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DOCTORAL THESIS
Doctor of Philosophy (PhD)

**DEVELOPING A MODEL FOR MEASURING THE
CAPACITY OF DRY BULK PORTS IN TURKEY**

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İZMİR-2019

THESIS APPROVAL PAGE



DECLARATION

I hereby declare that this doctoral thesis titled as “Developing a Model for Measuring the Capacity of Dry Bulk Ports in Turkey” has been written myself in accordance with the academic rules and ethical conduct. I also declare that all materials benefited in this thesis consist of mentioned resources in the reference list. I verify all these with my honour.

20/05/2019

Seçil GÜLMEZ

ABSTRACT
Doctoral Thesis
Doctor of Philosophy
Developing a Model for Measuring the Capacity of Dry Bulk Ports in Turkey
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Ports are defined as critical nodes in international trade and one of the critical part of international transport. For this reason, these essential infrastructures are a strategic point for both stakeholders and port operators. Continuous development of maritime transport, macro, and micro environmental factors triggered and accelerated the development of ports. To keep up with these ongoing developments, the ports are continuously improving themselves technologically and expand and upgrading their infrastructure or tend to invest in building new ports to satisfy the demand created by increasing trade volume. Under these circumstances, port operators should plan the capacity regarding the supply and demand conditions.

In this study, it was attempted to develop a capacity measurement model for dry bulk terminals within an integrated viewpoint. A literature review was conducted at first to develop a capacity measurement model, and factors affecting the port capacity were determined in line with information achieved from the literature. Measurable factors were attempted to reflect empirical equations for measuring berth handling capacity, storage yard capacity, and transfer equipment capacity of the dry bulk terminals. These factors constitute the basis of the empirical equations. Empirical equations were also tested by a simulation model using real-world data obtained from the port, which serve multiple bulk

cargoes. To test these equations by using simulation, the conceptual model was generated. Simulation model and conceptual model were verified by comparing and testing the equations manually.

Apart from developing a capacity measurement model for the dry bulk terminal, this study introduced two concepts. These concepts are realizable capacity level and theoretical gang number. These concepts were discussed thoroughly, and the effects of these concepts were measured within the context of the study. In addition to that, the effects of the berth occupancy ratio, which was frequently used by researchers in measuring berth handling capacity, was deeply discussed to determine its function in berth handling capacity measurements and functional comparison between the berth occupancy rate and berth utilization factor was discussed.

The result of the study has shown that the model could be used for measuring the capacity dry bulk terminal capacity. Apart from the actual capacity of the port, results showed that realizable capacity might be considered when measuring the port capacity. The results implied that theoretical number of gang and berth utilization factor could be used for determining the realizable capacity of the port in addition to actual or proper capacity of the port.

Keywords: Dry Bulk Terminal, Capacity Measurement, Berth Handling Capacity, Storage Yard Capacity, Transfer Equipment Capacity, Simulation Model, Empirical Equation.

ÖZET
Doktora Tezi
Kuru Yük Limanlarında Kapasite Ölçümü Üzerine Bir Model Önerisi
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Limanlar uluslararası ticarete önemli düğüm noktaları ve uluslararası taşımacılığın önemli bir parçası olarak tanımlanmaktadır. Bu sebeple bu önemli altyapılar hem liman operatörleri hem de paydaşları için stratejik noktalardır. Deniz taşımacılığının sürekli olarak gelişme kaydetmesi, makro ve mikro çevresel faktörler de liman gelişimini tetikleyerek bu gelişimi hızlandırmıştır. Devam eden gelişmelere ayak uydurabilmek ve artan ticaret hacminin yarattığı talebe karşılık verebilmek adına limanlar kendilerini altyapısal ve teknolojik olarak geliştirmekte ve hatta yeni liman inşası yatırımlarına yönelmektedirler. Bu koşullar altında liman operatörlerinin arz ve talep koşullarını dikkate alarak kapasite planlaması yapmaları gerekmektedir.

Bu çalışmada, bütünsel bir bakış açısıyla dökme yük terminalleri için bir kapasite ölçüm modeli geliştirilmeye çalışılmıştır. Kapasite ölçüm modelini oluşturmak için öncelikle bir literatür taraması gerçekleştirilmiştir ve literatürden elde edilen bilgiler doğrultusunda liman kapasitesine etki eden faktörler belirlenmiştir. Ölçülebilir faktörler, dökme yük terminallerinin rıhtım elleçleme kapasitesi, depolama sahası kapasitesi ve transfer ekipmanı kapasitesi ölçümü için geliştirilen ampirik denklemlere yansıtılmaya çalışılmıştır. Bu faktörler ampirik denklemlerin temelini oluşturmaktadır. Ayrıca ampirik formüller çok çeşitli yük türüne hizmet veren bir dökme yük terminalinden elde edilen uygulamaya dayanan veriler aracılığıyla test edilmiştir. Bu formülleri

simülasyon aracılığıyla test edebilmek için kavramsal model oluşturulmuştur. Oluşturulan simülasyon modeli ve kavramsal model birbirleri ile karşılaştırılarak ve formüllerin manuel olarak çözümlenmesi ile doğrulanmıştır.

Dökme yük terminalleri için kapasite ölçüm modeli geliştirilmesinin dışında bu çalışma iki farklı kavram ortaya koymuştur. Bu iki kavram gerçekleştirilebilir kapasite ve ekipmanın saatlik teorik hareket sayısıdır. Bu kavramlar tez kapsamında etraflıca tartışılmış ve bu kavramların etkisi ölçülmüştür. Buna ek olarak, literatürde konunun uzmanları tarafından sıklıkla kullanılan rıhtım işgal oranının liman kapasitesi üzerindeki etkisi ve liman kapasitesi hesaplamasındaki rolü derinlemesine tartışılmış ve rıhtım işgal oranı ve rıhtım kullanım faktörünün fonksiyonel olarak karşılaştırılması tartışılmıştır.

Çalışmanın sonuçları, oluşturulan modelin dökme yük terminalleri kapasite ölçümü için kullanılabileceğini göstermiştir. Çalışmaya ait sonuçlar, güncel kapasiteden farklı olarak, gerçekleştirilebilir kapasitenin de dökme yük terminalleri kapasite ölçümünde kullanılabileceğini göstermiştir. Limanın güncel kapasite ölçümüne ek olarak, ekipmanın saatlik teorik hareket sayısı ve rıhtım kullanım faktörü gerçekleştirilebilir kapasite hesaplamalarında kullanılabileceğini göstermiştir.

Anahtar Kelimeler: Dökme Yük Terminali, Kapasite Ölçümü, Rıhtım Elleçleme Kapasitesi, Depolama Sahası Kapasitesi, Transfer Ekipmanı Kapasitesi, Simülasyon Modeli, Ampirik Formül.

DEVELOPING A MODEL FOR MEASURING THE CAPACITY OF DRY BULK PORTS IN TURKEY

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LIST OF ABBREVIATIONS

AST	Average Service Time
AWT	Average Waiting Time
BOR	Berth Occupancy Ratio
d	Day
dm	Decimetre
DWT	Deadweight ton
fpm	Feet per Meter
ft³	Cubic Feet
G	Gang
g	Grams
GPH	Gang per Hour
GRT	Gross Tonnage
ha	Hectare
h, hr, hrs	Hour
in	Inches
Kg	Kilogram
kt	Kiloton
lb	Libre
LOA	Length Overall
m²	Square Meter
m³	Cubic Meter
MHC	Mobile Harbour Crane
mm	Millimetre
NRT	Net Registered Tonnage
s, sec	Second
SOF	Statement of Fact
t	Ton
TAT	Turn Around Time
T_b	Service Time
TGN	Theoretical Gang Number

tpg	Ton per Gang
tph	Ton per Hour
T_w	Waiting Time
t/y	Ton per Year



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INTRODUCTION

Ports are one of the critical infrastructure and strategical nodes in international transportation by reason of linking other modes of transport. These infrastructures are nodal interfaces where logistics, distribution, and trade activities performed (Bichou, 2013: 1). The increasing impact of the technological development on transport, cargo handling, storage activities and the transshipping have transformed the ports into highly specialized facilities for specific cargo types (Dundovic and Kovacic, 2007:247). Although the ports serve with multipurpose facilities, the latest form of ports and operation systems are highly designed to serve specific ship type or trade (Bichou, 2013: 135).

Ports have several functions. The primary functions of the ports can be listed as follows (Frankel, 1985:3-4; Ligteringen, 2012: 45; Stopford, 2009: 29; Frankel, 1987: 7-9)

- Loading and unloading of the cargoes
- Giving service to vessels and cargoes (packaging, safeguarding, consolidation, deconsolidation, classification of the cargoes, storage of the cargoes, maintenance, etc.)
- Packaging and safeguarding of the cargoes
- Documentation and managing the information about cargo and vessels
- Providing commercial and financial services
- Supporting industrial activities
- Interfeeder transferring
- Direct transferring of the cargoes

The variety of these services can differ according to the port/terminal type. Generally main terminal types can be listed as follows: (i) general cargo terminals; (ii) multipurpose terminals, (iii) RO-RO terminals, (iv) container terminals, (v) liquid bulk terminals; (vi) inland water transport terminals, (vii) cruise terminals, and (viii) dry bulk terminals. The types of terminals are generally specialized according to the types of cargoes handled (Ligteringen, 1999: 6-5). Within the context of the study and the research objectives, it is focused on the dry bulk terminals.

A broad definition of dry bulk terminal is "*A bulk port terminal is a zone of the port where sea-freight docks on a berth and is stored in a buffer area called yard for loading, unloading or transshipment of cargo.*" (Robenek et al. 2012: 2). In addition to the definition, dry bulk terminals can be evaluated as a single or multi-channel system that comprises several sub-systems divided into functions according to the availability of the resources (Hess et al. 2007: 61; Schott and Lodewijks, 2007:375). Dry bulk terminals are different from the other types of terminals regarding the factors such as location, draft, infrastructure type, terminal layout, storage facilities, terminal equipment and additional services (UNCTAD, 1985b: 168). The characteristics of the terminal also show difference because dry bulk cargoes can vary by the density of the material (Bugaric et al. 2012:1508). Dry bulk terminals specialized in dry bulk cargoes (Burns, 2015: 124). These types of cargoes generally assessed under the two main categories as "major dry bulk cargoes" and "minor dry bulk cargoes" (UNCTAD, 1985b: 168). There is a more specific distinction for major dry bulk commodities. Five major bulk commodities are iron ore, coal, grain, bauxite and alumina, phosphate rock. The remaining dry bulk commodities such as steel, cement, fertilizer, forest products, sulfur, scrap, etc. are classified as minor dry bulk commodities (RMT, 2014: 1; Frankel et al. 1985: 3).

Dry bulk terminals need to be planned and be designed in line with the requirements as well as other terminals types which are specialized on specific cargo group. Macro and microenvironmental factors compel seaports to develop (UNCTAD, 1985b; Kleinheerenbrink, 2012:21). By the port planning, the balance between idle and inadequate capacity can be achieved, and throughput capability of the terminal can be controlled and be directed in line with the business interests (Frankel, 1987:11).

Planning and designing the terminals are multifaceted issues that planners should be addressed. For this reason, the issue consists of various disciplines such as coastal engineering, policy, statistics, traffic engineering, economics, etc. (Velsink, 1990:7). The terminal design includes seaside and landside interfaces as essential components of the terminal. The seaside interface comprises berth infrastructures and superstructures, channels, berth handling equipment, whereas the landside interface of the terminal encompasses the storage yard area, storage yard equipment, gate and hinterland connection links of the terminal (Ramirez-Naffarrate et al. 2016: 1; Roy et

al. 2016: 472). Even though the synchronization of these areas is quite difficult, it can be achieved with an integrated approach (Wu, 2014:61; Ramirez-Naffarrate et al. 2016: 3). The essential factor in planning is capacity considerations (Malavasi, 2005: 471). The Capacity subject is an important indicator that the port can provide specific services with a particular infrastructure (Dekker, 2005:3; Bichou, 2013: 51). The layout design is highly associated with the capacity issue. Terminal planning and design regarding sea and landside affect the capacity and the other related issues due to equipment planning and other critical issues related to capacity. Planning and designing of the terminals or ports to be performed in this context will enable the port to achieve its ultimate aims in the capacity subject.

This study attempts to develop a new measurement model regardless of the export or import dry bulk cargo terminal by integrating measurable factors that affect the capacity stated in the literature and based on the capacity measurement equations. Generic equations were simulated with real-world data of the dry bulk terminal. The results obtained through the simulation were illustrated, and the simulation model was verified.

Several processes were followed to reach this aim. The existing equations were analysed through the literature review and content analysis, and the disregarded parameters were identified. Empirical equations were attempted to develop by considering measurable neglected parameters in the literature. While doing this, the simulation model was generated by regarding different alternatives that the port might implement, and the model was tested. The details of the study are evaluated under the below titles.

a. Specifying the Research Questions and Aim of the Study

Capacity is one of the critical characteristics of transport infrastructures (Bichou, 2013). Deciding on the port capacity, the balance between shortages and over-capacity should be appropriately balanced (Dekker and Verhaeghe, 2006). Port must provide adequate capacity to vessels with cargo handling infrastructure and intermodal transport options (Gaur et al. 2011). In the event of a failure in proper planning of port capacity, vessel congestion frequently occurs in the port area

(UNCTAD, 1985). In another case, the excess capacity may lead to inefficient port investments.

According to Çağlar (2012:122), the importance of capacity planning can be evaluated under four title;

- Unnecessary investments will create idle capacity and it will not only create disadvantages but also harms port tariff structure
- Determining the right capacity requirements is the most critical parameter that will show when the port infrastructure investments should start
- Port capacity is a parameter used to determine efficiency and effectiveness levels at ports to find capacity utilization rates, to improve the operational and administrative process and to increase port profitability
- Seaport capacity is an important issue in terms of port privatization. One of the main aims of port privatization is to increase efficiency and effectiveness based on the port capacity.

The research article of Esmer and Duru (2017), “Port Governance in Turkey: The Age of Global Terminal Operators” emphasized on the changing structure of the port industry and governance implementations in Turkey. In the study, researchers discussed devolution processes and throughput increase of Turkish ports. The study also pointed on the rise in throughput capacity of the national port. In addition to this study, TÜRKLİM (2017) report on “Turkish Ports” drawn attention on the Turkish port sector and the capacity developments of Turkish port. In line with these researches, the research field specified as “port capacity”. Accordingly, research questions can be stated as follows:

R.Q. 1. How is port capacity measured?

R.Q.2.Which methods/approaches have been conducted to measure the capacity of ports in the extant literature?

R.Q.3.What are the critical issues addressed in capacity measurement in ports?

R.Q.4.What are the main factors affecting port capacity?

R.Q.5.What is the relationship between the measurable factors affecting the port capacity? How do these factors affect the port capacity, and what is the direction of this impact?

R.Q.6. What do different capacity output values mean and for which purpose do different capacity outputs use?

When specifying the research aim, an initial literature review was conducted on several databases. After examination of the studies on port capacity measurement and factors affecting the port capacity, it was found that the researches on the capacity measurement of ports are relatively limited. Moreover, as far as the author's knowledge, dry bulk terminals were addressed as an issue with a lesser extent of scientific papers than that of the other terminal types.

After conducting an initial literature review, a meeting was held with two sector representatives for 90 minutes. One of the participants works as a manager at the port, and the other participator works at the port as a port operation chief. During the meeting, factors affecting port capacity and equations utilized for measuring terminal capacity, especially in dry bulk terminals, were argued. All the equations and related parameters were explained to the participators placed in the equations. Sector representatives drew attention on that specific bulk density, diversity of the equipment, human factor, the capacity of equipment according to bulk material's characteristics, the efficiency of the operation processes of the port, and speed of the customs clearance had not been regarded in capacity measuring equations. Depending on this situation, they stated that the equipment, berth handling, and the storage yard capacity would change.

As a result of specifying the research aim efforts and in accordance with the research questions, the objective of the study is to explore the current methodology on port capacity measurement and critical issues addressed in capacity measurement in dry bulk terminals in accordance with the factors affecting terminal capacity. Besides, this study attempts to explore and to explain the relationship between the primary issues in port capacity measurement, the effects of these factors on port capacity and direction of these effects. In addition to above-mentioned objectives, this study also aims to find the means and intended use of different capacity output values. This study aims to develop empirical capacity measurement equations for dry bulk terminals by analysing the existing formulations systematically and to develop a capacity

measurement model for dry bulk terminals regarding berth handling, equipment, and storage yard.

b. Research Design and Process of the Study

In this part of the “Introduction” section, it has been attempted to explain the research design characteristics and research approaches and methods conducted in this study.

The research design refers to the general idea behind the research and includes a strategy of inquiry and method employed in the study (Creswell, 2014: 5). The strategy for both designing and performing research depend on the nature of the study, whether it is qualitative or quantitative (Neuman, 2014:165). According to Thomas (2010:301), research mode is commonly classified as qualitative and quantitative, although research methods are being classified in different perspectives. In addition to that, Thomas (2010:301) stated that qualitative and quantitative concept could be explained on two different levels. At the first level, qualitative and quantitative imply the nature of the knowledge of how the world and the ultimate aim of the research are interpreted. At the second level, qualitative and quantitative imply nature of the research method as a way of data collection, analysis approach, interpreting the results obtained through analysis approach. Also qualitative and quantitative research methods, mixed research method was commonly referred in several studies (Sounders et al., 2009: 137; Rolfe, 2013; Creswell, 2014: 4; Thomas, 2010:302). Mixed research methods can be evaluated as an inquiry approach to the study. This concept brings both qualitative and quantitative approaches together in the study (Creswell, 2014: 14). In line with these approaches, this study adopts both qualitative and quantitative methods together.

Strategies of inquiry refer to the type of three methods of design (qualitative, quantitative and mixed methods) or pattern which provides a particular path for procedures conducted in designing the researches (Creswell, 2014: 11). In this study, research methodology was built on the literature review (by conducting content analysis), and simulation.

The research design also performed according to exploratory, explanatory, and descriptive research purposes (Altunışık et al. 2012:71). The objectives of this study include three research purposes as well. This study aims to explore the current methodology on port capacity measurement and critical issues addressed in capacity measurement in dry bulk terminals in accordance with the factors affecting terminal capacity and the explanation of the relationship between the primary issues in port capacity measurement. Explanatory aim of this study constitutes the explanation of the effects of these factors on port capacity and direction of these effects. Besides, it was descriptively attempted to provide the means and intended use of different capacity output values.

The qualitative part of this study was performed to investigate the critical variables addressed in capacity measurement in ports, factors affecting the port capacity, how port capacity is measured, which methods/approaches was conducted to measure port capacity. A literature review was conducted on several databases to find these answers. In addition to that, a content analysis was conducted to examine these aims, as mentioned above.

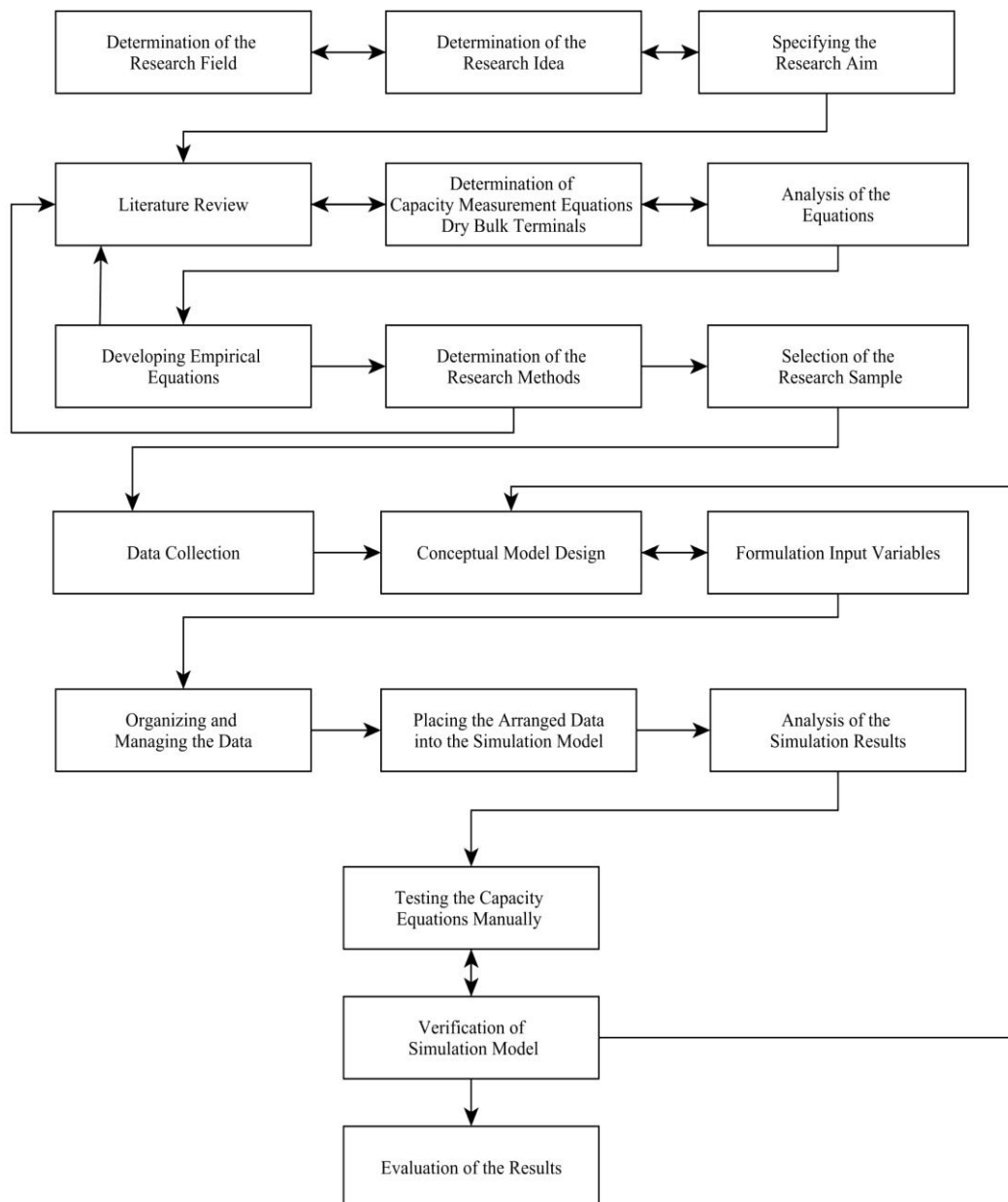
The quantitative part of the study was performed to develop capacity measurement equations for dry bulk terminals and simulate this equation through RProject software. The simulation and its conceptual model explain the relationships between the primary issues in port capacity measurement and how port capacity is affected by the factors and the direction of these impacts on port capacity based on the literature. It should be highlighted that the relationships between the parameters that affect the port capacity, can be identified as causal and any change of in value of parameters will change the whole functional operation of the equation (Bertrand and Fransoo, 2002:249).

Means of different capacity output values and the intended purposes of its outputs were attempted to describe through both simulation model and literature review. Iterative cycle of evaluation of was performed to explain the meanings of capacity types and how these capacity types can be used in evaluating the port capacity.

Considering the time interval, this study is classified as cross-sectional in terms of collecting the information about port capacity and collecting the cross-sectional data only for testing the empirical equations.

To answer the research questions and to reach the research aims, several processes were followed. Main steps followed during the research is illustrated in Figure 1.

Figure 1: Research Processes



Source: Compiled by Author

Research process started with the determination of the research field. Determination of the research idea pursued this process. To determine the research aim, this process was supported by the literature review. An initial literature review process and specifying research aim processes were carried out simultaneously to enlarge the research aims and to analyse the gap. Within this process, capacity measurement equations were determined through the literature review, and these equations were analysed thoroughly. Apart from finding the existing equations in the literature, factors affecting the port capacity were analysed. By using these equations and related parameters related to port capacity, empirical equations were developed for berth handling capacity, storage yard capacity, and transfer equipment capacity. When developing the equations, the iterative research effort was conducted to determine certain functions of these parameters on the capacity and to eliminate the faults. After completion of the equation development process, the research sample was determined. While determining the research sample, it was paid attention to be a dry bulk terminal with a certain throughput volume. Data were obtained as a result of a series of meetings. The conceptual model design was formed according to the simulation model requirements. After that, the input variables were listed to make sure about all the parameters reflected in the simulation and conceptual model. Data obtained from the terminal was not suitable for direct use in the simulation model. For this reason, real-world data was made suitable for entering the simulation model by organizing and managing. After obtaining the simulation outcomes, these results were tested by operating the equations manually. In addition to that conceptual model and simulation model were compared in terms of checking the compatibility and verification was provided. After all these processes results were evaluated in terms of examining the applicability of the model.

c. Originality of the Study

When the literature review was conducted, the relatively limited study was obtained. Generally, studies on port capacity progressed based on performance, capacity planning, and forecasting and market analysis. Studies mostly employed the optimization techniques to model the capacity of the port and mostly focused on the

container terminals. It was found out that performance, capacity planning, cost, and economic analysis researches fed themselves.

With this literature review, it was focused on the reports, books, and dissertation to investigate the capacity measurement approaches. Generally, UNCTAD reports and other reports published by UNCTAD (Thomas, 1985; de Monie, 1987; Haeidi, 2014) focused on capacity measurement and capacity planning of the several terminal types by considering performance issues of the terminal. The studies focused only on the capacity calculation, and equation development for ports were commonly performed for container terminal in the literature. UDHB (2015b:231), Park et al. (2014: 185), National Research Council (1998: 81) and KMI (1998) provided berth handling capacity measurement equations based on the several assumptions. These assumptions were not explicitly explained by the researches and meaning of parameters reflected capacity measurement equations were not explained in detail. Also, these equations did not provide a piece of significant information about the calculation of equipment capacity. Nearly all these equations reflected the number of gang and gang per ton, but this implicit approach did not provide detailed information.

Scholars generally used design approaches for storage yard, and the required terminal area was considered commonly. When existing equations were examined, it was seen that the National Research Council, (1998: 81) Salminen (2013:32-33) and UDHB (2015b: 231) did not consider the stockpile implementations. Besides, the peak factor of storage yard and sousplan shipments were not reflected in the current equations. Even though the annual throughput is included in the measurement formula, each shipment may not be transferred to the storage yard area. This circumstance impedes estimation of the storage yard capacity when demand fluctuates. Moreover, joint evaluation of the peak factor for both berth and storage yard capacity may result in overinvestments. Studies also did not make a clear distinction about sousplan shipments. Only National Research Council (1998:81) considered the cargoes handled at the storage yard.

Apart from developing capacity measurement equations, this study introduces theoretical gang number and realizable capacity. Finding the number of the gang is difficult when certain service time is unknown. If ports record the number of gang performed in an hour, that value can be used. Otherwise, the catalog values can be

used. That is why researches did not point on this issue. Oral (2014) mentioned the gang number, grab filling rate, weight of grab, lifting capacity of the grab equipment. However, grab filling rate was based on several assumptions (Oral, 2014). A concept used for determining the number of gang under the normal operational conditions considering material characteristics was introduced called as theoretical number of gang. Theoretical gang number is different from the actual gang number. Hold structure, picking and dropping height of the cargo, material nature, crane operator skill affect the hourly gang capacity of the grab cranes directly. In typical operation conditions, grab crane performs more gang in an hour. However, grab filling rate is not constant during the operation. Grab filling differs in different height of the hold and differs according to material density. Grab crane can perform more gang than the gang theoretically can perform. For this reason, theoretical number of gang is always lower than the actual number of gang.

When evaluating the definitions of capacity types in the literature, it can be made a clear distinction between the capacity types. Theoretical capacity takes into account the amount of cargo that the port can perform 365 days and 24 hours. Besides, actual capacity considers the usual traffic conditions of the port. Accordingly, actual capacity calculations take into account the berth occupancy levels while theoretical capacity accepts the berth(s) as fully utilized. However, there is no capacity type explains the circumstance that the port can reach under the real conditions and the port does not suffer from the low demand as far as it is known. This situation leads to an uncertainty about evaluating the capacity of the port and creates a gap in the literature to measure the port capacity.

Realizable capacity explains the possible output levels where the terminal is independent of actual demand conditions and the capacity output that can be realized by its resources as if the ships always called to the port. This gap also brings other questions such as the function of berth occupancy ratio. Accordingly, the function of berth occupancy ratio needs to be discussed thoroughly in the light of the literature on berth occupancy to find its intended function.

Apart from the reasons mentioned above, the majority of the researches divided the ports according to their import and export activities or focused on the port handled single material. In this study, it was attempted to develop a capacity measurement

model for dry bulk terminals served to multiple cargoes and without discrimination, whether export or import activities.

d. Structure of the Study

This study structured in four chapters. **Chapter I** provides a snapshot of dry bulk terminals. This chapter summarizes the dry bulk terminal designing and planning concepts, physical characteristics of the dry bulk terminals, terminal layout and its components (equipment, berth, storage yard, and gate), terminal operations performed in the terminal and cargo flow processes.

Chapter II explains the scope and concept of the port capacity. In this chapter, port capacity is defined from the different viewpoints. Subsections explain the capacity concept of each terminal component. Factors affecting the port capacity are illustrated, and several capacity types are explained in this chapter.

Chapter III reviews the existing capacity measurement equations of port for only dry bulk terminals. These equations sectioned as berth handling, storage yard handling, and transfer equipment capacity measurement equations. Relatively limited equations are analysed in detail.

Chapter IV comprises the research methodology. This chapter provides the literature review, content analysis, equation development approaches, and developing simulation model efforts.

Conclusions, recommendations, and appendices are provided in the related section.

CHAPTER ONE

DRY BULK TERMINALS: AN INTRODUCTION TO TERMINAL SYSTEM

1.1.A SHORT VIEW OF PLANNING AND DESIGN CONCEPTS OF THE DRY BULK TERMINALS

Development in maritime trade, equipment and information technologies have been resulted in continuous development of the ports. Moreover, increasing in maritime demand pushes ports to develop their infrastructure and superstructure (UNCTAD, 1985b: 27). With the development of commercial activities, cargo technology and the port users' requirements push the ports to modernize (Frankel, 1987: 11). The need of changing forces the ports to develop its terminal and the connection links (Kleinheerenbrink, 2012:21).

Port development means that constructing new ports or expansion of the current port facilities or sites (Tsinker, 2004:7.). Kleinheerenbrink, 2012:21) summarized the characteristics of the terminal development:

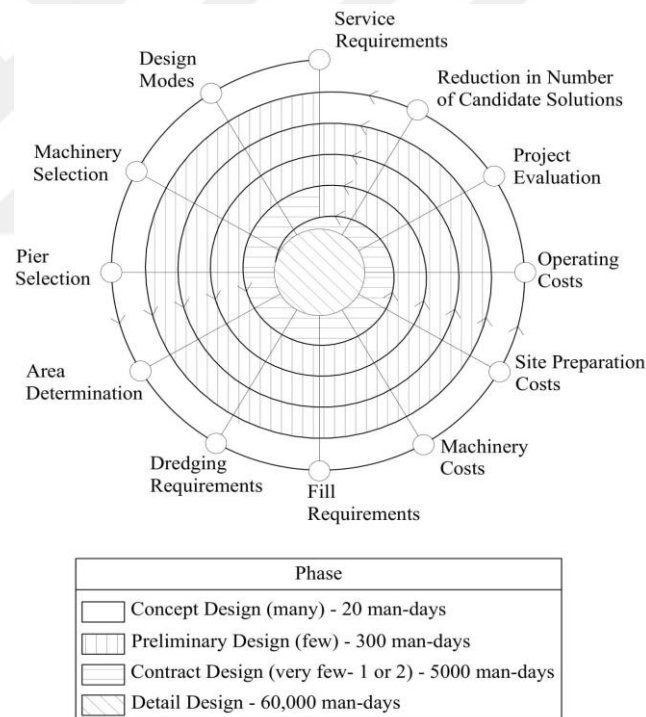
- New terminal requirement
- Expanding the present terminal infrastructure
- Enhancing the existing terminal activities
 - Equipping the terminal with highly specialized, automated, flexible, and sufficient equipment
 - Increasing the performance outputs of the facilities
- More awareness of the environmental impacts
- Accelerating the service level by developing infrastructures of connection links (infrastructure)

In conjunction with the development trends in port, port planning has gained importance. The primary goal of the port planning is to provide balance between inadequacy and excess capacity at reasonable cost, price and service levels. It is about the finding the balance between the economic, business factor and the constraints caused by the land availability, spatial planning factors, sustainability issues, and political factors (Bichou, 2013: 51). With the port planning, the capabilities of the port can be further controlled and capitalized on business interests (Frankel, 1987: 11).

Once planning the layout of the terminal, the subject should be assessed as multi-faceted (Wiese et al. 2013: 222). Port planning task requires the combination of different disciplines and evaluation from a broad perspective. For this reason, port planning is assessed an interdisciplinary activity that includes several topics associated with the investment, operation, design, capacity, and policy (Bichou, 2013: 51). Associated disciplines are oceanography, coastal engineering, hydraulics, traffic engineering, transport engineering, civil engineering, maritime engineering, geology, seismology, geo-technology, hydro-nautics, economics, econometrics, management and organization, sociology, biology, ecology (Velsink, 1994: 7).

Port planning includes several steps processes. The iterative process spiral of the port development are illustrated in Figure 2.

Figure 2: Iterative Phases of the Terminal Planning



Source: Frankel et al., 1985:191

Scroll wheel represents the iterative planning processes of the ports based on the major tasks. The conceptual level aims to improve a feasible solution spectrum by developing alternatives as much as possible. Rather than qualitative analysis, options are evaluated quantitatively. In this stage, a comprehensive evaluation must be

performed for dry bulk terminals. The density of the cargoes, equipment characteristics, and special requirements for the storage according to material characteristics must be criticized. Because, each cargo type necessitates different equipment and handling procedures (Keceli, 2016:3). A rough estimation of the sites, equipment, cost, and revenue are performed during the preliminary design level. The quantitative evaluations superseded qualitative assessments. These evaluations generally include eliminating the alternatives by calculating the costs and benefits per options. The contract design level of planning aims to determine the boundaries of exact planning specifications and information on the evaluation of bidding contract, which will include cost, and construction planning (Frankel, et al., 1985: 191-195).

Different substantial assignments guide the terminal planning. These assignments are (Frankel, 1987: 21)

- Economic foundations for port development
 - Analysis of economic and commercial activities
 - Analysis of commodity flow
- Transport System (Seaway, rail and road transport)
- Changes in freight pattern
 - Evaluation of the physical form of commodities and it flows
- Technological changes in land transport and change in shipping phenomena
 - Analysis of the trends in both vessel, shipping, equipment, and cost issues.
- Logistical aspects (cargo handling transfer and storage of the cargoes, documentation, etc.)
- Technologies of logistic activities
 - Assessment of existing methods
 - Evaluation of finance, marketing, and brokerage activities
- Facility inventories at the terminal and operation analysis
 - Assessment of port inventories (infrastructure, superstructures)
 - Operating and maintenance methods
 - Capacity and productivity evaluation
- Review of the existing facilities and forthcoming requirements

- Evaluation of current inventories and short-term development plan
- Engineering Studies
 - Hydrographical, geophysical, topographical navigational assessment of the port sites
- Specifying the alternatives for port development
 - Deciding on new establishment or developing the existing port sites, and facilities
 - Evaluation of alternative development paths based on the cost and benefit analysis
- Financial Studies
 - Analysis of expenditures and revenues of port operations
 - Deciding on port tariffs
 - Evaluation of the cash-flows, and competitive analysis
- Analysis of the environment
 - Assessment of the impact of these structures on the environment and community.
 - Evaluation of the physical, environmental and human resources

Planning of the ports are structured in three main periods (Velsink, 1994: 4-2) stated in Table 1:

Table 1: Planning Periods of the Ports

Type	Period (Years)	Examples of the Implementation
Short Term Planning	1-2	Minor changes in layout
Medium Term Planning	5-10	The first stage of the master plan
Long-Term Planning	20-30	Master plan

Source: Velsink, 1990: 4-2

Tsinker (2004:10) and Velsink (1994:5) stated the factors that should be considered both in long-term and medium-term planning as follows:

Long-term planning factors:

- Determination of the functions of ports (foreign trade oriented; supporting the industrial and mercantile development; appealing the transshipment activities)
- Determination of the responsibilities of the port in the construction of facilities and operations.
- Forecasting the land usage and future expansion plan to satisfy the master plan's needs.
- Estimating the cargo flows, alternative sites
- Optimizing all sublevels of the planning performed by several disciplines that included in the port planning

Medium-term planning factors:

- Analysis of the performance and capacity
- Operational and physical design of the port in the limits of budget
- Financial analysis
- Deciding on the investments
- Comprehensive design

Due to its capital-intensive nature, the planner should pay attention to the financial and economic practicability of the investments considering long process of return on investment, and payback periods. In the previous years, the master plans had a function of land use plan that was centrally controlled and primarily linked to the growth strategies and financing of the state. However, nowadays the role of the master plan have changed as business cases (Taneja, et al. 2011: 6-7). Masterplans can be assessed as the blueprint for the future development of the port. The primary objective of a master plan is to make space reservation for the feature requirements by considering the environmental and legal issues, to establish sustainable port operations. In comparison with the past, national and regional port masterplans aimed to generate optimum allotments of the outputs throughout the country or the region, new function of the port master plan considers the port capacity, interface of port-hinterland link, industrial progress and the cost of the port infrastructure (Ligteringen, 1999: 4-2).

Dry bulk terminals have three essential components in terms of designing the terminal. These are berth and quay, storage yard, equipment and gate (Kleinheerenbrink et al. 2012: 107). Within this context, the following sections are designed considering berth, storage yard, equipment, and gate.

1.2. PHYSICAL CHARACTERISTICS OF THE DRY BULK TERMINALS

Choosing the most suitable port layout and form is a strategic and long-run decision that should be decided at the initial stages of the planning (Bichou, 2013: 315). The terminal layout should be planned considering the transfer points to facilitate all transportation needs (van Vianen et al., 2015:1). All system should be designed and planned to achieve the connection between the whole sea and land transport chain and, be planned to adopt the changing demand and supply patterns (Schott and Lodewijks, 2007:376-378).

Several layout combinations can be implemented in the dry bulk terminal. Terminal requirements generally determine the layout of the terminal. In general, the needs of the dry bulk terminal are the adequate size of the area, handling equipment, infrastructure, and storage area (Dundovic and Kovacic, 2007:252). Regarding the requirements, terminal design is highly depend on the equipment type, stockyard management, routing, maintenance options, ambient, commodity type, size of the vessel, regional cargo characteristics, and options of expansions, (UNCTAD, 1985a: 15-16; UNCTAD, 1985b: 168; Schott and Lodewijks, 2007:378; Agerschou, et al. 2004: 315). The factors affecting the terminal layout and the form of the facilities can be summarized as follows (Bichou, 2013: 135).

- General specifications of the vessels, i.e. draft, length, gears, superstructure, beam, ship size, derrick
- Type of cargo traffic, i.e. general cargo, container, breakbulk, bulk, passenger, transshipment, export, import, direct call
- Environmental characteristics of the region considering the topographic, oceanographic, climatic factors and engineering factors such as dredging, construction

- Type of cargo, i.e. hazardous, refrigerated, standard; type of packaging, i.e. full-load, less load, palletized, containerized
- Area, cost and capacity restrictions
- Operational considerations, i.e. labor and equipment
- Locational settlement and form of the freight site planned to establish within or outside of the port or terminal.

All of these factors also interact with each other. For example, the size of the vessels called to port determines the characteristics of the terminal in terms of infrastructure and superstructure. The port should provide adequate services to vessels with suitable berths, draft, equipment, infrastructure, and superstructure. In case of failing to provide proper services to vessels, the ports may need to install new offshore equipment, storage facilities, and suitable berths (UNCTAD, 1985a: 15-16; UNCTAD, 1985b: 168).

The effect of the cargo type on the terminal layout shows similar characteristics as the effect of the ship sizes on the terminal design. Rather than a single cargo type, the port may prefer to provide services to multiple cargoes. In such cases, the terminal must be planned flexibly to serve various cargoes types (Dundovic and Kovacic, 2007:255). Different cargo types may require specialized equipment and storage type (UNCTAD, 1985a: 15-16; UNCTAD, 1985b: 168)

Apart from the physical infrastructure characteristics, the terminals diversify according to export, and import specialization and design of these terminals may differ according to these tendencies (Wu, 2014; 61). Dry bulk terminals are divided into two categories according to their export and import activities. Export and import terminals have specific layout due to provide export and import cargo flow. For the coal, ore and the other minerals, export terminals are generally located at the appropriate site that is close to the resources in general (Agerschou, et al., 2004: 315) Wu, 2014:61). These terminals targets accelerating the outflow of the cargoes (Wu, 2014:61). Even a terminal is not located near to the resources; it should be well linked to the resources via rail and road.

The export dry bulk terminal needs to direct connection with the loading equipment and ship to support the continuous loading with tolerating the movement of the vessel. In case of using single spout systems, the length of berth should be longer.

Because the vessel requires moving along the berth (Agerschou, et al., 2004: 315). In some cases, export terminal may stocks the commodities by considering the prices. In some other, due to the ownership and locational factors, export terminals focus on the limited cargo type (Wu, 2014:61).

The situation at the import terminals is not different from the export terminals. All equipment should be linked with the vessels. Thus, for the import terminals, it is entailed the smooth conditions comparing with the export terminals. It is difficult to keep a suitable position between the unloading equipment and the pile in the vessel hold due to the pitch and heave motions. Handling equipment used in export dry bulk terminals is pneumatic equipment, crane-mounted grabs, bucket wheels, screw conveyor and chain buckets (Agerschou, et al., 2004: 317).

1.2.1. Dry Bulk Terminal Layout

Ports are comprised of two main interfaces that are seaside and landside. The phase of loading/unloading and the temporary storage of cargoes at the storage yard encompasses seaside interface in which quayside resources (equipment etc.) of the terminal are used whereas landside interface includes the activities of the receiving and the sending the cargoes by rail and trucks (Ramirez-Naffarrate et al. 2016: 1; Roy et al. 2016: 472). Despite the difficulty at synchronization of the these activities, seaside and the landside activities should be interconnected in an integrative approach (Wu, 2014:61; Ramirez-Naffarrate et al. 2016: 3).

According to Hemert (1984: 45) terminal settlement is crucial for the planning considerations and its shape and size are restricted by the physical natural domain. The import and export activities of the terminal affect the terminal layout significantly. Because the storage needs of the cargoes have an impact on the terminal settlement.

General dry bulk terminal layout is shown in Figure 3.

Figure 3: General View of Dry Bulk Terminal Layout



Source: Port Technology (22.08.2012)

Layout planning process includes the seaside and landside layout planning (Wiese et al. 2013: 226). The main layout components of a dry bulk terminal are berth, storage yard, and gate. Following sections provide detailed information.

