations and can focus on the waiting times. However, in some cases, the operation speed not being at the desired level may be caused by external conditions. For example, long trolley time in large vessels and longer hoist time in in-hold operations may cause the operation to be slower than in small-sized vessels.

Source	Terminal		Vessel	Other
	Operation	Technique		
<b>TYPE</b>	Crane clash	Boom Up/Down Fault	Crane Stoppage by VESSEL Request	Bad weather
	Crane sequence change	Crane Translation	Bad Cell Guide	Waiting Customs Clearance during ops
	Crane Stoppage by ops	Hoist Fault	Bad Loading	Waiting Customs Clearance prior ops
	System Failure (TOS)	Power failure	Jammed twist lock use of Safety Cage	Other Delays avoidable
	Waiting TT	Spreader Fault	Line Planning Delays	Other Delays Inherent
	Hatch cover move	Trolley Fault	Mac Gregor Hatches	
	Lashing/ Unlashing	Crane Fueling during ops	Shifting vessel gear	
	Special Handling (Wire Slings & OOG)	Other Crane Breakdown	Waiting for gangway	
	Terminal Planning Delays		Waiting Reefer Unplug	
	Shift Change		Waiting for Vesselping Agent	
	Boom UP/Down For Crane Moves			
	Break Time		Waiting for vessels-convenience (specify)	

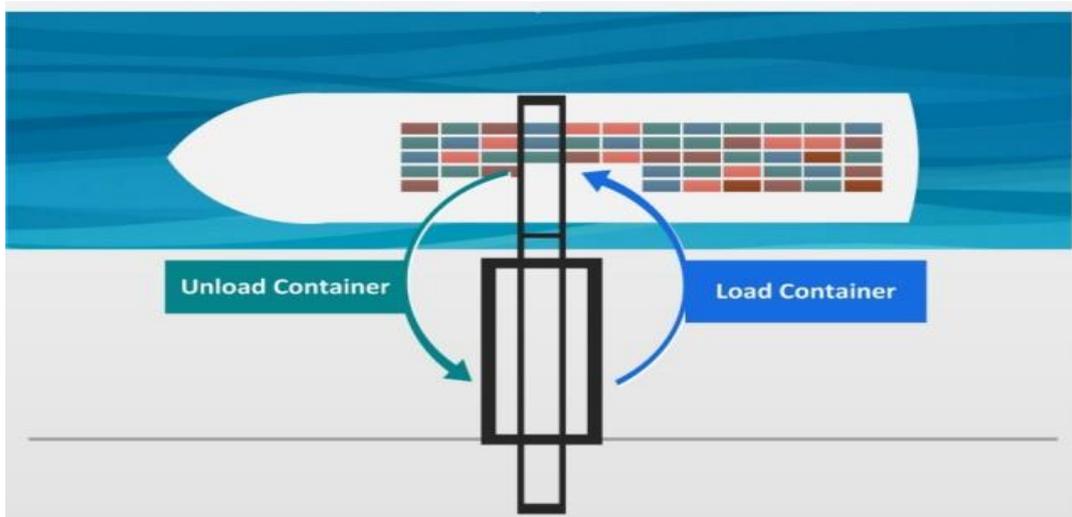
Table 3-5: Waiting Types

### 3.4.3 Dual Cycle Rate

Port operators want to use the equipment they have effectively in order to increase the speed of their operations and to get their investments in return. In order to increase the number of movements of the cranes working in vessel operation, spreaders are used that enable twin and tandem operations. The idle times of the cranes during the operation also directly affect the operation speed. In order to reduce these idle times, the crane is intended to be used in bidirectional movements during operation. Dual cycling is a semi-automatic application used along with sway control product that supports all working operation modes in a vessel, as loading and unloading sequence (Siemens, 2021). (Figure 3.3, Figure 3.4) The dual cycling allows QC to discharge a container in the same cycle as a loading operation, thus doubling the number of QC tasks in one cycle, and decreasing the empty movements (Drewry, 2014).



**Figure 3.2:** Single Moves  
**Source:** new.siemens.com



**Figure 3.3:** Double Moves  
**Source:** new.siemens.com

With Dual Cycle, the idle time of cranes working in vessel operations is reduced, and it enables the crane to make the second movement as produced movement. However, it is not possible to do dual cycles in all cases. Vessel holds and container positions in the hold must be in accordance with the dual cycle. Dual cycle has a positive effect on GMPH, it increases GMPH as the idle time of the cranes decreases in a certain hour. However, in order to avoid vehicle waiting in the dual cycle, the occupancy rate and the distribution of the containers in the yard must be appropriate.