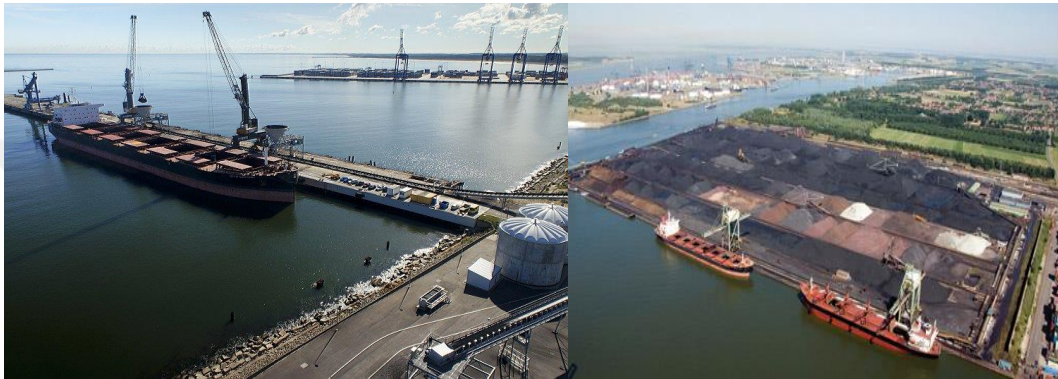
1.2.1.1. Berth Planning as a Component of Dry Bulk Terminal Layout

A berth is a designated area at the quayside of the terminal where the vessels can moor for handling activities. Berths can be categorized according to the cargo and ship type (tanker berth, general cargo berth, dry bulk berth, etc.), size and layout (deep-water berth, etc.) (Burns, 2015:120). A berth is one of the primary facility where the vessels berthed (Lun et al. 2010: 183). These facilities should be adequate to establish the related equipment to serve for loading and discharging the cargoes (Lu et al. 2010:183-184). Characteristics of the berth facilities at the ports depends on the several factors such as size and number of the vessels, cargo types and volume, basin for maneuvering, acceptable service time, need of the bow thruster or bow rudder for the berthing, and prevailing weather conditions (winds, wave etc.) (Stopford, 2009: 30; Thoresen, 2003:84; Vivek and Prasad, 2016:46; Burns, 2015:20).

Berth structures are called with different terms according to its construction as pier, and wharf or quay (UDHB, 2010: 4; Vivek and Durga Prasad, 2016:46). Pier is

the berthing places projecting to sea from shore (whether perpendicular or specified angle) that is built on concrete, steel, wood and stone props or as a floating platform. Wharf or quay is the berthing places structured parallel to the shoreline. These structures may be positioned adjacent to or near to the shore (UDHB, 2010: 4; Vivek and Prasad, 2016:46). Figure 4 illustrates the schematic representation of the typical pier and quay.

Figure 4: Examples of Dry Bulk Terminal Pier and Wharf



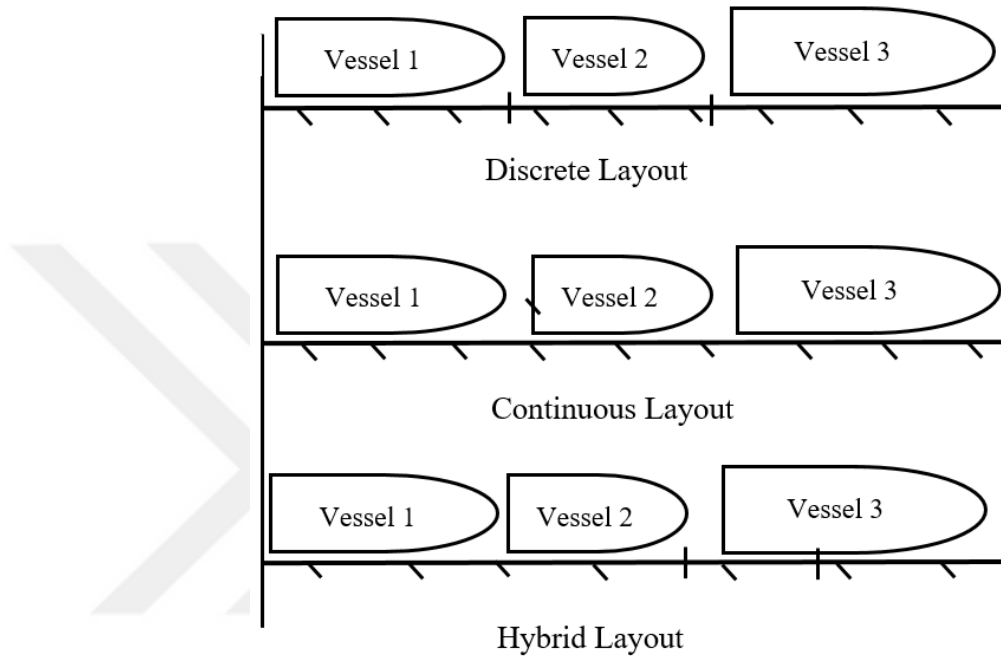
Source: Port Gdansk, 28.08.2019 (left); Sea-Invest, 28.08.2019 (right)

Apron as a part of the seaside layout encompasses the area between the quay wall and the transit sheds or open storage area. Besides, the apron may be seen as a combination of rail, road and the spaces interrupted by the equipment based on its functions in the previous years (Agerschou et. Al., 2004: 265). The layout of the seaside positioned between the storage yard area, and the quay wall should be designed with the aim of achieving high performance. Design outputs should be planned to perform operation more efficiently. Besides equipment constraints and features should be considered (Wiese et al. 2013; 222).

Several berth layout can be seen in real world. According to Bierwirth and Meisel (2015: 676) classified the berth layout according to spatial characteristics: The discrete layout, the continuous layout, and the hybrid layout. The discrete berth layout refers to the division of the quay into a smaller berth. Each berth can provide services to only a vessel at a given time. Besides, in continuous berth layout, vessels can berth to quay in the free position. Hybrid berth layout has the characteristics of both continuous and discrete layouts. Quay is divided into the smaller berths. However, the

vessel may berth the divided piece of a berth, or more than one ship may berth at the same piece owing to vessel size. Draft restricts the possible berthing position and dividing the berths (Bierwirth and Meisel, 2015:676; Umang et al. 2011: 12; Al-hammadi and Diabat, 2015:269; Umang et al. 2013: 14-15).

Figure 5: Different Types of Berth Layout



Source: Umang et al. 2013:15

As stated in Figure 5, positions of the vessels in the three berth layout shows the difference. While only one vessel can berth at allocated areas in discrete berth layout, there is not any classification in continuous berth layout. In hybrid berth areas, more than one vessel can berth or one vessel interrupt two discrete berth areas.

All berth planning activities aim to achieve operational efficiency, to increase the volume capacity by decreasing the service time, and to satisfy the requirements of the industry (Burns, 2015:125). For this reason, optimum handling choices should be made during the berth planning (Noritake and Kimura 1983:323). The planning system should provide flexible operations to overcome the tentative schedule of the vessel arrival and departure (Lun et al. 2010: 187).

There are several challenges in planning the berths. In case of the vessel arrive in port regularly, and loading and discharging times are constant, planning the berth

capacity would be simple. Thus, the full utilization of the berth would be provided by the port without the queue of the vessels. However, the actual conditions of the vessels are depended on the randomness, so planning the berth capacity is a complicated matter. The randomness of the ship arrival and ship service time affect the waiting time of the vessels and the vessel arrival rate. These two factors are critical for the determination of berth occupancy rate, which used in berth capacity planning (UNCTAD, 1985: 28).

One another important factor when planning the capacity of the berths is quay length factor. This factor is used when new construction and expanding the existing port. Quay length factor is the ratio of the annual throughput to the quay length (van Vianen et al. 2011:4). The factor shows the amount of cargo (ton) per meter by eliminating the effects of the difference in bulk densities. This factor provides an opinion about the berth capacity. The parameter is mainly used for determining the spatial requirements at the berth. Table 2 illustrates the quay length factors values.

Table 2: Proposed Quay-Length Factors for the Dry Bulk Terminals

Reference	Coal (kt/m)		Iron Ore (kt/m)	
Ligteringen, 2000	25-75		50-150	
	Import Terminal		Export Terminal	
	Coal	Iron Ore	Coal	Iron-Ore
van Vianen, 2011: 4	10-30		25-75	50-150

Source: Compiled in accordance with the information provided by Vianen et al. 2011:4

1.2.1.2.Storage Yard Planning as a Component of Dry Bulk Terminal Layout

Storage yard planning encompasses the management of area configuration, determination of export/import and transshipment requirements activities. Additionally, cargo transfer planning, stowing, allocation of the spaces and equipment and labor to the area where the operations are performed (Bichou, 2013: 73).

The dimensioning and design of the storage yards are essential in the planning of the terminal. What makes it so important is the cost and efficiency subjects. Undersized storage yard leads to an increase in the waiting time of the vessel, and it means the cost for the terminal operators. Besides, the return of investment takes time,

and the terminal operators have to bear the high investments cost (van Vianen et al. 2012:1).

The requirements of a flexible storage area and the stock control are presented below (van Vianen et al. 2012:1).

- Simultaneous unloading and loading operations possibility from ship to train or truck
- Discharged cargoes from the ship are transported by wagons.
- The terminal should be able to separate different cargo types and stack the cargoes separately.
- The terminal must have road access for the inspection
- All related equipment must be convenient for handling the several types of dry bulk cargoes.

Before introducing the main structures in the storage yard area, it is necessary to determine the storage yard requirements to construct appropriate structures and to effective design of the terminal storage yard area.

Port planners consider the required storage yard area in the stage of port construction or expansion to determine the terminal capacity. Required storage space in the terminal area differs due to the type and, stacking characteristics of the cargo. Regarding the capacity factor of the storage area, it is crucial to plan the allowable spaces for the predominant cargoes demanded by the terminal to provide flexibility in case of trade changes. This circumstance raises the challenges for the ports in terms of land surplus (UNCTAD, 1983: 4).

Once the evaluating of the required space in the terminal area, stacking factor should be established in the first step. Stacking factor of the cargo is contingent on the below-mentioned factors (UNCTAD, 1983:5):

- Bulk/weight rate or stowage factor of cargo
- The bearing strength of the area subjected to storage
- The height of the stack not excepting the angles of repose or resistance of the packing case or storage case or height and diameter of the tanks
- Characteristics of the equipment used at the storage area for the cargo transfer between the berth and the area and the width of the lanes and the turning circle.

- Required space for the classification of cargoes before performing the stacking and handling breakages.
- Required space for land transport loading/unloading operations
- Safety distance between the stocking piles, and pollution prevention measures.

Analysing the above-mentioned factors and practicing it with the real conditions provides stacking factor with regard to weight/volume per area utilized for the calculation of required spaces for any specific cargo (UNCTAD, 1983: 5).

There are number of capacity indicators used in determining the required storage yard area and these factors used in the planning of the below mentioned structures. These indicators are storage factor, total terminal factor, storage yard length-width ratio, lane length-width ratio.

Storage factor is assessed as the ratio of the annual throughput of the terminal and the specified area used for the storage (van Vianen et al. 2011: 4). This rule of thumbs method provides insights about capacity requirements in terminal area. In the literature, generalization has been performed for the coal and iron ore terminals. Table 3 indicates the storage factor values of import and export cargo terminals.

Table 3: Proposed Storage Factor Values for the Terminals

Reference	Import Cargo Terminal (t/m ²)		Export Cargo Terminal (t/m ²)	
	Coal	Iron Ore	Coal	Iron Ore
Ligteringen, 2000	15-75	45-80	60-180	70-210
van Vianen et al. 2011:6	15-25	30-40	15-20	30-40

Source: van Vianen, 2011: 6

Total terminal factor is the ratio of gross storage area to total terminal area. Gross storage area encompasses the stockpiles and the internal infrastructure constructed in the terminal area. Total terminal area involve the both landside and water side areas (apron, buildings, quay, etc.) (Kox, 2017:92). This factor is used in the determination of the required terminal area. The ranges of the total terminal factor are indicated in Table 4:

Table 4: Total Terminal Factor Values

Indicator	Import	Export
Total Terminal Factor	1-3	1-5

Source: Kleinheerenbrink, 2016:46

The range of the total terminal factor differs according to terminal type. Total terminal factor is between 1 and 3 in import terminals while this value is between 1 and 5 in export terminals.

Storage yard length-width ratio and lane length-width ratio provides useful insights into design process of dry bulk terminal. The values of the storage yard length-width ratio and the lane length and width are illustrated in Table 5.

Table 5: Ranges of the Storage Yard Length-Width Ratio and Lane Length-Width

Indicator	Import	Export
Storage Yard Length-Width Ratio	1.2 - 4.6	1.3 - 4.5
Length of Lanes (m)	300-1200	300-1300
Width of Lanes (m)	30-75	30-85

Source: Kleinheerenbrink, 2012:45

It can be deduced from the ratios that the design issues is differentiated from export to import terminals. The minimum and the maximum values covers a wider range, comparing to import terminals.

Storage yards can be classified according to both storage conditions and storage shapes. Storage conditions are associated with the storage of cargoes in open, closed-enclosed areas and silo shed or dome. In the classification of the storage yard according to storage shapes is assessed into two categories: Longitudinal and circular storage yards.

Installing the open storage areas are relatively inexpensive comparing to closed facilities. Open storage areas do not need to establish the buildings to storing the cargoes. However, taking additional measurements to prevent environmental pollution and preventing cargo contamination may necessitate the additional investment (Schott and Lodewijks, 2007: 377).

Open storage areas are used in the dry bulk terminals frequently. Generally, cargoes that are least affected by the weather conditions are stored in these areas. In the open areas, cargoes can be stacked in the long lanes. Lanes are separated by the equipment used by the stacking the cargoes (Ligteringen, 1999: 6-9). Bulk storage is fulfilled by the stockpiles in the open storage area. The stockpile must be planned to store maximum amount of material in the minimum area to obtain maximum utilization of the storage area. The presence of adequate land for the storage is restricted by the natural conditions and cost of acquisition. For this reason, the storage method should be well planned in terms of the maximum gaining utilization of the area (UNCTAD, 1985b: 180).

Long lanes and longitudinal stockpiles are implemented at the longitudinal storage yards. Besides, circular storage yards practices the circular stockpiles. Two storage yard types have pros and cons. According to Wolpers (24.02.2019) advantages and the disadvantages of the longitudinal and circular storage system are:

- The circular storage system has lower investment costs
- Storage volume in circular systems is higher than the longitudinal system
- The circular system requires shorter belt conveyor
- In case of there are enough spaces the layout design can be performed more flexible
- Longitudinal storage yards are agile to demand fluctuations comparing the circular systems.

Closed storage implementation is less flexible, and it limits the capacity comparing to the open area implementations in terms of storage and handling (Schott and Lodewijks, 2007:377). However, materials can be affected by weather conditions, and it needs unique storage. Protection-required commodities may be stored in the silo, shed, and bin. Moreover, low-density commodities need to be stored in closed areas for not to blow away (Frankel et al., 1985: 151).

Portal-framed (shed or horizontal storage) structures and domes are the primary types of closed storage. Materials are filled in these structures by a belt conveyor system positioned at the top of the structures while reclaimer equipment, bulldozers, and conveyors positioned on the ground performs the reclaiming of the materials (Kox, 2017:53; UNCTAD, 1985b: 181). Circular stackers, reclaimers, and bulldozers are

utilized in dome structures. Domes can be filled by using conveyor belts positioned at the top. Figure 6 illustrates the covered storage yard structures.

Figure 6: Dome Closed Storage Examples



Source: Green Port (24.02.2019) (left); CST (24.02.2019) (right)

In addition to the storage by type of cargo, increasing interest in preventing environmental pollution has also led to the storage of materials in closed storage areas. Another form of the closed storage area is illustrated in Figure 7.

Figure 7: Examples of Different Closed Areas



Source: EBS, 25.02.2019 (left); Dome Corp, 25.02.2019 (right and bottom)

Silos are cylindrical structures established in the dry bulk terminals. The conveyors or bucket elevators feed silo from the top of the structure. Reclaiming is performed by gravity feed tunnel from the base. By the gravity feed system, live storage is increased. Silo height determines the cargo amount that can be accessed in the gravity feed system namely the size of the silo. Cost of the silo installation depends on the size and the commodity characteristics (specific bulk density) to be stored in the silo (Frankel et al., 1985: 165-168). Figure 8 illustrates the silo structures.

Figure 8: Silo Structures at the Dry Bulk Terminals



Source: Port Consultants Rotterdam, 25.02.2019 (left); Jurong Port, (25.02.2015) (right); Copenhagen Merchants Group, (25.02.2019) (bottom)

Single or multiple silos can be established at the terminal. These structures are commonly utilized for storing the cereals and fodders. In these structures, protection measurements must be taken to prevent moisten of the commodities. Materials used for construction must be carefully selected so that the commodities are not corroded and not to be affected the cereals quality negatively (UNCTAD, 1985b, 181).

1.2.1.3. Gate Planning as a Component of Dry Bulk Terminal Layout

Gate planning encompasses the planning of lanes for the vehicles/trucks, sizing of waiting areas and parking areas, synchronizing the traffic between berth-yard-gate and the arranging the required gate components. In gate planning, locations where trucks loaded or unloaded, must be determined by the requirements of the terminal and equipment (Böse: 2015: 17). Port gate planning requires the forecasting of the gate throughout such as a number of road vehicles pass through the gate in a specific period (Keceli, 2016: 2). Port planners make an effort to decrease horizontal transport by utilizing the yard equipment to loading or unloading the trucks to minimize the operating costs in practice. This process also encompasses the railway station design in case the railway network (Böse: 2015: 17).

Working principle of gate planning is similar to berth planning. However, it focuses on the bookings of the inland vehicle, delivery, and receipt of the landside vehicles. In addition to planning rail and truck entry/exit, planning comprises the activities of storage yard-warehouse consignments, the configuration of the cargoes. The challenges faced in the gate planning are cut-off policies, delaying of arrivals, problems created by the documentation or clearance, and direct or indirect transfer options. Lack of proper gate planning leads to disruptions in inspections, queues, and congestion on the ports on both the roads and the port interface between the berth, storage yard, and gate, and between the port and hinterland connection link. For this reason, it is critical to plan the entrance and exit channels to provide better and efficient operations (Bichou, 2013:78).

1.2.1.4. Equipment Planning as a Component of Dry Bulk Terminal Layout

Handling equipment used at the dry bulk terminals is examined under the three categories as loading/unloading, horizontal transport equipment and storage yard equipment. Below sections provides the detailed information about the equipment used at the dry bulk terminals.

Vessel Loading Equipment

Comparing the discharging systems, vessel-loading systems are simpler. These systems require feed elevators or conveyor systems, loading chute. Many vessel loading system can easily perform the loading activity by using the gravity. Rest of the vessels loaders may equipped with the flight conveyors or helical chutes to avoid the material deterioration or may designed in accordance with the chutes or centrifugal slingers belts (UNCTAD, 1985b: 170).

Loading the vessel at the dry bulk terminal generally performed by using continuous loaders which fed by a belt system (Kleinheerenbrink, 2012:33). Continuous ship unloaders is designed to discharge the dry bulk materials by providing continuous flow. Generally, these equipment are evaluated under the four category. The details of the equipment are provided as follows:

Travelling Loaders: These type of loaders can move along a line, which is parallel to quay. Movable conveyors usually feed the travelling loader boom (UNCTAD, 1985b: 170; Kox, 2017: 49). The boom is designed either dynamically to fit the vessel or statically (UNCTAD, 1985b: 170).

Radial Loaders (Quadrant): Radial loaders include boom, which can perform slewing motion approximately 90 degrees of angle. Commodities are loaded through arm conveyor located at the end of the rotated boom (UNCTAD, 1985b: 171). This equipment equipped with a telescopic boom and bridge assisted by the pivot point. Radial or quadrant loaders can move circularly along the radial track through the tool fitted at the front (Kox, 2017: 49; Thyssenkrupp, 10.03.2019; 8).

Slewing Bridge Loaders: Comparing to travelling loaders, installation costs of slewing bridge-loaders are cheaper. In addition, installing dust control system and enclosing the conveyor belts are simple (UNCTAD, 1985b: 172).

Linear Loaders: This equipment travels linearly parallel to the vessel. (UNCTAD, 1985b: 172). A pivot point provides rotating motion. Boom of the linear loader has a shuttle motion, which provides forward and retraction moving. It can also move longitudinally to reach the entire warehouse of the ship on pivot point (Campbell, 2007:35; Ligteringen and Velsink, 2012: 213).

Figure 9 illustrates the different types of vessel loaders

Figure 9: Dry Bulk Vessel Loaders



Source: Genmacrane, 10.03.2019 (Travelling Loader (top-left)); Thyssenkrupp, 10.03.2019 (Radial Loader, (top-right); Direct Industry, 10.03.2019 (Linear Loader (bottom-left))

Vessel Unloading Equipment

There are several functional types of equipment used for unloading the vessel. Four basic systems (grabs, pneumatic system, vertical conveyor and bucket elevator) (UNCTAD, 1985b: 172; Ligteringen and Velsink, 2012: 203) are evaluated in this section.

Grab Unloading: Grab is an equipment that attached to the rope of the gantry type unloader or the mobile harbor crane. After picking the cargoes from the holds, it is dropped into a hopper, which feeds the belt conveyor (Ligteringen and Velsink, 2012: 205), or trucks. Many factor affects the obtainable rate of the grab such as speed of hoisting and travelling, distance of the vertical and horizontal, cargo characteristics, experience of the operator, and volumetric capacity of the ship holds. The mechanical and operator issues restrict number of crane gang (UNCTAD, 1985b: 172; Ligteringen and Velsink, 2012: 204). There are several grabbing cranes in operation. Types of grabbing cranes are evaluated under three category as travelling overhead trolley unloader, the revolving grabbing crane and mobile harbor crane.

Travelling Overhead Trolley Unloader: This equipment has a supported boom projection that extends over the ship holds (UNCTAD, 1985b: 173). Grab can move along the boom. Cargo transferring is performed through trolley from the ship hold to hopper positioned at the quay (UNCTAD, 1985b: 173). Hopper feeds conveyor or directly trucks. This equipment travels perpendicular to the quay (Kox, 2017: 50).

Revolving Grabbing Crane: The crane is similar to the level luffing type cranes and commonly used at the dry bulk terminals. The equipment lifts the cargo then drops a hopper positioned at the front of the equipment and on the same track. Hopper feeds the conveyors or drops the cargoes directly to the wagons or trucks (Ligteringen and Velsink, 2012: 205; UNCTAD, 1985b: 173).

Mobile Harbor Crane (MHC): This flexible equipment is widely used in the smaller dry bulk terminals. Several materials can be unloaded from the vessel. The crane type is equipped with the additional tower structure which enables the crane operator to control handling operation by viewing ship hold. Productivity rate of the MHC is similar to the revolving grabbing crane. Figure 10 illustrates the grab vessel unloaders.

Figure 10: Dry Bulk Grab Unloading Equipment



Source: Dry Cargo International, 10.03.2019 (Revolving Grabbing Crane, (left)); YNF Publishers, 10.03.2019 (Mobile Harbor Crane, (right)); Port Gantry Crane, 10.03.2019 (Travelling Overhead Trolley Unloader (bottom))

Pneumatic unloaders: Pneumatic ship unloaders are widely used in dry bulk cargo handling operations. This type of equipment are suitable for multiple uses in various size of vessels. Operational principle of the pneumatic ship unloaders are based on the air suction. The system comprise various parts such as suction nozzle, airlocks, telescopic spout and filter systems (Buhler, 17.08.2018). Key limitation of the pneumatic ship loaders is that the material is conveyed by the air. For this reason, pneumatic unloaders lose capacity in case of the vacuum pipes are extended and the system has less operation area (Dry Cargo International, 2010). One another limitation of the pneumatic systems are not suitable all types of dry bulk materials such as iron ore, sand (Kisslinger, 2010:99). Pneumatic systems are appropriate for grain, cement and coal in powder form of cargo types, which has low specific bulk density, and viscosity (UNCTAD, 1985b: 173). Rather than iron ore and sand, the system is more suitable for free flowing materials, which density of the material is less than 1 t/m³ (Kisslinger, 2010:99) such as grain (rapeseed, wheat, soybeans, cassava, corn etc.), alumina, biomass materials, materials in powder form (mineral powder, cement etc.) and some of special materials such as cement clinker, fertilizer, pulverized coal, salt etc. (Nauticexpo, 16.08.2018a; Kisslinger, 2010:99).

Pneumatic systems are classified under the two categories as vacuum or suction and pressure or blowing systems (Ligteringen and Velsink, 2012: 206). Vacuum or suction systems are suitable for the gathering the materials from various places to a point whereas the pressure or blowing systems are convenient for the vice versa flow (UNCTAD, 1985b: 173). Installations of the vacuum systems are less complex. Vacuum system provides controlling of cargo lose. Besides, energy consumption is higher than the other pneumatic systems (Ligteringen and Velsink, 2012: 206; UNCTAD, 1985b; 173). A typical example of the pneumatic equipment is illustrated in Figure 11.

Figure 11: Pneumatic Unloader



Source: Nauticexpo, 16.08.2018a

Vertical Screw Conveyors: These systems are equipped with a vertical screw placed in the tabular covering. The system can be used both horizontal and vertical angle. Vertical screw conveyors can handle granular powdered, fibrous and semi-liquid commodities. The throughput efficiency depends on the material free flowing. In order to overcome this problem, these conveyors equipped with a free driven spiral (UNCTAD, 1985b: 175). Figure 12 illustrates the vertical conveyor equipment.

Figure 12: Dry Bulk Cargo Vertical Handling Equipment



Source: Siwertell, 2017

Bucket Elevators: this system is equipped with the turning bucket wheels continuously, which is hang from the luffing boom. At the same time, bucket wheels dig the hardened materials. These systems are expensive in terms of requiring stronger quay structure (UNCTAD, 1985b: 175; Ligteringen and Velsink, 2012: 208).

Horizontal Transport Equipment

Conveyor systems are frequently used for transferring the cargo from the storage yard area to the berth side or vice-versa (Frankel et al., 1985: 173; Ligteringen and Velsink, 2012: 214). In addition to the conveyors, the trucks may perform this transfer. Conveyor system has a major effect on the terminal layout. In the long-run, the conveyor systems should be designed to suitable for efficient maintenance and repair activities (UNTAD, 1985b: 176).

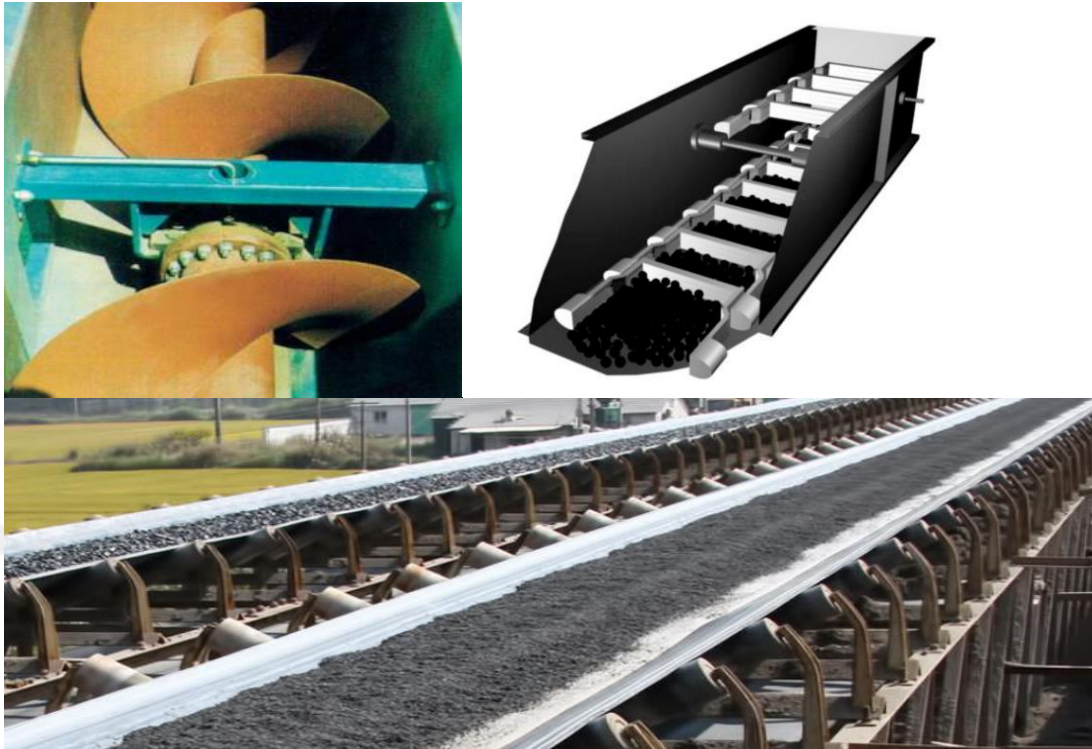
Conveyor belt usage is limited by the distance within the port area due to the economic and transport considerations. Road or rail transport equipment can be utilized to perform transferring activities when the distance between the berth and yard area is longer (Ligteringen and Velsink, 2012: 215).

The advantages of the conveyor systems are (Ligteringen and Velsin, 2012:215; UNCTAD, 1985b:176; Frankel et al.,1985: 173):

- Construction of these systems are easy
- Energy efficiency consumption
- These systems can be adopted to another systems
- It provides complete discharging
- Enables minimum friction and noise

There are several belt conveyor types in practice. These are wider rubber belts, chain conveyors, en-masse conveyor, screw conveyor, screw mounted, aeromechanical, fluidizing gravity conveyor, bi-cable systems, and vibratory (McGlinchey, 2008: 199; Bulk Inside, 11.03.2019; UNTAD, 1985b: 176). The shape of these systems may be in the form of U-shape, V-shape (Ligteringen and Velsink, 2012: 215), and flat. These systems can be designed as an enclosed system to prevent dust and cargo losses. Figure 13 illustrates the different types of conveyor belt systems.

Figure 13: Conveyor Systems



Source: Macgregor, 11.03.2019 (Screw Conveyor (left)); McGlinchey, 2008: 242 (En Masse Conveyor (right)); Sawhney Industries, 11.03.2019 (Belt Conveyor (bottom))

Storage Yard Equipment

Many equipment is used in the storage yard. Commonly used equipment are the stacker, reclaimer or stacker-reclaimer, bulldozers, and circular or longitudinal blending bed equipment.

The working principle of stacker equipment is to ensure that the cargoes are continuously stacked in the storage yard area. The equipment stacks the several material through a tripper, which enables the equipment to be allocate anywhere. When commodities are stacking out from the pile, stacking out conveyors equipped with a slewing maneuverable or fixed boom, are used (UNCTAD, 1985b: 177; Ligteringen and Velsink, 2012: 217).

Reclaimer equipment provides continuous retrieving of the materials from the storage area. Reclaimer is equipped with a bucket wheel, which mounted at the end of the boom and equipped with an intermediate belt conveyor fed by the bucket wheels (Ligteringen and Velsink, 2012: 217; UNCTAD, 1985b: 177-178).

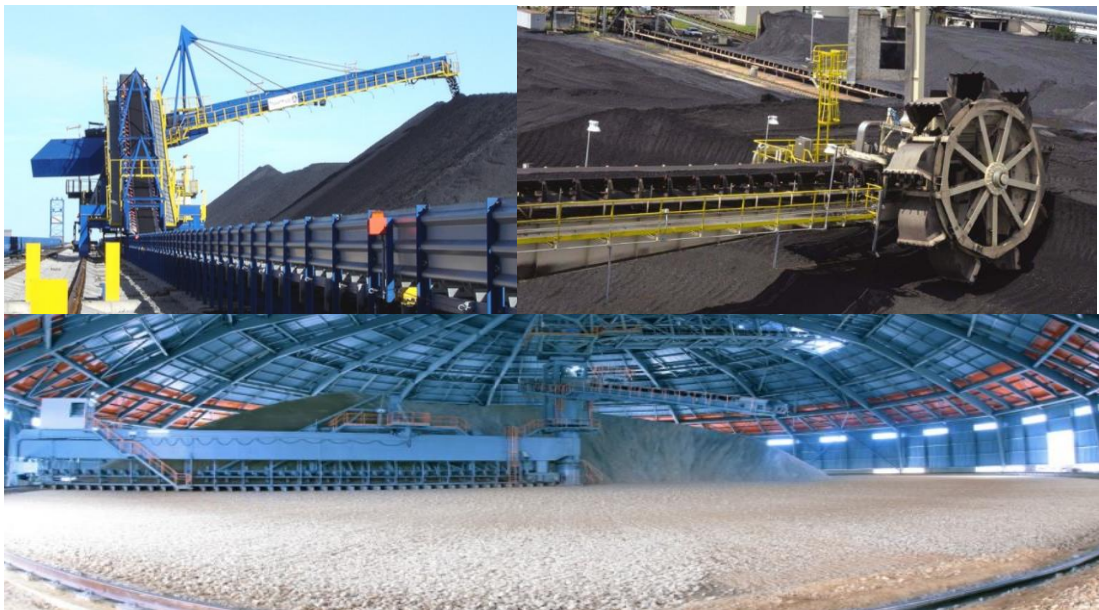
Stacking and reclaiming functions of these storage yard equipment can be built in one equipment: Stacker-reclaimer (Ligteringen and Velsink, 2012: 217). Stacker-reclaimer equipment is highly efficient equipment. The advantages of the stacker-reclaimer require limited number of conveyors. However, the system may decrease the total terminal performance due to perform simultaneous operation in vessels and trains (van Vianen, 2012: 101). Another disadvantage of the stacker reclaimer is that two functions (reclaiming and stacking) cannot be used at the same time. Because of having large capacity, stacker-reclaimer needs significant track establishment (UNCTAD, 1985b: 178).

Bulldozers can also be used at the dry bulk terminal to stack or transfer the materials to storage yard area. Moreover, the equipment can also be used for pushing the furthest stacks to more accessible points where reclaimer can reach (UNCTAD, 1985b: 178).

Circular blending bed is mostly used for homogenizing and storage of the materials. Circular blending bed has the ability of storing and reclaiming simultaneously (Thyssenkrupp, 11.03.2019b). In addition, longitudinal blending beds are widely used in the dry bulk terminals.

Figure 14 illustrates the storage yard equipment.

Figure 14: Storage Yard Equipment



Source: Thyssenkrupp, 11.03.2019a (Stacker (right)); Metso, 11.03.2019 (Stacker-reclaimer (left)); Thyssenkrupp, 11.03.2019b (Circular Blending Bed (bottom))

1.3.DRY BULK TERMINAL OPERATIONS

Planning the operations is the primary assignment for all activities in a terminal. Changeable activities require a systematic approach to plan port operations comprehensively. Comprehensive planning is significant to allocate the resources and provide the effective coordination of the operations, especially the involving parties outside the port. In case the operation is planned ineffectively, it is impossible to acquire the throughput although the berth is capable (Thomas, 1985c:1). Before making productivity and cost estimation, it is crucial that equipping, layout and method of cargo handling operations must be recognized (UNCTAD, 1985: 56).

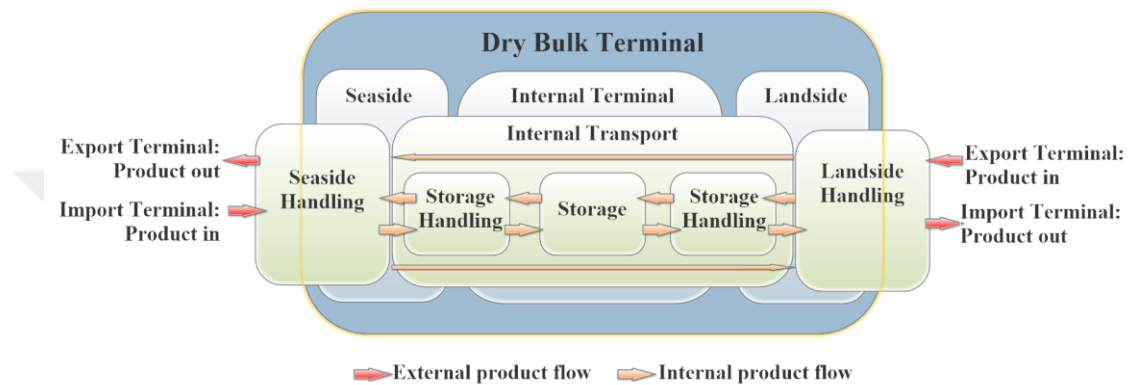
Robenek et al. (2012:2) evaluated dry bulk terminal operation planning under the two title: Tactical level and operational level. Tactical level refers to the allocation of the resources such as berth, storage policies, labor, equipment, and yard management. Besides, the operational level is associated with a series of decision making which encompasses the yard equipment and crane scheduling activities and flexible planning of these activities that are suitable according to last minute changes.

Dry bulk cargo handling encompasses the different organizations related to control and handling of cargo flow from ship to transport or storage and needs installations which ensure the maximum service to the ships with minimum costs (Bugaric et al. 2012:1508). Main consideration underlying the bulk terminal operations is to advance operational efficiency and to increase the ship turnaround time at ports providing the continual flow of cargo (UNCTAD, 1985:30; Burns, 2015:124). The system in the port should be planned to allow working with the full potential of loaders or unloaders and working in a synchronized manner (UNCTAD, 1985:30). Equipment and storage should also be taken into consideration to achieve the continual cargo flow.

In a general term, seaport terminals consist of three primary systems as the entrance, storage yard and exit systems (Schott and Lodewijks, 2007:376). The starting point of the systems is vary depending on the export or import activities of the dry bulk terminal. Based on the flow direction of the bulk cargoes, the terminal is denominated as “export terminal” or “import terminal” (Kleinheerenbrink et al., 2012: 108). Moreover, a queue of the dry bulk terminal operations can divergent regarding

equipment used in the terminal, services, layout of the terminal or types of cargo. It is difficult to illustrate the standard terminal operations queue and the flow of the cargoes due to the reasons mentioned above. For this reason, the operation queue of the dry bulk terminal is indicated in general terms considering the import and export cargo process in Figure 15.

Figure 15: Dry Bulk Terminal Process



Source: Kleinheerenbrink, 2012: 25

In import shipments, the process starts with the arriving of the vessels to the terminal. After berthing of the vessel, unloading operation of the cargoes begins. Unloaded cargoes are transferred to the storage yard. After the stacking process, the cargoes transferred to the exit by railway according to the availability of the railway links or trucks.

In the export cargo process, there is a reverse flow of cargo comparing to the import cargo operations. The process starts with the arriving of the trucks or wagons to the terminal. The cargoes arrive at the terminal gate to be transferred to the storage yard. After this process, cargoes are transferred to the berths vessel to be loaded, and the ship unberth.

Due to the reasons mentioned above (different processes in import/export cargo flow in the terminal), the process is evaluated under two main categories as seaside and landside operations. The general process in the dry bulk terminal cannot be schematization in a single process. For this reason, dry bulk terminal operations are described in general terms. More detailed operation process is explained as follows:

1.3.1. Import Cargo Operation Process¹

This section provides import cargo operation according to seaside and landside operations.

1.3.1.1. Seaside Operation Process

The queue of the seaside operations of the import materials are described as follows:

- **Pre-berthing operations:** A typical pre-berthing operation includes the processes of the permission to the berth, pilot guide requests (Wadhwa, 1990: 237). Before the vessel berths, it applies to a commercial service unit for various services such as proforma invoice, SAP, identification, reporting, etc. with the receipt of the commercial approval and the documentation unit forms the documentation control and the work orders. At this stage, the documentation such as preparation of the cargo manifest, mate's receipt packing list and discharging permissions are performed. After obtaining the operation approval, the operation unit monitors the operation, feedbacks, traces the vessel's documents and related operational documents.

- **Berthing:** In import dry bulk cargo operations, the entrance system includes the seaside where the vessels arrive and deliver the cargoes. Vessels may wait at the berth to get service after the arriving to the berth (Hess et al. 2007: 61). In this process, the vessel is allocated to the berth, and the port gives pilot guide instructions. After this process, the equipment is allocated to start handling operations. To be given this instruction, truck tracking should be performed, and the safety must be ensured.

- **Unloading of the cargoes:** After the berthing of dry bulk vessels, cargoes are unloaded by using ship unloaders such as mobile cranes, floating cranes, grabs, screw conveyor, cranes, continuous unloaders, chain bucket, hopper, crane-mounted grabs, bucket wheel etc. (Agerschou et al., 2004:318; Schott and Lodewijks, 2007:376; Bugaric et al. 2012:1512; Bugaric et al. 2012:406; Park and Noh, 1987:236; Burns, 2015:124;). Cranes discharge the materials to storage area directly or drop the

¹ In this section, the details of the operational processes are formed in the light of the information provided by Limak Uluslararası Liman İşletmeciliği A.Ş. and Atakaş Liman İşletmeciliği ve Ticaret A.Ş.

materials into a hopper which feed the conveyor (Agerschou et al., 2004:318). Pneumatic systems discharge materials in powder and granular form.

• ***Transferring the cargoes to storage yard:*** In this stage, conveyors are generally used as transfer equipment. Cargoes are dropped into a hopper (bunker) which feeds the conveyor belt system (Schott and Lodewijks, 2007:376). Belt system transfers the cargoes to the stackers which stacks the cargoes on the storage yard (Schott and Lodewijks, 2007:376). The cargo transfer is performed by the conveyor systems (Bugaric et al. 2012:1512; Agerschou et al., 2004: 318; Bugaric et al. 2012:406; Park and Noh, 1987:236). In this stage, different planning issues should be followed. If cargoes exit without being stored, the trucks that are allowed to pass are weighted. If the cargoes are to be stored, the trucks planned to perform this operation are directed to the storage yard area. Trucks are weighted in this area. After the equipment planning and the location determination activities, the cargoes are picked up to the storage area.

1.3.1.2.Landside Operation Process

• ***Storage Yard:*** The function of the storage yard in dry bulk terminals is the admittance of the cargoes from the berth if the land or railway transport is not fulfilled (Bugaric et al. 2012:1512; Bugaric et al. 2012:406; Park and Noh, 1987:236). While some of the dry bulk cargoes need to be stored in closed storage area, some of the cargoes are stored in open storage areas (Schott and Lodewijks, 2007: 377). The materials required the closed storage areas are transferred to silos or enclosed facilities alongside the berth in the terminal by conveyor systems. The materials which do not need closed storage area, are transferred in open storage areas for stacking (Burns, 2015:124). In the process of storage operation, the documentation unit records the cargo information to be stored in the area to the system.

• ***Transferring the cargoes to gate:*** Exit systems in the dry bulk terminal is fed by reclaimer which retrieving the cargoes from the storage yard. The exit systems are also feeding the conveyor belts (Schott and Lodewijks, 2007:376; Park and Noh, 1987:236). The cargoes leave from the storage area undergo a process of documentation. The planning unit sends the trucks to the storage area. The equipment

is assigned to the operation site as well as equipment allocations. After the cargoes are checked by the system, cargoes are moved from the storage area. The trucks are weighted before leaving from the port or entering to the port.

• **Gate Operations:** The operations in this stage is based on the efficient control of the entrance and exits to port areas. Planning includes the several services such as bookings, departure and arrival schedules, delivering the cargoes and picking up services, controlling, validation and inspection of the cargoes and monitoring the vehicle passages (Bichou, 2013:144). Pre-gate is exit channel where vehicles checked, weighted and examined before entry or exit (Keçeli, 2016:8; Mazouz et al. 2017: 610). This process includes many inspections of the cargo condition and the documents (Lai and Leung, 2000:89). For example, the license plate of the trucks and the customer are registered in the port system to leave the cargoes from the port area. Following these activities, the trucks are checked via the port system. If necessary, trucks are weighted. After these processes, access to the exit gate is provided. Besides dry bulk cargo is discharged in wagons, barge or train lead outstation (Schott and Lodewijks, 2007:376).

1.3.2. Export Cargo Operation Process²

This section provides import cargo operation according to seaside and landside operations.

1.3.2.1.Landside Operation Process

The queue of the landside operations of the export materials are described as follows:

• **Pre-gate and Gate Operations:** In export, dry bulk cargo operations start at the land side of the terminal. According to the situations that the railway connection is available, export dry bulk cargoes can be delivered by train, in the case of railway connection is not available, trucks perform this operation. In the terminal, which has

² In this section, the informations about the details of the operational prossess are formed in the light of the operational processess information provided by Limak Uluslararası Liman İşletmeciliği A.Ş. and Atakaş Liman İşletmeciliği ve Ticaret A.Ş.

railway connection, the tippers unload the cargoes, or self-unloading wagons are used to discharge the cargoes from the wagons (Schott and Lodewijks, 2007:376).

Entrance gate can be assessed as the important channel in which vehicles enter the port area, and checked weighted and examined (Mazouz et al. 2017: 610). Checking the trucks before entering the gate is performed in this stage (Keceli, 2016: 8). In this process, the planning department provides information about the vessel to the operation department. In case the trucks arrive at the port from the outside, truck list to be entered to port area is notified to the gate. Gate control unit checks the trucks and the trucks that are allowed to pass are registered, and the entry permissions are granted. If weighting is necessary, the vehicles are weighted. After these operations, the trucks are directed to the operation sites.

- **Transferring the cargoes to storage yard:** In truck-based delivering the export cargoes, truck unloaders are used for unloading operations. After dropping the cargoes which is discharged by the vibratory feeders or apron feeders to the hopper, the feeder equipment feeds the belt systems that transfer the cargoes to the storage yard (Schott and Lodewijks, 2007:376).

- **Storage yard:** The same activities fulfilled in the export storage yard are the same as the import storage yard (Schott and Lodewijks, 2007:376). For the materials stored in the open yards, a combination of usage of the reclaiming and stacking devices is commonly practiced. With reversing the boom conveyors, commodities drop onto the pile. Earth-moving equipment, i.e. bulldozers scraping the commodities into a fixed position, hoppers below ground level that bring it to belt conveyors are used in the closed storage area operations (Agerschou et al., 2004:316). Cargoes are stacked in the vehicles at the storage yard area. If the port supplies the vehicles (trucks etc.) and regards weighing as necessary, the trucks are weighed while vehicle is loaded.

1.3.2.2.Seaside Operation Process

- **Transferring the cargoes to the berth:** The trucks moved to the operation site leave the cargo to be loaded onto the vessel. At this stage, if necessary, trucks are weighted. The equipment is allocated to the berth.

• **Loading the cargoes:** Several techniques can be implemented for loading the vessels. According to the terminal layout and equipment, single spout systems may be used for the loading the materials. One another technique is that conveying the commodities to an elevated position alongside the vessel is up to load the ship hold by spouts. Gantry devices traveling below the tripping mechanism that spreads the materials over the hatch by slewing conveyor with controllable spout at the end (Agerschou et al., 2004:315). Vessels are loaded by the grab, bucket wheel, conveyor belts, loading spout, mobile cranes (Schott and Lodewijks, 2007:376; Burn, 2015:215).

• **Unberthing:** In export dry bulk terminals, exit systems are concluded at the berth (Schott and Lodewijks, 2007:376). At this stage the vessel departures from the berth by signing the operation documents.

Terminal operations must be organized to indicate the tonnage rate per hour for each of the equipment (UNCTAD, 1985b:184).

CHAPTER II

SCOPE AND CONCEPT OF PORT CAPACITY

2.1.AN OVERVIEW OF PORT CAPACITY

Capacity as a general terms is defined by the Swamidass (2000:74) as *“Capacity is the maximum possible output over a specified period of time. In cases where the output is nonhomogeneous, capacity may be measured in terms of the available machine hours”*. While Oxford Dictionary (01.05.2019) and Turkish Language Society (01.05.2019) define the capacity as *“The amount that something can produce”*, Olhager and Johansson (2012:23) defines the capacity as *“Capacity is concerned with the available (work) time per (calendar) time unit; e.g. hours per day.”*

Port capacity is well-defined by the Frankel (1987: 170): *“A port’s capacity is normally defined as the cargo volume that the port is capable of handling within 1 year and is often expressed as a throughput in tons per unit length of a wharf per year (MT/m/yr or LT/ft/yr), multiplied by the available berth length, for each type of berth separately”*. In the literature, various researchers define the port capacity. Gaur et al. (2011: 295) defined port capacity as a function of final output of production at each stage of the operations in the port. Zenzerovic et al. (2011:2), and Bassan (2007: 3) evaluated port capacity as loading or discharging amount of the specific berths at the terminal within the particular period (Ding, 2010: 126). Besides scholars assessed the port capacity from many different viewpoints. From the engineering perspective, Bichou (2013: 51) defined the port capacity as the maximum utilization rate obtained in short term with existing infrastructure and resources technically. From the supply perspective, port capacity is the ability of the port to accept a certain number of ships at the same time, and it is represented as the quantity of cargo, the number of handled the vessel, the total cargo quantity in a significant period (Dundovic, and Zenzerovic, 2000: 217). The level of service that the terminal can offer to its customer is another crucial factor for the supply side perspective. Therefore, the port capacity can also be defined from the supply viewpoint as the maximum throughput once the vessels arrive at the port and services are provided continuously (Ding, 2010:126). Besides, from the demand viewpoint, port capacity purports the port traffic capacity or the maximum

quantity of the throughput of specified berth (Zenzerovic: 2005: 168; Zenzerovic et al. 2011: 46). From the value-driven viewpoint, the capacity is the value corresponding to the highest vessel cycle that the port can handle while ensuring the minimum service quality. According to the value-driven perspective, port capacity cannot be separated from its service level, perceived quality, and the final value and these considerations are depended on the terminal characteristics, the performance of the terminal equipment, demand circumstances, and the outside factors (Morales-Fusco et al. 2010:696). It can be inferred from these definitions that port capacity shows not only the degree of the port capability but also the infrastructure capacity such as transport system. From the bottleneck perspective, port capacity can be evaluated as a measurement of determining the significant network constraints, and it enables the assessment of the port performance based on the safety and economic sense (Bellsola Olba et al., 2014:1).

The amount representing the handling unit is expressed in different terms in different port or terminal types. The units processed in the container ports are represented in TEU, in ton or pallets for bulk or general cargo ports, and in a number of the wheeled vehicles for Ro-Ro ports in a certain period (Bassan, 2007: 3). Moreover, the term capacity can be defined to indicate the different operational capabilities of the ports.

Many of the researches on port capacity and capacity planning problems focused on identifying the bottlenecks and constraints at the port and concentrated on solving these problems. Capacity constraint results in inadequate capacity at ports by preventing the port efficiency (Gaur et al. 2011: 298). Ports are divided into the main components to identify the bottlenecks. These components are vessel arrival capacity, berth capacity, ship-apron transfer capacity, apron-warehouse capacity, storage yard capacity, storage yard-land transport capacity, gate capacity, services, and hinterland connection capacity (Gaur et al. 2011: 5-6; Park et al. 2014:179; Meersman et al. 1997: 6) and these components are significant to determine the output level of a port (Gaur et al. 2011: 5-6). The bottleneck at the ports affects the operational aspects, i.e., waiting time, turnaround time, service time, etc. (Bassan, 2007:5). The cause of the bottleneck in ports originated in the inadequate capacity of subsystems of the port (Bugaric et al. 2012: 1509). From this perspective, capacity can be seen as an indicator and limiting

factor that assists in determining the constraints of any link (National Research Council, 1998: 10; Bellsola Olba et al. 2014: 1). It enables the assessment of the port performance systems (Bellsola et al. 2014: 1). Improvement efforts are shaped within the context of the constraints (Bassan, 2007:5). Within these subsystems, the weakest part determines the capacity of the entire port (Meersman et al. 1997: 6).

The growth in the world economy, acceleration in technology and investment, rising of new economic leaders in the world, increased international specialization, substantial world population growth have been possible with the growth of world trade. Industrialization has triggered the further development of overseas trade and unification of the economies (WTO, 2013:46). This massive progress has shaped the transport requirements, especially in ports, by pushing the port to integrate into the global supply chains and by increasing the need of specialized services (Ng and Pallis, 2010:2147). Moreover, factors such as growth in trade and cargo volume, economic activities and changing frame of the supply chain have increased the pressure on the ports in terms of both competition and capacity issues. Although many ports share the same hinterland, they have various competitive conditions. One of the factors that determine the competitive conditions between the ports is the capacity bottlenecks in the face of increasing demand (Asteris and Collins, 2007:2274).

Port capacity is the strategic point for the expansion of the ports and the development of the existing ports (Luo et al. 2012: 120). In response to the increase in demand, competition, and the ship sizes increase the ambitions of the port' expansion and development simultaneously (Fan et al., 2012: 1121). As mentioned earlier sections, the capacity should be balanced with the trade volume to sustain port performance as well as providing international and domestic competitiveness (Jeevan et al. 2015:85; Dekker and Verhaeghe, 2006:174). Therefore, the lack of understanding of the mechanism of market dynamics can lead to excess capacity in practice (Notteboom and Rodrigue, 2006:16). At this point, the port needs to examine its capacity to provide sufficient services to its customers and maintain its competitive advantages (Cullinane et al. 2006: 361). The accurate estimation of the supply and demand is an essential indicator for establishing or expanding the ports in terms of determining the capacity requirements, the continuity of capacity demand, income, investment timing, efficiency and effectiveness level of the ports. Because idle

capacity, which is the result of unnecessary investments, will damage not only the investors, but also other ports in the region and especially it harms the port tariff structure. Additionally, capacity utilization rates provide insights into the efficiency and effectiveness of the port. Improving these rates contributes to the operational and managerial process improvements (TÜRKLİM, 2017:101).

Port industry has capital-intensive nature and needs substantial investments in infrastructure and equipment by facing challenges of the environment of uncertainty (Haralambides, 2017: 27; Li et al. 2017:849; Lagoudis et al. 2014: 300). For this reason, these investments should be performed considering comprehensive capacity planning. Capacity planning differs from capacity management concept. Capacity management stands for the managerial approach of the owner under the service difficulties such as sufficient capacity or excess capacity. The capacity management decision depends on the results of the capacity planning (Dekker, 2005: 5).

Capacity planning is the primary decision process to meet the demand while building, enlarging or modernizing the port. In a broad sense, capacity planning refers to the examination of economic and technical aspects of balancing supply and demand (Dekker, 2005: 5). Being able to provide adequate services for port customers is the critical point in capacity planning (Tang et al. 2016:174). Port capacity design includes the examination of the expected demand and supplying sufficient capacity and improving the strategies to plan supply and demand (Bichou, 2013:53). Moreover, performance is another significant point in capacity planning. While this phenomenon includes the balancing supply and demand, it also aims to achieve both service level maximization and resource optimization (Li et al. 2017:849)

One of the main approaches to port capacity planning is the building new infrastructures and installing faster equipment (Kim and Morrison, 2012:2014). Although the physical expansion of port can be seen as the simplest method to expand beyond the port boundaries, this expensive choice may be constrained by the shortage in land areas where may impede future expansion, particularly the ports located in or near the city centre (Cullinane, et al. 2006: 361; Li et al. 2017:849). Physical expansion may lead to other issues in the competitive structure of the ports. After the investments are made, the ports may offer low-level prices to increase return on investment (Bae et al. 2013:480). Also, supplying more capacity by physical expansion lead to excess

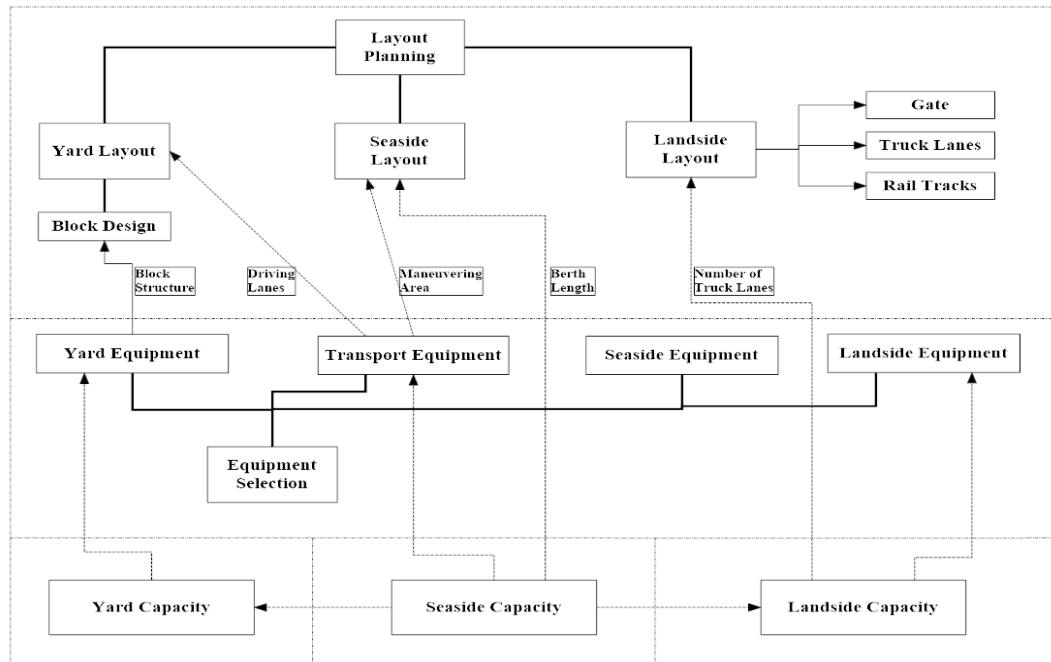
capacity problems. If there is an imbalance between the supply and demand, the level of competition will be affected. In that situation, ports need to compete rigorously to enhance its market share. This circumstance may cause to disruptive pricing. Inadequacy in creating demand will increase the tendency of the port to compete in existing services (De Langen and Pallis, 2007:439).

The competitive conditions are not only limited to capacity expansion. The use of maximum capacity, as well as the desire to reach minimum waiting times, also increased the pressures on ports for further improvements in productivity and efficiency (Haralambides, 2017:26-27). Besides, ocean carriers and shippers bear the time-related costs. Therefore, this situation determines the shippers and ocean carriers' port choices. Qualifications of the services of the port such as speed and quality of the services determine the time-related costs compensated by shippers, inland and water carrier such as inventory and depreciation costs (Talley, 2006:500).

The port capacity plays a vital part in planning the transport systems and its quality (Malavasi and Ricci, 2005: 471). It can be evaluated as an essential indicator of the transport infrastructure and capability of the port's ability to provide a specific service (Dekker, 2005:3; Bichou, 2013: 51). Ports should serve with adequate capacity to sea traffic regarding handling and transport options in its hinterland (Gaur et al. 2011:53).

As mentioned in *Chapter I*, the port layout design is closely related to port capacity. Layout planning to be carried out according to the planning of the seaside and landside directly affects the equipment and capacity to be used at the ports. Also, capacity planning affects the layout planning of the port. Schematic representation of the relationships of layout planning and the capacity is illustrated in Figure 16.

Figure 16: Relationship of Layout Planning and Capacity



Source: Wiese et al., 2013:227

According to Figure 16, seaside capacity is essential in determining the storage yard capacity and the landside capacity. The capacity, which is planned on this basis, affects the layout planning and design of the entire port through equipment choice.

2.1.1. Equipment Capacity

Selection of the type and capacity of the handling equipment is a complicated process due to the reasons such as operation economy, the convenience of the conveying systems for specific material and susceptibility of the cargoes to deterioration (Agerschou et al., 2004: 319) because the equipment capacity and its type is determinative for the overall terminal capacity.

There is a highly positive relationship between equipment performance parameters and the port capacity. Because the loading and discharging capacity of all the storage facilities restricted by the equipment capacity. There are three fundamental capacity types in the literature for the equipment as peak capacity, rated capacity and effective capacity (Ligteringen and Velsink, 2012:203; UNCTAD, 1985b: 170).

Peak capacity (cream digging rate) refers to the maximum hourly handling rate, which can be attained under certain optimum conditions. Unloading rate should be synchronized with all downstream facilities and equipment. Apart from the peak capacity, rated capacity (free digging rate) is the handling rate based on the cycle time of a fully loaded grab or bucket between the digging point and positioned point of the hopper and back. The value of the capacity can be found dividing the carrying capacity of the grab by the effective time required for the one cycle. Rated capacity is a useful indicator when comparing the equipment. Effective capacity refers to the average hourly rate achieved during the handling of the materials. The time includes the transition of the equipment between ship holds, cleaning of the holds, but non-working time is not counted. Effective capacity is used in planning stage of the port as an indicator. Port planner considers the effective capacity, whereas equipment designer pays attention to the peak capacity (Ligteringen and Velsink, 2012:203; UNCTAD, 1985:170).

In addition to indicators as mentioned above, which is related to equipment capacity, another factor, which provides insight into the equipment capacity when planning the terminals, is called as “*Equipment Installation Factor*”. Equipment installation factor is found by dividing the installed capacity (ton/h) by the required equipment capacity to handle the annual amount of cargo which attained by the terminal. In order to calculate this factor, required equipment capacity should be considered as the equipment is performing continuous operation (365 days, 24 hours) (van Vianen, 2015: 14).

Material types and the average capacity values of the equipment mentioned in *Chapter I, Section 1.2.1.4*. are specified in Table 6.

Table 6: Equipment Capacities, Vessel Sizes, and Suitable Materials ¹

Equipment Type	Capacity (tph*)	Suitable Material for Handling	Vessel Size (DWT)
Travelling Loader	500 - 9,200	Fertilizer, Urea, Ammonium Sulphate, Iron Ore, Coal, Petroleum Coke	40,000-270,000
Radial Loader	8,000-11,000	Iron Ore, Iron Ore Pellet	Up to 180,000
Slewing Bridge Loader	1,700-15,000	Fertilizer	52,000-270,000
Linear Loader	2,000-11,000	Coke, Sulphur, Coal	60,000-180,000
Travelling Overhead Trolley Unloader	1,000 - 15,000	Iron Ore, Coal, Ilmenite, Animal Feed, Clinker, Cement, Other Bulk Material	80,000-160,000
Mobile Harbour Crane	550 -2,300	Scrap, Agri-bulk,	Up to 30,000
Pneumatic Unloader	160 - 800	Cement, Malt Rice, Cocoa Beans, Urea, Cement	5,000-60,000
Vertical Screw Conveyors	100 - 800	Urea, Fly Ash, Gypsum, Cement, Lime, Raw Meal, Apatite, Limestone, Powder	15,000-6,000
Bucket Elevators	1,300 - 5,000	Free Flowing Granular Products, Coal Iron Ore	Up to 180,000
Belt Conveyors	2,000	Grain, Oilseed and derivatives, Coal, Ore, Mineral, Fertilizer, Woodchips, Lumpy or Granular Materials	Up to 130,000
Screw Conveyors	1,500	Cement, Grain, Coal, Lime, Raw Meal, Apatite, Urea, Fly Ash, Gypsum, Alumina, Biomass	-
En-masse Conveyors	286-1501,6	Agricultural Products	-
Stacker	1,600-3,000	Coal, Iron Ore Fines, Iron Ore Pellets, Coke, Olivine	-
Bucket Wheel Reclaimer	2,000	Coal, Iron Ore Fines, Iron Ore Pellets, Coke, Olivine	-

¹ Table 6 has been compiled from various equipment supplier's websites by taking into consideration the maximum and minimum values of the rated capacities. The values of equipment capacities vary according to the cargo type, equipment brand and model.

Table 6: Equipment Capacities, Vessel Sizes, and Suitable Materials (Continue)

Bucket Wheel Stacker Reclaimer		Coal, Iron Ore Fines, Iron Ore Pellets, Coke, Olivine	-
Stacking	500-6,000		
Reclaiming	4,500-20,000		
Circular Blending Bed		Coal, Limestone, Marl, Clay, Coal, Mine, Cement, Fertilizer, Grain	-
Stacking	2,500		
Reclaiming	1,200		

***tph:** ton per hour

Source: Adapted by the Author using the sources of Dahm, 11.03.2015; Liebherr, 13.03.2019; Vigan, 13.03.2019; IBAU Hamburg, 13.03.2019; DSD, 13.03.2019; Macgregor, 13.03.2019; Siwertell, 12.03.2019; Port Technology, 12.03.2019; Yuntian Machinery, 13.03.2019; Fam, 13.03.2019; Bühler, 12.03.2019; Siwertell, 12.03.2019; Konecrane, 13.03.2019; GSI, 13.03.2019; Thyssenkrupp, 13.03.2019 (a); Thyssenkrupp Robins, 13.03.2019; Thyssenkrupp, 13.03.2019 (b); Dry Cargo International, 01.10.2011.

2.1.2. Berth Handling Capacity

The berth where the cargoes are handled from/to terminal yards and vessels associates the landside and seaside activities (Salminen, 2013:23). Berth capacity of a port refers to the amount of cargo a port can handle from all the existing berths during the specified period (Oral, 2014:228; De Monie, 1987:12).

The berth is an essential factor in determining overall port capacity. Berths affect the operating principles of the other terminal subsystems in terms of meeting the ship traffic and handling the materials in these areas (Bugaric et al. 2012: 1508). Therefore, all performance factors and the service level of the berth will also affect the entire terminal system and its capacity. Level of service is the measure of the capability of the facilities to render service to the terminal (port) user. It refers to the operational conditions of the terminal regarding the determinants such as travel time, traffic, safety, suitability, maneuver freedom, speed, and elimination of damages (National Research Council, 1998: 18). Efficiency in cargo handling activities effects the service capacity of the port (Tan et al. 2015: 15). Assessing berth capacity within the viewpoint of the service level changes the berth capacity definition as the maximum amount of

cargo that can be handled at the berth within a specific period without decreasing the service level below a widely accepted level (Tang et al. 2016:175).

The common purpose of the ports is to offer higher service quality to all customers as well as achieving higher efficiency and minimizing costs (Mwasenga, 2012: 4). Meeting the targets of determined capacity is possible by keeping the performance indicators at the optimum levels because the performance indicators characterize the port service level and capacity (Lee et al. 2014:427).

There are several performance indicators in the literature. Although these indicators are used in the measurement of the port performance, these parameters are also used in planning and measuring berth capacity. One of these indicators is waiting time to service time ratio. It is expressed as T_w/T_b , where T_w is waiting time of vessels; T_b is the service time of vessels at the berth (Laing and Hecker, 1989: 83; Layaa and Duallert, 2014: 151; Bellasola Olba et al. 2017: 2). Although Tang et al. (2016:117) called this performance indicator as berth occupancy; it does not fully meet the concept of berth occupancy rate. The ratio indicates the level of service delivered by the terminal (UNCTAD, 1985a: 30). Waiting time-to-service time ratio describes the efficiency level of the port regarding the overall port with sailing time (Bellasola Olba et al. 2017:2). This ratio indicates the service level since the waiting time of a vessel depends on the amount of cargo carried by vessel (Layaa and Duallert, 2014:150). It is accepted that the waiting time should not exceed 10-50 % of the working time. However, this ratio is deceptive due to the service time deterioration. Therefore, this ratio can be seen as a useful tool only when the conditions are constant. The rate is advantageous when the economic optimum investment plan is prepared (less than 30 % is preferable) (UNCTAD, 1985a: 30). This ratio creates a discrepancy between the shipping lines, ship owners or charterers and the port authority. Shipping lines, ship owners or charterers choose the low waiting time-to-service time ratio. However, the port authorities want to achieve higher berth utilization. Hence, the balance between these claims should be considered (Layaa and Duallert, 2014: 151). Mostly ship owners and shippers consider this indicator as port selection criteria to save the time and money.

One of the main factors that should be considered in the measurement of berth capacity is statistical distributions. The correct evaluation of the berth capacity

depends on the statistical distribution parameters. Commonly used statistical distributions used in measuring the berth capacity are service time distribution, ship arrival distribution and ship inter-arrival time distribution. Service time distribution shows the distributions of the service time per ship. Service time primarily depends on the amount of cargo carried by vessel and loading/unloading rate of the equipment (Shabayek and Yeung, 2000: 329).

Moreover weather conditions, and cargo type affects the service time distribution. Inter-arrival time distribution shows the time at which ships arrive at the port. Arrival rate of the vessel illustrates the frequencies of the vessel's arrivals. These distributions affect the berth occupancy, storage yard utilization, and equipment utilization. In dry bulk terminals, vessel arrivals show a random tendency. According to the UNCTAD (1985: 187), Erlang 2 distribution is preferred to determine the inter-arrival time distribution and the service time distribution in queueing approach rather than Erlang 1 distribution due to the tendency of slightly simplifying the arrivals. Besides, Bugaric et al., (2012:1514) stated that the service time of the vessels is obtained in accordance with the normal distribution, whereas inter-arrival of the ships obtained according to Erlang 1 in bulk cargo import terminal. Dragovic et al. (2006: 290-291) stated the arrival of the vessels and the inter-arrival of the vessels were best fitted with the exponential distribution and the service time is measured by Erlang distribution although container terminal did not show the stochastic arrival. According to Altıok (2000: 6), the service time of the vessel fits the Erlang distribution in bulk loading ports. Kozan (1997: 242-243) specified the service time shows consistency with the Erlang distribution, whereas the inter-arrival distribution of the vessels consistent with the exponential distribution. According to van Vianen et al. (2012:3) distributions are highly correlated with the terminal type. In the ports, which give service to third parties, the distribution can be modeled by the negative exponential distribution because the owner of the cargo is different from the operator. Besides in single user terminals (e.g., power plants or steel producers), the best-fitted distribution is the Erlang 2.

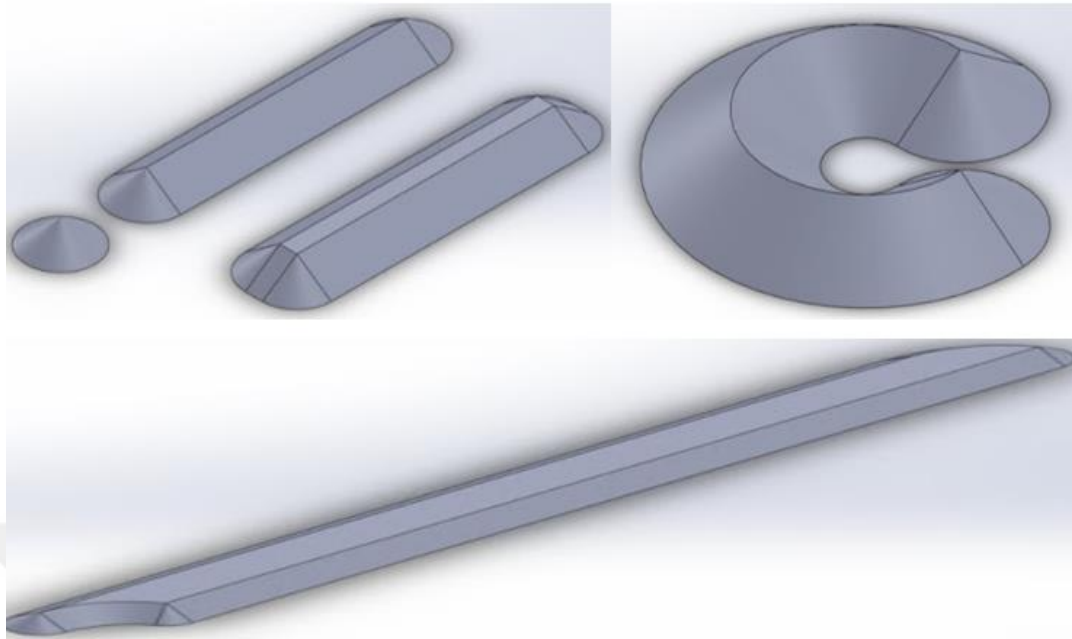
2.1.3. Storage Yard Capacity

When all components of the port are considered as a link of a chain that determines the port capacity, storage yard is one of the most critical chains when measuring the port capacity. The port capacity is highly associated with the size of the total yard area (Park et al. 2012:3; Park and Dragovic, 2009: 204) because the size of the storage is the limiting factor in managing the logistics activities for many terminals (Chen et al. 2004:1).

Since the port can be qualified as a system and all the subsystems, affect each other. All subsystems of the port must work harmoniously to achieve the goals. Because berths and storage yard area are the components of the port system, the parameters affecting the berth also affects the storage yard area. Therefore, statistical distribution determines the storage yard capacity as well as the berth capacity. Arrival rates, and the amount of the cargo brought by vessels to be stored in the storage yard area directly influence the port capacity. In addition to the above-mentioned statistical distributions, storage time distributions also affect the storage yard capacity. As stated in *Chapter I Section 1.1.*, decisions of constructing the new port or expanding the existing structures affected by the port capacity. Moreover, equipment types and characteristics, types of cargo, stockpile and stacking, and storage policy implemented in the terminal area directly affect the storage capacity of the port.

Stockpiles may be in the form of trapezoidal shape, a trapezoidal shape with end cones, conical, circular, triangular and triangular with end cones. The stockpile configuration is illustrated in Figure 17:

Figure 17: Different Stockpile Configurations



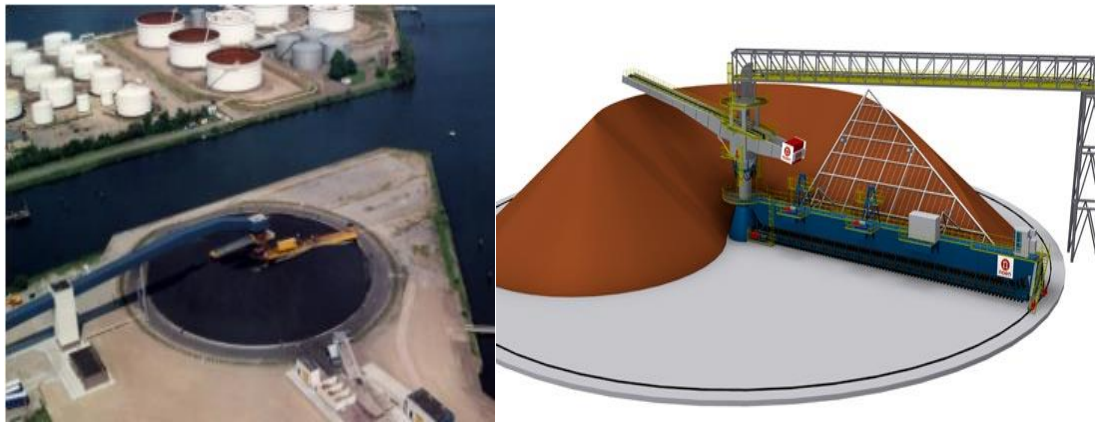
Source: Basics in Stacker Reclaimer, 28.11.2017

Several parameters restrict the stockpile capacity. These parameters are the bearing capacity of the ground, length, and width of the stockpile, the stockpile geometry, types, height and outreach of the stacking equipment. Determining the optimum pile size is crucial for the equipment because the volume of the storage yard capacity can be enlarged by the size of the pile (Frankel et al., 1985: 158).

In case the use of luffing non-slewing stackers, triangular and conical shapes can be formed, whereas luffing cum slewing stacker allows to the triangular, trapezoidal and triangular shape of the stockpile (Basics in Stacker Reclaimer, 28.11.2017).

Circular storage yard system is a circular system that the stockpiles established on the circular ground. Circular systems include the luffing-slewing stackers and bridge-type reclaimer, which can turn around the central column. The equipment can reach the total area where stockpile is formed (Wolpers, 24.02.2019; UNCTAD, 1985b: 181). In the case of limited storage spaces, circular storage yard implementations may be reasonable (UNCTAD, 1985b:181). Additionally, circular storage yards is generally applied when materials need to blending or when there is a need for immediate storage (Kleinheerenbrink, 2012: 43). Figure 18 shows the circular storage system.

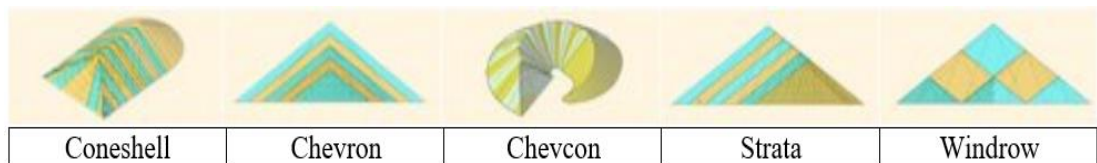
Figure 18: Examples of Circular Storage System



Source: Thyssenkrupp, (24.02.2019) (left); Noen, (24.02.2019) (right)

Commodities can be stacked to stockpiles with different stacking methods. The difference in stacking method stems from the blending requirements of the commodities, prevailing weather conditions, design and size of storage yard and equipment (Ökten et al. 2013:2; Beumer Group, 24.02.2019). Complex stacking methods allows for better blending percentages. The absence of blending requirement enables the use of simpler stacking methods (Beumer Group, 24.02.2019). There are several stacking methods in practice. Commonly used methods are chevron, chevcon, cone shell (Strata), and windrow stacking methods. Figure 19 illustrates the schematic representation of the stacking methods.

Figure 19: Stacking Methods



Source: Beumer Group, (24.02.2019)

Coneshell stacking method is used when there is no need for blending the commodities (Beumer Group, 24.02.2019). This method is developed for the portal scraper reclaimer. Blending has a limited effect because commodities are reclaimed laterally (Wolpers, 24.02.2019). In the cone shell type method, commodities are

stacked in conical shape until it is reaching the maximum height. After finishing the first cone, the equipment moves one step forward to form the second cone. Coneshell stacking is completed gradually (Ökten et al. 2013:2). Chevron stacking method is another choice when blending is required. This method does not need to slew gear equipped stackers. Chevron form is the same application of the chevron stacking method in circular storage (Beumer Group, 24.02.2019). Equipment moves with the constant speed on the line and turns back. The boom of the equipment can be raised or lowered according to the height of the stockpile (Wolpers, 24.02.2019). However, the stockpile height is limited by the height of the equipment. Stockpile shape in chevron stacking is triangular. Rain-water flows down the edges of the triangle stockpile (Ökten et al. 2013:2). Chevron is preferred due to less complicated and cheaper characteristics (Kolonja et al. 2016:4). Strata stacking method requires complex and expensive equipment (Beumer Group, 24.02.2019). Besides, in the windrow stacking method, commodities are stacked with the slewing movement. The equipment travels forth and back along the lane by changing the boom height (Ökten et al. 2013:2). Windrow method is the sophisticated methods that require high technology equipment (Kolonja et al., 2016:4).

There are several rules of thumbs estimation about the requirements of storage yard capacity. According to Hemert (1984:45-46), a terminal should be able to store the two months of the total annual throughput or the should have a potential of storing 5-6 times largest vessels called to the ports. Thereby the required storage yard capacity should be designed to be least affected by demand fluctuations (Hemert, 1984: 45). Storage yard requirements per cargo ton proposed by the Hemert (1984:46) are illustrated in Table 7:

Table 7: Required Gross Storage Area According to Cargo Ton

Category	Ton	Gross Storage Area (ha)
1	250,000 to 350,000	6-8
2	500,000 to 750,000	12-15
3	750,000 to 1,250,000	20-30

Source: Hemert, 1984:46

Besides Lodewijks, et al. (2007: 6) suggested that the conceivable amount of the stock accepted as 10% of the annual throughput of the terminal. However, according to van Vianen et al. (2011: 9), this percentage should be 5-22% in import coal and iron ore terminals, and 3-10% in export coal and iron ore terminals. Herewith percentage of the annual cargo volume provides insight into the needed storage area (Dundovic and Kovacic, 2007: 254).

2.1.4. Gate Capacity

Gate capacity encompasses the swift inspection of the cargo and data exchange, increasing the gate hours, installing the assignment system by improving the land-port interface and providing the connection between the port and its hinterland (Dekker, 2005: 41).

As with the berth and storage yard capacities, there are some challenges faced in the planning of gate capacity. Extra space is required to increase the gate capacity. In absence of sufficient space for the expansion, this situation creates a constraint for the ports. Excessive investment costs cause challenges in increasing gate capacity. Besides, expanding the gate capacity to relieve the congestion at the gate may results in underutilization of the gate structures (Guan, 2009: 143).

Terminal gate system is highly associated with traffic congestion at the terminal (Guan, 2009:12). Level of congestion at the terminal gate determines the terminals' accessibility with its hinterland. Congestion creates long queues at the terminal gate, meaning higher waiting times and inefficient gate operations (Ramirez-Naffarate et al. 2016: 2).

When planning the gate capacity, gate lane layout, forecasting cargo amount and truck arrivals should be designed in the gate capacity planning stage (Ramirez-Nafaratte et al. 2016: 4). Because gate capacity depends on the truck arrivals, processing time per trucks, and process quality (Sharda and Voß, 2015:309) thus, efficient planning of the terminal gates and gate-processing increases the gate capacity (Guan, 2009: 188). Additionally, gate-processing procedures affect the capacity of the terminal apart from the infrastructural problems faced at the terminal gate. Decreasing the gate processing time enables increasing in the truck passages, accordingly increase

gate capacity (Guan, 2009:183). Technological systems used at the terminal can solve the processing inefficiencies by accelerating the gate operations (Islam and Olsen, 2011:415).

2.2.FACTORS AFFECTING THE PORT CAPACITY

Even though measuring the port capacity is seen as simple, the capacity is a complex phenomenon because it is a function of various factors. Researchers carried out many researches on the terminal capacity focusing on the different component of the terminal. Ports as a complex system can be affected by the many factors. Table 8 indicates these factors:

Table 8: Port Capacity Related Factors

BERTH	
Length of the Quay Wall	Hartmann and Halecker, 2015:136-137; Sheikholeslami et al. 2013: 434; Ding, 2010: 125; Layaa and Dullaert, 2014: 150; Frankel, 1987: 171
Number of the Berth	Frankel, 1987: 171; Bugaric and Petrovic, 2012:1508; Park et al. 2014:186
Size of the Quay	Li et al. 2017: 849; Laya and Duallert, 2014: 150; Frankel, 1987: 171; Acar and Gürol, 2015: 5; Park et al. 2014 176; van Vianen, 2011: 4; van Vianen et al. 2012: 3
Number and Characteristics of Equipment	Hartmann and Halecker et al., 2015:136-137; Park el. al. 2014:176; Acar and Gürol, 2015:5; Li et al. 2017: 849; Ding, 2010: 125; Layaa and Dullaert, 2014: 150; Oral, 2014:228; Wiese et al. 2013: 226; Sheikholeslami et al. 2013: 434; Ding, 2010: 125; Frankel, 1987: 171; UNCTAD, 1985b: 180
Draft	Hartmann et al. 2015:136-137; National Research Council, 1998: 9; Acar and Gürol, 2015:5; Tang et al. 2016: 176; Souf-Aljen, et al., 2016: 39; Wadhwa, 1990: 240; Frankel, 1987: 171
Mooring Times	Hartmann and Halecker, 2015:136-137
Safety Distance	Hartmann and Halecker, 2015:136-137; Park et al. 2014:176;
Throughput Density (Handling Volume)	National Research Council, 1998:79; Bichou, 2013:58; Frankel, 1987: 171; Hartmann and Halecker, 2015:136-137
Stowage Plan	Hartmann and Halecker, 2015:136-137; Ashar, 2013:7; Casey and Kozan, 2012: 1126
Weather Conditions (Tides, Wind, Wave, Storms, Fog, Swells, etc.)	Hartmann and Halecker, 2015:136-137; Hess and Hess, 2010: 148; Bugaric et al. 2012: 1510; Sheikholeslami et al. 2013: 434; Wadhwa, 1990: 239
Bunkering Services	Özkan et al. 2016: 139

Table 8: Port Capacity Related Factors (Continued)

Type of the Cargo	UNCTAD, 1985b: 180; Bichou, 2013:75; van Vianen et al. 2012:3
Vessel Capacity	Hartmann and Halecker, 2015:136-137; Özkan et al. 2016: 139; Ding, 2010: 127; Frankel, 1987: 171-172; Bicho, 2013:75
Statistical Distributions (Arrival Rate of the Vessels, Inter-Arrival Rate, etc.)	Kia et al. 2002: 534; Hartmann and Halecker, 2015:136-137; National Research Council, 1998:79; Özkan et al. 2016: 139; van Vianen, 2012:3; Kleinherenbrink, 2012:43; Kox, 2017:35; Wanhill, 1976:121; Assadipour et al. 2015: 48; Radmilovic and Jovanovic, 2006: 99; Chang et al. 2012: 245; Noritake and Kimura, 1983: 339; UNCTAD, 1985: 28; Shabayek and Yeung, 2000: 327; Bot, 2012: 75
Conditions of the Entrance Channel (Physical Characteristics) and Vessel Queuing Capacity	Tang et al. 2016: 176; Sheikholeslami et al. 2013: 434; Maloni and Jackson, 2005: 2; Fan et al. 2012: 1122; Wadhwa, 1990: 239-240; Tang et al. 2016: 186; Frankel, 1987: 171; Frankel, 1987: 171 Hartmann and Halecker, 2015:136-137
STORAGE YARD	
Stacking Capacity	Hartmann and Halecker, 2015:136-137
Size of the Storage Yard Area	Dundovic and Zenzerovic, 2000: 219; Layaa and Dullaert, 2014: 150; Frankel, 1987: 171; National Research Council, 1998:79; Bichou,2013:58; Acar and Gürol, 2015:5; Li et al. 2017: 849; Sheikholeslami et al. 2013: 434
Bearing Capacity of the Ground	UNCTAD, 1985b: 180; Kleinheerenbrink, 2012:44; Kox, 2017:53
Conditions of the Internal Roads of the Port (Physical and Traffic Condition)	Roy et al. 2016: 475; Özkan et al. 2016: 139; Fan et al. 2012: 1122; Maloni and Jackson, 2005: 2; Fan et al. 2012: 1122; Wadhwa, 1990: 240; Hartmann and Halecker, 2015:136-137

Table 8: Port Capacity Related Factors (Continued)

Terminal Layout Planning	Wiese et al. 2015:226; Özkan et al. 2016: 139; Løyen, 2001: 91; Lee et al. 2014: 449; Bugaric et al. 2012: 1510; Mosca et al. 2000: 153; Zamanirad et al.2017:21
Stacking Height	UDHB, 2015: 235
Stacking Policy	UDHB, 2015: 235
Downtime (Due to maintenance, repair, shift change, weather conditions, the time taken by crane movement, waiting time, opening and closing the hatch covers, waiting times)	Oral, 2014: 228; Tang et al. 2016: 176; Hess and Hess, 2010: 148; Zamanirad et al. 2017: 22; Frankel, 1987: 171
GATE	
Number of Terminal Gate and Lane	Özkan et al. 2016: 139; Sharda and Voß, 2015: 209; Ramirez-Nafarrate et al. 2016:4
Security Control	Özkan et al. 2016: 139; Sharda and Voß, 2015: 209
Processing Time	Sharda and Voß, 2015: 209; Guan, 2009: 188
IT	Sharda and Voß, 2015: 209; Islam and Olsen, 2011:414; Guan, 2009: 188
Truck Arrival Rate	Guan, 2009: 226; Sharda and Voß, 2015: 309
EQUIPMENT	
Conditions of Infrastructure and Superstructure	Sheikholeslami et al. 2013: 434; Maloni and Jackson, 2005: 2; Li et al. 2017: 849; Frankel, 1987: 171

Table 8: Port Capacity Related Factors (Continued)

PERFORMANCE	
Dwell Time (Average Number of Days in Storage)	National Research Council, 1998:79; Kia et al. 2002: 536; UDHB, 2015:235; Chen et al. 2004:1
Gang Productivity	National Research Council, 1998:79
Level and Quality of the Service and Handling Operations	Bierwirth and Meisel, 2015:157
Berth Occupancy	Tang et al. 2016: 176; Zamanirad et al. 2017: 21; Frankel, 1987: 171
Overall Productivity	Bichou, 2013:58; Chang et al. 2012:243
Operational Productivity	Sheikholeslami et al. 2013: 434; Mosca et al. 2000: 153; Ding, 2010: 125
Labour Productivity	Frankel, 1987: 171; Park et al. 2014:176; Maloni and Jackson, 2005: 2; Wadhwa, 1990: 240; Islam and Olsen, 2011:414; Sharda and Voß, 2015: 310
Availability of the Ship Crane	Frankel, 1987: 172
Resource Utilization	Ding, 2010: 125; Fan et al. 2012: 1122
Technical Availability	Hartmann and Halecker, 2015:136-137
Service Time (actual handling time)	Kia et al. 2002: 534; De Wielle and Ray, 1968; Shabayek and Yeung, 2001:135; Lusby et al. 2009:2; Matella et al. 2012:62; Chang et al. 2012: 246; Ligteringen and Velsink, 2012:18; Jovovic et al., 2009:157
Total Waiting Time	De Wielle and Ray, 1968
Ship Idle Time	Kia et al. 2002: 534; Chang et al. 2012: 243
Working Days and Working Hours	Frankel, 1987: 171; Ding, 2010: 125

Table 8: Port Capacity Related Factors (Continued)

OPERATION	
Pilot and Tug Availability	Hartmann and Halecker, 2015:136-137
Operational Strategies	Lee et al. 2014: 449
Port price Policy	Santos et al. 2016:823
The speed of the Operation	National Research Council, 1998: 103-104
Scheduling and Bookings	Frankel, 1987: 171
Cargo Information	Hartmann and Halecker, 2015:136-137
Strikes	Hess and Hess, 2010:148
Full and Empty Container Repositioning in the Terminal	TRMTI, 2015: 235
Supply and Demand	Chang et al. 2012: 243; Wadhwa, 1990: 239; Frankel, 1987: 171
Stakeholders (Users, Stevedores, Governments, Shippers)	Maloni and Jackson, 2005: 2
Technological Developments	Maloni and Jackson, 2005: 2; Santos et al. 2016:823
Customs and Safety	Hartmann and Halecker, 2015:136-137; Özkan et al. 2016: 139
HINTERLAND	
Hinterland Connection	Loyen, 2001: 91; Wan et al. 2013:417; Özkan et al. 2016: 139; Maloni and Jackson, 2005: 2; Fan et al. 2012: 1122; Wadhwa, 1990: 240

Source: Compiled from Several Sources by the Author

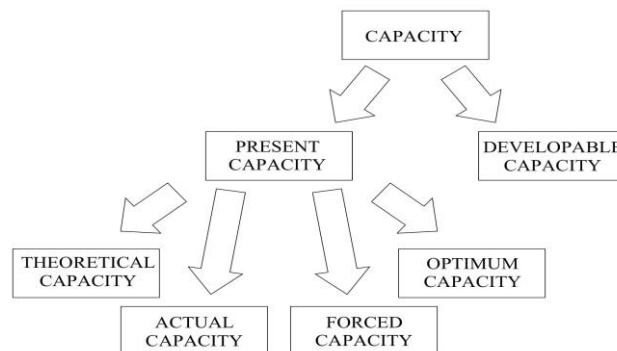
Within the context of the existing literature, the factors affecting port capacity are examined under five categories. Five categories are berth, storage yard, gate, productivity, operation, and hinterland. Not all variables affecting port capacity have the same effect, and the effects of these variables are not constant. When these variables are examined mathematically, the measurable parameters have different effects on capacity. When the port is considered as a system, all factors interact with each other, although it is categorized under five main headings.