## **4. OPTIMUM CAPACITY**

### **4.1 Definition**

The high share of maritime trade in total trade, the increase in supply chain demands in certain periods, the need for vessel and container slot supply for a certain time cause the demands in container transportation to increase in certain periods. Line operators, who maintain regular line transportation during these periods, want to make their vessels have more voyages as they cannot increase the slot supply in the short term. This is only possible by increasing the speed of the vessel and reducing the port times. This situation requires constant change and development for ports. For port operators, vessel operation speed is among the commitments they make to line operators in their contract negotiations. Fulfilling these commitments requires using its resources in the most efficient way. There are many factors that affect the performance of port operators. These factors have been described in the previous sections. In this section, the effect of yard capacity and occupancy rate on Gross Move Per Hour will be discussed. The importance of the optimum point, where the yard occupancy can be used most efficiently in terms of GMPH, will be emphasized.

Optimization is defined as a technology that enables to achieve certain goals (such as cost reduction, profit maximization, capacity utilization maximization and productivity maximization) by using the resources available in a system (such as labor, time, capital, processes, raw materials, capacity, equipment) in the most efficient way (Gass, 2000). Optimization is used effectively as a method to include the preferences and constraints of customers, employers and employees in the decision process, and to increase the quality of the resources in the system, as well as the economic benefits (Türkay, 2016). Indeed, the purpose of determining the effect of capacity on GMPH and the optimum point in terms of efficiency is to increase the quality of resources and increase customer satisfaction by determining constraints as well as economic interests. The main purpose of determining the optimum storage capacity is to define the constraints of the port operator to reach the promised speed (GMPH).

Defining and accurately calculating the storage capacity is of utmost importance for effective yard planning and operational flow (Sekin & Gençer, 2019). The ability of port operators to produce uninterrupted movement in vessel operations, to achieve the desired performance and to achieve the level of customer satisfaction depends on the effective use of all operational staff. One of these operational elements is yard operations. The movement (loading, discharging) produced by each crane during vessel operation has at least 1 counterpart in yard operations. The container to be loaded on the vessel must reach the quay crane at the right time from the yard, and the container discharged from the vessel must be delivered to the yard and the terminal truck must reach the quay crane at the right time to pick up the discharged container again. Otherwise, idle times will occur in cranes operating in vessel operations and will directly affect GMPH. All yard planning should be made specifically for each vessel operation to keep the truck turn time at the maximum level. At the same time, necessary yard arrangements should be made so that external trucks do not affect the vessel operation. Making all these plans depends on effective yard planning. This study is based on the hypothesis that the port operator should operate under a certain occupancy level for effective yard planning. Optimum storage capacity focused on vessel performance is the capacity where the yard storage capacity reaches fullness that will affect the vessel's operating speed (Sekin & Gençer, 2019).

Above a certain yard occupancy level (optimal capacity) will cause decreases in the service quality produced by the port operator. Although this study focused on GMPH, the fact that the port operator works above the optimum capacity may cause reductions in service quality and thus customer dissatisfaction due to the following malfunctions;

- Failure to perform CFS operations on time
- Failure to complete the weighing operations on time
- Failure to provide the necessary support on time for the completion of customs procedures.
- Causing long external truck queues in RTG truck lines
- Long waits and queues at the gates
- Local customers cannot reach the cargoes on time due to the fact that the vessel operations cannot be completed at the desired time.

- Failures in stuffing/stripping operations
- Frequent accidents due to yard occupancy
- High energy consumption
- The excess of idle movements and the risks they pose
- Inability to make regular movement distribution in cranes
- Frequent failures in equipment
- High housekeeping rate

In the continuation of the research, it will be tried to determine the effects of factors such as yard density, housekeeping movements, the number of containers loaded to the vessel, and the number of containers departing during the day on GMPH. For the research, the relations between the variables will be tried to be determined by using the regression analysis method.