Within the context of the study, the port capacity measuring model is focused on the variables that can be measured technically.

2.3.TYPES OF THE PORT CAPACITY

According to UNCTAD report on “*Berth Throughput: Systematic Methods for Improving General Cargo Operations*” (1973), cargo handling capacity of ports was divided into two categories as intrinsic capacity and proper capacity. Intrinsic capacity refers to throughput level which can be achieved only under the ideal circumstances without any constraints at all the levels of the ports (storage, transfer, berth utilization) whereas proper capacity implies achievable throughput level under the actual working conditions regarding reasonable interruptions and operational conditions. However, some other studies on port capacity stated additional capacity types, for instance, optimum capacity, forced capacity, developable capacity, maximum capacity and idle capacity (Oral, 2014; 227; Esmer, 2003). Types of the port capacity are indicated in Figure 20.

Figure 20: Diversities of the Capacity Types



Source: TÜRKLİM, 2017: 102

2.3.1. Theoretical Capacity

The capacity is the amount of goods and services that a port can obtain by using its production abilities within a specified period of time (per hour per ship for 24 hours per day and 365 days per year) without any bottleneck or constraint at different operation processes (National Research Council, 1998; Esmer, 2003; UNCTAD, 1985b; Park et al. 2014; Layaa and Dullaert, 2011; Ligteringen and Velsink, 2012: 122). It is mainly linked to physical conditions and the size of the infrastructure (Meersman et al. 2012). The mathematical calculation determines the capacity under certain assumptions, and the capacity illustrates how much cargo can be handled per year (Oral, 2014:227).

Theoretical capacity is considered as the desired maximum usage of the terminal's physical facilities, equipment or persons, and maximum achievable cargo flow within a specific period (Lasalle and Hendry, 2009: 40; National Research Council, 1998: 10). Correct timing of the maintenance of the equipment, the accurate stock control will prevent the delay and increase the theoretical capacity (Oral, 2014:227). Theoretical capacity must be evaluated from an integrated development approach, and it includes all operation processes at the terminal (Gaur et al. 2011:298).

2.3.2. Actual Capacity

Actual capacity refers to a practical and obtainable throughput level calculated by regarding actual operating circumstances at the port (National Research Council, 1998) and needs utilization of berth, handling equipment ratio, actual handling time, actual quay working days (Park et al. 2014). The capacity is generally calculated by considering available resources of ports with the cargo volume data and the ship traffic based on the previous years (Oral, 2014:227). The capacity is affected by the amount of cargoes and sharing of the cargoes between the ports in the region based on considering the amount of cargoes and number of ships called to the port (TÜRKLİM, 2017: 103).

2.3.3. Forced Capacity

In contrast to optimum capacity, forced capacity is defined as exceeding the actual capacity under certain circumstances (TÜRKLİM, 2017: 104; Oral, 2014:227). Forced capacity might be possible by extending working hours, postponing the equipment maintenance, supplying additional equipment from the outside of the port temporarily (Oral, 2014:227; TÜRKLİM, 2017: 104). Although there are numbers of disadvantages of excess capacity over workers' health, equipment usage (Oral, 2014:227), it can be seen as an operational necessity in terms of providing shorter turnaround time to ships and increasing customer satisfaction (Haralambides, 2002).

2.3.4. Developable Capacity

It can be attainable when the port invests in infrastructure and superstructure in the future and in the case providing optimum equipment for ships in terms of both technically and numerically (Oral, 2014:227).

Developable capacity is vital in terms of indicating the maximum cargo volume and vessel traffic that the port can reach in the future. Developable capacity shows the potential capacity of the port, and it is possible by developing the existing port facilities and equipment. Ports may develop its capacity by constructing new berths, gates, storage buildings or areas, increasing the berth draft by dredging activities, and investing in new equipment (TÜRKLİM, 2017: 105).

2.3.5. Optimum Capacity

Optimum capacity can be defined as the capacity that the port can operate the most efficiently and effectively (Oral, 2014:227). When the capacity is evaluated from the other viewpoint, it refers to the capacity level at which the services and activities carried out at the port begins to increase the average operating costs (Bichou, 2013: 51-52). Economic analysis specifies the critical point of the capacity where extra resources and spending are not worth to cost of the capacity increase. The economic

analysis aims to achieve maximization of the total benefits that provides the maximum commercial and economic gains (National Research Council, 1998: 10; Meersman et al. 1997: 6). According to Ligteringen and Velsink (2012:123) optimum capacity stands for both economically optimum capacity and optimized capacity. Economically optimum capacity refers to attain minimum cost level per cargo ton. Accordingly, reaching maximum throughput level with the minimum costs. Besides optimized capacity means that the optimizing the port resources to attain maximum throughput by eliminating the deficiencies.

Optimum capacity of a port should fulfill the optimization requirements and specified limits to serve to its customers by reducing the delays and increasing the profits (Dundovic and Zenzerovic, 2000: 217). Generally, the optimum capacity rate should be 75% of the theoretical capacity. If the rate below 75%, it is accepted as inefficiency in port service delivery (TÜRKLİM, 2017:103).

When evaluating the definitions mentioned above on capacity types, it can be made a clear distinction between the capacity types. Theoretical capacity takes into account the amount of cargo that the port can perform 365 days and 24 hours. Besides, actual capacity considers the usual traffic conditions of the port. Accordingly, actual capacity calculations take into account the berth occupancy levels while theoretical capacity accepts the berth(s) as fully utilized. However, which capacity type explains the circumstance that the port can reach under the real conditions (interruptions due to weather conditions, equipment downtime, periodical maintenance of the equipment, equipment movement, lunchtime etc.) and the port does not suffer from the low demand as far as it is known. As described in the earlier section in this chapter, the capacity level is determined by considering maximum possible output within a specified period (Swamidess, 2000:74) and this capacity level is significant for deciding on investment, marketing, planning strategies.

Apart from the inadequacy of port infrastructure and superstructure, a port may suffer from the low demand with existing infrastructure. In that situation, the capacity level of port and realizable capacity level should be explained according to capacity types. Which capacity type does explain the situation mentioned above? Can the actual capacity concept explain this circumstance? The impact of the demand (vessel traffic) is essential in actual capacity because it takes into account the actual traffic conditions,

but it has been considered that this capacity type does not fully explain this situation. The possible output level should be discussed by considering the above-mentioned questions.

For this reason, a definition is required that explains the possible output levels where the terminal is independent of actual demand conditions and the capacity output that can be realized by its resources as if the ships always called to the port. Within the context of the study, the type of capacity that explains this concept called as realizable capacity. This subject has been discussed in *Chapter IV, Section 4.2.1.4*.

This study focuses on the theoretical, actual, and realizable capacity measurement of dry bulk terminals.

2.4.THE RELATIONSHIP BETWEEN THE PORT CAPACITY AND COSTS

There are various uncertainties regarding measurement, planning, and management of the capacity. These uncertainties delimit several decision-making and activities in the port. The long-term estimation of the direction and the volume of the development is a challenge faced by the port planners as a severely limiting factor in predicting future network demand (Dekker, 2005: 68; Dekker and Verhaeghe, 2006, 174). Determination of the cost model for the port is another unpredictable factor that determines the demand level. In addition to that, methods used in prediction of the demand level have been performed under several assumptions. As the premises have an uncertain structure, it creates constraints in term of a valid demand estimation. Data reliability is the factor which increases the uncertainty, and which leads to certain complexity in planning and measuring the capacity (Dekker, 2005: 68).

With the investigation of the existing situation of the ports considering both uncertainties, excess capacity, capacity shortages, and related performance subjects, the port planner should develop the possible competition strategies to survive within the highly competitive environment (Dekker and Verhaeghe, 2006: 174).

The competition conditions, which were continued at the different stages in the past, have now been replaced by competition through logistics chains. In general, ports still have an essential place in the transport chain (Meersman et al. 1997: 12). The competitiveness of the ports continues in many different functional areas. Some of

these areas are capacity, design, cost and performance dimensions. The port planner should make a customized design within the context of the supply-demand and cost-benefit analysis (Dekker and Verhaeghe, 2006: 174).

When the port competition is evaluated from the long-term perspective, ports desire to ensure about that the existing capacity will not create a potential capacity shortage in the future (Meersman et al. 1997: 13). It is necessary to make the difficult decision to balance the capacity shortage and excess capacity, (Dekker and Verhaeghe, 2006:174). The decision process starts with accurate demand estimation (Meersman et al. 1997: 13). Port planners can review several alternatives at the decision-making phase. These alternatives usually consist of two assessments as structural and non-structural. Structural and non-structural alternatives motivate the port planning in different directions. Non-structural methods imply the increasing productivity and managing supply and demand whereas expansion planning and hereafter additional investments

Decisions are further prominent in the non-structural methods implementations (Dekker and Verhaeghe, 2006:174). The additional capacity may be acquired by improving the performance parameters in non-structural planning methods (Fung, 2002: 77). These alternatives can also be evaluated as a level of activities. The first level is the increasing performance of the current structure and advancing the system at a second level (Gaur, et al. 2011: 310). The situations that require the evaluation of these alternatives are the problems caused by inadequate capacity and excess capacity subjects.

Capacity shortages cause congestion and impede the flow of the cargo. As the distinction between the supply and demand closes, this results in possible congestion and unsafe conditions (Cambridge Systematic, 1998:103). Inadequate capacity causes the port to increase its prices and decrease the demand. (Dekker and Verhaeghe, 2006: 174; Dekker, 2005: 11; Islam and Olsen, 2013:86). Moreover, it creates a series of problems such as inefficiency in supply chain activities, delays, storage yard congestion, excessive lead-time, and transit time, extreme costs and imbalance in inventory levels of the shippers, trading activities, and accident risks (Islam and Olsen, 2013:86; Maloni and Jackson, 2005:2; National Research Council, 1998: 103). In competition conditions, this situation decreases the service demand of the ports in

question, and the ports are highly sensitive against the seasonal demand changes in the short term (Dekker, 2005: 11).

The capacity shortage may stimulate the capacity expansion decision. Expanding the ports can be seen as a strategic argument to broaden competitiveness (Dekker and Verhaeghe, 2006: 174). However, over-investment in capacity to expand the port capacity brings about many severe problems by leading excessive capacity. Excess capacity is the sign of the unnecessary capacity supply, which results in extreme competition, offering services to customers with lower prices (Dekker, 2005: 11). Excess capacity affects the price and tariff structure of the port services. When the port overcomes the congestion problem, it may serve more vessels with higher sizes. At the same time, other competing ports may lower their prices to attract more customers. Therefore, the demand level limits the congestion level of the port at this stage. The congestion at the port also affects the demand for other competing ports (Bae, et al. 2013:480-489; Turner et al. 2004: 344).

Both excess capacity and capacity shortage is a prospective reason to profit losses in terms of giving cause for ineffective use of the port's resources (Chang et al. 2012: 242). Thereby capacity, performance, and cost are closely related. Bae et al. (2013:482) explained the relations as:

- The ports capable of servicing an adequate amount of ships can attract more customers if they can overcome the congestion.
- Ports with excess capacity may set lower prices to attract more customers whereas ports with an inadequate capacity may set higher prices to reduce the effect of the congestion. Nevertheless, the port with an insufficient capacity will have to set lower prices to maintain its market share in this case.

CHAPTER THREE

REVIEW OF THE PORT CAPACITY MEASUREMENT EQUATIONS

3.1. THE CAPACITY CALCULATION IN DRY BULK TERMINALS

In this section, all empirical equations used in the terminal capacity measurement in the research streams have been examined. As mentioned in earlier chapters, the port or terminal capacity is measured by determining each component of the terminal (the berth, storage yard, gate, and equipment capacities). The minimum value of these components are regarded as the terminal capacity as a restricted factor. In the current section, the equations employed in measuring dry bulk terminal capacity are reviewed with the aim of determining each factor used for measuring terminal capacity comprehensively and developing the capacity-measuring method for dry bulk terminals in *Chapter IV*.

This section is structured as follows: Measuring equations used in the dry bulk terminal collected under the title of berth handling capacity, storage yard capacity, and equipment capacity. Each measuring equation is explained. Variables used in the measuring dry bulk terminal capacity is assessed in detail in *Section 5.2*. Measuring approaches related to berth handling capacity, storage yard capacity and equipment capacity have been examined within the context of the study. Gate capacity is out of the scope of this study.

3.1.1. Berth Handling Capacity Measurement Approaches in Dry Bulk Terminals

Dry bulk terminal differs from the other terminal types due to material and equipment characteristics. Approaches to the capacity measurement of berth handling capacity of the dry bulk terminals are the same with the general cargo terminals. No certain discrimination has been found in the literature.

In this section, berth handling capacity-measuring methodology is given. Scholars developed several approaches to measure berth handling capacity. Several calculation methods can be found in the literature. This diversities stem from both the

material characteristics, the equipment types and evaluation of the capacity issue with the different viewpoints.

The equation mentioned in the UDHB (2015b: 231) assessed that the maximum handling capacity of a berth as a function of quay and quay cranes:

$$K_y = n_v * t * p_v * \phi_y ; \quad \text{Equation (1)}$$

Where K_y is the maximum handling capacity of berth [ton], n_v is the number of quay crane [-]; t is the number of hours worked in a year [hour]; p_v is the quay crane productivity [ton/hours]; ϕ_y is the berth occupancy rate [-]. In the second equation of UDHB (2015:231), maximum handling capacity of the berth is a function of vessel and quay cranes:

$$K_y = p * GT * \left(\frac{t * \phi_y}{\frac{GT}{n_v * p_v} + t_{m+e}} \right); \quad \text{Equation (2)}$$

Where GT is the average amount of cargo per ship [ton]; t_{m+e} is the time taken by the ship maneuvering and sum of additional time [hour]; p is the peak factor [-]. UDHB (2015:231) assessed the port capacity as a function of the average amount of cargo handled at the berth in the second formula.

UDHB (2015b:231) assessed the terminal capacity in two different ways: Quay-quay crane and vessel-quay crane. Peak factor and the additional time for berthing were regarded in Equation 2.

National Research Council (1998:81) assessed berth handling capacity of the terminal as vessel/apron-apron/vessel transfer capacity. The equation that is evaluated as a function of the number of vessel calls and, the average amount of cargo per vessel is mentioned in the below Equation (3).

$$Q_l = \frac{(A * T)}{365}; \quad T = TU + TL = DWT * L; \quad A = \frac{365}{l}; \quad DWT = (D - 5)^2 ;$$

$$D = MLLW - 1 \text{ for } MLLW \leq CD; \quad D = CD - 1 \text{ for } CD \leq MLLW; \quad \text{Equation (3)}$$

Where Q_1 is the total amount of throughput in the berth per day [ton]; A is the ship calls in a year [-]; T is the average amount of cargo per vessel [ton]. TU is the amount of cargoes unloaded per vessel [ton]; TL is the amount of cargoes loaded per vessel [ton]. I is the average interarrival time [day]; DWT is the maximum size of the vessels arrived; D is the maximum draft of the berths [meter]; MLLW is the average value of the lower water depth [meter]; CD is the depth of the channel [meter]; L is the load factor per vessel ($0.00 \leq L \leq 1.00$) [-].

Another approach of National Research Council (1998:81) that evaluates the vessel/apron-apron/vessel capacity is mentioned in the following equation:

$$Q_2 = \frac{(G_2 * H_2)}{365}; \quad G_2 = N_2 * W_2 * Y_2 * B; \quad B = \frac{O_2}{Y_2}; \quad \text{Equation (4)}$$

Where Q_2 refers to the vessel to apron or apron to vessel transfer capacity [ton/day]; G_2 is the transfer unit hours in a year between vessel and apron or apron and vessel [hour]. H_2 refers transfer rate [tons per hour or per gang]; N_2 indicates how much gang is performed per ship [-]; W_2 shows operational time (working hours) per day [hour]; Y_2 is the operational time in a year (working days per year) [day]; B is the occupancy ratio of berth [-]; O_2 is the total number of days the berth is utilized [day].

KMI (1998) calculated specialized berth handling capacity with the following equation (Park et al. 2014:181):

$$\text{Berth handling capacity} = B * N * C * \sum P_i * E * H * D * O * U; \quad \text{Equation (5)}$$

Where B is the number of berth [-]; N is the number of the quay crane [-]; C is the capability of the crane that performs hourly (nominal recovery*10 turns) [ton/hour]; $\sum P_i$ is the occupancy ratio of the cargo i (in case two or more types of cargo handled in the same berth) [-]; E is the working efficiency of the crane (70%) [%]; H is the working hours in a day (standard value is 16 hours) [hour]; D is the working days in a year (standard value is 300 days) [day]; O is the berth occupancy ratio (from 10%, 50% to 60% as a standard rate depending on number of berth) [-]; U is the utilization factor of machine (standard value is 90%) [%]. In the equation mentioned above, KMI (1998) paid regard to the occupancy ratio of the different

cargoes in addition to berth occupancy ratio. This approach stems from distinguishing specialized berth, and the berth handles more than one cargo.

Park et al. (2014:185) performed a comprehensive evaluation. The study proposed a capacity calculation equation for general cargo berth as:

$$Y=B*(\sum_{i=1}^n \sum_{j=1}^m C_i * V_j * T_{ij}) * D_k * H_k * O_l; \quad \text{Equation (6)}$$

Where Y is the handling capacity of the specified berth [ton]; B is the number of the berth [-]; C_i is the ratio of cargo type handled at each berth [%]; V_j is the ratio of the vessel size arrived in a berth (i.e., ratio of the vessels which less than 5,000 tons are 3.2%) [%]; T_{ij} is the hourly handling capacity concerning the type of cargo and size of vessel (multiplying the number of the gang with the hourly gang capacity) [ton/hour]; D_k is the working days in a year [day]; H_k is the working hours in a day [hour]; O_l is the berth occupancy ratio (40% for one berth, 50% for 2 berths, 55% for 3 berths, 60% for 4 berths, 65% for 5 berths, 70% for 6 or more berths) [-]; i refers to a particular type of cargo [-]; j refers to a particular vessel size [-]; k refers to the handling method (mechanic/non-mechanic) [-]; l refers to the number of berths in which the handling activity is performed [-].

Ligteringen and Velsink (2012:155) submitted another approach to measure general cargo terminal capacity. The equation is as follows:

$$C_b=P*N_{gs}*n_{hy}*m_b \quad \text{Equation (7)}$$

Where C_b is the total amount of cargo per berth [ton/year]; P is the average productivity of gang; N_{gs} is a number of gang per vessel [-]; total operational working hours per year [-]; m_b is the berth occupancy ratio [-]. *Equation (7)* is used when the early level of the terminal planning to perform a rough estimation.

3.1.2. Storage Yard Capacity Measurement Approaches

Existing literature addressed the storage yard capacity of terminals into two perspectives. The first one is the static capacity of the terminal. The static capacity of

the storage yard terminal means storage capability of the terminal in per m². The second one refers to the volumetric storage capability of the storage yard area.

Measuring the dry bulk terminal capacity is possible with the regarding several parameters. Comparing with the other terminal types, measuring or estimating storage yard capacity of the dry bulk terminal shows difference according to the storage policy, stacking types, stockpile form, and the storage types (longitudinal or circular). In this section, several approaches to storage types and amount of cargo that is stacked in the particular stockpile form have been analyzed. When comparing the equations for measuring berth handling capacity of dry bulk terminals, scholars paid more attention to storage yard capacity of the dry bulk terminals. However, many of these equations have been developed for determining the required storage yard capacity in the planning phase of the dry bulk terminals.

Calculation approaches of required storage yard capacity, the storage yard capacity and the stockpile capacity in the extant literature is stated in the following subsections.

3.1.2.1. Measuring Required Storage Yard Capacity of Dry Bulk Terminals

Some of the capacity studies focused on the determination of the required storage yard capacity (Kox, 2014:58; UNCTAD, 1985:223; Vianen et al. 2012:10; Bot 2012:27; van Vianen et al. 2014:122). Measuring required storage yard capacity is performed at the planning stage of the dry bulk terminals. At this stage, the required storage yard capacity, which will satisfy the demand, is measured after the estimation of the cargo amount. For this reason, required storage yard capacity is evaluated as a function of the annual throughput of a terminal in these equations.

Below-mentioned equations indicate that how the required storage yard capacity is estimated.

UNCTAD (1983: 7-8) calculated the required storage area with the following formula;

$$A = \frac{[C - t * r + (n - 1) * (C - (t + x) * r)]}{F}, \quad \text{Equation (8)}$$

Where C is the ship capacity for cargo [ton]; t number of days that handling operations are performed in the berth [day]; F is the stacking characteristics of the port according to cargo type [ton/ha]; r is the arrival and departure rate of vehicles for the land transport [ton/day]; n is the total vessel calls during a year [-]; x is the interarrival time of the vessels [days].

Ligteringen and Velsink (2012:157) calculated the required area for general cargo terminals with the following equations:

$$A_{gr} = \frac{f_{area} * f_{bulk} * N_c * \bar{t}_d}{m_c * h_s * \rho_{cargo} * 365}, \quad \text{Equation (9)}$$

Where N_c is the total cargo amount which is stored at the terminal [ton]; ρ_{cargo} is the average density of the cargoes [ton/m³]; f_{bulk} is the bulking factor caused by stripping and stacking the cargoes separately [-]; f_{area} is the ratio of the net and gross area including traffic lanes; $\bar{t}_d$ is the average dwell time of the cargoes; h_s is the average stockpile height [meter]; m_c is the estimated storage occupancy ratio [-].

Kleinheerenbrink (2012: 66) determined the required storage yard area based on the size of pile lines:

*required storage yard area = width of the stockyard * length of the stockyard; Equation (10)*

$$w_{stockyard} = n_{piles} * (w + s) + s; \quad \text{Equation (11)}$$

Where $w_{stockyard}$ is the width of the storage yard; w is the pile lane width; s is the distance between the two pile lanes.

In addition to the approaches developed for estimating the storage yard capacity of the dry bulk terminals, required storage yard area [m²] should be determined to measure the required storage yard capacity. PIANC (2014) and Kox (2017: 58-60) approached the required storage area capacity hereinbelow.

PIANC (2014) calculated the needed gross storage area with the following equation (Kox, 2014:58):

$$A_{gr,i} = \frac{C_i * \bar{t}_d * f_{area}}{\bar{\rho}_c * h_s * 365 * m_s}; \quad \text{Equation (12)}$$

Where $A_{gr,i}$ is the needed gross storage area for each cargo type [m^2] (including roads, the area occupied by the equipment, infrastructure, and superstructure); C_i is the total amount of cargo handled in a year considering cargo type [ton/year], $\bar{t}_d$ is the average dwell time of the cargo [days]; f_{area} is the ratio of gross and net storage area; $\bar{\rho}_c$ is the mean number of specific bulk density of the cargoes [ton/m^3]; $\bar{h}_s$ is the mean number of stacking height [m]; m_s is estimated storage occupancy ratio (the ratio is calculated by the dividing average stack of the cargo in the stockpile to design capacity of the stockpile) [-].

Kox (2017: 58) also transformed the Equation (12) into the below-stated formula to measure the required storage volume in the cubic base:

$$V_{storage, i} = \frac{C_i * \bar{t}_d}{\bar{\rho}_c * 365 * m_s}; \quad \text{Equation (13)}$$

Where $V_{storage, i}$ is the required storage volume per specific cargo type [m^3], C_i is the amount of the cargo handled in a year by cargo type [ton/year]; $\bar{t}_d$ is the average dwell time of the specific cargo in the stockpile [days]; $\bar{\rho}_c$ is the mean number of specific bulk density of the cargoes [ton/m^3]; m_s is estimated storage occupancy ratio (the ratio is calculated by the dividing average stack of the cargo in the stockpile to design capacity of the stockpile) [-].

Kox (2017: 59) utilized the following equation for calculating the needed gross storage area according to cargo types:

$$A_{gr,i} = n_{lanes} * l_{lane} * w_{lane} * f_{area}; \quad \text{Equation (14)}$$

Where $A_{gr,i}$ is the needed gross storage area per cargo type [m^2]; n_{lanes} is the total number of lanes; l_{lane} is the needed lane length [m]; w_{lane} is the needed lane width [m]; f_{area} is the gross and net storage area ratio. Moreover, Kox (2017:60) proposed an equation to calculate the gross required total terminal area regarding further areas such as administrative buildings, terminal infrastructure, and superstructure:

$$A_t = \frac{\sum A_{gr,i}}{a}; \quad \text{Equation (15)}$$

Where A_t is the total storage area in m^2 required for the terminal (along with the area occupied by the stockpiles, infrastructure and superstructure of the terminal; $A_{gr,i}$ is the gross needed area [m^2]; a is the total terminal factor that refers to percentage of gross storage area (including the roads within the stockpile) according to the total area of terminal [-].

3.1.2.2. Measuring Storage Yard Capacity of Dry Bulk Terminal

In this section, the equations in the existing literature have been examined. Limited study has been found in the literature to be used for estimating the storage yard capacity of the dry bulk terminals.

National Research Council (1998:81) explained the functional relationship of storage yard capacity of the terminals by using the below-mentioned equation:

$$\begin{aligned}
 Q4 &= \frac{QY}{365} \\
 QY &= \frac{HC * 365}{TA}; \\
 HC &= \frac{GH * SF}{2000}; \\
 GH &= NH * (1 + SB); \\
 NH &= AA * AH; \\
 AA &= AS * SP; \\
 AS &= TS * (1 - DS);
 \end{aligned}
 \tag{Equation (16)}$$

Where $Q4$ is the average cargo amount handled in storage yard [ton]; QY is the annual cargo throughput handled in the storage yard [ton]. HC is the handling capacity of cargo [ton]; TA is the average dwell time in the storage yard [day]; GH is gross holding volume; SF is the stowage factor of the specific cargo; NH is the net holding volume of the cargo; SB broken stowage factor (unused spaces); AA is the mean of stacking area; AH is the mean number of stacking height; AS is the standard storage area (regular); SP is the percentage of the total storage area which is utilized for stacking; TS is the entire storage area; DS is the safety factor for demand fluctuations.

National Research Council (1998:81) approached the storage yard capacity of the dry bulk terminal as the function of annual throughput achieved by the terminal.

Salminen (2013:32-33). developed another approach. The study assessed the dry bulk and the general cargo terminal capacity in the same equation considering both static and dynamic capacity of the terminal. Moreover, the study of the Salminen (2013:32-33) measured both storage yard and warehouse capacity of dry bulk-general cargo terminals based on theoric and actual capacities. For dry bulk yard capacity, the study presented a series of equations as:

$$ST_{DBY}(mass) = \frac{s_{DBY}}{d_{DBY}}; \quad s_{DBY} = \frac{r_{DBY}}{\frac{o_{DBY} - m_{DBY}}{t_{DBY}}}; \quad \text{Equation (17)}$$

$$ST_{DBY}(volume) = d_{DBY} * h_{DBY}; \quad \text{Equation (18)}$$

$$SA_{DBY} = ST_{DBY} * u_{DBY}; \quad \text{Equation (19)}$$

$$DT_{DBY}(mass) = s_{DBY} * \frac{\frac{o_{DBY} - m_{DBY}}{t_{DBY}}}{d_{DBY}}; \quad \text{Equation (20)}$$

$$DT_{DBY}(volume) = ST_{DBY} * \frac{t_{DBY}}{o_{DBY} - m_{DBY}}; \quad \text{Equation (21)}$$

$$DA_{DBY} = DT_{DBY} * u_{DBY}; \quad \text{Equation (22)}$$

Where ST_{DBY} is the theoric capacity (static); SA_{DBY} is the actual capacity of the dry bulk terminal (static); DT_{DBY} is the theoric capacity of the dry bulk terminal (dynamic); d_{DBY} is the determined area for the terminal yard; h_{DBY} is the stacking implementations in the terminal; o_{DBY} is the working days; m_{DBY} is the nonworking days; r_{DBY} is the annual throughput; s_{DBY} is the size of bulk commodities; t_{DBY} is the average idle time of dry bulk commodities; u_{DBY} is the utilization lower limits.

In addition to storage yard capacity regarding the mass and volume, dry bulk warehouse capacity as called by the Salminen (2013:33-34) estimated with the following equations (Salminen, 2013: 33-34):

$$ST_{DBWH}(mass) = \frac{c_{DBWH}}{s_{DBWH}}; \quad (\text{The equation can be equals to } c_{DBWH}) \quad \text{Equation (23)}$$

$$ST_{DBWH}(volume) = d_{DBWH} * s_{DBWH}; \quad \text{Equation (24)}$$

$$SA_{DBWH} = ST_{DBWH} * u_{DBWH}; \quad \text{Equation (25)}$$

$$DT_{DBWH}(mass) = \frac{ST_{DBWH} * o_{DBWH}}{t_{DBWH}}; \quad \text{Equation (26)}$$

$$DT_{DBWH}(\text{volume}) = \frac{ST_{DBWH}}{\frac{t_{DBWH}}{o_{DBWH}}}; \quad \text{Equation (27)}$$

$$DA_{DBWH}(\text{mass}) = SA_{DBWH} * \frac{o_{DBWH}}{t_{DBWH}}; \quad \text{Equation (28)}$$

$$DA_{DBWH}(\text{volume}) = DT_{DBWH} * u_{DBWH} \quad \text{Equation (29)}$$

Where ST_{DBWH} is the theoric capacity of dry bulk terminal warehouse (static); SA_{DBWH} is the actual capacity of the terminal warehouse (static); DT_{DBWH} is the theoric capacity of terminal warehouse (dynamic); DA_{DBWH} is the actual capacity of the terminal warehouse; c_{DBWH} is the size of the bulk commodities stored in the terminal warehouse (i.e., maximum acceptable mass of bulk commodities); d_{DBWH} determined area for terminal warehouse; o_{DBWH} is the working days in a year; s_{DBWH} is the stacking implementations; t_{DBWH} is the average aligning time of the commodities at the terminal; u_{DBWH} is the utilization of lower limits for the dry bulk terminal warehouse.

UDHB (2015:235) used the below-mentioned equation when calculating the storage yard capacity of the dry bulk and general cargo terminals:

$$K_D = \frac{365}{t_k} * A_d * h_d * p * a * h * \gamma; \quad \text{Equation (30)}$$

Where K_D is the annual storage capacity of the dry bulk or general cargo terminals [ton]; t_k is the average dwell time of the cargo at the terminal [day]; A_d is the storage yard area [m² or ha] h_d is the average storage occupancy factor (0.50-0.80)[-]; p is the occupancy reduction coefficient (0.80-0.85) [-]; a is the net storage coefficient (0.55-0.85) [-]; h is the stacking height [-]; γ is the specific bulk density of the cargo [ton/m³].

3.1.2.3. Measuring Stacking Capacity of the Stockpiles

Apart from measuring the storage capacity of the dry bulk terminal area, stockpile design and layout are important factors to achieve maximum storage efficiency from the total terminal area. When estimating the storage yard capacity of a dry bulk terminal, these factors should be taken into consideration. Several studies (Kox, 2017:59), van Vianen et al. 2014:21; UNCTAD, 1985:189; Bot, 2012:27-28)

accounted the stockpile design to measure the mass of cargo stored at the dry bulk terminals.

UNCTAD (1985:223) considered that the dry bulk terminals mostly utilized the trapezoidal shape stockpiles. When calculating the stockpile capacity, UNCTAD (1985: 223) assessed trapezoidal stockpile dimension with the following formula:

$$h_{max}=0.5*b*\tan (\alpha)$$

$$A_{max}=0.5*b*h_{max}= 0.25*b^2 *\tan (\alpha)$$

$$A= r/h_{max} *(0.2)= r/h_{max} * A_{max}$$

Below-mentioned formula is obtained:

$$A=(b-h \cot (\alpha))h; \text{ or } A=(b-rh_{max}\cot (\alpha))rh_{max};$$

$$A= (b-r(0.5 b \tan (\alpha)) \cot (\alpha))rh_{max};$$

$$A_{max}=0.5bh_{max} \quad \text{Thus;}$$

$$A=r (2-r)$$

$$\text{Volume}=A*\text{length}$$

Equation (31)

$$\text{Capacity in tons}=\frac{\text{volume}}{\text{Stowage Factor}}$$

Equation (32)

Where α is the angle of repose; h is the stockpile height; b is the base of stockpile; h_{max} is the maximum stockpile height; r is the stockpile height and maximum height ratio; A is the stockpile cross-sectional area; A_{max} is maximum cross sectional area of stockpile.

Moreover van Vianen et al. (2012:10) transformed the UNCTAD (1985:181) equation into the following equation:

$$m=\left[\frac{h}{h_{max}}\left(2-\frac{h}{h_{max}}\right)\left(\frac{l}{4}w^2\tan\alpha\right)l\rho\right]; \quad h_{max}=\frac{w\tan(\alpha)}{2}$$

Equation (33)

Where m is the stockpile mass; h is the stockpile height; h_{max} is the maximum stockpile height; w is the stockpile width; α angle of repose; l is the stockpile length; ρ is the specific bulk density.

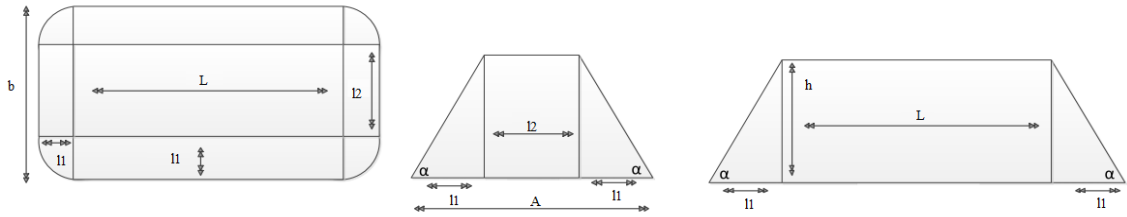
Kox (2017: 60) developed an approach to specifying the required stockpile volume for the particular material:

$$V_{sp,i} = \frac{C_i * r_c}{\bar{\rho}_c}; \quad \text{Equation (34)}$$

Where the $V_{sp,i}$ is the needed storage volume of the stockpile according to commodity type [m^3]; C_i is the annual throughput [ton]; r_c is the capacity ratio which shows the percentage of the total amount of cargo handled in a year that should be stored at the terminal at a given time [-]; $\bar{\rho}_c$ is the average specific bulk density [ton/m^3].

Then, Bot (2012:27) modified UNCTAD (1985:223) equation to calculate the stockpile length. Schematic representation of the components of the equation used for determining the stockpile length is indicated in Figure 21.

Figure 21: View of an End Coned Trapezoid Stockpile from Top-Front-Side



Source: Bot, 2012:27

$$Length_{stockpile} = \frac{Mass.Stowage\ Factor - \frac{\pi * l_1^2 * h}{3} - l_1 * l_2 * h}{(l_1 + l_2)h} * 2l_1; \quad \text{Equation (35)}$$

$$l_1 = \frac{h}{\tan(\alpha)} \quad \text{And} \quad l_2 = b - \frac{2h}{\tan(\alpha)};$$

Where b is the base of the stockpile ($2l_1 + l_2$) [meter]; α is the angle of repose of the stockpile of specific bulk commodity [$^\circ$]; h is the height [meter]; l_1 is the base of right triangle part of the trapezoid [meter]; l_2 is the distance between the two right triangle part [meter].

Kox, (2017:59) determined the number of the lane that stockpiles are positioned with the following equation:

$$l_{lane} = \frac{V_{storage}}{\left[\frac{h_{pile}}{h_{pile,max}} * \left(2 - \frac{h_{pile}}{h_{pile,max}} \right) * \left(\frac{l}{4} w_{lane}^2 * \tan \theta \right) \right] * n_{lanes}}; \quad \text{Equation (36)}$$

Where l_{lane} required length of stockpile [meter]; $V_{storage}$ is the total required storage volume [m³]; h_{pile} is the stockpile height [meter]; w_{lane} is the stockpile width [meter]; θ angle of repose [°]; n_{lanes} is number of stockpile lane [meter]; $h_{pile,max}$ is the maximum height of stockpile can reach ($= \frac{l}{2} w_{lane} * \tan \theta$) [meter].

In addition to the trapezoidal shape of the stockpile, van Vianen et al. (2012:10), van Vianen et al. (2014:122) regarded the end cones to their equation to measure stockpile mass considering the shear effect of bulk commodities. The study stated that trapezoidal shape with end cones is commonly used in practice rather than the trapezoidal stockpiles. The equation is stated as follows:

$$m = h l \rho \left(w - \frac{h}{\tan(\alpha)} \right) + \frac{l}{3} \rho \Pi \left(\frac{h^3}{\tan^2(\alpha)} \right) + \rho h \left(w - \frac{2h}{\tan(\alpha)} \right) \frac{h}{\tan(\alpha)}; \quad \text{Equation (37)}$$

Where m is the stockpile mass [ton]; h is the stockpile height [meter]; l is the stockpile length (trapezoidal part) [meter]; ρ is the specific bulk density [ton/m³]; w is the stockpile width [meter]; α is the angle of repose of bulk commodity [°].

Ligteringen and Velsink (2012: 218) calculated the stockpile capacity in cross-section triangular pile form by using the below-mentioned equation:

$$V = b * \frac{l}{2} * h * m_b; \quad \text{Equation (38)}$$

Where V is the maximum volume of the cargo in the storage yard [m³]; b is the stockpile width [meter]; h is the stockpile height [meter]; l is the sum of stockpile length [meter]; m_b is the utilization rate of the stockpile [-].

3.1.3. Equipment Capacity Measurement Approaches

In this section, the capacity measuring formulas of the equipment used in the dry bulk terminals are examined. Although many equipment is used for the unloading and loading operations at the dry bulk terminal, many of this equipment have similar parts and similar working principles. For this reason, only fundamental calculation principles of belt conveyor, screw conveyor, and reclaimer considered to the evaluation of the equipment capacity. There is no study on the mobile harbour cranes or modelling of mobile harbour crane motion in the existing body of the literature. For this reason, the equation on an average number of gang per vessel (if the port does not provide the total number of gang performed within a specific period) and the amount of cargo (ton basis) per gang have been attempted to develop a formula in *Chapter IV, Section 4.2.1.3*.

3.1.3.1. Belt Conveyor Capacity

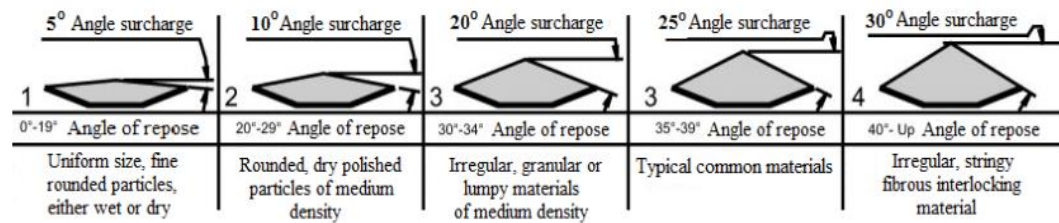
As mentioned in the earlier sections, several types of belt conveyors can be found in practice (T shape, U shape, Flatted, etc.). The shape of the belt conveyors based on the idler drums laid under the belt.

Belt capacity is the function of the belt width, the speed of the belts, specific bulk density of the materials, the troughing angle, surcharge angle and the angle of repose, capacity factor, idler configuration and inclination angle (Tsakalakis and Michalakopoulos, 2015:2; Scholtz, 2017: 966; Fenner Dunlop, 2009).

Apart from the factors which determine the belt conveyor carrying capacity such as belt width, belt speed, specific bulk density and angle of repose, some other important factors (surcharge angle, inclination angle, troughing angle and idler configuration should be specified clearly. The angle of surcharge is crucial in calculating the cross-sectional area. The angle of surcharge is defined as the dynamic angle of repose. When materials loaded onto the belt surface, the material is agitated with the movement of the belts. With the crossing over the carrying idler, the surface of the materials is inclined to flatten the slope of the surface. This angle is less than

the angle of repose, and in practice, the range of the troughed conveyor belt conveyor angles are 0°, 20°, 35°, and 45° (Schultz, 1985: 969).

Figure 22: Different Angle of Surcharge Values according to Material Characteristics



Source: CEMA; Tsakalakis and Michalakopoulos, 2015:2

The inclination angle is another important factor which determines the belt conveyor capacity. Belt conveyor does not always establish the 0° angle. According to the configuration, belt conveyor moves the inclination. The cross-sectional area of the inclined load is less than the horizontal cross-sectional area of the load. A rough estimation of the inclined load capacity of the belt conveyor can be calculated as multiplying the horizontal load capacity by the cosine of the angle of inclination ($\cos\theta$). Troughing angle is the angle of idler rollers' position according to a horizontal plane. Idler configuration refers to several idlers used in the belt configuration. Generally, belt configurations are flatted, three idler rollers or five idler rollers in practice. However, three equal rolls are mostly used (Fenner Dunlop, 2009: 19).