## **4.2 Methodology**

### **4.2.1 Scope of the Research**

Within the scope of the research, the acceleration of the increase in maritime transport and container transport in total transport, the importance and role of ports in maritime transport and the trends in container transport in recent years have been examined, capacity measurements and performance calculations in ports have been defined. The importance of performance output for port operators and global line operators, the pressures on port operators due to seasonal increases in demand and new trends in maritime transport were mentioned.

Studies and reports in similar fields were examined and references were made in the research. The research addressed the effect of yard occupancy rate on performance outputs in container terminals and aimed to create a meaningful model with regression analysis. At the same time, the negative and positive correlations between the variables were examined and the effects on each other were mentioned.

With the created regression equation, it is aimed to determine the expected vessel performance for port operators. As a result of the difference between the expected GMPH as a result of the regression equation and the GMPH targeted by the port operator, it is aimed to guide the port operator to take precautions, determine the optimum point in density (occupancy), and activate certain constraints in yard operations. With the regression analysis, it is aimed to determine how effective the yard occupancy and the variables such as housekeeping, gate in, gate out in yard operations will be on GMPH.

#### **4.2.2 Data Collection**

The data used in the analyzes were obtained from a port operator which operating in Turkey. The dataset is mixed and does not have a specific date sequence.

In the analysis, GMPH was used as the dependent variable, and as the independent variable, used following variables; the yard occupancy rate, the number of containers loaded to the vessel, the number of housekeeping made in the yard for the containers loaded to the vessel, the number of containers gating in on daily basis, the number of containers gating out on daily basis, the number of containers under CFS operations, again on daily basis. Some criteria were taken into consideration in order to analyze the data correctly, which are as follows;

1. Since it is aimed to reveal the effects of other variables on the operation speed, the data of the vessel which is operating one post during the operation were not included in the dataset. Since all the resources of the port operator are working for a single quay crane, the GMPH is higher than the averages in the vessels working with one post.
2. Vessels to which made special loadings are not included. Since the project cargo loading and discharging requires great attention and care, a lot of time is lost during the operation. So, as it is thought that project cargo operations

negatively affect the vessel operation speed, they are not included in the dataset.

3. The data of the vessels berthed at different quays at the same time were evaluated separately.
4. The yard occupancy rate represents the instant yard occupancy rate of the port, in percentage terms, at 08:00 a.m. on the day of the vessel operation which is in the same data row.

#### **4.2.3 Analysis of Data**

The SPSS (Statistical Package For Social Sciences for Windows, Release ver. 25.0) package program was used in the statistical analysis of the data. In this section, information is given about the tests used, descriptive statistics (descriptive statistics, mean, standard deviation, minimum, maximum), correlation analysis and regression analysis.

Descriptive statistics such as frequency and percentage of the data were used and analytical comparisons were made. Non-parametric statistics were used in categorical and numerical data. Regression analysis was used to explain the relationship between a dependent variable and an independent variable with mathematical equations. Correlation analysis was used to measure the degree and direction of the linear relationship between the two variables. The significance level of the study was taken as 0.05. It has been determined that there is a significant difference when the p value seen in the tables is less than 0.05, and there is no significant difference between the views of the groups when the p value is greater than 0.05.

The research hypotheses are as follows;

H<sub>0a</sub>: There is no relationship between yard occupancy and vessel operation speed.

H<sub>0b</sub>: There is no relationship between the vessel loading variable and the vessel operation speed.

H<sub>0c</sub>: There is no relationship between vessel housekeeping variable and vessel operation speed.

H<sub>0d</sub>: There is no relationship between the input variable and the vessel operating speed.

H<sub>0e</sub>: There is no relationship between the output variable and the vessel operation speed.

H<sub>0f</sub>: There is no relationship between CFS variable and vessel operation speed.

H<sub>0g</sub>: The yard occupancy variable is not an effective variable on the vessel's operating speed.

H<sub>0h</sub>: Vessel loading variable is not an effective variable on vessel operation speed.

H<sub>0i</sub>: Vessel housekeeping variable is not an effective variable on vessel operation speed.

H<sub>0j</sub>: Input variable is not an effective variable on vessel operation speed.

H<sub>0k</sub>: Output variable is not an effective variable on vessel operation speed.

H<sub>0m</sub>: CFS variable is not an effective variable on vessel operation speed.

The research aims to determine the optimum storage quality with a focus on vessel operation speed. The mean (average), standard deviation, minimum and maximum values of the variables obtained in this context are shown in Table 4-1 below.