The most important parameter for calculating the conveyor belt carrying capacity is the cross-sectional area. Despite its complexity, several approaches have been developed to measure the cross-sectional area of the material loaded onto the belt. The cross-sectional area of the material loaded onto the belt that is perpendicular to the belt surface is the crucial factor determining the belt conveyor capacity. The value depends on the characteristics of the material, belt width, and the idler configuration (Woodcock and Mason, 1987: 277). The most critical parameters, which are used to calculate, cross-sectional area troughing angle, the angle of repose, and the angle of the surcharge. The angle specifications of the materials are shown in **Appendix I**.

Several studies developed calculation approaches to belt conveyor capacity (Schultz, 1985: 969; Woodcock and Mason, 1987: 277; Fruchtbaum (1988: 23); Fenner Dunlop, 2009:20). Calculation approaches of the belt conveyor capacity in the literature are reviewed and stated as follows.

$$TPH = \frac{A * BD * S}{4800}; \quad \text{Equation (39)}$$

Woodcock and Mason, 1987: 277 expressed the flat belt conveyor capacity as follows:

$$\begin{aligned} \dot{m}_s &= \rho_b k_s A v \\ A &= \frac{1}{6} b^2 \tan \delta; \text{ Then,} \\ \dot{m}_s &= \frac{1}{6} \rho_b v b^2 \tan \delta; \end{aligned} \quad \text{Equation (40)}$$

Where $\dot{m}_s$ is the belt conveyor carrying capacity [ton/s]; ρ_b is the specific bulk density [ton/m³]; A is the average cross-sectional area of the material shape (the shape is perpendicular to the belt surface) [m²]; v is the speed of the belt [m/s]; k_s is the slope factor [-]; b is the width of the flow of the load placed onto the belt (contact perimeter) [m]; δ is the surcharge angle [°].

However, not all the belt conveyors only designed as a flat, but also two or three troughing idler belts are widely used in practice. Calculation of the cross-sectional area of the material loaded onto the belt can be measured as follows (Woodcock and Mason, 1987: 279).

$$A = Ub^2$$

$$\dot{m}_s = \rho_b k_s Ub^2 v \quad \text{Equation (41)}$$

Where b is the contact perimeter of the materials and U is the shape factor. Although U can be clearly expressed as $(\frac{\tan \delta}{6})$, for two, three or five troughing belts, it can be taken advantage from the conversion table to determine the shape factor.

Fruchtbaum (1988: 23) evaluated the belt conveyor carrying capacity for the three rolling idler as follows:

$$e = 0.055E + 0.9(*)$$

$$\text{Area of surcharge} = F * E^2$$

$$\text{Total Area } A_r = A_s + FE^2$$

$$\text{Total capacity in ton} = \frac{A_r w v}{2000}, \quad \text{Equation (42)}$$

(*) Empirical value differs according to the model of the belt conveyor.

Where e is the edge distance [in], E is the bottom length of the belt [in]; F is the surcharge factor required for calculating the cross-sectional area of the surcharge; w is the specific bulk density [lb/ft³]; v is the speed of the belt [fpm]; A_r is the cross-sectional area; A_s is the cross-sectional area of the surcharged part of the shape.

Fenner Dunlop (2009:20) used the below-mentioned formula to calculate belt conveyor carrying capacity:

Capacity=3.6*Load Cross Section Area [m²]*Belt Speed [m/s]* Material Density [kg/m³]

The load cross-section area differs according to the roll idler configuration. For the three or five roll idler configuration below mentioned formula could be used to calculate the carrying capacity of the belt conveyor in ton per hour (tph) (Fenner Dunlop, 2009:20):

Capacity (tph)= Capacity (According to the belt width and belt speed) Material Density (kg/m³)* Capacity Factor*Belt Speed(m/s)/1000 (three idlers)* **Equation (43)**

Capacity (tph)= Capacity (According to the belt width and surcharge angle) Material Density* Belt Speed/1000 (five idler)* **Equation (44)**

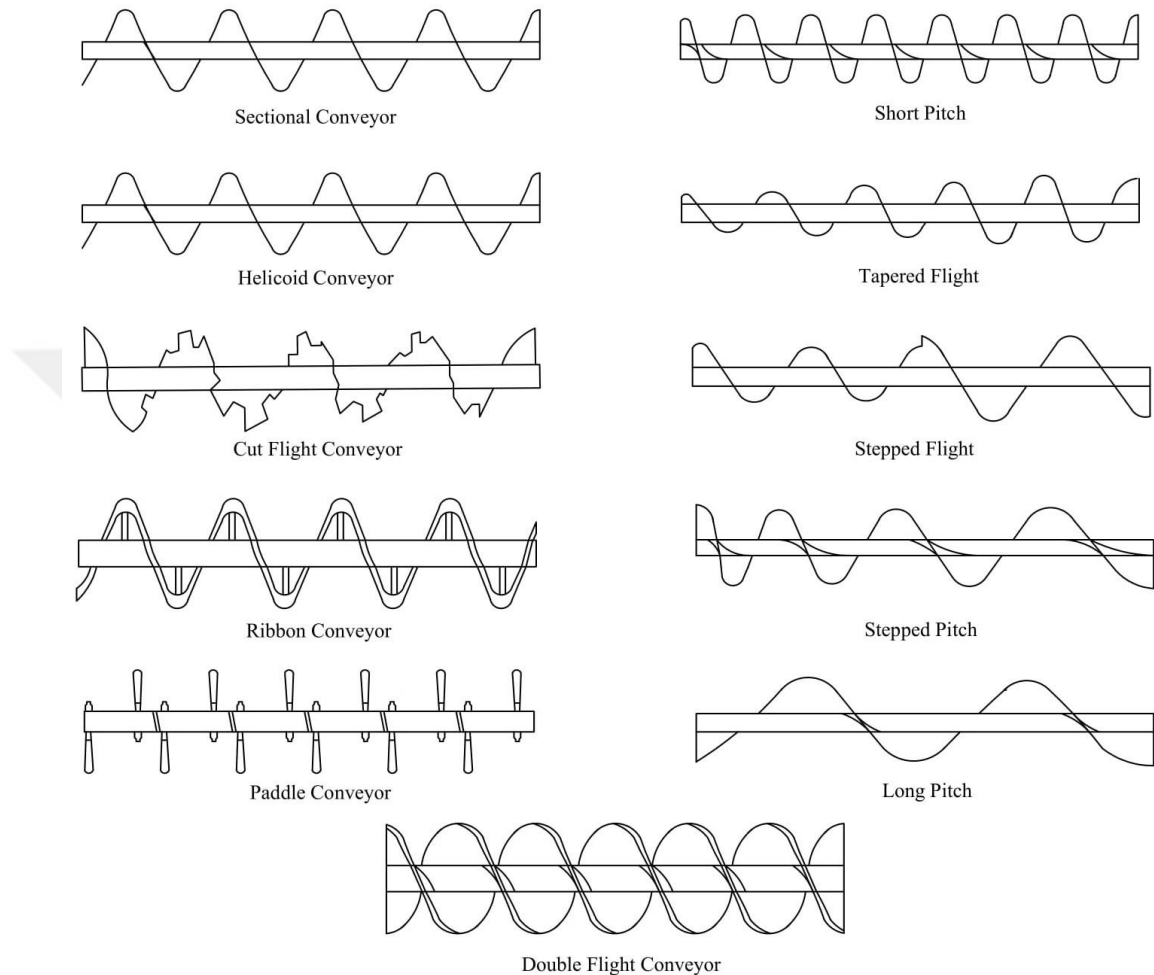
In general sense, the equipment producers provide the capacity factor and capacity according to the cross-sectional area in the equipment manual. The capacity factors and the capacity according to the cross-sectional area are presented in **Appendix II**.

3.1.3.2.Screw Conveyor/Unloader Capacity

As mentioned in the Chapter I section 1.2.1.4., screw conveyors are commonly used equipment in the dry bulk terminals. The crucial parameters for calculating the screw conveyor capacity are the diameter of the screw, the diameter of the outer frame, specific bulk density, material factor, nature of the material (flowability, size, abrasiveness miscellaneous or hazards) (See **Appendix III**), percentage of the filling (trough loading), screw pitch, speed of the revs, types of the conveyor (sectional, helicoid, cut flight, ribbon, and paddle) and the type of the pitch (standard pitch, variable pitch, short pitch, tapered flight, stepped flight, stepped pitch) (Fruchtbaum, 1988:141; Woodcock and Mason, 1987:344; Hinterlong and Sinden, 1985:1033;

KWS, 04.01.2016). Several types of conveyors and the pitches are illustrated in Figure 24.

Figure 24: Types of the Screw Conveyor and Pitches



Source: Fruchtbaum, 1988:141

Screw conveyors contain several parts and consist of pipe, helix (flight), flight mounting, etc. (Bucklin et al. 2013: 154; Hinterlong and Sinden, 1985:1035). Helix means flight of the screw. Besides the distance between two helixes is denominated as the pitch (Bucklin et al. 2013: 154). Flights of the screw conveyors can be produced either helicoid or sectional. Helicoid flights are produced by rolling the straight frame or lane thro rod into the running helix. Besides sectional flights are produced from a straight disc (Hinterlong and Sinden, 1985: 1035). U shape or tube shape implementations of the screw conveyor can be found in practice. The coverage

of the screws may be composed of the cylinder for tube coverage or trough for U shape of screw conveyors (Bucklin et al. 2013: 154-155).

The usage of U shape conveyors or enclosed conveyors can differ according to intended purposes and its flexibility. For example, U shape conveyors are the most flexible choice for horizontal transport within the perspective of the easy of the maintenance and economical reasons. However, it cannot be applicable for the inclination angle greater than the 20° (Powder Bulk Solids, 21.02.2017).

Trough-loading refers to the percentage of the loading of the pitch. Trough loading factor is crucial for the screw conveyor size. It is highly recommended that the trough loading of the abrasive materials should be kept a minimum filling percentage, whereas nonabrasive materials may be kept higher levels of trough filling (KWS, 04.01.2016). Several trough-filling configurations and particular materials in accordance with the filling rates are shown in Table 9:

Table 9: Through Filling Configurations with regard to Material Characteristics

Material Characteristics				Trough Filling Rate [%]	Schematic Illustration
Density [lbs/ft ³]	Material Type	Abrasiveness*	Flowability**		
50-120	Alumina, glass cullet, potash	Extremely	Hard	15	
15-60	Carbon black, spent brewer grain, fish meal,	Mildly	Free-flowing	30A	
30-80	Flue dust, crushed bauxite, cement clinker	Very	Average	30B	
5-40	Baking soda, alfalfa, hulled rice	Non	Very	45	

Source: KWS, 04.01.2016

*Abrasiveness: Mildly: 1-17; Moderately: 18-67; Extremely: 66-416

** Flowability: Very Free Flowing-Flow Function>10; Free Flowing-Flow Function>4 but<10; Average Flowability-Flow Function>2 but<4; Sluggish-Flow Function<2 (FMC Technologies (2009:25-34)

The inclination of the screw conveyor is also essential in terms of the horsepower and the capacity. The angle of inclination is essential for equipment to be called vertically. In some resources, the inclination angle should be greater than

20° (Woodcock and Mason, 1987; 354) while other sources accept screw conveyor as vertical with upper than 35° inclination angle (Fruchtbaum, 1988: 154) or 70°-90° (Fayed and Skocir, 1997) or 45° (Powder Bulk Solid, 04.04.2019). The capacity of the screw conveyors decreases with increasing inclination angle. According to Fayed and Skocir (1997), the screw conveyor losses efficiency between the 20% and 50%. According to Bucklin et al. (2013: 154-155), the gradient changes in capacity efficiency of the screw conveyors are illustrated in Table 10:

Table 10: Rate Changes of the Screw Conveyors with regard to Inclination Angle

Inclination Angle [°]	The rate of Change of Capacity [%]	Reference
10-20	10-40	Powder Bulk Solids, 21.02.2017; KWS, 04.01.2016
15	30	Bucklin et al., 2013: 155-154
15	25	Kase Conveyor, 03.04.2019
25	55	Bucklin et al., 2013: 155-154
25	50	Tomaskova and Sinay, 2014: 228; Kase Conveyor, 03.04.2019
30	10-70	Powder Bulk Solids, 21.02.2017; KWS, 04.01.2016
45	30-90	Powder Bulk Solids, 21.02.2017; KWS, 04.01.2016

Source: Compiled from several sources

Apart from the inclination angle, the other capacity factors such as mixing peddle, type of flight, the shape of the coverage (U or cylinder) also affect the mass throughput of the equipment. For this reason, when calculating the screw conveyor capacity, the equipment capacity tables should be used similar to capacity calculations of belt conveyors.

Various calculation approaches can be found in the existing literature. The calculation approaches are examined as noted below.

Hinterlong and Sinden (1985), CEMA, 2003: 19-45 and Wable and Kurkute (2015: 293) and determined the capacity of the screw conveyors with the following equation:

$$\frac{C}{rpm} = \frac{0.7458 (D_s^2 - D_p^2) P K 60}{1728} \quad \text{Equation (45)}$$

Where C denotes the capacity [ft^3/hr]; rpm is the revs of the screw per minute [revs/min]; D_s is the screw diameter [in]; D_p is the diameter of the tube [in]; P is the distance between the pitches [in]; K is the percentage of the referenced trough loading [%, e.g., 0.45, etc.]

Woodcock and Mason (1987:340) attempted to calculate enclosed screw conveyor speed with the following formula:

$$\dot{V}_s = \frac{\pi}{4} (D_c^2 - D_{sh}^2) (\lambda - t_s) N; \quad \text{Equation (46)}$$

Where D_c is the diameter of the screw; D_{sh} is the diameter of the outside of the conveyor which the screw is embedded; λ is the screw pitch, t_s is the thickness of a screw, N is the speed of revolution [revs/s]. Moreover, the research of Woodcock and Mason (1987: 346) stated the velocity of the screw conveyor; then the calculated the volumetric throughput of the U shape screw conveyor equipment as:

$$U = \lambda N;$$

$$\dot{V}_s = A_b \lambda N;$$

Moreover, mass flow rate of the screw conveyor can be calculated finally by using Equation (47):

$$\dot{m}_s = \rho_b A_b \lambda N; \quad \text{Equation (47)}$$

Where U is the average speed of the screw, λ is the screw pitch (the distance between the two flights); N is the speed of the revolution; V_s is the volumetric throughput of the equipment; m_s is the mass flow rate of the equipment; A_b is the cross-sectional area of the material which is moving between the two flights; ρ_b is the specific bulk density of the material. When including the cross sectional area into the formula of the mass flow rate, below-stated equation can be obtained:

$$\dot{m}_s = \rho_b \frac{1}{4} \Pi (D_c^2 - D_{sh}^2) k \lambda N \quad \text{Equation (48)}$$

Where k is the filling factor [%]. The further specific type of screw conveyor can be used in practice. It also has an effect on the screw conveyor capacity. If the special type of the flight and the mixing paddles positioned into the flights are considered for the capacity of the screw conveyors, Equation (48) then becomes as follows:

$$\dot{m}_s = \rho_b \frac{1}{4} \Pi (D_c^2 - D_{sh}^2) \frac{k \lambda N}{CF_f CF_m}; \quad \text{Equation (49)}$$

Where CF_f is the factor of particular types of flight; CF_m is the factor of the mixing paddles positioned into the flights. For the standard screw conveyor type, the value of CF_f should be taken as 1.

Bates (2008: 206) measured the effective screw conveyor capacity with the following equation:

$$\text{Effective conveyed volume per revs} = 0.45 * 3.142 / 4 (D^2 - K^2) P \quad \text{Equation (50)}$$

Where K is the outer screw diameter (d or $D * \tan * \phi_w$), P is the flight; d is the shaft diameter, ϕ_w denotes the side friction of the bulk commodities on the flight surface.

Bucklin et al. (2013: 155) calculated the theoretical capacity of screw conveyor considering filling factor 100% with the following equation.

$$C_{cap} = \frac{(D^2 - d^2) P N}{36.6}; \quad \text{Equation (51)}$$

Where C_{cap} refers to the volumetric capacity of the screw conveyor (filling factor 1.0) [ft³/h]; D is the screw diameter [in]; d is the shaft diameter [in]; P refers to pitch (the value is the generally equals to D); N is the revs per minute.

Vav (24.02.2019) calculated the screw conveyor capacity as follows:

$$Q = \frac{3.14 * D^2}{4} * s * n * sg * i * 60 \quad \text{Equation (52)}$$

$$V = \frac{\text{Screw Diameter} * 3.14 * \text{Rotations Per Minute}}{60}; \quad \text{Equation (53)}$$

Where Q is the capacity of the equipment [kg/h]; D is the diameter of the screw [dm]; s is the pitch [dm]; n is the number of revs [revs/min]; sg is the specific bulk density [g]; i is the trough filling factor [-], and V is the speed of the screw conveyor [m/s].

According to German DIN 15262 (Minkin et al. 2017:88), screw conveyor equipment capacity is calculated as follows:

$$l_m = d_s^2 \frac{\pi}{4} v_F \rho_b; \quad \text{Equation (54)}$$

$$v_s = n_s * l_{st};$$

Where l_m is the mass of throughput [t/h]; d_s is the outer diameter of the screw [m]; v_F is the velocity of conveying [m/s]; ρ_b is the specific bulk density of the material [kg/m³]; v_s is the ideal speed of the conveying [m/s]; n_s refers to revs speed of the screw [rps, rpm]; l_{st} is the pitch [m].

Bolat and Boğuşoğlu (2012:2) and Tomaskova and Sinay (2014: 228) mathematically expressed the approximate efficiency of the related equipment as:

$$Q = \frac{\pi}{4} * (D^2 - d^2) * S * n * \rho * \psi * k; \quad \text{Equation (55)}$$

Where Q is the mass of throughput [m³/s]; D is the diameter of the screw [m]; d is the shaft diameter [m]; S is the pitch of screw [m]; n is the speed of revs [rpm]; ρ is the specific bulk density; ψ is the filling factor of the screw conveyor [%]; k is the incline factor [-]. k or C (capacity factor termed in the Tomaskova and Sinay (2014:228) as “ C ”) used only the inclination occurred. In the horizontal screw conveyor, the factor may not be used.

3.1.3.3.Pneumatic Conveyor System Capacity

Several flow modes can be found in practice. These are dilute phase (positive pressure, negative pressure or vacuum and negative-positive combination), and dense phase (Bhaita, 05.04.2019; Woodcock and Mason, 1987: 386; Mills, 2004:5; Pan, 1999:157)

Dilute phase flow mode is commonly used for transferring the materials. In the dilute phase conveying method, high mass of flow is achieved based on the material characteristics and the air velocity of the conveying with a high flow speed and low pressure while the materials are suspended in the air (Bhaita, 1986: 18; Woodcock and Mason, 1987: 386; Fruchtbaum, 1988:429; Mills, 2004:5). However, this system conveys a high amount of air and a small amount of particles. Due to achieving the high velocities, dilute phase implementations needs a higher power to perform the flow (Bhaita, 1986: 18), and running costs are much higher than the mechanical conveyors (Woodcock and Mason, 1987:392).

In the dense-phase, the system needs to fewer velocities and enables cleaning performance more efficiently. Fluidized dense-phase flow mode is an option that is more suitable when there are long distance implementations to minimise airflow, power, and speed of the transport. However, for materials, which are not suitable for the fluidized dense-phase, flow, dilute-phase or by-pass can be seen as another choice (Wypych, 1999: 284:285). Manufacturers and designers heavily tend to use of dense-phase pneumatic conveying systems in terms of lower air consumption. Thus, the running costs can be decreased (Woodcock and Mason, 1987: 393; Fruchtbaum, 1988: 434).

The capacity measuring of the pneumatic systems is more complicated comparing to other equipment types. The factors determining the conveying capacity of a pneumatic system are material characteristics, air flow rate, material flow rate, mass flow rate ratio, diameter of the pipe, and velocity (Wypych, 1999:283; Pan, 1999:158-159; Raj P et al. 2017: 248-250; Mills, 2004: 5-13)

However, the most important efforts to calculate the pneumatic conveyor is to the determination of the velocity of the particles and the air flow within the pipe. Scholars mostly attempted to calculate the velocity of the airflow and solid flow. The

most implicit approach to calculation of pneumatic conveying capacity was found in the Raj P (2017). The equation employed in the study stated as follows:

$$\dot{m} = \phi * \rho * A * v; \quad \text{Equation (56)}$$

$$\phi = \frac{\dot{m}_{\text{powder}}}{3.6 \dot{m}_{\text{air}}};$$

Where $\dot{m}$ is the mass flow rate of the material; ρ is the mixture density; A is the cross-sectional area of the pipe; v is the velocity; ϕ is the solid loading ratio (the ratio of material mass flow rate and air flow rate; $\dot{m}_{\text{powder}}$ and $\dot{m}_{\text{air}}$ is the mass flow rate of the material and mass flow rate of the air, respectively.

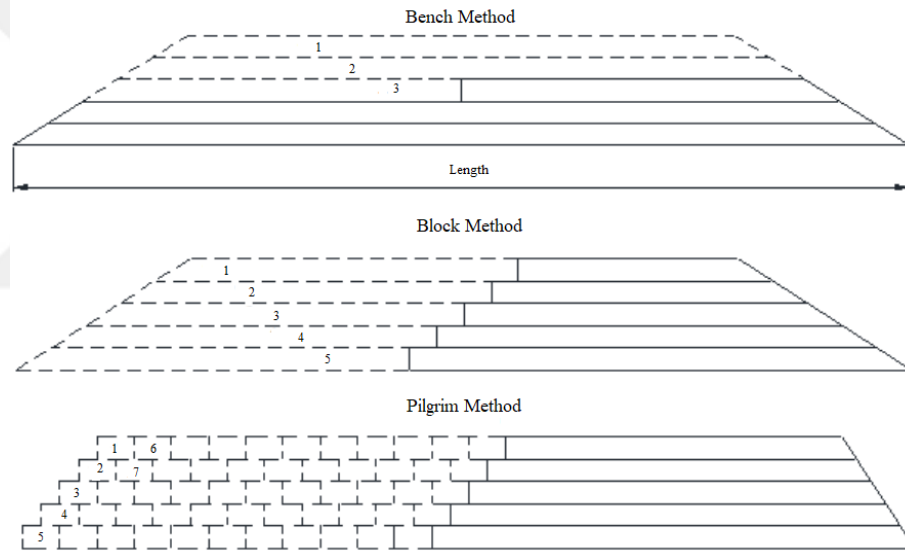
3.1.3.4. Reclaimer Capacity

Stacker reclaimer is commonly used at the dry bulk terminals, which handle the coal. Stackers are equipped with the belts, and the belt conveyor capacity has been examined in *Section 3.1.3.1.* in detail. For this reason, only the reclaimer capacity is examined in this section.

The effective capacity of the stacker-reclaimer (or only reclaimer) is directly proportionate to the reclaiming methods. The stacking methods (chevron, chevcon, windrow, etc.) has been investigated in the earlier chapter (Chapter II, Section 2.1.3.). Besides, there are also different reclaiming methods in practice. These are long travel, bench reclaim, block reclaim, and pilgrim step (van Horssen, 2013: 11). van Horssen, (2013: 11) well explained the difference between these reclaiming methods. Long travel reclaiming method refers that the equipment travels along the stockpile without performing boom movement. The reclaim height and depth do not change during the reclaiming efforts. When reaching to the end of the stockpile, the equipment moves back along the stockpile by rearranging the depth and height of the reclaim. In the bench reclaiming method (this method also called as modular type in the study of Komljenovic et al., 2004:3), the equipment reclaims the materials slice by slice by performing the slewing motion. When the equipment reaches the maximum width of the stockpile, the reclaimer moves one-step forward. After finishing the first layer, which is called a bench, the equipment turns to the starting point of the stockpile.

Despite its resemblance to the bench reclaiming, the equipment does not travel until the end of the stockpile in block reclaiming method. When reaching a certain distance, reclaimer equipment moves backward to reclaim the next layer. Pilgrim step method of the reclaim is another method of the block reclaim. However, reclaimer travels back after performing the particular slewing motions in the pilgrim method. Generally, slewing motions comprise of even numbers (6, 8 or 10). While the reclaimer moves back, the boom of the equipment is positioned above the rails with the same angle of rail (van Horssen, 2013:11-13; Komljenovic et al., 2004:3). The difference of these methods are schematically illustrated in Figure 25:

Figure 25: Schematic Illustration of the Difference between the Bench, Block and Pilgrim Step Reclaiming Methods



Source: van Horssen, 2013:13

A limited research streams have been found in measuring reclaimer capacity. Although the calculation of the theoretical capacity seems simple, the effective capacity of the reclaimer is a little bit complex. The approaches to calculating the reclaimer capacity are investigated as follows:

van Horssen (2013: 3) evaluated the reclaiming capacity of the reclaimer as:

$$Q = A * v; \quad \text{Equation (57)}$$

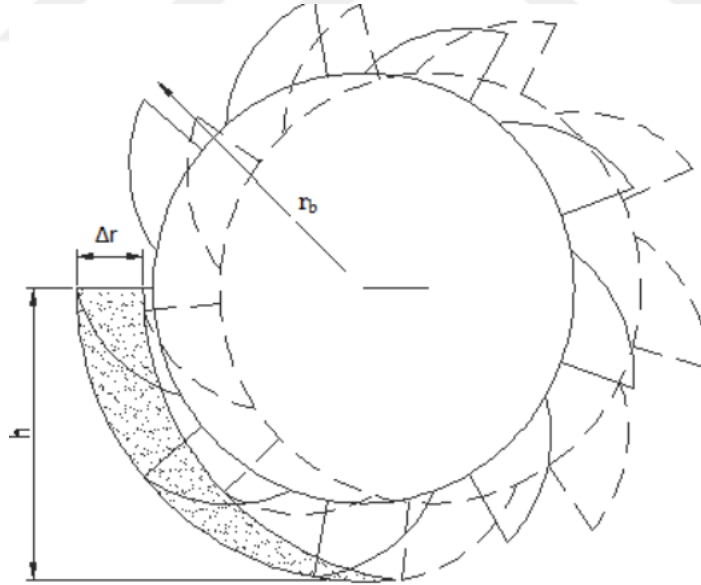
$$Q = \frac{V}{\Delta t}; \quad \text{Equation (58)}$$

Where Q is the current reclaiming capacity [m^3/s]; A is the cross-sectional area of the piece at the specified point [m^2]; v is the current velocity of the bucket [m/s]. Equation (58) calculates the reclaiming capacity of each segment where V is the volume of each segment [m^3]; Δt is the time when the segment is reclaimed [s]. The important parameter when calculating the reclaiming capacity is the determination of the cross-sectional area. van Horssen (2013:18) stated the formula of the cross-sectional area of a slice as follows:

$$A = r_b^2 \left(\pi - 2 \cos^{-1} \left(\frac{\Delta_r}{2r_b} \right) - \sin \left(2 \cos^{-1} \left(\frac{\Delta_r}{2r_b} \right) \right) \right); \quad \text{Equation (59)}$$

Where r_b is the radius of the bucket wheel [m]; h is the reclaim height [m]; Δ_r is the thickness of the slice [m]. As illustrated in Figure 25, Δ_r can be equals to the length of the bucket edge. Each of the variables used in the calculation of the cross-sectional area of a slice illustrated in Figure 24:

Figure 26: Schematic Representation of the Cross-Sectional Area Variables



Source: van Horssen, 2013:18

Komljenovic et al. (2004) studied the effective reclaiming capacity. The study stated the theoretical capacity of the reclaiming as follows:

$$Q_t = 60 \cdot E_r \cdot n_i$$

Equation (60)

Where Q_t is the theoretical reclaiming rate [m^3/h]; E_r is the volume of the bucket; discharge density of buckets [$1/\text{min}$]. Komljenovic et al. (2004: 3) stated that the effective capacity of the reclaimer is more important than the theoretical capacity of the equipment in terms of reflecting the real world situations. According to Komljenovic et al. (2004: 9), the general formula of the effective capacity of the reclaimer is stated as below:

$$Q_{eff} = \frac{V}{t_k + t_m};$$

Equation (61)

Where Q_{eff} is the effective reclaiming capacity [m^3/ton]; V is the mass volume of reclaimed material [m^3]; t_k is the digging time taken by a cut [h]; t_m is the maneuvering time the equipment during the reclaiming operation [h]. Equation (52) can be employed in the bench type, and block method is reclaiming.

3.1.4. Other Related Factors Used in Measurement of Dry Bulk Terminal Capacity

As mentioned in *Chapter II and Section 2.2.* several factors have an impact on the terminal capacity. However many factors cannot be measured or modeled. Generally modeled parameters are berth occupancy ratio, peak factor ship turnaround time, storage yard utilization and turnover rate. For this reason, only the parameters which can be expressed or be reflected in the equations are examined in this study.

3.1.4.1. Berth Occupancy Ratio

The term berth occupancy ratio (BOR) describes the percentage of time that a group of berth facilities is occupied by the ships to be serviced (Tsinker, 2004: 33). In another word, the berth occupancy rate shows the utilization degree of the berth (de Weille and Ray, 1968: 5). While 25% of the berth occupancy rate signs the underutilization of the resources, 70% of the berth occupancy value can be regarded

as a sign of congestion (de Langen and Helminen, 2015: 20). The optimum value range of the BOR is 60-70% (India Ministry of Shipping, 2011: 73). Throughput requirements and locational constraints determine the optimum rates (Zamanirad et al. 2017: 21). This indicator also shows the level of average service rate that higher levels of average service rate signs low berth occupancy rates, but lower service rates suggest higher berth utilization levels (Layaa and Duallert, 2014: 151). The higher utilization levels may be the consequence of either traffic intensity of the port or slower operations. It creates excessive service time and the higher demurrage costs for the port authority (Jagerman and Altiok, 2003:224).

Although berth occupancy ratio is a performance indicator of a terminal, it is commonly used in measuring berth handling capacity. Researchers developed several approaches to measure BOR. These approaches are based on the queuing theory or empirical expressions of the current situations. In this section, several approaches to berth occupancy ratio, and the variables used to calculate berth occupancy rate is examined.

Tsinker (2004: 33) assumed that the $M/E_2/n$ queue model is suitable to measure berth occupancy level of the berths and expressed the berth occupancy formula as:

$$k_o = \frac{\lambda\mu}{n}; \quad \text{Equation (62)}$$

Where k_o is the occupancy factor of a berth; λ is the average arrival rate per day; μ is average service time per ship; n is the number of berths. Similarly, de Weille and Ray (1968: 5) emitted *Equation (62)* as a berth occupancy ratio. However, they regarded the time as a yearly basis as well as de Langen and Helminen (2015: 20). The equation of de Langen and Helminen stated as follows:

$$BOR(\%) = \frac{\mu(\text{in days})}{n} * \frac{100}{360 \text{ days}} \quad \text{Equation (63)}$$

Where μ is servicing time at berths (total time of ships at berths); n refers the total number of the berth.

India Ministry of Shipping (2011: 73) refers to the BOR formula in the report on “Performance Audit of Functioning of Major Port Trust in India of Union Government”. The equation is:

$$\frac{\text{the time that berth is utilized}}{\text{total available time}}; \quad \text{Equation (64)}$$

It can be deduced from this implicit formula that the “*time that berth is utilized*” regards only the times when the berth is used. “*Total available time*” is considered as the working days in a year or observed period.

Gurning and Fikri (2016: 10) considered the below-mentioned formula when assessing the BOR to obtain optimum throughput:

$$BOR = \frac{V_s * S_t}{\text{Effective time} * n} * 100\% \quad \text{Equation (65)}$$

Where V_s is a total number of ships served in a year [unit/year], S_t is service time [hours/days]; “*Effective Time*” is total berthing time in a year [h]. The equation of Gurning and Fikri (2016:10) is similar to Tsinker (2004:33) and de Langen and Helminen (2015:20). However, apart from Tsinker (2004: 33) and de Langen and Helminen, Gurning and Fikri (2016:20) evaluated all the variables in a yearly basis rather than distributional rates and regarded the effective time at the berth, not the 360 days fully (2015:20).

Chung (1993: 5) assessed berth occupancy ratio as:

$$BOR \% = \frac{\text{Total time that ships work}}{\text{Total time of ships alongside}} * 100; \quad \text{Equation (66)}$$

According to Equation 66, Chung (1993:5) developed a formula based on the time spent by the ships at the berth rather than the probabilistic evaluation of the ship arrival rate and service rate.

National Research Council (1998:81) assessed the berth occupancy ratio with the following equation:

$$BOR = \frac{O_2}{Y_2}; \quad \text{Equation (67)}$$

Where O_2 indicates the number of days, the berth is occupied within a year; Y_2 is the operational time in a year (total working hours in a year). National Research Council (1998:81) considered BOR as a function of the total amount of cargo handled at the terminal. However, other factors such as vessel and quay lengths, idle times at the berth, waiting time, service time, etc. did not consider. This equation is similar to the equation used by Chung (1993:5) (Equation 66).

Tang et al. (2016:175) calculated the BOR based on the average waiting time and average service time as:

$$BOR = \frac{AWT}{AST}; \quad \text{Equation (68)}$$

Where AWT refers to the average waiting time of the vessels at the berth; AST is the average service time offered to vessels at the berth.

Timur (2017:2) used the below-mentioned formula:

$$BOR = \left(\frac{V_s * St}{H * n} \right) 100\% \quad \text{Equation (69)}$$

Where V_s is the number of vessels called in a year [-]; St is service time [h/d]; H refers to working days in a year [d]; n is the number of the berth [-]. This approach is the same as de Langen and Helminen (2015:20) and Gurning and Fikri (2016:10).

Radmilovic and Jovanovic (2006:101) formulated the BOR in their study as:

$$\rho = \frac{\lambda \bar{a}}{\mu c}; \quad \text{Equation (70)}$$

Where ρ is the berth occupancy ratio; λ is the average arrival rate of ships; μ is the average service rate of containers; $\bar{a}$ is the mean number of containers at each set in the queue system; c is the number of service channel. The study considered the ship arrival or container groups and the average quantity of the containers in each group (group sizes regarded as random variables).

Kuznetsov and Kirichenko (2016: 491) developed a different approach independent from queue approach:

$$K_{OCC} = \left(\frac{\sum l^{ship} p_i t^{ship} p_i}{L \cdot T_{\sigma}} \right); \quad \text{Equation (71)}$$

$$\begin{aligned} \sum_{i=1}^L p_i &= 1; & \sum_{i=1}^L n_i V_i &= Q; & n_i &= N p_i \\ N \sum_{i=1}^L n_i p_i &= Q; & N &= \frac{Q}{\sum_{i=1}^L n_i p_i} \end{aligned} \quad \text{Equation (72)}$$

Where K_{OCC} is the berth occupancy; L is the total berth length; T_{σ} is the specific period, l is the ship length, t is the ship handling time. In Equation (72), n is the number of the berth; V_i is the capacity of ships arrived at the port; N refers to several ships; Q is the quantity of the cargo which the terminal handled over some time; p_i is the probabilities of the variables. This probabilistic approach calculates the waiting time of each ship; those have different sizes and occupancy level of different berths. Kuznetsov and Kirichenko (2016:491) proposed a measuring equation for BOR (in Equation 71) considering ship length and berth length. K_{OCC} is the ratio of the area occupied by the ship both in quay wall and in seaside.

Zamanirad et al. (2017: 22) considered below mentioned BOR equation for a single berth as:

$$BOR: \frac{T_o}{T_t} * 100 \quad \text{Equation (73)}$$

Where T_o is the total time which the berth is utilized that registered in the statement of fact (SOF) documents between the berthing and unberthing of the vessels (refers vessel turnaround time) (service time); T_t is total available time to service (total working time). Zamanirad et al. (2017:22) took into the consideration the vessel turnaround time, but they did not specify time factors included to the total registered time between the berthing and unberthing of the vessel. BOR illustrates the utilization level of the port facilities (Tsinker, 2004: 33; de Weille and Ray, 1968: 5). Vessel turnaround time does not only imply that the berth is physically occupied, but also encompasses the time the ship wait to berth. For this reason, it can be inferred from

the formula that the study assumed that vessel berthed just after it arrived at the port. Considering this statement, T_o can be interpreted as service time at berth.

Layaa and Duallert (2014:151) explained the correlation between berth occupancy and service rates as:

$$\Theta = \frac{\lambda}{\mu K} \quad \text{Equation (74)}$$

Where Θ is the BOR; λ refers to the average arrival rate of the vessels, μ is the average service rate; and K is the number of a service channel in the port (berth). Layaa and Duallert (2014:151) analyzed the BOR from the viewpoint of the queuing approach as de Langen and Helminen (2015: 20).

Metalla et al. (2012: 62) considered BOR as hourly-occupied meters:

$$\text{BOR} = \left[\frac{\sum \text{Service time in port (hrs*meters used)}}{\sum \text{Available hours*meters}} \right] * 100 ; \quad \text{Equation (75)}$$

Apart from the queuing approach, Metalla et al. (2012:62) considered the meters used by the vessels during the total service time and divided the total available meters of the quay wall during the total available time to serve.

Thoresen (2003: 332) evaluated the BOR as:

$$B_{OR} = \frac{T_{WTC} * 100}{B_N * W_D * W_H * S_{CS}} ; \quad \text{Equation (76)}$$

$$B_{OR} = \frac{G_{STS} * 100}{B_N * W_D * W_H} \quad \text{Equation (77)}$$

Where T_{WTC} is total working hours between arrival and departure time of the vessel from/to berth; B_N is the number of the berth; W_D is the working days in a week; W_H working hours in a day; S_{CS} is the total number of container ships berthing in a week; G_{STS} is total quay cranes working hours in a week regarding peak factor. In Equation (76), Thoresen (2003: 332) considered nearly the same approach with the Layaa and Duallert (2014:151), Timur (2016:2), Gurning and Fikri (2016:10), Tsinker (2004: 33) and de Langen and Helminen (2015: 20) except for weekly calculation of

berth occupancy. In *Equation (77)*, crane working hours are distributed between berths by total time worked per week.

In the formulation of Saanen (2004:102), berth occupancy ratio assessed as:

$$BOR = \frac{\sum_{i=1}^n \text{Vessel Length}_i * \text{Vessel Service Time}_i}{\text{Quay Length} * \text{Measurement Period}}; \quad \text{Equation (78)}$$

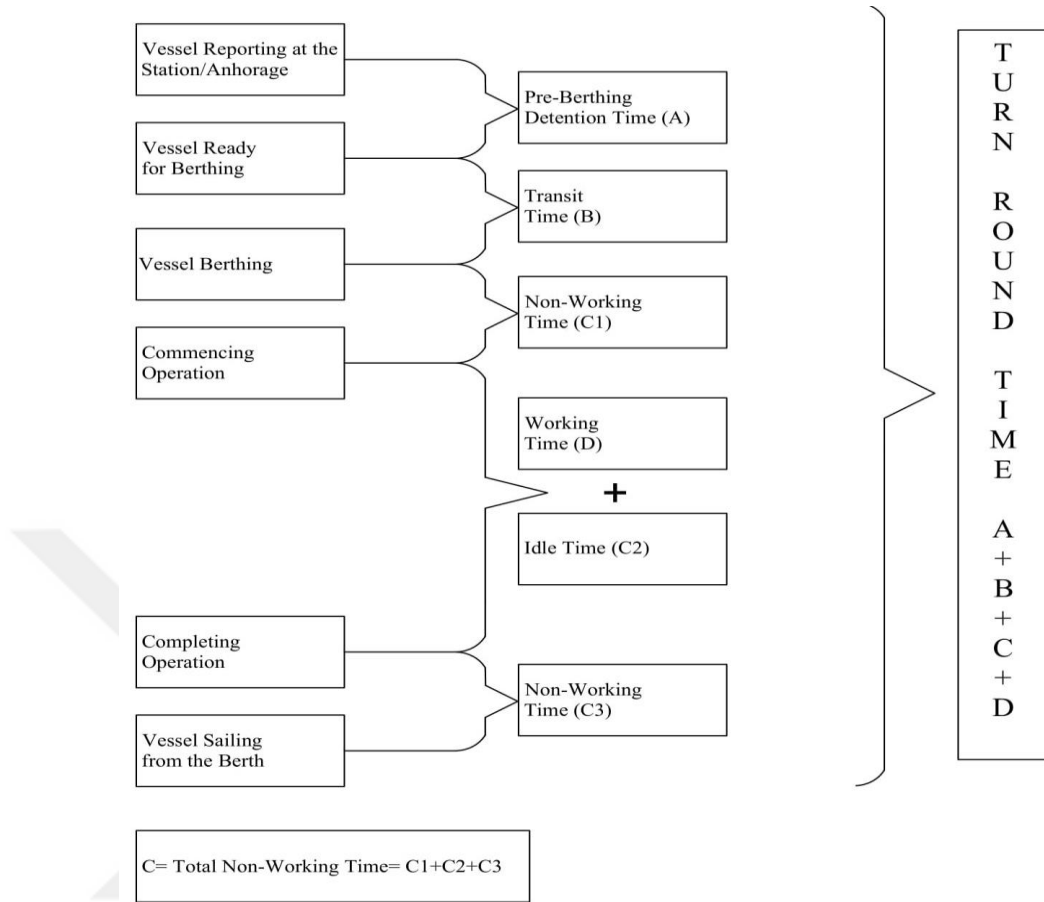
Where n is the total number of the vessels berthed in a specific period (i.e., a year); “vessel service time” refers to the total berthing time of the vessels (service time). In this formula, the length of the quay occupied by vessels within a specified period was calculated by time. According to Saanen (2004:102), alternative measurement approaches poorly calculate berth occupancy due to disregarding vessel length. Since, either one or two vessels may berth on the same berth at a different time.

3.1.4.2. Ship Turnaround Time

Ship turnaround time is the main indicator of vessel performance (Chung, 1993: 1), and identified as a total time spent by ships from entering time to departure time at the port. It is also affected by all services offered to the vessel as well as waiting time at the port and additional delays (de Langen and Helminen, 2015: 18; India Ministry of Shipping, 2011: 65; Mwasenga, 2012: 4). As an efficiency indicator, ship turnaround time creates financial value for both ship owner/charterer and port (de Langen and Helminen, 2015: 18). Ship turnaround time does not mean only the idle time spent at the port but also affected by cargo volume, port facility conditions, and cargo nature (Chung, 1993: 1). In this section, measurement approaches to ship turnaround time are reviewed to perform more accurate estimation of berth occupancy rate by specifying the functions of the waiting time and service time.

Figure 27 illustrates the schematic portrayal of ship turnaround time:

Figure 27: Schematic Representation of Ship Turnaround Time



Source: India Ministry of Shipping, 2011:69

Ship turnaround time covers all times which spent by a vessel at the port. Ship turnaround time (TAT) is calculated as follows (de Langen and Helminen 2015:18; Radmilovic and Jovanovic, 2006):

$$TAT = T_w + T_b + T_{ber} + T_{unber} \quad \text{Equation (79)}$$

Where T_w is waiting time for the berth, T_b is the servicing time at the terminal, T_{ber} is berthing time of a vessel, and T_{unber} means the unberthing time of a vessel.

3.1.4.3. Service Time

Service time refers to the period that the ship serviced at the berth. Thus, service time as a function of the time depends on the amount of cargo to be loaded to ship or

unloaded from the ship, specifications of the ship, cargo characteristics, design efficiency of equipment and other related resourced utilized at the berth (Mwasenga, 2012: 6). As a function of the total amount of cargo, service time, thus the total amount of cargo, affects the waiting time of other vessels that are currently waiting in the queue. Average service time may show the utilization level of the terminal superstructure. While long service time is the sign of low utilization level, short service time is assumed as high utilization level of the terminal superstructure (Layaa and Duallert, 2014:150). This parameter determines the berth occupancy level of the berths.