	N	Average	Standard Deviation	Minimum	Maximum
GMPH	251	20.075	3.3972	9.0	28.0
Yard Occupancy	251	89.599	8.1890	68.7	110.0
Vessel Loading	251	474.05	391.648	22	1877
Vessel Housekeeping	251	103.25	113.885	0	566
Input	251	349.10	256.617	0	998
Output	251	447.44	289.124	0	1013
CFS	251	139.79	86.332	0	357

**Table 4-1:** Average, SD, Minimum and Maximum Values of All Variables

The mean (average) vessel operation speed is 20.07, its standard deviation is 3.39, its minimum value is 9.0, and its maximum value is 28. The mean of the yard occupancy variable is 89.59, the mean of the vessel loading variable is 474.05, the mean of the vessel housekeeping variable is 103.25, the mean of the input variable is 349.10, the mean of the output variable is 447.44 and finally the mean of the CFS variable is 139.79. The sample size is 251 for each variable.

### **Correlation Analysis between Yard Occupancy and Other Variables and Vessel Operation Speed**

In this section, the evaluation of the hypothesis created to examine the relationship between yard occupancy and vessel operation speed is presented. Correlation analysis determines the correlation coefficient, which allows to test the linear relationship between two variables or the relationship of a variable with two or more variables. The correlation coefficient is denoted by “r” and takes a value between -1 and +1 (Kalaycı, 2018).

Spearman correlation method was preferred because the analysis data showed normal distribution. The correlation coefficient “r” indicates a negative relationship between “-1 and 0, a positive relationship between 0 and +1, and no relationship if it is equal to 0. The value of Spearman correlation coefficient between two variables is very weak between  $0.00 < r < 0.25$ , weak between  $0.26 < r < 0.49$ , moderate between  $0.50 < r < 0.69$ ,  $0.70 < r$  It is concluded that there is a high correlation between  $< 0.89$  and very high between  $0.90 < r < 1.00$  (Kalaycı, 2018). In this context, Spearman correlation analysis performed for the relationship between vessel operation speed and yard occupancy rate and other variables are given in Table 4-2 below.

		GMPH	Occupancy Vessel Loading	Vessel H.keeping	Input	Output	CFS	
GMPH	Correlation	1.000	-.565**	.047	-.102	-	-.139*	-.047
	Sig. (2-tailed)	.	.000	.460	.106	.001	.028	.458
	N	251	251	251	251	251	251	251
Occupancy	Correlation	-	1.000	-.094	.082	.049	.055	.000
	Sig. (2-tailed)	.000*	.	.139	.196	.441	.384	.997
	N	251	251	251	251	251	251	251
Vessel Loading	Correlation	.047	-.094	1.000	.843**	.020	.015	-.035
	Sig. (2-tailed)	.460	.139	.	.000	.754	.813	.576
	N	251	251	251	251	251	251	251
Vessel Housekeeping	Correlation	-.102	.082	.843**	1.000	.024	.028	-.009
	Sig. (2-tailed)	.106	.196	.000	.	.704	.658	.885
	N	251	251	251	251	251	251	251
Input	Correlation	-	.049	.020	.024	1.000	.609**	.459**
	Sig. (2-tailed)	.001*	.441	.754	.704	.	.000	.000
	N	251	251	251	251	251	251	251
Output	Correlation	-	.055	.015	.028	.609*	1.000	.386**
	Sig. (2-tailed)	.028*	.384	.813	.658	.000	.	.000
	N	251	251	251	251	251	251	251
CFS	Correlation	-.047	.000	-.035	-.009	.459*	.386**	1.000
	Sig. (2-tailed)	.458	.997	.576	.885	.000	.000	.
	N	251	251	251	251	251	251	251

**Table 4-2:** Relationships Between Vessel Operation Speed and Yard Occupancy and Other Variables  
Correlation analysis \*p<0.05 \*\*p<0.01

An inverse (negative) and moderately significant correlation was found between vessel operation speed and occupancy ( $P < 0.01$ ). In this context, while an increase is observed in the yard occupancy, there is a decrease in the vessel's operational speed. With the P value less than 0.05 significance level, the  $H_0$  hypothesis was rejected, and it was determined that the inverse (negative) relationship between the vessel operation speed and the yard occupancy rate was statistically significant.