Zamanirad et al. (2017:22) used the below-mentioned formula to calculate service time:

$$T_o = \sum_{i=1}^n (T_{unberthed} - T_{allmade\ fast}) i ; \quad \text{Equation (80)}$$

alternatively, in dry bulk terminals;

$$T_o = \frac{A.T.}{P_B} + N_s * T_{other} ; \quad \text{Equation (81)}$$

Where $T_{unberthed}$ is the official recording time that the ship departed from the berth; $T_{allmade\ fast}$ is the time the ship berthed and ready for cargo operations and inspections; i is a total number of the ship berthed within the specific period. In Equation (47), $A.T.$ refers to the total amount of cargo which berth(s) handled in a year; P_B is the productivity of quay equipment [ton or TEU per hour]; N is the total number of vessels berthed within a year; T_{other} is the time spent to perform inspections, surveys, clearance, and documentation.

Wanhill (1976: 121) stated the total time required for service to V vessels during the given T (days) (S) is:

$$S = \left(\frac{Q}{r} \right) + \gamma V ; \quad \text{Equation (82)}$$

Where r is the average handling rate per day; y is the fraction of a day needed for berthing and unberthing a vessel; Q is the total amount of cargo to be handled over T days; V is the number of vessels called to the port.

Then the service time (s) required per day expressed as follows:

$$s = \frac{1}{T} \left(\frac{Q}{r} + \gamma V \right) = \frac{q}{r} + \gamma \lambda \quad \text{Equation (83)}$$

Where the q refers to the total amount of cargo to be discharged daily; λ shows the mean of ship arrival per day. Service time per ship $\left(\frac{1}{\mu} \right)$ can be expressed as:

$$\frac{1}{\mu} = \frac{s}{\lambda} = \frac{q}{\lambda r} + \gamma ; \quad \text{Equation (84)}$$

Where $\frac{q}{\lambda} = G$. G refers to the average amount of cargo per vessel.

3.1.4.4. Storage Yard Utilization

Apart from the storage yard utilization which indicates the utilization level of storage, storage occupancy term found in the dry bulk terminal (Mwasenga, 2012: 15). Apart from the berth utilization, Beaumont (2017:49) assessed storage yard utilization as the utilization degree of the remaining available areas. An excessive level of storage yard utilization affects the service time of the cargoes and leads to congestion at the storage yard area (Raballand et al. 2012:70).

This term is expressed as proportionally in the literature (Ligteringen and PIANC Velsink, 2012:157; PIANC, 2014; Kox, 2017: 58):

$$\frac{\text{Net Storage Area}}{\text{Gross Storage Area}} ; \quad \text{Equation (85)}$$

Net storage area refers to the areas only used for the storage, whereas gross storage area includes both internal roads, buildings, and all facilities.

Besides PIANC (2014) assessed the storage yard utilization in terms of the stockpile. The approach addressed the occupancy factor in the dry bulk terminals in B

$$\text{Storage occupancy} = \frac{\text{Average mass of cargo in the stockpile}}{\text{Design capacity of the stockpile}}; \quad \text{Equation (86)}$$

3.1.4.5. Turnover Rate

The turnover rate represents the replenishment rate or replenishment rate of a storage yard within a certain period. This also means that the port can stack the materials directly proportionate to the turnover rate. Turnover rate added to the equations as a multiplier. Turnover rate is closely linked to the dwell time of the cargoes, and it expressed in the literature as follows (UDHB, 2015b: 235; Salminen, 2013:32-34; National Research Council (1998:81; PIANC, 2014; Kox, 2017:58; Ligteringen and Velsink, 2012:157):

$$\frac{\text{dwell time}}{365} \text{ or } \frac{365}{\text{dwell time}}; \quad \text{Equation (87)}$$

Total days in a year (365) was represented in some studies as effective days.

3.1.4.6. Peak Factor

Peak factor refers to the peaks of the throughput volume during a certain time in a year (Scholtz, 2017:51). Due to demand fluctuations of cargo, throughput level shows difference over the observed time. This situation leads complexity in capacity usage during the peak periods of cargo throughput.

Peak factor has two effects on the capacity. The first one is the boosting effect on the capacity. When measuring the required storage yard area, berth handling capacity peak factor can be used as boosting factor. Because when making the required capacity calculation for a certain amount of load, planning should be performed considering the increase caused by demand fluctuations. The results shows how much capacity can be supplied for the certain volume of cargo. Accordingly Tsinker (2004:34) and Scholtz (2017:51,83,90,96), used the peak factor as a multiplier to determine required storage yard and required container ground slot, respectively.

However, when determining the maximum or realizable capacity of a terminal, peak factor has a limiting effect on the capacity. For this reason, it indicates how much capacity the port will supply against the demand fluctuations when demand is peak.

According to Scholtz (2017: 127), peak factor is calculated by dividing the monthly peak throughput volume by mean number of throughput volume for each month during the observed period.

3.2. EVALUATION OF THE CAPACITY MEASUREMENT EQUATIONS

In this section, the equations obtained from the literature, and the variables used in measuring the dry bulk terminal capacity are determined. Parameters used in measuring both berth and storage yard capacity are analyzed. Besides existing equations related to the berth occupancy ratio are mathematically expressed.

3.2.1. Evaluation of the Berth Handling Capacity Measurement Equations

With the reviewing of the different calculation equations, variables used for the measure the berth handling capacity is summarized in Table 11.

Table 11: Variables Accounted in Measuring Berth Handling Capacity

Variable	Reference
Number of the Equipment	UDHB, 2015b: 231; KMI (1998); Park et al. 2014:181
Number of Berth	Park et al. (2014:185)
Equipment Productivity	UDHB, 2015b: 231; KMI (1998); Park et al. 2014:181; Ligteringen and Velsink (2012:155)
Crane Efficiency	KMI (1998); Park et al. 2014:181
Equipment Utilization	KMI (1998); Park et al. 2014:181
Occupancy Ratio of Particular Cargo	KMI (1998); Park et al. 2014:181
Working Hours	UDHB, 2015b: 231; National Research Council, 1998:91; KMI (1998); Park et al. 2014:181; Ligteringen and Velsink (2012:155)

Table 11: Variables Accounted in Measuring Berth Handling Capacity (Continued)

Working Days	National Research Council, 1998:91; KMI (1998); Park et al. 2014:181
Berth Occupancy Rate	UDHB, 2015b: 231; National Research Council, 1998:91; KMI (1998); Park et al. 2014:181; Ligteringen and Velsink (2012:155)
Total Days the Berth is Utilized	National Research Council, 1998:91
Average Amount of Cargo per Ship	UDHB, 2015b: 231; National Research Council, 1998:91
Peak Factor	UDHB, 2015b: 231
Additional Time (maneuvering, etc)	UDHB, 2015b: 231
Number of Ship	National Research Council, 1998:91
Average Arrival Time of the Vessels	National Research Council, 1998:91
Size of the Vessels	National Research Council, 1998:91; Park et al. (2014:185)
Draft	National Research Council, 1998:91
Load Factor	National Research Council, 1998:91
Number of Gang	National Research Council, 1998:91; Ligteringen and Velsink (2012:155)

Source: Compiled by Author from Several Studies

Considering the equations of berth handling capacity calculation for dry bulk terminals, most of the equations expresses that the berth handling capacity is the function of the amount of cargo handled at the berth. Therefore, the total number arrivals of the vessel, average cargo amount per ship or ship size variables are included in the berth handling capacity calculation equations. Additionally, equipment capacity has an essential position in these equations. Equipment capacity determines the total amount of cargo (ton basis) that can be handled within a certain period with the existing equipment. Generally, the daily/weekly/annual working hours are considered to be actual operation time or the distinction between these time indicators are considered indiscriminately (Daily working hour is considered as 24 hours and the annual working

days are considered as 365 days). Berth occupancy ratio is generally placed in the equations.

Once reviewing the existing literature, a little attention has been paid on the capacity calculation methodology dry bulk terminal. It was noticed that the general cargo terminal capacity equations were also regarded for the dry bulk cargo terminals (UDHB, 2015b:231; National Research Council, 1998: 81; KMI, 1998; Park et al. 2014:185).

With the examination of the existing literature on the berth handling capacity of the dry bulk terminals, it was noticed that the equations did not provide the detailed information of the equipment capacity. However, vessel size and cargo types affects the equipment capacity. Particular equipment does not reveal the same performance in different cargo types. For this reason, the handling rate of the equipment according to the different cargo types should be determined. In order to state this detail in the equations, it should be specified according to particular cargo type (i.e., 2,000 ton/hour for grain) or be added as a coefficient, which determines the equipment capacity according to the cargo type (i.e., 75%). KMI (1998) stated the “working efficiency of the crane” also the equipment capacity, yet *Equation (5)* did not consider the vessel sizes. Because the same cargo type may be carried by the different size of the vessel. Only Park et al. (2014:185) paid attention to this situation. However, the study did not consider the peak factor.

National Research Council (1998:91) did not consider the working days and hours. *Equation (3)* provides only the daily handling amount of the cargoes and actual berth handling capacity of the terminal. Due to the demand fluctuations, a terminal may perform throughput below its capacity level. Therefore terminal capacity is neither limited to a number of vessels called to the terminal nor carrying capacities of these vessels.

3.2.2. Evaluation of the Storage Yard Capacity Measurement Equations

Examination of the capacity calculation equations of storage yard has been provided the parameters specified in Table 12 are obtained.

Table 12: Parameters Accounted in Measuring the Storage Yard Capacity

Variable	Reference
Size of the Storage Yard Area	National Research Council (1998:81); Salminen (2013:32-33); UDHB (2015:235)
Vessel Capacity (ton basis)	UNCTAD (1983: 7-8)
Working Days	UNCTAD (1983: 7-8); Salminen (2013:32-33)
Stacking Characteristics	UNCTAD (1983: 7-8); Salminen (2013:32-33)
Arrival and departure Rate of the Truck	UNCTAD (1983: 7-8)
Number of Vessels	UNCTAD (1983: 7-8)
Interarrival Time of the Vessel	UNCTAD (1983: 7-8)
The total amount of Cargo stored at the terminal	Ligteringen and Velsink (2012:157)
Specific Bulk Density	Ligteringen and Velsink (2012:157); PIANC, 2014; Kox, 2014:59; National Research Council (1998:81); UDHB (2015:235); UNCTAD (1985:223); Vianen et al. (2012:10); Kox, 2017:60; Bot, 2012:27
Bulking Factor	Ligteringen and Velsink (2012:157)
Ratio of Net and Gross Storage Area	Ligteringen and Velsink (2012:157); PIANC, 2014; Kox, 2014:58; National Research Council (1998:81); UDHB (2015:235)
Stockpile Height	Ligteringen and Velsink (2012:157); PIANC, 2014; Kox, 2014:58; National Research Council (1998:81); UDHB (2015:235); UNCTAD (1985:223); van Vianen et al. (2012:10); Bot, 2012:27; Kox, (2014:59); Ligteringen and Velsink (2012: 218)
Stockpile Length	UNCTAD (1985:223); van Vianen et al. (2012:10); Bot, 2012:27; Ligteringen and Velsink (2012: 218)
Stockpile Width	Vianen et al. (2012:10); Bot, 2012:27; Kox, (2014:59); Ligteringen and Velsink (2012: 218);
Storage Occupancy Ratio	Ligteringen and Velsink (2012:157); PIANC, 2014; Kox, 2014:58; Salminen (2013:32-33); UDHB (2015:235); Ligteringen and Velsink (2012: 218)

Table 12: Parameters Accounted in Measuring the Storage Yard Capacity

The width of the Storage Yard	Kleinheerenbrink (2012: 66)
Number of a Lane	Kox (2014: 59)
Length of the Storage Yard	Kleinheerenbrink (2012: 66)
Length of the Lane	Kleinheerenbrink (2012: 66); Kox (2014: 59)
Width of a Lane	Kox (2014: 59)
Distance between the Lanes	Kleinheerenbrink (2012: 66)
Annual Throughput	PIANC, 2014; Kox, 2014:58; National Research Council (1998:81); Salminen (2013:32-33); Kox (2017:60);
Average Dwell Time	Ligteringen and Velsink (2012:157); PIANC, 2014; Kox, 2014:58; National Research Council (1998:81); Salminen (2013:32-33); UDHB (2015:235)
Gross Holding Volume	National Research Council (1998:81)
Peak Factor	National Research Council (1998:81)
Unused Spaces	National Research Council (1998:81)
Angle of Repose	UNCTAD (1985:223); Bot, 2012:27; van Vianen et. al. (2012:10); Kox, (2014:59)

Source: Compiled by the Authors from Several Studies

Generally, studies measured the required terminal area. Thereby the amount of cargo handled at the terminals was considered as a function of the required terminal area. It can be deduced from the equations in the literature that dwell time (storage time of the cargoes), specific bulk density, stockpile geometry, the angle of repose are important factors affecting the storage yard capacity of the terminals. Because dwell time provides that how many times the terminal is replenished. Stacking efficiency is one of the other important parameters in the utilization of the terminal area statically. While stacking efficiency measured by considering stacking height and container slot utilization in the container terminals, in dry bulk and general cargo terminals stacking efficiency was measured by stockpile efficiency.

As in the berth handling capacity, dry bulk terminals and general cargo terminals were evaluated in the same formulas. In dry bulk terminals, extant studies focused on designing storage yard capacity of the dry bulk terminals. In the stage of designing of dry bulk terminals, studies centred on stockpile design.

Scholars mostly performed various studies on the storage yard capacity of the dry bulk terminals comparing the berth handling capacity. However, this progression has continued in the planning and the designing of the storage yard terminals. The underlying reason of propensity to the planning and designing may stem from adoption of the different implementations of the terminals.

When existing equations was examined, it was seen that National Research Council (1998:81) did not reflect the working hours and days in a specific period. Moreover, the National Research Council equation disregarded the stockpile form as well as Salminen (2013:32-33) and UDHB (2015: 231). Besides the peak factor of storage yard, and sousplan shipments was not reflected in the current equations. Even though the annual throughput is included in the formula, each shipment may not be transferred to the storage yard area. This circumstance impedes estimation of the storage yard capacity when demand fluctuates. Moreover, joint evaluation of the peak factor for both berth and storage yard capacity may result in overinvestments.

In the measuring equations of storage yard capacity, studies did not differentiate sousplan shipments. National Research Council (1998:81) considered the cargoes handled at the storage yard.

3.2.3. Evaluation of the Equipment Capacity Measurement Equations

Sufficient approaches have been found in the literature. Scholars, generally, addressed the belt conveyors, 3 idlers and five idlers belt conveyors. Flat and 3 idler rollers are commonly used in practice. Calculation approaches of the belt conveyors mainly based on the cross-sectional area of the mass of materials (perpendicular to the belt), idler angle, the angle of surcharge, etc. when calculating the belt conveyor capacity, capacity factors can be taken as reference.

Screw conveyor capacity is based on the material, screw pitch, cross-sectional area of the material filled into the pipe, material characteristics, filling rate and the slope angle. As well as in the determination of the belt conveyor capacity, design guidelines for the screw conveyors should be referenced to specify the related factors such as shape, flight, inclination, mixing paddles.

Pneumatic conveyor capacity has more complicated approaches than the other equipment. Due to conveying the material and air together, the mass flow rate of the mixture should be considered. In addition to that one important issue in calculating the conveying capacity of the pneumatic equipment is solid loading ratio. Several calculation parameter and coefficients change the hourly capacity of the equipment. As well as other equipment, these parameters also stand for the pneumatic conveyors. Solid loading ratio show difference according to the air density, material density, and conveying characteristics. Scholars heavily addressed the velocity, losses power, etc. To make the capacity measuring formula more explicit, an empirical equation is tried to be developed in *Chapter IV Section 4.2.1.3*.

3.2.4. Evaluation of the Other Related Factors used in Measurement of Dry Bulk Terminal Capacity

Turnover rate, and storage yard utilization is clearly explained in the literature. However, several approaches to berth occupancy ratio have been found in the existing body of the literature. Scholars attempted to measure berth occupancy ratio with the queueing approach and the empirical models. For this reason, berth occupancy ratio addressed thoroughly in this section.

3.2.4.1. Evaluation of Measurement Approaches of Berth Occupancy Ratio

When BOR equations are evaluated, the fundamental required parameters to calculate BOR are average service time, average arrival times of the vessels and number of servers (berths). Average service time is included in the BOR equation by taking reciprocal of the service time (1/the time between berthing and deberthing time) (Layaa and Duallert, 2014: 153; Radmilovic and Javanovic, 2006:101). Other studies (Tsinker, 2004: 43; de Langen and Helminen, 2015:20; Gurning and Fikri, 2016:10 Timur, 2016:2) considered the total service time in an observed period. Dividing the total number of vessels calls within a year by 365 days provides the average arrival rate of the vessels (Layaa and Duallert, 2014: 153).

Although Tang et al. (2016: 174) stated that the AWT/ AST ratio could be used to determine BOR in the master planning phase, BOR level is affected by the several variables such as size of the ship, efficiency of the quay cranes, number of hatch, amount of cargo, characteristics of the cargo, safety procedures etc. Because of the changing of these variables from case to case, rough estimations may not reflect the real-world situations. Besides, waiting time of the vessels with less cargo may not be tolerated by comparing the vessels, which have more cargo. This ratio may be deceptive. Waiting time to-service time will increase if the service time worsens. Thus, AWT/AST is used for measuring the service level of the port (UNCTAD, 1985: 30). As a different approach, Chung (1993:5) evaluated BOR as an independent indicator from the number of berth or meters used.

Considering the equations to be used for determining BOR level, these approaches do not enable to calculate locational occupation of berth facilities in meters as mentioned in the Bellsola Olba et al. (2017: 3). Although BOR equations seem different, each of mathematical operations implies the same logic and considers the meters used by the vessels. The variables used to calculate BOR in the literature is illustrated in Table 13.

Table 13: The Parameters used in Measuring Berth Occupancy Ratio

Variables	References
Average Arrival Rate of the Vessels	Tsinker (2004: 33); de Langen and Helminen (2015: 20); Radmilovic and Jovanovic (2006:101); Layaa and Duallert (2014:151)
Average Service Time per Vessel (or service time hours/days or total time the berth is utilized)	Tsinker (2004: 33); Gurning and Fikri (2016: 10); Timur (2016:2); Radmilovic and Jovanovic (2006:101); Zamanirad et al. (2017:22); Layaa and Duallert (2014:151); Metalla et al. (2012: 62); Thoresen (2003: 332); Saanen (2004:102)
Total available time (Effective time or working days or total time of ship alongside or working days in a year or measurement period)	de Langen and Helminen (2015: 20); India Ministry of Shipping (2011: 73); Gurning and Fikri (2016: 10); Timur (2016:2); Kuznetsov and Kirichenko (2016:491); Zamanirad et al. (2017:22); Metalla et al. (2012: 62); Thoresen (2003: 332); Saanen (2004:102)

Table 13: The Parameters used in Measuring Berth Occupancy Ratio (Continued)

Handling Time or Crane Working Hour	Kuznetsov and Kirichenko (2016: 491); Thoresen (2003: 332)
Length of the Vessel	Kuznetsov and Kirichenko (2016: 491); Metalla et al. (2012: 62); Saanen (2004:102)
Number of Vessels (in a year or a week or average calls per day)	Gurning and Fikri (2016: 10); Timur (2016:2); Kuznetsov and Kirichenko (2016: 491); Thoresen (2003: 332)
Length of the Quay Wall	Kuznetsov and Kirichenko (2016: 491); Metalla et al. (2012: 62); Saanen (2004:102)
Number of Service Channel (Berths)	Tsinker (2004: 33); de Langen and Helminen (2015: 20); Gurning and Fikri (2016: 10); Timur (2016:2); Radmilovic and Jovanovic (2006:101); Layaa and Duallert (2014:151); Thoresen (2003: 332)
Average Amount of Cargo per Vessel	Radmilovic and Jovanovic (2006:101); Kuznetsov and Kirichenko (2016: 491)

Source: Compiled by the author from several resources

As it can be seen from the equations, berth occupancy ratio is the parameter that indicates the utilization of the berth. This parameter is commonly used in calculation of berth handling capacity (Equation 1, 4, 5, 6, and 7). Generally, berth occupancy ratio calculations consider average arrival rate, number of ship call, equipment working hours, and average service time per ship parameters. As can be seen from the equations mentioned above, berth occupancy ratio refers to the time consumed at the berth by vessels and this concept depends on the vessel traffic.

BOR determines utilization level of the berths from the viewpoint of port, and determines service level of the port from the viewpoint of the port customers by considering the vessel traffic and equipment-working hour.

CHAPTER FOUR

A RESEARCH ON CAPACITY MEASUREMENT IN DRY BULK TERMINALS IN TURKEY

This study is designed and the research questions supported qualitatively and quantitatively. In the first step, the literature review has been performed in accordance with the research questions and content analysis has been conducted to the existing literature on port capacity. The content analysis of port capacity has been presented at the 8th National Logistics and Supply Chain Congress (Gülmez and Esmer, 2019). In the second step, empirical equations have been attempted to develop in the light of Chapter 3. At the final stage, these equations have been simulated via RProject. In additionally, the results have been tested.

4.1.QUALITATIVE RESEARCH

In this section, the literature on capacity measurement in ports was analysed by systematic content analysis to evaluate the critical issues addressed in the capacity measurement in ports, focused themes, modelling approaches, the interrelation between the themes. Google Scholar and peer-reviewed databases (Scopus and Web of Science) were chosen for the analysis of the considerations mentioned above. The result of the content analysis and the specified research gaps were used to develop the capacity measurement model for dry bulk terminals.

4.1.1. The Logic of Content Analysis

There are many methods to analyse qualitative data (Elo and Kyngas, 2008:107). The content analysis method is one of the analysis methods to analyse data. Content analysis is a series of the technique used for the systematic analysis of text (Mayring, 2000: 1). The method can be used for any document with the aim of determining the inference from the data (Kondracki et al. 2002: 224). Content analysis as a powerful tool enables researchers to analyse phenomena and drawings in the

specified document (Stemler, 2001:2). Documents can be text, video, voice record, picture form (Forman and Damschroder, 2008:59).

Pros and cons of the content analysis can be listed as follows (Mayring, 2000:2-3; Kondracki et al. 2002:227):

- It allows materials to be placed in a logical model to deduce related messages
- It allows performing a systematic analysis of the data in accordance with the objectives by pursuing the analysis rules
- It provides flexibility in building categories in terms of revising them to interpret data.
- It enables the reliability and validity tests of the analysis by coder agreement standards.
- Generalization of theory, implications are limited with the research sample included in the sample.
- It is not a suitable method for requiring labor-intensive researches.
- It fails to explain correlations and causal relationships between the materials.

Content analysis can be performed both qualitatively and quantitatively (Seuring and Gold, 2012: 546; Kondracki et al. 2002:227; White and Marsh, 2006: 27; Forman and Damschroder, 2008: 39-40). The distinction of two approaches to content analysis stems from objectives of understanding the phenomena and making inferences from the events. The objective of the qualitative content analysis is to comprehend the facts such as views, motivations, and processes rather than generalization of the theories and approaches from the sample by statistical implications (Forman and Damschroder, 2008:41). This approach interested in picturizing the events and not identifying the issues objectively (White and Marsh, 2006:38). Besides quantitative content analysis is defined by the Berelson (1952:18) as a quantitative illustration of the content systematically and objectively (Rourke and Anderson, 2004:5). The debate on the difference between quantitative and qualitative content analysis was placed in several studies. According to Forman and Damschroder (2008: 41), qualitative analysis can be conducted to interpret quantitative results or to create objects for closed-end surveys. Besides Rourke and Anderson, 2004:5 specified that the quantitative content analysis implies splitting the content into smaller units, building the categories by the units and scoring each category. The difference between

the quantitative and qualitative content analysis was also evaluated based on the inductive and deductive analysis approaches. Kondracki et al. (2002:225) generalized the studies according to apply deductive and inductive approaches. According to this point of view, the qualitative content analysis employs inductive analysis, whereas quantitative content analysis employs deductive analysis as implied by the White and Marsh, (2006: 34-35). White and Marsh (2006: 35) performed specific classification of qualitative and quantitative content analysis according to research approaches, research orientations, purpose, data, categorization diagram, coding, proof argument, usage of the computer-based analysis program. The highlighted issues in the quantitative content analysis can be listed as follows:

- Being deductive
- Formulation of the hypotheses hyperlinks between the variables
- Enabling to generalizable population
- Developing a coding diagram
- Objectivity
- Validity and reliability testing
- Providing statistical tests
- Proofing results supported by the evidence from the text

Whereas, from the perspective of qualitative content analysis, the highlighted issues can be listed as follows:

- Being inductive
- Based on the research question
- Analyzing data may reproduce new themes
- Sampling selection serves to research questions
- Developing coding scheme iteratively
- Subjectivity in some circumstances
- Presenting the data as a percentage

Different type of steps or methods for conducting content analysis can be found in the extant literature. Here, it is focused on the Seuring and Gold (2012), Forman and Damschroder (2008) and White and Marsh (2006: 30), since these processes complement each other.

Figure 28: Content Analysis Steps of Forman and Damschroder (2008)



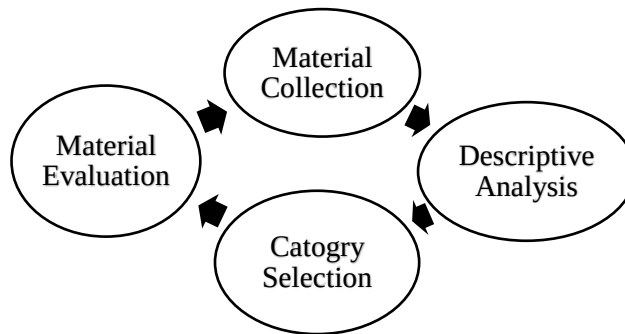
Source: Generated from Forman and Damschroder (2008: 42-59)

According to Forman and Damschroder (2008), the design of the study begins with the determining research questions as a first step of conducting the content analysis. Due to data may be collected in different forms (video record, interview or complex text, etc.) transcription technique of different types of data is essential for data labeling. The management process encompasses transforming the different forms of data into apparent labeling for coding. As a third step, the researcher reaches the consensus on data coherence before organizing the data for the analysis. The underlying reason is that the relevant links will be established by ensuring the data coherence. The reduction is divided into three sub-processes. (1) Reducing the data: It provides a logical approach to data. This process comprises simplifying the raw data required to response to the research question. (2) Dividing data into controllable themes. (3) Building the categories to meet the requirements of research questions by rearranging the data. Coding activity is placed in the “Immersion, Reduction, and Interpretation of Data” category. The codes, themes, and memos obtained in three stages are interpreted in the final stage (Forman and Damschroder, 2008:48).

Apart from the Forman and Damschroder (2008: 42-59), White and Marsh, 2006: 30 developed a process for quantitative content analysis: (i) Hypothesizing the phenomenon: (ii) defining the suitable data; (iii) selecting the sampling and application method; (iv) illustration the sample; (v) building data collection unit; (vi) building coding plan to test hypothesis; (vii) data coding; (viii) controlling the reliability of coding (if required); (ix) examining coded data and performing statistical tests; (x) provide the results.

The other analytic process of content analysis is proposed by Seuring and Gold (2012). Figure 29 illustrates these processes:

Figure 29: Analytic Steps of the Content Analysis



Source: Created from Seuring and Gold, 2012:547-548

Seuring and Gold (2012) methodology refers the materials subjected to content analysis are specified with the predetermined keywords, journals, topics in the first step, In the descriptive statistics process, the statistical distributions of the data on the years or subjects are determined in accordance with the research objectives. At the stage of category selection, categories are prepared for content analysis. Categories are built by inductive and deductive approaches. The evaluation of the data consists of processes of subcategorization of the categories by performing iterative coding for content analysis. According to Mayring (2000:4) categories can be built with the systematically implementing of inductive and deductive approaches. The main idea behind the inductive categorization is to develop a descriptive category, which is based on the theory or research questions. In the inductive categorization, initial process sustains tentatively, and categories are gradually simplified. Feedback cycles follow the initial process. In the feedback cycle process, categories iteratively analyzed and final categories are reduced concerning reliability considerations. Besides, deductive categorization renders the theoretical facets of analysis in conjunction with the text.

Once the content analysis is performed, computer software programmes can also be used. Software programs provide a broad spectrum of flexibility for researchers to analyze texts. The researcher can find the determined words and extract the paragraphs or sentences which contains the determined word. This strategy supports enhancing the validity of the arguments (Stemler, 2001:3). Despite providing greater flexibility to manage data, it does not provide the data analysis (Forman and Damschroder, 2008:59).

Researchers benefit from this software such as linking the materials, building theoretical models, performing queries, reporting, making a comparison (Forman and Damschroder, 2008:60). Moreover, counting words, frequency analysis can also be employed by the programmes. The functions of the software tools can be listed as Processing the data, segmenting the text into smaller unit, writing the notes, grouping the classifications, coding; linking the text with the determined words to serve coding objectives; monitoring the each step of analysis and duplicating the analysis(if it is necessary); performing quantitative analysis of the data (i.e. frequency analysis) (White and Marsh, 2006: 40).

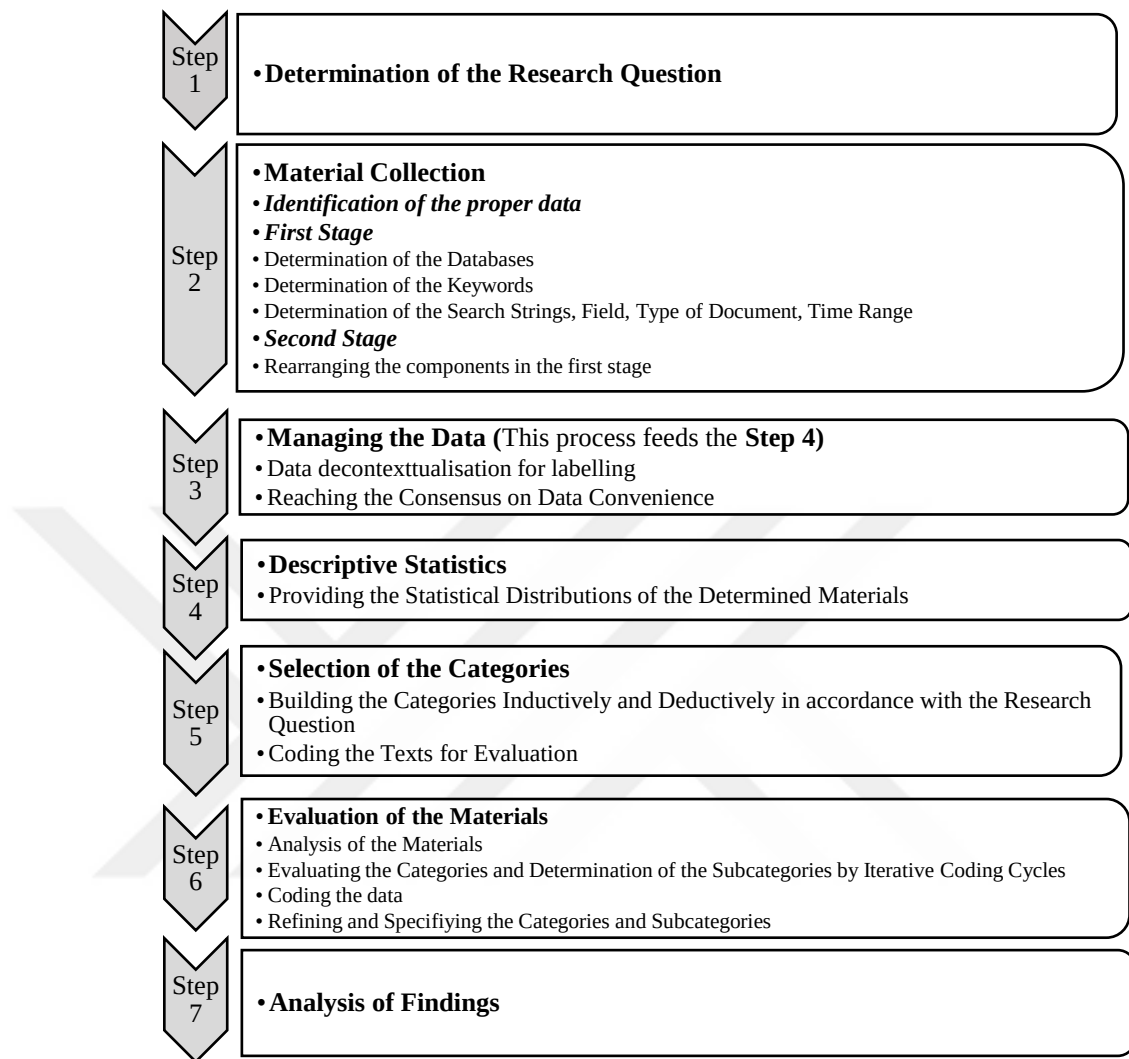
There are many tools for performing content analysis by software. Nvivo is one of the computer software. Nvivo is a useful tool for transforming the mass qualitative data into meaningful themes and categories (QSR International (a), 30.01.2019). Nvivo can transform the static data to the dynamic base and makes the relationship network between the categories more visible by text formatting command. Moreover, the software hyperlinks documents and categories (Çetin and Baştuğ, 2018:310).

Nvivo allows researchers to create code reports, codes or to link the code documents with other data set involved in the software (Forman and Damschroder, 2008:60). With this program, cases, attributes, codes, and nodes can be stored in the body of software to explore, change and arrange. The process of document arrangement can be maintained throughout the project. The researcher can import the data to Nvivo with the broad spectrum of text format (Bazeley and Richards, 2000:5; Richards, 1999:4). Moreover, records, matches, and links can be associated with each other by maintaining access to data or context to satisfy the research questions (Bazeley and Jackson, 2013:2).

4.1.2. The Research Process of Content Analysis

In the light of the Seuring and Gold (2012:547-548) and Forman and Damschroder (2008: 42-59; White and Marsh, 2006: 27), the process of the research is formulated in Figure 30:

Figure 30: Research Steps followed in Content Analysis



Source: Created by author

The detailed explanations of the steps are provided in the below-related headings. Research approach of this study was built based on the qualitative content analysis method. Research questions were developed, and themes were developed after the data collection process. However, analysis and the implications were performed based on the statistical data (frequencies, tests, etc.). In terms of selecting the sample of the research from the generalizable population and receiving the correct answers to the research question, this study employed both qualitative and quantitative content analysis method.

4.1.2.1.Determination of the Research Questions

As the ports are essential nodes in terms of international transportation, they are considered as strategic places for the port users and the port operators. Due to the rapid technological developments in maritime transport and the increased integration of air, sea, land and railway modes of transport, the need for design and planning of cargo handling technologies in the terminal facilities has increased (Frankel, 1987).

Port planning is a field that investment, capacity, design, operation, strategy and policy issues are examined simultaneously. The primary purpose of port planning is to establish a balance between capacity shortage and overcapacity at a reasonable cost, reasonable price and service levels (Bichou, 2013:51). Because of ports show capital-intensive nature, it is necessary to determine the demand, the infrastructure of a port that can meet the demand, the service structure, the utilization levels of the infrastructure, the investment cost, service tariffs, economic benefits and the applicability of the port investment project for port capacity planning (Dekker, 2005:16). Therefore, port planning and capacity planning cannot be evaluated independently from each other. While capacity in ports is considered to be an essential feature of the infrastructure that demonstrates the ability to provide a specific service, such as cargo handling (Dekker, 2005:7), it also demonstrates the ability to provide relevant services at specific costs and service life levels (Bichou, 2013:51). Capacity measurement as an indicator of the critical elements of ports, determining the necessity of new port investments, competition status, determining the tariff structure to be applied, the appropriateness of the investment time, determining the demand, increasing the port performance and profitability, change depending on the capacity (Oral, 2014:226). Thus, capacity affects port planning and design directly (Ding, 2010:124).

From this point of view and the objective of the dissertation, the following research questions were determined to perform a systematic content analysis of port capacity literature:

R.Q. 1: *What are the critical issues addressed in capacity measurement in ports?*

R.Q.2: *Which methods/approaches have been conducted to measure the capacity of ports in the extant literature?*

R.Q.3: *What is the relationship between the primary issues in port capacity measurement?*

4.1.2.2. Material Selection: Determination of the Target Population, Sampling, Keywords and Research Strings

The literature review was performed four times in previous periods. The studies on capacity measurement in ports were lastly obtained from Google Scholar and the peer-reviewed databases (Web of Science and Scopus) by using Harzing's Publish or Perish software on 15.01.2019.

The material selection process was performed in three stages. In the initial stage, the keywords used for the search were determined as "port capacity", "capacity calculation" in English and 365 studies were obtained in total. Once these studies were examined, it was determined that the obtained materials include the studies in different research fields. For this reason, keywords were refined and narrowed to achieve research streams on capacity measurement in ports directly. In the first stage, it was observed that only the research streams on measurement in port capacity were provided with the determined research string.

It was realized that scholars performed the port capacity measurement studies in more specific titles such as "berth capacity", "storage yard or yard capacity", "gate capacity". Therefore, the keywords were altered, and the search outputs were included in the sampling of the study. Table 14 illustrates the processes followed for material collection.

Table 14: Material Collection Approach

	Database	Search Strings	Query Limitations			Output
			Field of Search	Type of the Document	Time Range	
INITIAL STAGE						
1	Scopus	"port capacity" AND "capacity calculation."	Title, Abstract, Keyword, Content	Article, Review, Conference Proceedings	-	200
2	Web of Science	“port capacity” OR “capacity calculation”	Title or Topic	Article, Review, Conference Proceedings	-	128
3	Google Scholar	"port capacity" AND "capacity calculation"	Title, Abstract, Keyword, Content, Thesis	Article, Review, Conference Proceedings	-	37
FIRST STAGE						
4	Scopus	"port capacity" AND "capacity calculation" ("seaport" OR "terminal")	Title, Abstract, Keyword, Content	Article, Review, Conference Proceedings	-	45
5	Web of Science	"port capacity" OR "seaport capacity" OR "port terminal capacity"	Title or Topic	Article, Review, Conference Proceedings	-	13
6	Google Scholar	“port capacity” OR “capacity calculation”-“seaport” OR “terminal” OR “port”-NOT “airport”	Title, Abstract, Keyword, Content, Thesis	Article, Review, Conference Proceedings, Thesis	-	10
SECOND STAGE						
7	Scopus	("capacity calculation" AND "berth capacity") OR ("capacity calculation" AND "storage yard capacity") OR ("capacity calculation" AND "yard capacity") OR ("capacity calculation" AND "stockyard capacity") OR ("capacity calculation" AND "gate capacity")-(“seaport” OR “terminal”)- NOT “airport”	Title, Abstract, Keyword, Content	Article, Review, Conference Proceedings	-	2 (Duplication)

Table 14: Material Collection Approach (Continued)

8	Web of Science	"port capacity" OR "berth capacity" OR "storage yard capacity" OR "yard capacity" OR "stockyard capacity" OR "gate capacity"	Title or Topic	Article, Review, Conference Proceedings	-	15 (13 Duplications, 2 New)
9	Google Scholar	"port capacity" OR "berth capacity" OR "storage yard capacity" OR "yard capacity" OR "stockyard capacity" OR "gate capacity"	Title, Abstract, Keyword, Content	Article, Review, Conference Proceedings, Thesis	-	4 (Duplication)

Source: Compiled by the Author

As a result of the query, achieved studies were evaluated, the studies that included the related keywords, but not directly related to the capacity measurement of ports were eliminated. Additionally, two studies (1 study in Scopus, and one study in Web of Science) were written in English, but the full texts of these studies were written in different languages. Therefore, these studies were eliminated. Table 15 shows the final achieved studies from the databases.

Table 15: Number of Studies

Database	Number of the Studies (at the end of the first stage)	Number of the Studies (after the final elimination)
Scopus	45	26
Web of Science	15	14
Google Scholar	10	9
Total	70	49

Source: Compiled by the Author

Ultimately, 49 studies indexed in the Scopus, Web of Science and Google Scholar were examined.

4.1.2.3.Descriptive Analysis

The classification of the data was carried out by using Nvivo 12 software. All studies obtained from databases were imported to the software as individual cases, and values assigned to each case as attributes: these attributes are name of the journal, type of the document (review, article, book, book section, thesis, conference proceedings), category of the document (empirical and theoretical), the method, which is employed, focused type of port (bulk cargo terminal, general cargo terminal, container terminal, Ro-Ro terminal, liquid bulk terminal and all ports for the studies that did not specified the terminal type), focused topic of the study, focused section of the port (berth, storage yard, gate and all sections for the studies did not specify the section of the terminal) and database. The studies were tabulated and descriptively analyzed.

4.1.2.4. Selection of the Categories

The categories subject to content analysis were prepared in accordance with the research questions. Each of the studies were examined, and the focused topics of the studies were found out. Detailed evaluation of the categories was provided in the “Evaluating the Materials” section and the categories used in the coding were redeveloped.

4.1.2.5. Evaluation of the Materials

“Developing Capacity Measurement Method”, “Capacity Planning”, “Cost and Economic Analysis”, “Analysis of Existing Methods”, “Performance”, and “Forecasting and Market Analysis” that were assessed under the “Focused Topic of the Study” category were re-examined to employ content analysis with the Nvivo software. As a result of the re-examining, “Developing Capacity Measurement Method” and “Analysis of Existing Methods” were eliminated. Sub-categories were developed under the “Capacity Planning”, “Cost and Economic Analysis”, “Performance”, and “Forecasting and Market Analysis” categories. When building sub-categories, keywords, which evokes these themes, were determined. These categories were built as deductive and inductive iterative coding cycles (Seuring and Gold, 2012: 546) and each sub-category was iteratively eliminated or added. Since the languages of the studies are English, the subcategories determined in English.

Table 16: Categories and Sub-Categories

CATEGORIES			
Capacity Planning	Cost and Economic Analysis	Performance	Forecasting and Market Analysis
SUB-CATEGORIES			
Construction	Cost	Utilization	Forecast
Expansion	Capital	Efficiency	Market
Design	Investment	Effectiveness	Supply
Bottleneck	Economic	Service Level	Demand

Table 16: Categories and Sub-Categories (Continued)

Inadequate	Depreciation	Congestion	Consumer
Overcapacity		Performance	
Planning			
Development			

Source: Compiled by the Author

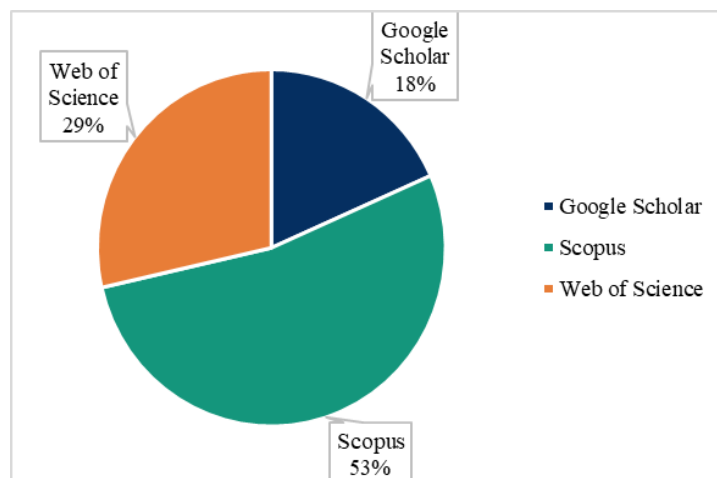
Statistical Distributions of the Researches

Within the scope of the research, the studies obtained regardless of the date range. Distribution of the studies over databases, distribution of the category of document over type of the document, distribution of focused topic of the study over databases and time, the method employed in the study and focused topic of the study, distribution of the focused topic of the study over focused type of the port and distribution of the focused topic of the study over focused section of the port were analysed under seven different topics.

Distribution of the Researches and Databases

The distribution of the studies obtained from three different databases over databases is illustrated in Figure 31.