An inverse (negative), weakly significant correlation was found between vessel operation speed and input ( $P < 0.01$ ). In this context, while an increase in input is observed, there is a decrease in vessel operation speed. With the P value less than 0.05, the  $H_0d$  hypothesis was rejected, and it was determined that the reverse (negative) relationship between the vessel operation speed and the input was statistically significant.

An inverse (negative) and weakly significant correlation was found between vessel operation speed and output ( $P < 0.01$ ). In this context, while an increase is observed in the output, there is a decrease in the vessel operation speed. With the P value less than 0.05, the  $H_0e$  hypothesis was rejected, and it was determined that the inverse (negative) relationship between vessel operation speed and output was statistically significant.

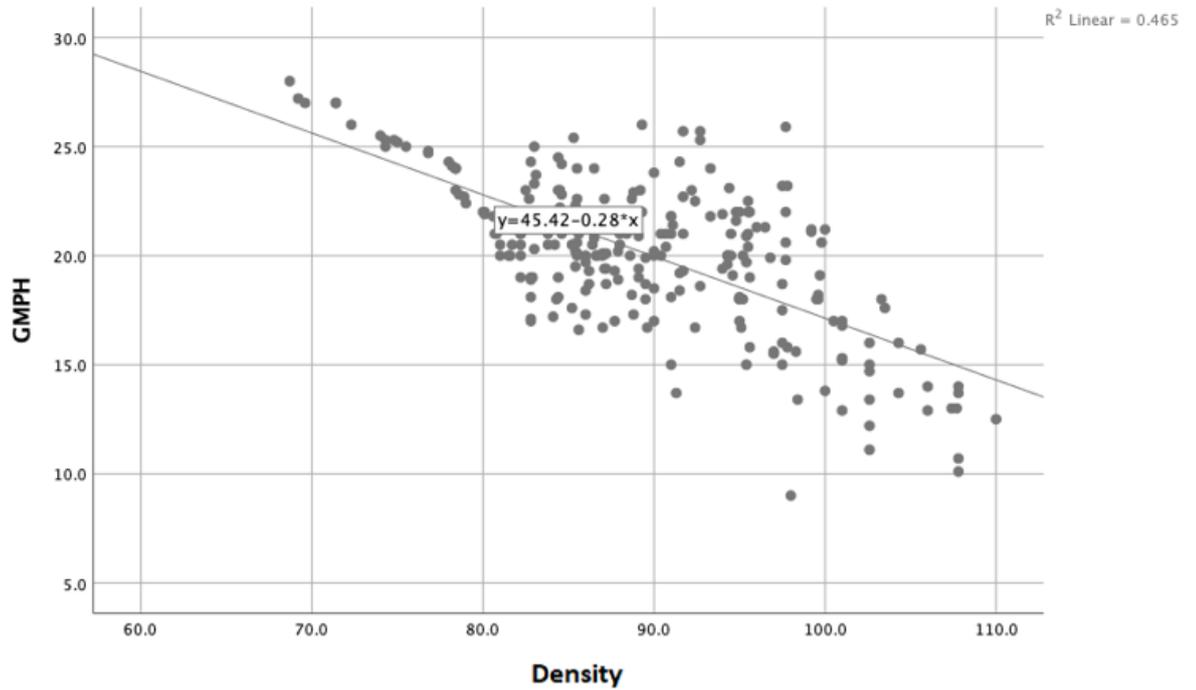
A parallel (positive) strong significant relationship was found between vessel loading and vessel housekeeping, which is one of the independent variables ( $P < 0.01$ ). In this context, while an increase is observed in vessel loading, there is also an increase in vessel housekeeping rate. With the P value less than 0.05, it was determined that the parallel (positive) relationship between vessel loading and vessel housekeeping was statistically significant.

When the correlation analyzes between the variables are examined, as the number of containers loaded to the vessel increases, the number of housekeeping for vessel loadings also increases. In addition, it was revealed by the negative correlation between the two variables that the dependent variable GMPH decreased with the increase in the yard occupancy rate.

## **Regression Analysis on Determination of Variables Affecting Operation Speed**

Regression analysis is performed in order to determine the relationship between two or more variables that have a cause-effect relationship between them and to make estimations or predictions about that subject by using this relationship. Regression analysis was applied to determine the variables affecting the operation speed. The dependent variable, the vessel operation speed, is also continuous, while the independent variables such as yard occupancy, vessel loading, vessel housekeeping, input, output and CFS are also continuous.