Figure 31: Distribution of the Studies over Databases



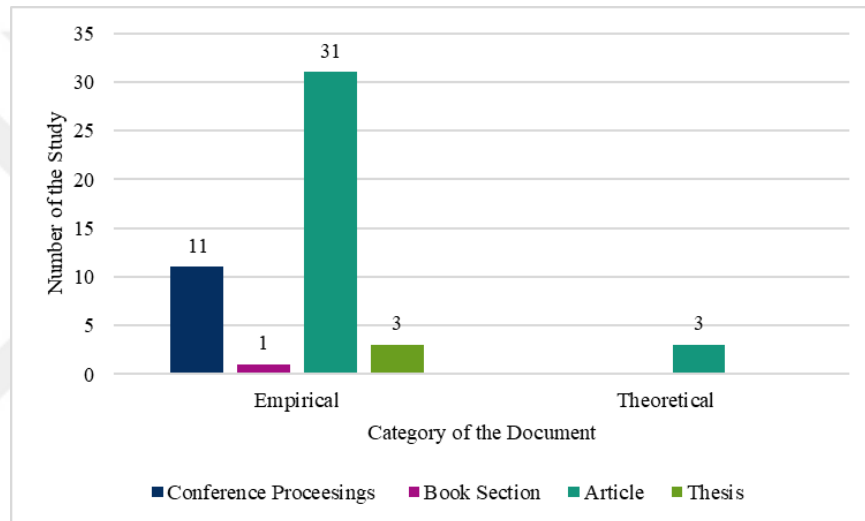
Source: Compiled by the Author

Predominant research streams on capacity measurement in ports were obtained from the Scopus. Web of Science constitutes 29% of the total studies whereas Google Scholar has 18% of this share.

Distribution of the Categories of the Document and Document Type

As a consequence of the classification efforts of the studies as empirical and theoretical, findings are shown in Figure 32:

Figure 32: Distribution of the Categories of the Document over Document Type



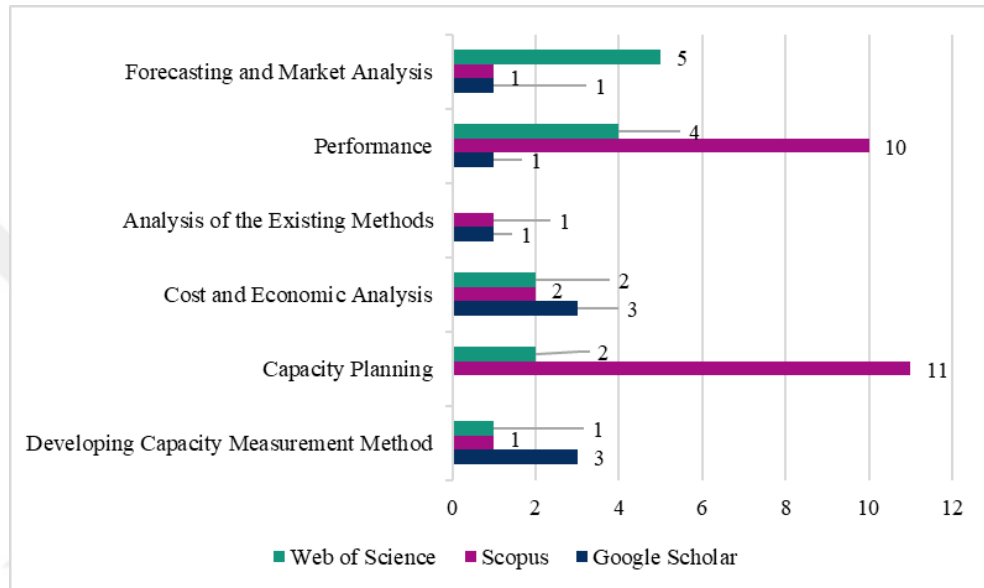
Source: Compiled by the Author

In the initial phase, the studies were classified as a review, conference proceedings, article, book, book section, and thesis. However, after the analysis of the studies, the studies were obtained in “conference proceedings, article, book section and thesis” categories. As a result of the classification, 46 studies were performed in empirically, whereas only three studies were carried out in theoretically. While article type of studies have the highest number of empirical studies, only one study which is the book section was obtained. Theoretical studies were performed as an article. The studies evaluated in the theoretical category are considerably less than the empirical category.

Distribution of the Focused Topics and Databases

Focused points of the study were developed by analysing the existing studies in the literature. Figure 33 shows the distribution of the focused point of the studies over databases.

Figure 33: The Distribution of the Focused Topics of the Study over Databases



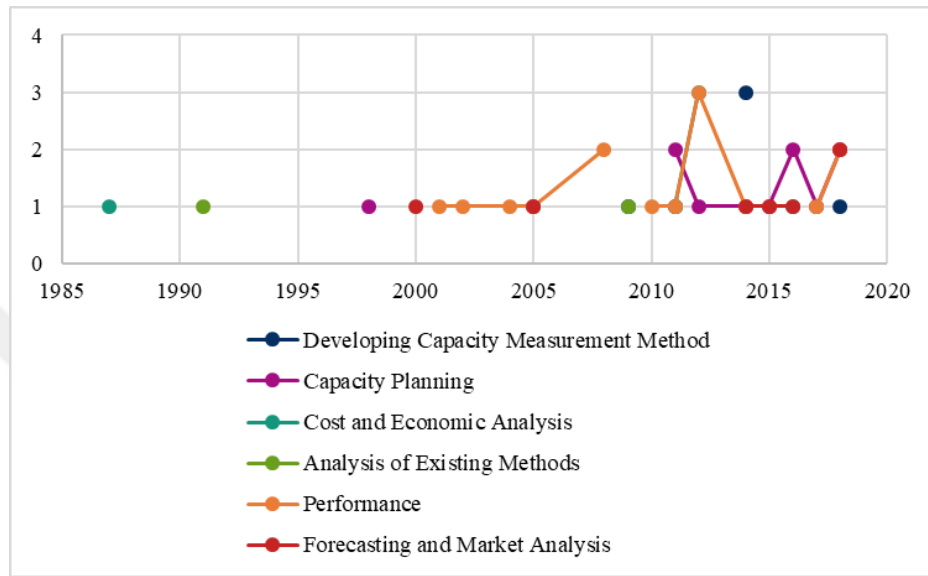
Source: Compiled by the Author

The highest number of studies in which capacity measurement methods were developed were obtained from the Google Scholar database. While the studies on capacity planning were mostly obtained from the Scopus, no study was obtained from the Google Scholar. Cost and economic analysis were found in all of the databases. There were no studies on the testing or analyzing of the existing measurement methods in the Web of Science. Comparing to other databases, Scopus has more study on performance. Web of Science predominantly focused on forecasting and market analysis studies. Extant researches mostly focused on the capacity planning and performance categories in the literature of capacity measurement in ports.

Distribution of Focused Topics and Year

Figure 34 illustrates the distribution of the focused topic of the study over the years.

Figure 34: The Distribution of the Focused Topic of the Studies over Years



Source: Compiled by the Author

According to Figure 34 performance and capacity planning subjects were continuously studied. It was determined that studies focused on the performance were increased by the year 2000. In addition, a higher increase was recorded in the years between 2010-2015 compared to other categories. The studies on developing the capacity measurement methods were progressed in discretely. According to the findings, only one study has been conducted in recent years. Although the studies focused on forecasting and market analysis was addressed in the previous years (2000 and 2005) discretely, it showed the continuity between the years of 2014 and 2016.

Analysis of the Methods Employed in the Researches and Focused Topics

49 studies obtained as a result of the database query was examined. It was determined that 21 methods were employed in these studies. Table 17 demonstrates modeling approaches to analyze the focused topic of the study.

Table 17: Modelling Approaches Employed in Port Capacity Measurement Literature

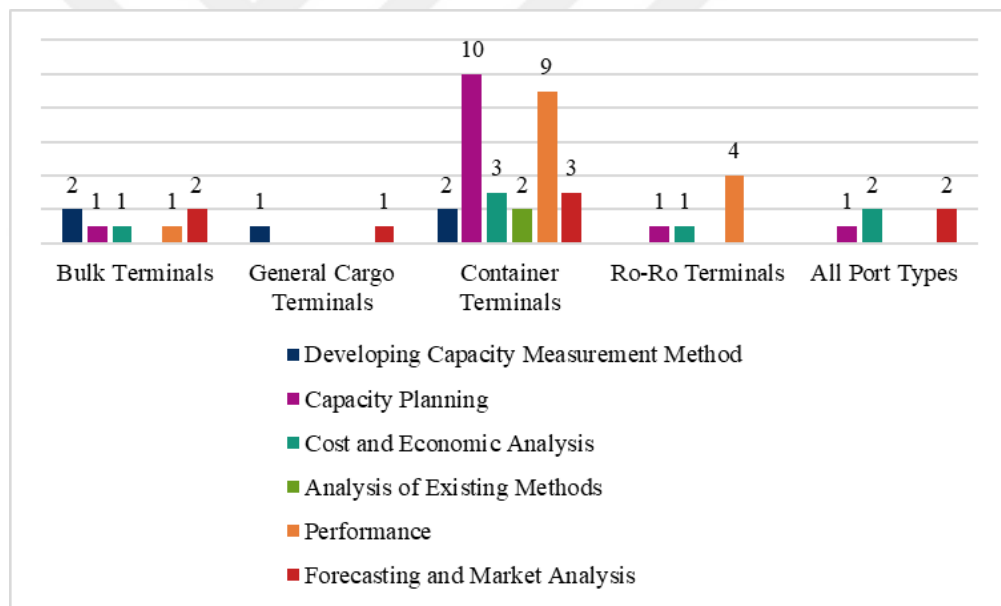
Methods	Developing Capacity Measurement Method	Capacity Planning	Cost and Economic Analysis	Analysis of Existing Methods	Performance	Forecasting and Market Analysis	Total
Survey						1	1
Discrete Event Simulation		1			2	1	4
Computer-based Simulation Methods	1	2	1		4		8
Fuzzy Comprehensive Evaluation		1					1
Non-linear Programming			1				1
General Equilibrium Model			1				1
Genetic Algorithm	1	1			1		3
Goal Programming					1		1
Statistical Methods-Data Analysis		1	2	1		1	5
Queuing Approach		4	1		4		9
Literature Review		1					1
Mathematical Programming						1	1
Interview					1		1
Game Theory			1				1
Case Study	2			1			3
Regression Analysis						1	1
Heuristic Algorithm		1					1
Simulation-Markov Chain	1						1
Simulation-System Dynamics		1					1
Neural Artificial Network					1		1
Time Series Analysis					1	2	3
Total	5	13	7	2	15	7	49

The most commonly employed methods/approaches in the extant studies are computer-based simulation methods and queuing approach. It was determined that the literature on capacity measurement in port employed the quantitative methods rather than qualitative. Besides, optimization techniques were frequently employed in the analysis of capacity measurement in ports.

Distribution of Focused Topics and Focused Port Type

In accordance with the research questions, the main topics concentrated on the types of ports were determined. Figure 35 demonstrates the main topics concentrated on the port types.

Figure 35: The Distribution of the Focused Topic of the Study over Types of Ports



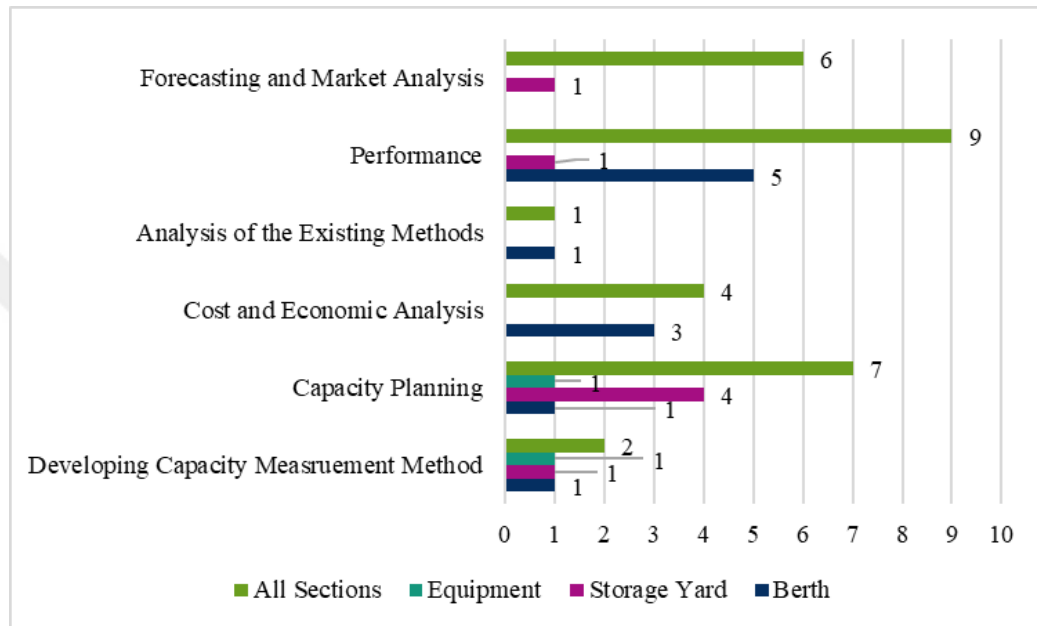
Source: Compiled by the Author

Concentration was observed on the container terminals in all the key themes. The minimum interest was paid on the general cargo terminals. Extant literature mostly focused on the capacity planning and performance themes in container terminals comparing the other related topics.

Distribution of the Focused Themes and Focused Port Section

It has been determined that the focused port sections, where the main topics concentrated were investigated. Figure 36 illustrates the findings.

Figure 36: The Distribution of the Focused Themes over Focused Port Section



Source: Compiled by the Author

In the light of the findings, all themes were discussed the all port sections as a whole. The other noteworthy aspect was that the studies focused on the berth section after all sections in the performance category whereas the studies secondarily focused on the storage yard section in the capacity-planning theme.

4.1.2.6. Findings of the Content Analysis

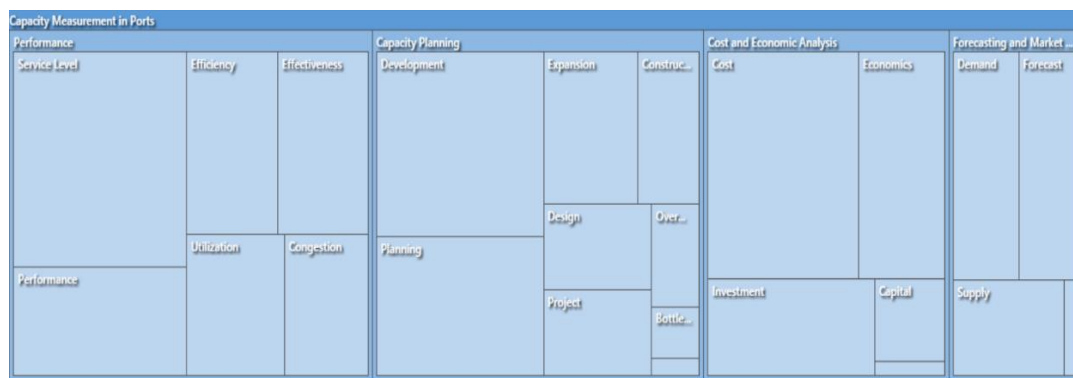
The content analysis applied by using Nvivo 12 software package. As stated in the “Descriptive Analysis”, 49 documents were imported to Nvivo as cases. Then the attribute values (name of the journal, type of the document, category of the document, focused type of the document, focused topic of the study, the focused section of the port, database) were introduced to the programme. Categories and sub-categories were assigned as nodes to perform the content analysis.

Once the content analysis was performed categories added as free nodes in the “Node” tab, sub-categories were assigned under the free nodes as tree nodes. Heading of the sub-categories were searched in the 49 studies by text query. “Text Query” tab opened, and the keywords of sub-categories determined for text search were written in the search box. Searching the exact meanings of the keywords leads to incomplete evaluation of the texts. Because a word has synonyms and it may be in simple past, simple present, infinitive form, etc.

For this reason, “Exact Matching” level fails to satisfy conducting content analysis. Instead of fixing the “Exact Matching”, the query was executed with “With Stemmed Words” in “Broad Context”. The paragraphs involving the determined words were coded to the corresponding nodes.

The word frequencies of sub-categories and the number of references in the paragraphs were determined. Service level (1603 words), performance (807 words) sub-categories were the most repetitive words in the “Performance” category. Frequencies of development (1331 words) and planning (1000 words) repeated more than the other sub-categories in the “Capacity Planning” category. Cost (1492 words) and economics (855 words) keywords were the most repetitive words in “Cost and Economic Analysis” category, whereas frequencies of the demand (668 words) and forecast (612 words) keywords repeated more in “Forecasting and Market Analysis” category. Hierarchy chart of the sub-categories is demonstrated in Figure 37.

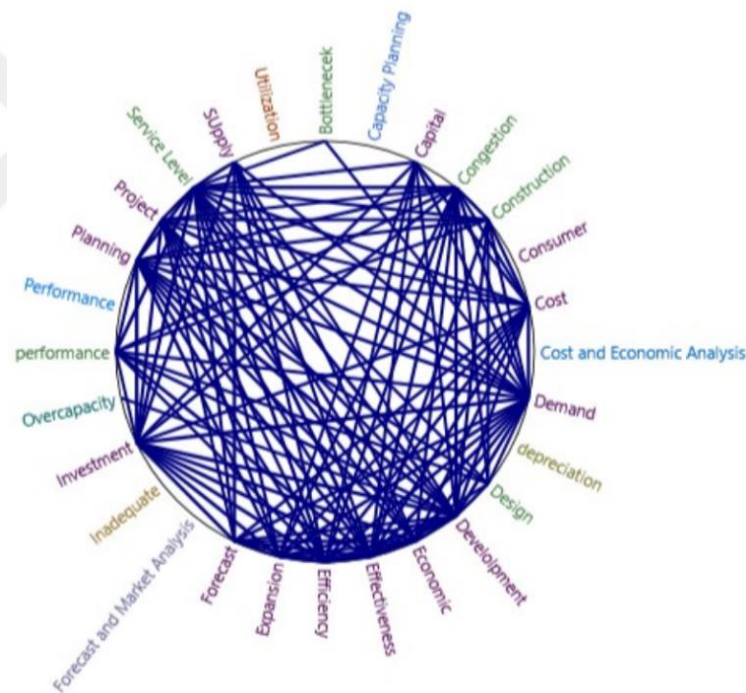
Figure 37: Hierarchy Chart of the Categories and Sub-Categories



Source: Compiled by the Author

Cluster analysis was conducted to determine the relationship between the key themes which research streams paid attention. Clustering analysis distinguishes meaningless components by combining the components with an ordinary meaning to ensure perceptual integrity (Krippendorff, 2004:208). The clustering analysis can determine the similarity between the nodes where the coding is performed. The similarity metric is the statistical methods that calculated the correlation between the determined items such as nodes, attributes, etc. Nvivo enables the usage of the Pearson Correlation Coefficient, Jaccard's Coefficient and Sorensen's Coefficient (QSR International (b), 31.10.2019). Figure 38 indicates the relationship between the identified sub-categories.

Figure 38: Similarity Analysis of the Nodes



Source: Compiled by the Author

The relationship networks were found in the sub-categories of “Investment”, “Efficiency”, “Demand”, “Congestion”, “Planning”, “Cost”, “Service Level”, “Development” and “Expansion”. Relationship level of determined categories was obtained Pearson Correlation Coefficient. “Service Level”, “Performance”, “Congestion”, “Construction” and “Design” is highly correlated with each other.

While the relationship between “Demand”, “Effectiveness”, “Investment”, “Expansion” and “Project” sub-categories is highly correlated, a high correlation was found between “Efficiency”, “Economics” and “Forecasting” sub-categories.

4.1.3. Concluding the Content Analysis

The literature on capacity measurement in ports made progress on capacity planning, cost and economic analysis, evaluation of existing measurement methods, performance, forecasting, and market analysis. Capacity measurement methods in the studies were generally based on optimization techniques. It was observed that the studies mostly focused on the container terminals rather than the other terminal types. These studies encompass all parts of the terminals (storage yard, equipment, berth, and gate) predominantly. In the “Performance” category, the most discussed topics were service level and performance, while in “Capacity Planning” category, the most discussed topics were development and planning. In “Cost and Economic Analysis” category, the mostly focused topics were cost and investment whereas in “Forecasting and Market Analysis” category, demand and forecast were the highly focused theme. As a result of the clustering analysis, it was observed that the strongest relation networks were found in the “investment, efficiency, demand, congestion, planning, cost, performance and capacity planning issues. Moreover, service level, performance, congestion, construction, and design are highly correlated subcategories. While demand, effectiveness, investment, expansion, project subcategories were highly correlated, a high correlation was found between efficiency, economics, forecast, and analysis. This results were supported by the extant literature (Bichou, 2013:5; Dekker, 2005:16; Oral, 2014:226; Ding, 2010:124; UNCTAD, 1985:27-38; Wu, 2014:62; Kleinheerenbrink, 2012; 22; Bot, 2012:117; Kox, 2017:82).

Most of the research streams generally focused on the container terminals. The consequences showed that the capacity measurement issue was addressed scantily for different terminal types. It was also investigated that capacity measurement was progressed based on the optimization. These measurements are based on several assumptions and constraints. However, a limited number of studies calculated installed capacity of the port were identified.

4.2. QUANTITATIVE RESEARCH

In this section, empirical equations for measuring dry bulk terminal capacity have been attempted to develop in the light of the empirical equations mentioned in *Chapter III* in the first step. As a second step, the equations have been coded at the RProject to simulate and test the developed equations.

4.2.1. Development of Empirical Capacity Measurement Equations for Dry Bulk Terminals

In this section, it is aimed to develop capacity measurement equations for measuring the berth handling capacity, storage yard capacity, equipment capacity, and berth occupancy ratio. The related equations have been examined and the variables used in these equations in *Chapter III* have been reviewed. Accordingly, several variables, which are underestimated by the scholars, have been added to the related equations. The details of the equations have been explained below mentioned sections.

4.2.1.1. Formulation of the Berth Handling Capacity of Dry Bulk Terminals

As stated in *Chapter III*, various formulas were developed in the existing literature to measure berth handling capacity of the port. Based on these equations, the main parameters to be used to measure the berth handling capacity of dry bulk terminals are given in Table 18.

Table 18: Nomenclatures of the Berth Handling Capacity Measurement Parameters of Dry Bulk Terminals

Measuring Parameters of Berth Handling Capacity	Symbol	Unit
Number of Berth	B_n	[-]
• Number of Handling Equipment (j)	$E_{j,n}$	[-]
• Number of Grab Unloader	$E_{G,n}$	[-]
• Number of Pneumatic Unloader	$E_{pne,n}$	[-]
• Number of Stacker Equipment	$E_{stc,n}$	[-]

Table 18: Nomenclatures of the Berth Handling Capacity Measurement Parameters of Dry Bulk Terminals (Continued)

• Number of Screw Type Unloader	$E_{scr,n}$	$[-]$
Hour capability of handling equipment (j) according to cargo (i) (ton per hour or a ton per gang per hour) (For general representation)	$C_{j,i}$	t/h
Grab Unloader/Loaders (ton per gang per hour)	$C_{mhc,i}$	t/h
• The Volume of Grab *	V_g	m^3
• Number of Gang*	Gng_n	g/h
• Ton per Gang*	Gng_t	t/g
• Maximum Lifting Capacity of the Grab Unloader/Loader*	$C_{max,lift}$	t
• Net Weight of the Grab*	$WT_{g,net}$	t
Pneumatic Loaders/Unloaders	$C_{pneu,i}$	t/h
Screw Loader/Unloader Capacity	$C_{scr,i}$	t/h
Bulk Density of the Cargo (i)	ρ_i	t/m^3
Berth Occupancy Ratio	BOR	$-$
Working Hours in a Day	t_{pd}	h
Working Days in a Year	t	d
Peak Factor	PF	$\%$

Source: Compiled by Author

*Values explained under “*Formulation of number of Gang according to Different Commodity Types*” subheading

With the evaluation of the berth handling capacity equations in the extant literature and considering the parameters placed in Table 18, the below-mentioned equation is determined to be measured realizable berth handling capacity of dry bulk terminals:

$$C_{berth} = \sum_{B=1}^n (C_{j,i} * E_{j,n} * BUF) * t_{pd} * t / PF; \quad \text{Equation (89)}$$

Where B is the berth number $[-]$; $C_{j,i}$ is the capacity of equipment (j) according to cargo (i); $E_{j,n}$ is the number of equipment (j); t_{pd} working hours per day; t is the working days in a year; BUF is berth utilization factor (explained in Section 4.2.1.4.) $[-]$; PF is the peak factor $[-]$.

Equation 89 is the formula in which the berth handling capacity is generally represented. When developing the equation mentioned above *Equation 5* (KMI, 1998), and *Equation 6* (Park et al., 2014:185) were referenced to place the ton per gang and hourly number of gang. However, BUF was developed with a different approach from BOR.

In practice, berth-handling capacity should be calculated by considering the particular berth and berth occupancy ratio belonging to the particular berth. For this reason, existing equipment is allocated to the particular berth and calculation is performed by each individual berth. After this process, the general berth handling capacity can be found by summing up the each values belonging to each berth.

Despite its simplicity, *Equation (89)* constitutes originality in terms of taking into consideration of the different dry bulk materials and real operational conditions. Generally, producers provide standard rates for the handling capacity of the equipment. However, crane hourly capacity is directly associated with the maximum weight which crane can lift, weight of the grab and volumetric capacity of the grab, crane operators. Only Oral (2014:231) addressed these issues by considering several assumptions. Other studies that developed a calculation formula for berth handling capacity did not pointed on this issue. Although all equations mentioned hourly capacity of the equipment (Park et al., 2014:185; KMI, 1998; Ligteringen and Velsink, 2012:155; National Research Council, 1998:81; UDHB, 2015b: 231), these researches did not point on how hourly capacity of the equipment was calculated. This formula is original in terms of determining the equipment capacities in accordance with the real operation conditions and considering different materials. Moreover, the feature that distinguishes *Equation 89* from the other equations is not only the parameters, but also the way this equation is applied. Since net service time regarded as the time that the equipment worked, the working efficiency of the equipment stated in the KMI (1998) was not taken into account. With this approach, vessel size, hatch structure of the vessel, the effect of crane operator and the effect of the bulk material type on the capacity can be measured.

Equipment capacities differs by the material types in practice. Specific bulk density changes hourly rate of the berth handling equipment. For this reason, *Equation (89)* has been mainly built on the equipment capability, which differs according to dry

bulk solid material. Although grab is not fully loaded, crane may have reached its maximum achievable weight. Therefore, ton per gang indicator should be determined by regarding the maximum lifting weight of the crane rather than grab volume for these type of solid bulk materials. In the opposite case, hourly capacity of the crane should be determined based on volumetric capacity of grab.

Existing equations evaluated the berth handling capacity by considering only gang capacity or one type of equipment. However, a port may use several equipment together. Every equipment has different working principles; therefore, the result achieved by regarding single equipment can provide misleading values about the capacity.

As it mentioned in the study of Park et al. (2014), the discrimination of the ratios of cargo type, vessel size, handling type parameters are reasonable in terms of identification of the effects of ships size on equipment capacity. However, measuring the equipment capacity regarding the several parameters requires the motion modelling of grab loaders/unloaders. Because, when the ship size increase, the equipment outreach increases at the same time. In this situation, the lifting capacity can be changed in the different angles, or these motions take much more time. Increasing the time extends the elapsed time to perform a gang. Because of that, the hourly capacity of the equipment differs. The fact that the actual number of gang per hour has not clearly determined. It is the most important limitation of this study. The assumptions about number of gang and the ton per hour capacity of the mobile harbour crane is explained under “***Formulation of Theoretical Gang Number by Commodity Types***” subheading in this chapter. Finding number of gang according to the *Equation (108)* is possible only when the actual service time is known.

4.2.1.2. Formulation of the Storage Yard Capacity of Dry Bulk Terminals

Measuring the dry bulk terminals’ storage yard capacity is more complicated comparing the berth handling capacity. As mentioned in *Chapter I, Section 1.2.1.2.*, open storage area, enclosed or covered storage area, silos, domes, and sheds should be assessed separately. Because, while covered storage area and silos have determined shape and volume, open storage area has not a specified shape. However, in an open

storage area of the terminal, there is not a specified volume. This situation creates a challenge for measuring the storage capacity of the area.

Extant literature generally focused on the design of the storage area (Ligteringen and Velsink, 2012: 157; Kox, 2017: 58). Measuring equations determine the required storage capacity, required lane length (Kox, 2017: 59), lane width, required stockpile length (Kleinheerenbrink, 2012, 28). In this study, the capacity of the terminals, which have been designed and perform its handling activities, has been tried to be measured. For this reason, design parameters were not considered to measure dry bulk storage yard capacity.

Once evaluating the equations of storage yard capacity, the significant parameters founded in the research streams have been listed in Chapter II, Section 2.2. Table 8. The main parameters to be taken into account in the calculation of the storage yard capacity of dry bulk terminals are given in Table 19.

Table 19: Nomenclature of the Storage Yard Capacity Measurement Parameters of Dry Bulk Terminals

Measuring Parameters of Storage Yard Capacity	Symbol	Unit
Storage Yard Capacity of a Dry Bulk Terminal	$C_{storage}$	t
Open Storage Area Capacity	C_{OA}	t
Open Longitudinal Storage Yard Capacity (ID-Preserved Policy)	$C_{OA, IID}$	t
• Number of Lane	n_{lane}	$[-]$
• Number of Stockpile	n_s	$[-]$
• Mass of Stockpile (about stockpile geometry)	m_s	t
○ The Distance between Two Stockpiles	d_s	m
○ Maximum Height of the Equipment	$h_{eq, max}$	m
○ Height allowed by the bearing capacity	$\frac{q_{max}}{\bar{\rho}}$	m
○ Length of the Lane	l_{lane}	m
○ The width of a Lane	w_{lane}	m
○ The height of the Stockpile	h_s	m
○ Length of the Stockpile	l_s	m
○ The width of the Stockpile	w_s	m
○ Maximum Height allowed by Lane Width	$h_{w, max}$	m
○ The tangent of the Mean Angle of Repose	$\tan \bar{\theta}$	$^{\circ}$

Table 19: Nomenclature of the Storage Yard Capacity Measurement Parameters of Dry Bulk Terminals (Continued)

• Average Amount of Cargo per Vessel • Average Dwell Time of the Cargoes • Peak Factor of Cargoes Stored in Open Storage Area	$\bar{V}_{s,ton}$	t
	$\bar{t}_{d,OA}$	d
	PF_{OA}	$[-]$
Open Longitudinal Storage Yard Capacity (CAM-Policy)	$C_{OA,ICAM}$	t
• Number of Lane	n_{lane}	$[-]$
• Length of a Lane	l_{lane}	$[-]$
• Mass of Stockpile (General representation of stockpile geometry)	m_s	t
• Mass of a Stockpile (by trapezoidal shape)	$m_{s,ts}$	t
• Mass of a Stockpile (by trapezoidal shape with end cones)	$m_{s,tec}$	t
• Mass of a Stockpile (by triangular shape with end cones)	$m_{s,trec}$	t
• Length of the Stockpile	l_s	m
• Average Dwell Time of the Cargoes in Open Storage Area • Peak Factor of Cargoes Stored in Open Storage Area	$\bar{t}_{d,OA}$	d
	PF_{OA}	$[-]$
Open Circular Storage Yard Capacity (Circular Stockpile)	$C_{OA,c,cir}$	t
• Number of Circular Bed	n_{bed}	$[-]$
• Mass of Cargo in the Circular Stockpile ○ The radius of the Area covered by the Equipment ○ The radius of the Top of Circular Mass ○ Net Angle seen from the Centre of the Circle	$m_{s,cir}$	t
	r_1	m
	r_2	m
	K	$^{\circ}$
• Peak Factor of Cargoes Stored in Open Storage Area	PF_{OA}	$[-]$
Open Circular Storage Yard Capacity (Conical Stockpile)	$C_{OA,c,con}$	t
• Number of Spaces Allocated for the Conical Stockpile	$n_{oA,c}$	$[-]$
• Mass of Cargo in Conical Stockpile	$m_{s,con}$	t
• Radius of the Circular Ground	r	m
• Average Dwell Time of the Cargoes	$\bar{t}_{d,OA}$	d
• Peak Factor of Cargoes Stored in Open Storage Area	PF_{OA}	$[-]$
Closed Storage Area Capacity	C_{CA}	t
Silo Storage Capacity	C_{silo}	t
• Installed Volume of the Silo	V_{silo}	m^3
• Number of Silo	n_{silo}	$[-]$
• Peak Factor of the Cargoes Stored in the Silo	PF_{silo}	$[-]$
• Averages of the Specific Bulk Density of Cargo (i)	$\bar{\rho}_i$	t/m^3
• Average Dwell Time of the Cargoes Stored in the Silo	$\bar{t}_{d,silo}$	d

Dome Storage Capacity • Installed Volume of the Dome • Number of Dome • Peak Factor of the Cargoes Stored in the Dome	C_{dome}	t
	V_{dome}	m^3
	n_{dome}	$[-]$
	PF_{dome}	$[-]$
• Averages of the Specific Bulk Density of the Cargoes	$\bar{\rho}_i$	t/m^3
• Average Dwell Time of the Cargoes Stored in the Dome	$\bar{t}_{d,dome}$	d
Shed Storage Capacity • Installed Volume of the Shed • Number of Shed	C_{shed}	t
	V_{shed}	m^3
	n_{shed}	$[-]$
• Peak Factor of the Cargoes Stored in the Shed	PF_{shed}	$[-]$
• Averages of the Specific Bulk Density of the Cargoes	$\bar{\rho}_i$	t/m^3
• Average Dwell Time of the Cargoes Stored in the Dome	$\bar{t}_{d,shed}$	d
Enclosed-Covered Storage Area capacity (In Stockpile Form) • Mass of Cargo in Stockpile • Mass of a Stockpile (by trapezoidal shape) • Mass of a Stockpile (by trapezoidal shape with end cones) • Mass of a Stockpile (by triangular shape with end cones) • Number of Enclosed-Covered Area • Peak Factor of Cargoes Stored in Enclosed Areas in Stockpile Form • Averages of the Specific Bulk Density of the Cargoes • Average Dwell Time of The Cargoes Stored in the Closed Areas in Stockpile Forms	$C_{EA, s}$	t
	m_s	t
	$m_{s,ts}$	t
	$m_{s,tec}$	t
	$m_{s,trec}$	t
	n_{EA}	$[-]$
	PF_{EA}	$[-]$
	$\bar{\rho}_i$	t/m^3
	$\bar{t}_{d,EA, s}$	d

Source: Compiled by Author

$$C_{storage} = \sum C_{OAl,CAM} C_{OAl,ID} C_{OA,c,cir} C_{OA,c,con} C_{silo} C_{dome} C_{shed} C_{EA,s}; \quad \text{Equation (90)}$$

Where $C_{storage}$ is the total storage yard capacity of a dry bulk terminal; $C_{OAl,CAM}$ is the open longitudinal storage yard area capacity which CAM policy implemented, $C_{OAl,ID}$ is the open longitudinal storage yard area capacity which ID-Preserved policy implemented; $C_{OA,c,cir}$ refers to the capacity of the open circular storage yard area that the cargoes are stored in circular stockpiles; $C_{OA,c,con}$ is the open circular storage yard area capacity that the cargoes stacked in conical stockpiles; C_{silo} is the silo storage capacity; C_{silo} is the storage capacity of the silo; C_{dome} is the storage

capacity of the dome; C_{shed} is the storage capacity of the shed; $C_{EA,s}$ is the storage capacity of the enclosed area that cargoes are stacked in a stockpile form.

A dry bulk terminal may not apply all storage implementations simultaneously. For this reason, in *Equation 90*, related variables can be eliminated in line with the measurement objectives.

The following equation was used when calculating the open storage area capacity of ports, which was implemented ID-preserved storage policy.

$$C_{OAI,ID} = n_{lane} * n_s * \bar{V}_{s,ton} * \frac{365}{\bar{t}_{d,OA} * PF_{OA}}; \quad \text{Equation (91)}$$

Where $C_{OAI,ID}$ is the storage capacity of the longitudinal open storage area of the terminal where ID-Preserved policy is implemented [ton]; n_{lane} is the number of lanes [-]; $\bar{V}_{s,ton}$ is the average amount of cargo per vessel subjected to storage [ton]; $\bar{t}_d$ is the average dwell time. PF_{OA} is the peak factor of cargoes stored in the open storage areas [-].

In addition to the equation as mentioned above, *Equation (92)* was built to measure the open storage area of the dry bulk terminal that CAM-Policy is implemented

$$C_{OAI,CAM} = n_{lane} * m_s * \frac{365}{\bar{t}_{d,OA} * PF_{OA}}; \quad \text{Equation (92)}$$

Where $C_{OAI,CAM}$ is the storage capacity of the longitudinal open storage area of the terminal where CAM storage policy is implemented [ton]; m_s refers to the mass of cargo in the stockpile concerning stockpile geometry (the value of the mass of stockpile changes by stockpile geometry) [ton]; $\bar{t}_{d,OA}$ is the average dwell time of the cargoes [day]; PF_{OA} is the peak factor of the cargoes stored in open area [-].

The dry bulk terminals also use circular storage systems in accordance with their functions. In case the circular storage yard is used, storage yard capacity of the circular storage yard can be measured with the following equation:

$$C_{OA,c,cir} = n_{bed} * m_{s,c} * \frac{365}{\bar{t}_{d,OA} * PF_{OA}}; \quad \text{Equation (93)}$$

Where $C_{OA,cir}$ is the circular storage yard capacity [ton]; n_{bed} is the number of circular bed [-], $m_{s,c}$ is the mass of circular stockpile [ton]; $\bar{t}_{d,OA}$ is the average dwell time of the cargoes [day]; PF_{OA} is the peak factor of cargoes stored in the open areas [-].

In the case of the conical stockpile is used in the dry bulk terminal, storage yard capacity of the terminal can be measured with the following formula:

$$C_{OA,c,con} = n_{OA,c} * m_{s,con} * \frac{365}{\bar{t}_{d,OA} * PF_{OA}}; \quad \text{Equation (94)}$$

Where $C_{OA,con}$ is the dry bulk storage yard capacity in case of conical stockpile [ton]; $n_{OA,c}$ is the number of spaces allocated for the conical stockpile [-]; $m_{s,con}$ is the stockpile mass in each allocated area [ton]; $\bar{t}_{d,OA}$ is the average dwell time of the cargoes (day); PF_{OA} is the peak factor of cargoes stored in the open areas [-].

The storage capacity of the enclosed areas is designed in two different methods. The first method depends on the installed volume of these structures. The reason behind this is usage of these structures as silos. Depending on the equipment used to load dome or shed, dome and sheds can be used in the same functions as a silo. The storage capacity of the enclosed areas equals to total storage capacity of these areas (C_{CA})

If silos are used in the dry bulk terminals, the following equation is employed to measure the capacity of the silos:

$$C_{silo} = \frac{V_{silo} * n_{silo} * \bar{\rho}_i * 365}{\bar{t}_{d,silo} * PF_{silo}}; \quad \text{Equation (95)}$$

Where C_{silo} is the storage capacity of the silo [ton]; V_{silo} is the volume of the silo [m^3]; PF_{silo} is the peak factor of the cargoes subject to storage in silos [-]; $\bar{\rho}_i$ is the average of the specific bulk density of the commodities [ton/m^3], $\bar{t}_{d,silo}$ is the average dwell time of the cargoes stored in the silos [day].

Similar to silo capacity, dome capacity is measured by using the following equation:

$$C_{dome} = \frac{V_{dome} * n_{dome} * \bar{\rho}_i * 365}{\bar{t}_{d,dome} * PF_{dome}}; \quad \text{Equation (96)}$$

Where C_{dome} is the storage capacity of the dome [ton]; V_{dome} is the installed volume of the dome [m³]; n_{dome} is the number of domes; PF_{dome} is the peak factor of the cargoes stored in the dome [-]; $\bar{\rho}_i$ is the averages of the specific bulk density [ton/m³]; $\bar{t}_{d,dome}$ is the average dwell time of the cargoes stored in the dome [day].

The shed is another enclosed structure used in dry bulk terminals. As in silo and dome, shed capacity is measured regarding its installed capacity;

$$C_{shed} = \frac{V_{shed} * n_{shed} * \bar{\rho}_i * 365}{\bar{t}_{d,shed} * PF_{shed}}; \quad \text{Equation (97)}$$

Where C_{shed} is the storage capacity of the shed [ton]; V_{shed} is the installed volume of the shed [m³]; n_{shed} is the number of sheds installed at the terminal (-); PF_{shed} is the peak factor of the cargoes subject to storage [-]; $\bar{\rho}_i$ is the average of the specific bulk density of the commodities [ton/m³]; $\bar{t}_{d,shed}$ is the average dwell time of the cargoes stored in the sheds [day].

In the second method of measuring enclosed or covered areas, the number of stockpile and stockpile geometry variables are used to measure storage capacity. Only shed and dome structure is considered.

If the cargoes are stacked as stockpiles in these enclosed structures, the following equation can be used to measure the specified closed areas;

$$C_{EA, s} = \frac{m_s * n_{EA} * 365}{\bar{t}_{d,EA, s} * PF_{EA, s}}; \quad \text{Equation (100)}$$

Where $C_{EA, s}$ is the storage capacity of the enclosed areas where the cargoes stacked in stocks [ton]; m_s is the mass of cargo in the determined stockpile geometry (when calculating this variable, the equation of that geometry should be considered) [ton]; $PF_{EA, s}$ is the peak factor of the cargoes that stored in closed areas where stockpile is used [-]; $\bar{t}_{d,EA, s}$ is the average dwell time of the cargoes stored in the closed areas in the stockpile forms [day].

Generally, storage yard capacity has been addressed twofold in the literature. The first one is required storage yard capacity which is mostly used port and terminal design. The second one is stacking capacity of the stockpile. Required storage yard capacity measurement is the calculation based on how much capacity will be needed in the future or in terminal design phase depending on the estimation of the potential of port throughput. With such an assessment, the capacity of port to be realized with the existing facilities may not yield accurate results. Because although the port throughput is related to capacity issue, it is directly proportional to the port marketing efforts, relationships between its stakeholders, the potential and requirement of the region where port is located. Although the existing capacity of the port has the potential to handle certain level of cargo, port's actual cargo potential may fall behind these levels. For this reason, these levels may not provide the actual results.

Stacking capacity is another important factor that determines the storage yard capacity of the terminal, and capacity levels can change according to stacking characteristics and stacking policy. Stacking characteristics and stacking policy determine actual capacity levels of the port capacity. These issues were addressed separately in the literature. Stacking characteristics and stacking policy have been poorly integrated in evaluation formula of storage yard capacity. This study integrates stacking characteristics with regard to stockpile geometry and stacking policy, much as it has been reflected as binary. All the areas such as open area, enclosed area, silo, dome, shed have been modelled regarding stockpile geometry and ID-Preserved and CAM storage policy by expressing capacity of these areas algebraically. Additionally, peak factor of the storage yard areas has been evaluated differently from berth. Given the fluctuations in demand, peak factor of storage yard needs to be evaluated apart from berth. Because sousplan implementation reduce the amount of cargo stored in the area. In this case, storage yard capacity is not affected as high as berth capacity.

Details of the development processes of the equations are explained in the following sections.

Equation Development Steps of Storage Yard Capacity for Dry Bulk Terminals

The storage yard capacity of the open area is highly associated with the design parameters, types of storage yard (i.e. longitudinal, circular (Kox, 2017, 43), length of the lanes, width of the lanes, equipment used at the terminal area, technical features of the equipment (max outreach of the boom, height of the boom etc.), stockpile geometry (trapezoidal shape with end cones, trapezoidal shape, triangular shape with end cones, coned), average cargo amount in a stockpile, number of stockpile in the lane.