Linear regression analysis is to create a model that predicts the variable to be determined, based on the variables that can be detected more easily or earlier than the variable to be determined (Alpar, 2010). The use of one dependent variable and more than one independent variable in linear regression analysis is defined as multivariate regression analysis. In this study, one dependent variable (GMPH) and more than one independent variable (yard occupancy rate, number of containers loaded to the vessel, number of housekeeping made in the yard for the containers loaded to the vessel, number of containers gating in on daily basis, number of containers gating out on daily basis, number of containers applied CFS operations on Daily basis) are used. There is a linear relationship between the variables used (Figure 4.1).



**Figure 4.1:** Linearity relationship between vessel operation speed and yard occupancy

According to Figure 4.1 above, there is a strong and negative relationship between vessel operation speed and yard occupancy. As the occupancy rates increase, it is seen in the figure above that the vessel operation speed values decrease.

Model	Statistics									
	R	R Square	Adjusted R Square	Standart Error of Estimate	R Square Change	F	df1	df2	P value	Durbin-Watson
1	0.703 <sup>a</sup>	0.50	0.48	2.45	0.495	39.69	6	244	0.000	1.455

**Table 4-3:** Regression Analysis on Variables Affecting Vessel Operation Speed  
**Estimators:** (Fixed), CFS, Occupancy, Vessel Loading, Output, Input, Vessel Housekeeping Dependent Variable: GMPH

Model summary values are shown in the table 4-3 above. The R2 value found here was found to be 0.50. According to this result, the 50% change in vessel operation speed is explained by the independent variables included in the model.

Model		Sum of Squares		Mean	Squares	P value
		(SS)	df	(MS)	F	
1	Regression	1425.031	6	237.505	39.689	.000 <sup>b</sup>
	Errors	1460.146	244	5.984		
	Total	2885.177	250			

**Table 4-4:** Variance Analysis Table

Dependent Variable: GMPH Predictors: (Constant), CFS, Occupancy, Vessel Loading, Output, Input, Vessel Housekeeping

In Table 4-4, the important value to be interpreted is the F statistic, which shows the significance of the model, and the P value, which shows the significance level of this value. When the F value is found to be significant, it is concluded that the model is completely statistically significant ( $P=0.000$ ;  $P<0.05$ ). Our model, in which we explain the vessel operation speed with the variables of yard occupancy, vessel loading, vessel housekeeping, input, output and CFS, is a meaningful model.

Model		Non-standardized Coefficients		Standardized Coefficients		
		B	Standard Error	Beta	t Value	P Value
1	(Fixed)	45.090	1.828		24.669	.000
	Yard occupancy	-.272	.020	-.655	-13.677	.000*
	Vessel Loading	.000	.001	.056	.709	.479
	Vessel Housekeeping	-.003	.002	-.088	-1.116	.266
	Input	-.002	.001	-.149	-2.485	.014*
	Output	-.001	.001	-.052	-.900	.369
	CFS	.002	.002	.063	1.212	.227

**Table 4-5:** Parameter Estimations

Table 4-5 shows the effects of yard occupancy, vessel loading, vessel housekeeping, input, output and CFS variables on vessel operation speed. The model established according to the F test is significant ( $F=39.689$ ). It is seen that 48% of the change in vessel operation speed (dependent variable) is explained by the independent variable used (Adjusted  $R^2=0.48$ ).

According to the results of the regression analysis, it was determined that the yard occupancy had a significant effect on the vessel's operation speed ( $P=0.000$ ;  $*P<0.05$ ). With the P value less than 0.05, the  $H_0$  hypothesis was rejected, and it was determined that the effect of the yard occupancy on the vessel's operational speed was statistically significant. According to the results obtained, it was determined by the minus sign in the beta coefficient that the yard occupancy reduces the vessel's operating speed. It was determined that as the yard occupancy increased, the operation speed of the vessels decreased. The parameter value of the yard occupancy is -0.272.

According to the results of the regression analysis, it was determined that the entrance had a significant effect on the vessel operating speed ( $P=0.000$ ;  $*P<0.05$ ). With the P value less than 0.05, the  $H_0$  hypothesis was rejected and it was determined that the effect of the input on the vessel's operation speed was statistically significant. According to the results obtained, it has been determined by the minus sign in the beta coefficient that the input reduces the vessel's operational speed. It was determined that the operational speed of the vessels decreased as the input increased. The parameter value of the input is -0.002. As a result of one unit increase in the input, the operational speed of the vessel decreases by 0.002 times.

## **5. CONCLUSION, RECOMMENDATIONS AND FUTURE RESEARCH**

The performance and efficiency of ports can directly affect the economic output of regions and countries, since maritime transportation has the largest share among transportation types in global trade and as the ports are the starting and ending points of maritime transportation. In many countries, new port investments and capacity increases are carried out with government policies, and industry and market hinterland are considered in the selection of port location. It was aimed to draw attention to the importance of performance and capacity calculations in ports throughout the study.

Port performance and capacity become much more important, especially during periods of increased demand in maritime transport, when export/import volumes increase rapidly depending on the economic policies of countries, and during periods of disruption and changes in the supply chain.

For port operators, performance and capacity are always mentioned together. In port terminology, it is always a universal consent fact that there is an inverse correlation between port capacity/occupancy and port performances. In this study, it is aimed to scientifically reveal this generally accepted hypothesis by using some research methods. As a result of the research, the findings and the views of the author are as follows;

A data set consisting of 251 datasets including instant occupancy of the port area and vessel performances was examined and in the correlation analysis, an inverse correlation relationship was determined between the area occupancy and gross move per hour. As a result of the analysis, it can be said that our hypothesis and common views are supported that the speed of the vessel operation decreases as the yard occupancy increases. Port operations are multi-factor and dynamic operations, each vessel operation and yard situation

may not meet the analysis results exactly. However, as a general view, it can be said that the increase in the yard occupancy negatively affects the services to be produced by the port operator, especially the vessel performance.

In the multivariate regression analysis performed on the same data set, a significant relationship was found between the dependent variable (GMPH) and the independent variables (yard occupancy, vessel loading, vessel housekeeping, input, output, CFS). The regression equation resulting from the analysis is as follows;

$$Y = B_0 + B_1X_1 + B_2X_2 + \dots + B_NX_N$$

$$\text{GMPH} = 45.090(\text{Coefficient}) - 0,2272 \times (\text{Yard Occupancy}) + 0,00 \times (\text{Vessel Loading}) - 0,003 \times (\text{Vessel Housekeeping}) - 0,002 \times (\text{Input}) - 0,001 \times (\text{Output}) + 0,002 \times (\text{CFS})$$

In the resulting regression equation, when the mean (average) values of the independent variables in the data set are taken, the result is as follows:

$$\text{GMPH} = 45.090 - 0,2272 \times 89,59 + 0,00 \times 474,05 - 0,003 \times 103,24 - 0,002 \times 349,09 - 0,001 \times 447,43 + 0,002 \times 139,78$$

$$\text{GMPH} = 19,54$$

The GMPH target of the port operator from which the data set is obtained is determined as 25. The calculation made by considering the averages of the dependent variables in the data set in order to reach the target of 25 GMPH over the regression equation is as follows;

$$\text{GMPH} = 45.090 - 0,2272 \times X_1 + 0,00 \times 474,05 - 0,003 \times 103,24 - 0,002 \times 349,09 - 0,001 \times 447,43 + 0,002 \times 139,78$$

$$25 = 45.090 - 0,2272 \times X_1 + 0,00 \times 474,05 - 0,003 \times 103,24 - 0,002 \times 349,09 - 0,001 \times 447,43 + 0,002 \times 139,78$$

$$X_1 = 69,54$$

Considering the arithmetic mean of the independent variables in the data set and the target value of the dependent variable, the port operator needs to work with 69.54 area occupancy in order to achieve the targeted GMPH. This value can be named as the optimum occupancy rate of the GMPH value targeted for the port operation. “It is internationally accepted that a utilization figure of up to 70% will allow the terminal to work at maximum efficiency” (Drewry, 2014). His statement supports the analysis results. When all these results are considered, it is concluded that the optimum storage capacity focused on GMPH is 69.54% for the port operator used as a sample.

The sectoral equivalent of the results of the analysis method used in the research shows that multivariate regression analysis can be used to determine the optimum storage capacity focused on GMPH for port operators. On the other hand, the regression model should also be tested with more data or data from other ports. Depending on this, the model may provide a different optimum rate for each port. Moreover, other factors or variables can also be considered in the calculation of optimum capacity in future studies

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