Therefore, it was decided that some steps should be followed to measure the storage capacity of the open areas. The actions to be considered in measuring storage yard capacity of the dry bulk terminals are as follow:

- ***Open Storage Area (Storage Capacity)***
 - Determining the open storage yard type (longitudinal or circular)
 - Determining the designed lane width (If longitudinal is used) (Also stockpile width)
 - Determining the number of lanes installed (If longitudinal is used)
 - Determining the designed lane length (If longitudinal is used)
 - Determining the stockpile height
 - Determining the size of the planned circular area (If circular storage is used)
 - Determining the number of circular areas established (If circular storage is used)
 - Designing stockpile geometry used at the terminal
 - Trapezoidal shape with end cones
 - Triangular shaped with end cones
 - Coned shape
 - Determining the average amount of cargo in a stockpile
 - The average angle of repose of the cargoes
 - The average bulk density of the cargoes
 - Determining stockpile length (concerning CAM or ID preserved storage policy)
 - Determining stockpile width

- Determining stockpile height (concerning the maximum height of the equipment can reach, bearing capacity of the ground, height allowed by the specified width)
- The diameter of the ground (if circular storage is used)
- **Covered Storage Area (Storage Capacity)**
 - Determining the enclosed or covered storage yard type (longitudinal or circular)
 - Determining the designed lane length (If longitudinal is used)
 - Determining the designed lane width (If longitudinal is used)
 - Determining the number of lanes
 - Determining the size of the planned circular area (If circular storage is used)
 - Determining the number of circular areas installed (If circular storage is used)
 - Designed stockpile geometry used at the terminal
 - Trapezoidal shape with end cones
 - Triangular shaped with end cones
 - Coned shape
 - Determining the average amount of cargo in a stockpile
 - The average angle of repose of the cargoes
 - The average bulk density of the cargoes
 - Determining stockpile length (concerning CAM or ID preserved storage policy)
 - Determining stockpile width
 - Determining stockpile height (concerning the maximum height of the equipment can reach, bearing capacity of the ground, height allowed by the specified width)
 - The diameter of the ground (if circular storage is used)
- **Silo (Storage Capacity)**
 - The diameter of the silo
 - The height of the silo
 - Determining the average amount of cargo in a silo

- The average angle of repose of the cargoes
- The average bulk density of the cargoes
- Number of Silo

Measuring the Storage Capacity of Longitudinal Open Storage Area

The capacity measurement of open areas was performed in accordance with the steps mentioned above. The details are provided below.

Determination of Lane Length

In case the longitudinal storage is used, lane width, lane length, the number of the lane, stockpile geometry, the maximum height of the equipment used at the terminal, maximum outreach of the equipment and bearing capacity are determined at the designing phase of the terminal.

For this reason, the lane width and the lane length is considered as the designed size. ID-Preserved policy logic is based on the fact that cargoes of customers do not mix. Stockpile is created into the separate stacks. Therefore, the determination of the required length for the stockpile within the designated lane width can be achieved by determining the tonnage of the cargoes in each stockpile. It would be reasonable to consider the averages of the cargo tonnages subjected to storage for determining the amount of cargo in each stock (Ligteringen and Velsink, 2012). Once this length has been identified, it is possible to determine how many stockpiles can be placed in the specified lane length. Besides, stocks are not separated if CAM-based storage policy is implemented. Hence, by considering the stockpile geometry, it is possible to calculate the storage capacity by the lane width and length.

Storage capacity can be calculated through the width and length of the lane considered the stockpile geometry.

Determination of Stockpile Width

The stockpile width is limited to the width of the lane. Therefore, this study attempts to determine the cargo amount that can be stored in the installed and allocated areas. The factors that restrict the height of the stockpile are the maximum height of the equipment and the bearing capacity of the ground. Height restriction will also affect the width of the stockpile. After reaching a certain height, the cargo shifts towards the edges. Therefore, the cargo can be stacked at a certain height, to the extent that the certain width permits. As the stack height increases, the area to be covered by the stockpile on the ground increases. Because of these factors, designed capacity and the amount of cargo that can be stacked show difference in the implementation.

Determination of Stockpile Height

The height of the stockpile is restricted by the bearing capacity of the ground and the maximum height of the equipment used for stacking the cargoes at the terminal. This situation added to the model as binary variables to determine the stockpile height. Thus,

If $h_{eq,max} > \frac{q_{max}}{\bar{\rho}}$,

The allowable height of the stockpile is $\frac{q_{max}}{\bar{\rho}_i}$

If $h_{eq,max} < \frac{q_{max}}{\bar{\rho}}$; maximum allowable height is $h_{eq,max}$

Where $\frac{q_{max}}{\bar{\rho}}$ is the maximum allowable height concerning bearing capacity of the ground [m], $\bar{\rho}_i$ is the average density of the cargoes [t/m³]; $h_{eq,max}$ is the maximum height of the equipment [m].

Besides, lane width has a particular effect on the stockpile height. The height can be determined to the extent the lane width permits. However, if the stockpile height allowed by the lane width is higher than the bearing capacity of the ground and maximum height allowed by the equipment, the stockpile width is narrowed accordingly. Conversely, in case the bearing capacity of the ground and the equipment

height exceeds the maximum height allowed by the lane width, the height-determining factor is the width of a lane. Under these circumstances;

$$l_{lane}=l_s$$

$$w_{lane}=w_s$$

$$h_s=\min \left\{ \frac{q_{max}}{\bar{\rho}}; h_{eq,max}; h_{w,max} \right\}$$

Where h_s is the height of stockpile [m].

Stockpile Geometry

Generally, several geometric shapes are used in the designing of a stockpile. These shapes are a trapezoid, trapezoidal with end cones, triangular, triangular with end cones, coned, etc.

The below-mentioned section explains the calculations of the mass of cargo in the stockpile with regard to pile geometry.

Trapezoidal Shape of Stockpile

Equation (33) that was adopted from the UNCTAD (1985) by van Vianen et al. (2012:10) can be employed for the trapezoidal shape of a stockpile. The following formula, which is obtained from van Vianen (2012:10) by making little modification, can be used to calculate the mass of cargo at the stockpile.

$$\bar{V}_{s,ton} = m_{s,ts} = \frac{2*h*(2*w*tan\bar{\theta}-2h)*w^2*tan\bar{\theta}*\bar{\rho}_i}{w^2*tan^2\bar{\theta}*4}; \quad \text{Equation (101)}$$

Where $\bar{V}_{s,ton}$ is the average amount of cargo per ship (The ratio of the total amount of cargo to be stored in the terminal to the number of the vessel which carries the cargoes subjected to storage); $\bar{\theta}$ is the averages of the angle of repose of the commodities; $\bar{\rho}_i$ is the averages of the specific bulk density of the commodities. As this thesis focuses on the calculation of the dry bulk terminals where multiple commodities are handled simultaneously, averages of the angle of repose and specific

bulk density of the commodities are taken into account to calculate the total mass of cargo in stockpiles in the same equation.

Trapezoidal Shape with end Cones Stockpiles

In the calculation of the mass of cargo in a trapezoidal shape with end cones, the following equation that is obtained from van Vianen, (2015:78) by little modifying:

$$\bar{V}_{s,ton}=m_{s,tec}=\left(l-\frac{2h}{\tan\theta}\right)h\left(w-\frac{h}{\tan\theta}\right)+\frac{h^2}{\tan\theta}\left(w-\frac{2h}{\tan\theta}\right)+\frac{\pi h^3}{3\tan^2\theta} \quad \text{Equation (102)}$$

The logic of the averages of specific bulk density in the trapezoid shape of the stockpile is applied in the type of trapezoidal shape with end cones stockpile.

Triangular Shape with End Cones of Stockpile

One another stockpile geometry frequently used stacking the cargoes is triangular with end cones.

$$m_{s,trec}=\left(\frac{\bar{\rho}_i(3hwl+h\pi w^2)}{6}\right); \quad \text{Equation (103)}$$

Where $m_{s,trec}$ is the mass of triangular stockpile with end cones; h is the height of the stockpile; w is the width of the stockpile (also it equals to $\frac{2h}{\tan\theta}$); l is the length of the triangular stockpile; $\bar{\rho}_i$ is the averages of the specific bulk densities of the commodities.

Determination of Stockpile Size in ID-Preserved Implementations

With the determination of the height, the width of the stockpile, and stockpile geometry, the amount of cargo that can be placed in a lane can be found out.

Stockpile height and width determination criteria were described in *Section 1.1.1.* and *Section 1.1.2.* Now, it is explained how many stockpiles can be placed by considering stockpile geometry, width and height into a lane.

Determination of the Number of Stockpiles placed into a Lane

With the determination of stockpile height, width and geometry, as stated in the ID-preserved policy, there must be a certain distance between the two stockpiles so that the loads do not interfere. The gap between the two stocks is limited to the implementations of the port.

In the case of a given length of the stockpile, the number of stockpiles that can be placed in a lane is calculated by the following equation:

$$n_s = \frac{l_{lane}}{(l_s + d_s)}; \quad \text{Equation (104)}$$

Where n_s is the number of stockpiles placed in a lane; l_{lane} is the length of a lane; l_s is the length of a stockpile; d_s is the distance between two stockpiles. The equation mentioned above is built by the fact that there is a space left in the front and back of each stockpile.

Determination of Stockpile Size in CAM-Policy Implementations

In the CAM-Policy implementations, commodities are not considered separately. All commodities are stored in a single stockpile. As is the case with the ID-Preserved policy, the average amount of cargo subjected to storage is not taken into account to measure the stockpile capacity that can be stored in a lane. Therefore, the lane length limits the length of the stockpile, and the width of the stockpile is limited by the lane width. The cargo amount that can be stored depends on the stockpile geometry, the bearing capacity of the ground and the maximum height of the equipment.

Measuring the Storage Capacity of Circular Open Storage Area

In this type of storage and stacking system, the number of circular ground allocated, the diameter of the circular bed, are the important variables in the measuring number of tons in a stockpile. As is the case with the other stacking implementations, the maximum height of the equipment, the bearing capacity, and the height that the diameter can allow are important to determine the height of the stockpile.

Circular open storage area has circular beds created for the blending of the cargoes. However, the stockpile formed by stacker type equipment is conical, and it is not evaluated under the longitudinal storage yards. For this reason, conical-shaped stockpile was assessed under the circular open storage areas.

Circular Stockpile: Chevron type stacking is commonly used in circular open storage. Blending type equipment is frequently used equipment for chevron-type circular storage. The stockpile geometry of this type of storage is formed on a circular bed.

In this type of circular storage, the configuration of both ends may show a difference. While the starting point of the stockpile is a rectangular shape due to equipment specifications, the form at the end point is conical. The detail was considered when developing the equation.

To measure the determined shape of stockpile following formula is developed:

$$m_{s,c} = \bar{\rho}_i \left[\left(\frac{h(r_1-r_2)}{2} * \frac{K}{360} * \pi(r_1-r_2) \right) + \frac{(r_1-r_2)^2 \pi h}{12} + \frac{(r_1-r_2)h^2}{2 \tan \theta} \right]; \quad \text{Equation (105)}$$

Where $m_{c,s}$ is the mass of circle stockpile; r_1-r_2 is the stockpile width, h is the height of the stockpile; K is the net angle to be considered for the calculation. K is calculated by eliminating the areas over the circle, where occupied by the width of equipment and stockpile ends. In the above-mentioned formula, the ends of the stockpile are different. One side ends with the conical shape whereas the other side ends with a triangular shape (with the smooth surface).

Conical Stockpile: The height of the conical stockpiles depends on the bearing capacity of the ground, the maximum height of the ground, and the diameter of the conic as in other examples of the stockpile. Under these circumstances, provided that

the lowest value of the $\frac{q_{max}}{\bar{\rho}}$, $h_{eq,max}$, and $h_{w,max}$ is taken, the capacity of conical stockpile can be measured as follows:

$$m_{s,con} = \frac{\pi * r^2 * h}{3} * \bar{\rho}_i; \quad \text{Equation (106)}$$

To measure the conical stockpile capacity at the dry port ports where multiple bulk solids are handled, Equation 106 can be transformed into the following equation:

$$m_{s,con} = \frac{\pi * r^3 * \tan \bar{\theta}}{3} * \bar{\rho}_i;$$

Where $m_{s,con}$ is the conical stockpile capacity; r is the radius of the base circle [m]; $\tan \bar{\theta}$ is the tangent of the mean of the angle of repose [°]; $\bar{\rho}_i$ is the mean of the specific bulk density of the commodities [ton/m³].

Hence, the circular storage yard capacity which conical stockpiles is used can be calculated as follows:

$$C_{OA,c,c} = n_{OA,c} * m_{s,con} * \frac{365}{\bar{t}_{d,OA} * PF_{OA}}; \quad \text{Equation (107)}$$

Where $C_{OA,c,c}$ is the circular storage yard capacity which conical stockpile is used [ton]; $n_{OA,c}$ is the number of the allocated area for the conical stockpile (similar to bed) [-]; $m_{s,con}$ is the mass of the cargo in conical stockpile; $\bar{t}_{d,OA}$ is the average dwell time of the cargoes [day]; PF_{OA} is the peak factor of cargoes stored in the open areas [-].

Measuring Storage Capacity of the Enclosed Storage Area

Different forms of the enclosed area can be seen at the dry bulk terminals. These forms can be either shed, silo or domes. Storage in closed or covered areas varies depending on the equipment to be used. In addition, commodities can be stored in these areas longitudinally and circularly or stacked in a silo, dome and shed geometry. In

case of continuous filling of these areas (i.e., band) the installed volume of these structures should be taken into consideration. Besides, if the commodities are to be stored as stockpiles in enclosed or covered areas, capacity measurement of the method of these areas will be the same as the method followed in measuring the longitudinal open storage areas.

Measuring the Silo, Dome and Shed Storage Capacity

Generally, as these structures are filled throughout their volumes, the installed size is used to calculate the storage capacity of these structures. Commodities to be stored in the dome, shed and silo may vary and the variables such as peak factor and dwell time of the cargoes to be stored in these areas may also differ. These variables are indicated in *Equation (95)*, *(96)*, and *(97)*.

Apart from the equations mentioned above, if the cargoes are stacked as stockpiles in sheds and domes structures (only one stock is considered per structure), *Equation (100)* can be used.

4.2.1.3. Formulation of the Dry Bulk Equipment Capacity

In this section, the approaches have been addressed to develop measuring equations for the pneumatic conveyors, the number of gang (for the grab loading or unloading) and amount of cargo per gang (regarding the specific bulk densities of the materials), truck carrying and bulldozer carrying capacity. To measure the equipment capacity, the equations in *Chapter III, Section 3.1.3* have been used for the modelling within the context of the dissertation. For the measuring screw conveyor and belt conveyor capacity (for three idlers), and flat belt conveyor carrying capacity, *Equation 55* and *Equation 43* and *Equation 40* has been employed, respectively. For calculating storage yard stacking equipment capacity, van Horssen (2013: 3) approach (*Equation 57* and *Equation 59*) has been used in the study.

Formulation of Theoretical Gang Number by Commodity Types

The mobile harbour cranes and travelling overhead trolley, revolving grabbing crane and mobile harbour crane perform loading/unloading operations via grab. Equipment has different motions and specifications. Revolving grabbing crane and mobile harbour crane have three main motions as hoisting, luffing and slewing. Hoisting motion refers to lifting motion whereas luffing is the linear motion of boom through up and down. Besides, the slewing motion refers to the rotation movement of the boom. It is quite difficult to model the motion of the equipment due to complexity of the operator experience. Modelling requires observation of crane motions in practice and differs according to the operator's experience. For this reason, an assumption has been made considering the grab volume and the total number of gang performed for a particular material. This approach can be considered for each berth if the berths are divided for a particular material. To do this, it is necessary to determine the amount of cargo that can be handled per gang by considering the specific bulk density.

If it is necessary, for the calculation of grab actual capacity, the below-mentioned equation can be used:

$$gph = \frac{m_{i,tll}}{(\rho_i * V_g) \text{ or } (C_{max, lift} - WT_{g, net})}; \quad \text{Equation (108)}$$

$$ST_{i, act}$$

Where gph is the number of gang per hour [g/h]; $m_{i,tll}$ is the total amount of cargo for the material (i) [t]; ρ_i is the specific bulk density [t/m³]; V_g is the volume of the grab [m³]; $ST_{i, act}$ is the actual berth service time for the cargo (i) [h]. Then the hourly handling capacity of the grab equipment can be found by multiplying the Equation (108) with the gang per ton. Gang per ton differs according to the specific bulk density of the material and maximum lifting capacity of the crane, weight of the grab and grab volume. For this reason, grab capacity has been represented as a binary object in the model as mentioned below:

$$\left\{ \begin{array}{l} \text{If } \rho_i * V_g < C_{max, lift} - WT_{g, net}; \quad Gng_t = \rho_i * V_g \\ \text{If } \rho_i * V_g > C_{max, lift} - WT_{g, net}; \quad Gng_t = C_{max, lift} - WT_{g, net} \end{array} \right\};$$

Where $C_{max, lift}$ is the maximum lifting capacity of the crane [t]; $WT_{g, net}$ is the net weight of the grab [t].

Equation (108), it can be useful when the number of gang is not available. Indeed, mobile crane manufacturers do not provide the gang number in their manuals. Equipment manuals only provided the lifting capacity, jib length, total weight the crane can lift, hoisting lowering speeds, and maximum radius (Liebherr, 15.05.2019; Konecranes, 15.05.2019; Mina, 15.05.2019; Crane Market, 15.05.2019; Bromma, 15.05.2019).

Additionally, the determination of the number of gang is difficult when certain values of net service time is not available. If ports record the number of gang performed in an hour, that value can be used. Otherwise, the catalogue values can be employed.

In this study, a concept used for determining the number of gang under the normal operational conditions considering material characteristics was introduced called as theoretical number of gang. Theoretical gang number is different from the actual gang number. Hold structure, picking and dropping height of the cargo, material nature, crane operator skill directly affect the hourly gang capacity of the grab cranes. In normal operational conditions, grab crane performs more gang in an hour. However, grab filling rate is not constant. Grab filling differs in different height of the hold. For example, grab filling rate decrease as it reaches to the bottom of the holds (assuming the weight allowed by the volume fills the internal clearance).

It is not possible to establish a certain equation to determine the number of gang if the port or stevedores do not record gang number. For this reason, assuming that the grab handling equipment performs loading and discharging operation with a full filling rate in each gang during the net operation time, it can provide a theoretical number of gang within an operation time per vessel.

Grab crane can perform more gang than the gang theoretically can perform. For this reason, theoretical number of gang is always lower than the actual number of gang. Theoretical gang number that can be performed for a given material within specific operation times can be determined by Equation (108).

Formulation of Pneumatic Conveyor Carrying Capacity

As mentioned in *Chapter III Section 3.1.3.3.*, several approaches developed for the pneumatic conveying capacity in the literature. These studies generally attempted the estimate the velocity of the air, material, material losses and design of the pneumatic conveying. For this reason, a rough estimation has been performed to estimate pneumatic conveying capacity.

Table 20: Nomenclature of the Pneumatic Conveyor Capacity

Measuring Parameters of Pneumatic Conveyor Capacity	Symbol	Unit
Volumetric Flow Rate	$\dot{V}$	m^3/s
Conveying Velocity	v	m/s
Cross-Sectional Area of the Pipe	A	m^2
The density of the Air plus Material	ρ_{mix}	kg/m^3
The volume of Material (i)	V_i	m^3
Total of Mass Flow Rate of Air and Material (i) per Second	$\dot{m}_{mix}$	kg/s
Mass Flow Rate of the Material (i)	$\dot{m}_i$	kg/s
Solid Loading Ratio	ϕ	$[-]$

Source: Compiled by Author

To find the pneumatic conveying capacity, the volumetric mass of flow rate should be determined in the first step. Volumetric flow rate can be calculated by using the below-mentioned equation:

$$\dot{V} = vA$$

Where $\dot{V}$ denotes volumetric mass of flow rate [m^3/s]; v is the conveying velocity [m/s]; A is the cross-sectional area of the pipe. However, finding volumetric mass flow rate is not enough for calculation of the ton per hour capacity of the pneumatic conveyor capacity. For this reason, mass of material and air mixture should be determined considering the material-air ratio (solid loading ratio). The equation used to find the mass of material and air mixture is mentioned in the following equation:

$$\dot{m}_{mix} = \dot{V} \rho_{mix};$$

Where $\dot{m}_{mix}$ is the total flow rate of the mixture [kg/s]; ρ_{mix} is the density of the mixture [kg/m³]. Solid loading ratio [ϕ] which has been referenced to in the literature as material/gas flow (Mills, 2004:243) can change according to conveying characteristics (dilute or dense phase). By using this ratio, cubic meter value of 1kg of material and air can be found. To find the mass of mixture flow rate, the mass of air and material divided by the volumetric mass of flow of the material and air. By determination of the result of the equations as mentioned above, *Equation (109)* can be used for the measuring conveying capacity of the pneumatic system can be calculated with the following formula:

$$\dot{m}_i = \frac{vA\rho_{mix}\phi}{\phi+1}; \quad \text{Equation (109)}$$

Formulation of Truck and Bulldozer Carrying Capacity

Trucks and bulldozers can be used as transfer equipment at the dry bulk terminals as well as belt and screw conveyor. As well as in the determination of the number of gang, the binary object has been generated for the truck and bulldozer carrying capacity as follows:

$$\left\{ \begin{array}{l} \text{If } \rho_i * V_{trk} > Max_{trk}, \quad CC_{trk} = Max_{trk} \\ \text{If } \rho_i * V_{trk} < Max_{trk}, \quad CC_{trk} = \rho_i * V_{trk} \end{array} \right\};$$

$$\left\{ \begin{array}{l} \text{If } \rho_i * V_{bld} > Max_{bld}, \quad CC_{bld} = Max_{bld} \\ \text{If } \rho_i * V_{bld} < Max_{bld}, \quad CC_{bld} = \rho_i * V_{bld} \end{array} \right\};$$

Where V_{trk} is the volume of the truck bed [m³]; Max_{trk} is the maximum capacity of the truck [ton]; CC_{trk} is the truck carrying capacity [ton]; V_{bld} is the volume of the bulldozer grab; Max_{bld} is the maximum capacity of the bulldozer [ton]; CC_{bld} is the bulldozer carrying capacity [ton]. Thus, hourly carrying capacity of the trucks and bulldozers can be calculated with the following equation.

$$C_{trk} = E_{trk,n} * CC_{trk} * T/O_{n,trk,i} * t_{pd} * t;$$

$$C_{bld} = E_{bld,n} * CC_{bld} * T/O_{n,bld,i} * t_{pd} * t;$$

Equation (110)

Where C_{trk} is the hourly transfer capacity of the truck for cargo (i) [ton/h]; $E_{trk,n}$ is the number of truck [-]; CC_{trk} is the carrying capacity of the truck with regard to volume of the truck, specific bulk density and maximum weight the truck can carry [ton]; $T/O_{n,trk,i}$ is the number of turnover of the truck in an hour [truck/h]; C_{bld} is the hourly transfer capacity of the bulldozer for cargo (i); $CC_{bld,i}$ the carrying capacity of the bulldozer with regard to volume of the truck, specific bulk density and maximum weight the bulldozer can carry [ton]; [ton/h]; $E_{bld,n}$ is the number of bulldozer [-]; $T/O_{n,bld,i}$ is the number of turnover of the bulldozer in an hour [bulldozer/h].

4.2.1.4. Formulation of the Berth Utilization Factor

Berth occupancy ratio, as mentioned in the literature, has an indicator function that shows congestion level of the berth, and traffic and operational berth utilization level. As mentioned in *Chapter III, Section 3.2.4.1.*, berth occupancy rate is commonly used for the berth handling capacity calculations. However, this concept should be discussed within the context of the capacity types and following questions: “Which factor or coefficient differs when calculating the different capacity types and why?”, “What is the real function of the berth occupancy rate?”, “What do different capacity outputs mean?”, “Is there any relationship between the installed and existing port capacity and ship traffic?”, “Is ship traffic a decisive factor in the determination of port capacity?”, “How does the attainable capacity of the port be measured?”, “How does the right combination of parameters be performed to measure the capacity that the port can achieve?”. These questions have not been discussed thoroughly in the literature as far as is known. Besides, the existing capacity calculation efforts did not state which capacity results were obtained. An assumption can be made to deepen these differences further and to make a clear distinction.

Berths are the major facilities at the port to handle the cargo and utilization of these structures is essential for measuring the cargo throughput. Asset utilization of

the berths is evaluated concerning the ship tonnage and cargo amount handled at the berth (Chung, 1993:2). While Chung (1993:2) assessed the berth utilization differently from the berth occupancy rate, de Wielle and Ray (1968:4), Timur (2016:7), Kuznetsov and Kirichenko (2016: 490) evaluated the berth utilisation from the berth occupancy perspective. Besides Tang et al. (2016: 174) evaluated the berth occupancy levels as an indicator of both port service level and utilization of the facilities, Layaa and Duallert (2014) used the BOR for determining the capacity utilization level and service level.

Berth utilization is evaluated as the time consumed at the berth and physically utilization of the berth (Tsinker, 2004:33). In the light of the formula in the literature, it can be said that berth utilization is evaluated in two different viewpoints: Operational utilization (service time of vessels for handling the materials) and utilization depending on the vessel traffic. Operational utilization depends on equipment capacity, vessel size, cargo amount, and material characteristics, whereas in utilization depending on the vessel traffic, the crucial parameter is number of vessel calls. That is why researchers developed different calculation methods and denominated these efforts as berth occupancy ratio. However, only Chung (1993:2) distinguished the berth utilization and berth occupancy rate. Chung (1993:2) also stated that measuring the berth utilization is more advantageous than berth occupancy rate.

Berth occupancy ratio, which is commonly used in measuring port capacity level, is a parameter that depends on the vessel traffic (utilization depending on vessel traffic) and service time (operational utilization). Queuing approach was frequently applied to determine berth occupancy level (Tsinker, 2004: 33; de Langen and Helminen, 2015:20; Gurning and Fikri, 2016:10; Timur, 2017:2; Radmilovic and Jovanovic, 2006:101; Layaa and Duallert, 2014:151; UNCTAD, 1985; Ligteringen and Velsink, 2012). This approach mainly depends on the vessels calls and service time. Therefore, any change that may be observed at number of vessel calls and service rate accordingly berth occupancy ratio, changes the capacity level. In this point, these questions should be asked: “Is vessel traffic a decisive factor in the determination of port capacity?”, “Are there any relationships between the installed and existing port capacity and vessel traffic?”. There are two different cases to explain these questions. In the first case, demand is constant and serves with unlimited equipment, storage yard

area, and berth handling facilities. This port has actual capacity depending on the vessel traffic, has a theoretical capacity depending on working hours and a realizable capacity level. In the second case, assume that the same port cannot provide service due to the demand insufficiency (low vessel calls). The following questions should be asked, “Can this situation change the actual, realizable, and theoretical capacity of the port?”. The second case does not change the attainable realizable capacity and theoretical capacity of the port. However, the actual capacity will change due to vessel traffic conditions. This case also differentiates the capacity types, and realizable capacity concept asserted in *Chapter II, Section 2.3*. Although National Research Council (1998:78) and UNCTAD (1973) defined the intrinsic and practical capacity, different studies in the literature utilized the berth occupancy ratio for measuring throughput capacity of the port. However, these studies did not explain the situations mentioned above. This creates the need for a new concept for realizable capacity measurement. This concept is called as berth utilization factor in this study.

Berth occupancy ratio (employs queueing approach) which considers the ship traffic and service time can be used in actual capacity measurement attempts. However, it may fall behind to determine berth utilization level that the port can attain independently of vessel traffic. For this reason, operational utilization of the berth needs to be considered to measure realizable capacity, which explains the possible output levels where the terminal is independent of actual demand conditions (vessel traffic). Determination of berth utilization level according to operational utilization of the berth may show realizable capacity level when the port is not affected by the vessel traffic.

Berth utilization factor, which considers only operational utilization of the berth, can be expressed mathematically as follows:

$$\sum_{i=1}^n \left(\frac{\sum_{v=1}^n ST_{i,act}}{(\sum_{v=1}^n Bt) + (V_n * t_{be})} \right); \quad \text{Equation (111)}$$

Where $ST_{i,act}$ is total actual service time in the berth [hour]; Bt is the total time the berth is occupied by a vessel [hour]; V_n is the number of vessel [-]; t_{be} is the time taken by berthing operation of a vessel; i refers to number of berth [-], v refers to vessel

number [-]. i is the berth number [-]. $ST_{i,act}$ refers to the net service time whereas Bt includes both net service time and idle time at the berth. *Equation (111)* is similar to Zamanirad et al. (2017:22), Chung, (1993:5) and India Ministry of Shipping (2011:73), but it differs from the other formula in terms of reflecting the berthing operation.

4.2.2. Simulating Port Capacity Calculation Model

Simulation modelling employed by computer specialists, mathematicians provides many advantages for the several industrial areas and organizations (governmental, military, educational, traffic control, computer system design, electronics, physics, environmental, economics and social sciences, chemical industries, designing of transport, communication, manufacturing, computer system design) about enhancing the effectiveness and efficiency (Ülgen and Williams, 2002: 3; Praehofer, 1991: 287). Simulation modelling and analysis can solve large spectrum of problems. The reasons behind the being popular in the business environment are the increase in boundless competition, cost-reduction efforts, explanation and estimation capabilities of the simulation, and requirements of effective decision-making, effective problem identification considerations (Ülgen and Williams, 2002: 3).

According to Gilbert and Troitzsch (2005:17) the logic of the simulation is starts with the model development. Modelling is the illustration of the real world phenomena in the form of mathematical equations, flow charts, software programme or algorithm. Therefore, simulation is the technique that is drawn in connection with the model to acquire the answer about complicated matters (Lewis and Orav, 2018:9).

Several steps have been identified for the simulation-based studies in the literature. This process mainly starts with the determination of research question(s) as well as in the scientific research process (Mihram, 1976:72; Gilbert and Troitzsch 2005:19; Ülgen and Williams, 2002: 13; Ülgen, et al. 1998: 2). This process directs the basis of the model. Models can be built based on the several assumptions. These assumptions, inputs and process definitions drive the model (Gilbert and Troitzsch 2005:19; Ülgen and Williams, 2002: 13). After determination of the assumptions, the model can be designed. When designing the model, simplification creates a set of challenges for the model developer deciding about the exclusion of pointless or

inclusion of parameters. It will be necessary to measure more parameters with the addition of these parameters. This will be challenging in terms of the validity of these results (Gilbert and Troitzsch 2005:19-26). Model building process follows the model designing. The model designer can utilize the several software programs after completion of the model building; simulation results can be obtained by executing the program (Gilbert and Troitzsch (2005:19). However, the model should be checked in terms of validation and verification. In this stage, model builder should examine the model in terms of building the model correctly (verification) and building the correct model (Ülgen and Williams, 2002:18; Ülgen and Williams, 2001:107; Andersson, 1974:6-7). This stage will be possible running the model and measuring the model behaviours. Moreover, the sensitivity test can also be applied to investigate the model in terms of measuring the behaviour of the model against the stated assumptions. The last stage is publishing the simulation results (Gilbert and Troitzsch, 2005:17).

There are several analytical tools to perform simulation analysis. Java, C, FORTRAN, GPSS, ARENA, Simple++, Prolog, C++, Smalltalk, SIMSCRIPT, Lisp etc. (Gilbert and Troitzsch, 2005:19; Ülgen and Williams, 2002:18; Ülgen and Williams, 2001:115).

4.2.2.1. Sampling and Data Collection Process for Model Testing¹

For the testing the generated model, the population of the research was chosen as dry bulk terminals in Iskenderun Region. Iskenderun region has wide hinterland and the hinterland can reach three countries and fifteen cities located near this region (Ateş, 2014:448, İsdemir, 2017). The ports located in Iskenderun Bay are Limak Port, Milangaz LPG Terminal, Sasa Terminal, Petrol Ofisi Pier Port, Yazıcı Port, Orhan Ekinci Port, Assan Port, Isdemir Port, MMK Metalurji Port, Delta Terminal, Aygaz Terminal, Port of Toros, Ceyhan Marine Export Terminal, Botaş Terminal, İskem Port, and Denbirport Terminal. While the ports in the north of the region perform mostly in liquid cargo handling activities, the ports mostly in bulk, general cargo and container are located in the south of the region (UDHB, 2015).

¹ The some of the information mentioned under this title was published as a research article in “Gülmez, S., Esmer, S. And Ateş, A. (2018). An Analysis of Seaborne Trade through Iskenderun Bay. Maritime Faculty Journal. 10(1), 83-107”

Research sample has been chosen among the ports located in Iskenderun Bay, which its core business is dry bulk commodities. For choosing the right sample, preliminary study was performed. In the study, amount of cargo tonnages and commodity groups of bulk cargoes were explored on the basis of ports (Gülmez et. al. 2018). The tendencies of the region is illustrated in Table 21.

Table 21: Cargo Groups and Materials subjected to Import and Export in Iskenderun Region

Cargo Groups	Materials
Iron	Iron and steel products, pig iron, slab, processed iron, steel roll, iron pipes, iron wire rod, sheet metal, slag, iron wire rod, iron ore, iron ore concentrate
Mineral	Aluminium, florspat, barium, calcite, aluminium ore, bauxite, manganese ore, calcite, chromium, chromium ore
Coal	Coking coal, pit coal, goudron
Fertilizer	Urea fertilizer, phosphatic fertilizer, compound fertilizer, compost fertilizer
Cement	White cement, cement
Petroleum	Benzole, natural bitumen, gas oil, diesel oil, petroleum coke
Chemical	Coustic soda, paraxylene
Other	Pumice stone, tufa, gypsum, ingot, gypsoplast, wheat, plant equipment, wind turbine tower, tank truck, tanker truck bed, miscellaneous materials, cossette, corn, pallet, plastic tank, prefabricated materials, trailer, fodder and pasture, soy beans, flour, floating platform

Source: Gülmez, et al. 2018: 92

An interview was held with the sectoral consultants to choose the right sample among the ports. In accordance with the advices of sectoral consultants, the sample subjected to capacity calculation was chosen as a port having a certain volume of cargo and maintaining continuity of its cargo volume. However, name of the port and the data set obtained from the port were not shared in this study. In order to test the model, a data set template was generated in 64 items. 64 items was prepared to be used directly in the model. During the creation of this template, model inputs were determined in detail. The requested items are shown in the Table 22:

Table 22: Data Set Items

ITEMS	
The Name of the Vessel	Specific Bulk Density of the Material
GRT	Amount of Cargo much greater than the Normal Condition
DWT	Duration of the Closing and Opening Hatch Covers
NRT	Duration of Berthing
LOA	Duration of Unberthing
Beam	Technical Specifications of the Equipment Used in the Berth
Number of Hold which Handling Operation is Performed	Periodical Maintenance
Date and Time of Application for Berthing	Average Number of Movements between Ship Holds
Date and Time of Berthing	Technical Specifications of the Equipment Used in the Storage Yard Area
Date and Time of Application for Unberthing	Technical Specifications of the Transfer Equipment
Date and Time of Unberthing	Maximum Speed Limit Within the Port Area
Duration of Berthing and Unberthing	Total m ² of the Port Area
Net Working Time	Net Storage Area (m ²)
Material Type	Area of Service Buildings (m ²)
Amount of Stored Cargo	Total Area of the Roads (m ²)
Amount of Sousplan	Stacking Policy
Open Storage or Closed Storage	Number of Lane
Cargo Type (Dry form or big bag)	Average Stacking Height
Amount of Transit	The Distance between the Stockpile
Handling Equipment	Number of Closed Area (Shed, Silo, Dome, etc)
Loading Tonnage	Stacking Characteristics of Closed Areas
Unloading Tonnage	The Average Distance between Storage Yard and Berth
Number of Gang	Bearing Capacity of the Ground
Berth No	Working Days
Specific Bulk Density of the Material	Working Hours in a Day
Dwell Time	Average Downtime due to Weather Conditions
Cargo Type (Dry form or big bag)	Average Downtime due to Equipment Failure
Amount of Transit	Number of Berth and Size of the Berths

Table 22: Data Set Items (Continued)

Handling Equipment	Draft of the Berths
Loading Tonnage	Working Hours of the Berths
Unloading Tonnage	Additional Downtime
Berth No	

Source: Compiled by the Author

The port determined as a sample, serves multiple cargo groups. Moreover, it performs both export and import activities at the same time. In the first step, we contacted port managers via e-mail and got an appointment. Interview was held at the port. During the 90 minutes, research motivations and model were discussed and shared with the port managers. In addition to this, cargo groups, equipment, infrastructure and port process are discussed. The template include 64 items was shared with the port managers. After 6 days, the data set covering 3 years was sent from the port via e-mail. However, the data obtained from the port was not suitable for direct implementation. For this reason, some of parts of the data were processed and transformed into suitable data to be used for the model. Features of the port determined as the research sample is illustrated in Table 23.

Table 23: Specifications of the Port

SPECIFICATIONS OF BERTHS AND BERTH HANDLING EQUIPMENTS					
Number of Berths #		4			
Berth Handling Equipment	Berth Length	Draft	Grab Weight	SWL	Capacity
Grab Crane at #1	185	10.5	2 ton	6 ton	125 tph
Grab Crane at #1			3 ton	8 ton	175 tph
Grab Crane at #2	270	13	6.5ton	17 ton	400 tph
Grab Crane at #2			6.5ton	17 ton	400 tph
Grab Crane at #3	270	13	13.2 ton	30 ton	600 tph
Grab Crane at #3			13.2 ton	30 ton	600 tph
Grab Crane at #4	220	10	8 ton	20 ton	580 tph
Grab Crane at #4			8 ton	20 ton	580 tph
SPECIFICATIONS OF TRANSFER EQUIPMENTS					
Belt Conveyor #2,#4					600 tph

Table 23: Specifications of the Port (Continued)

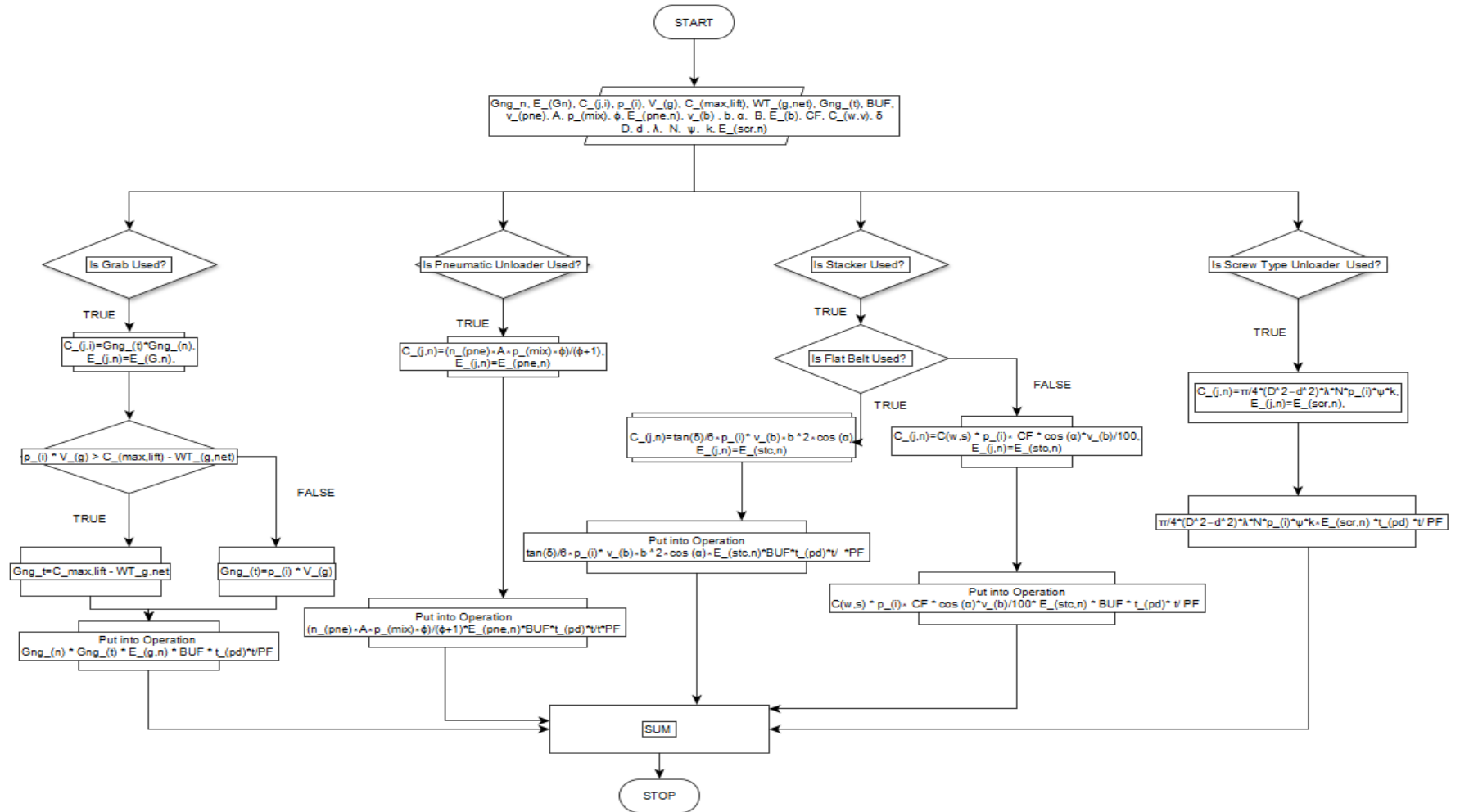
Belt Conveyor #1	400 tph	
Belt Conveyor #5, #7	800 tph	
STORAGE AREA SPECIFICATIONS		
Closed Area Facilities	Installed Volume	Capacity
Flat Grain	211*54*10	60,000 ton
Fertilizer 1	204*51*11	35,000 ton
Fertilizer 2	204*48*10	32,000 ton
Dwell Time	45 days	
OPEN STORAGE AREA SPECIFICATIONS		
Dedicated Area	Area	
Concentrated Open Storage Area	11,500 m ²	
Non Paved Storage Space for Coal	500,000 m ²	
Additional Storage Space for General Purpose with Capacity	275,000 m ²	
Office Building	10,000 m ²	
Roads	32,407.5 m ²	
Bearing Capacity of the Ground	7 t	
Average Stacking Height	10 m	
Dwell Time	45 days	
GENERAL SPECIFICATIONS		
Working Days	347	
Working Hours in a Day		
Three Shifts in a Day	22,5 h	

Source: Compiled by the Author

4.2.2.2.Designing of the Conceptual Model

Designing of the conceptual model includes decision-making process about how the system should be demonstrated concerning the capabilities and components ensured by the tool. Creation of conceptual modelling efforts reduces the risk of running the simulation. Building conceptual model provides greater advantages to ensure that all variables are included in the model and that certain subjects are examined (Ulgen et al. 1994). Within the context of the study, conceptual model was generated based on the calculation process of port capacity regarding three basic component of the port and illustrated in Figure 39.

Figure 39: Conceptual Model of Berth Handling Capacity Calculation



In conceptual model of berth handling capacity, the calculation process has been abstracted. Ports use several combinations of equipment. In this study, the issue has been addressed in broader perspective considering the possibility of using different handling equipment combination. For this reason, all the berth handling equipment previously examined in *Chapter I* has been included in the simulation model. Generated empirical equations mentioned in Chapter IV, Section 4.2.1.1. for measuring berth handling capacity is included in the simulation model.

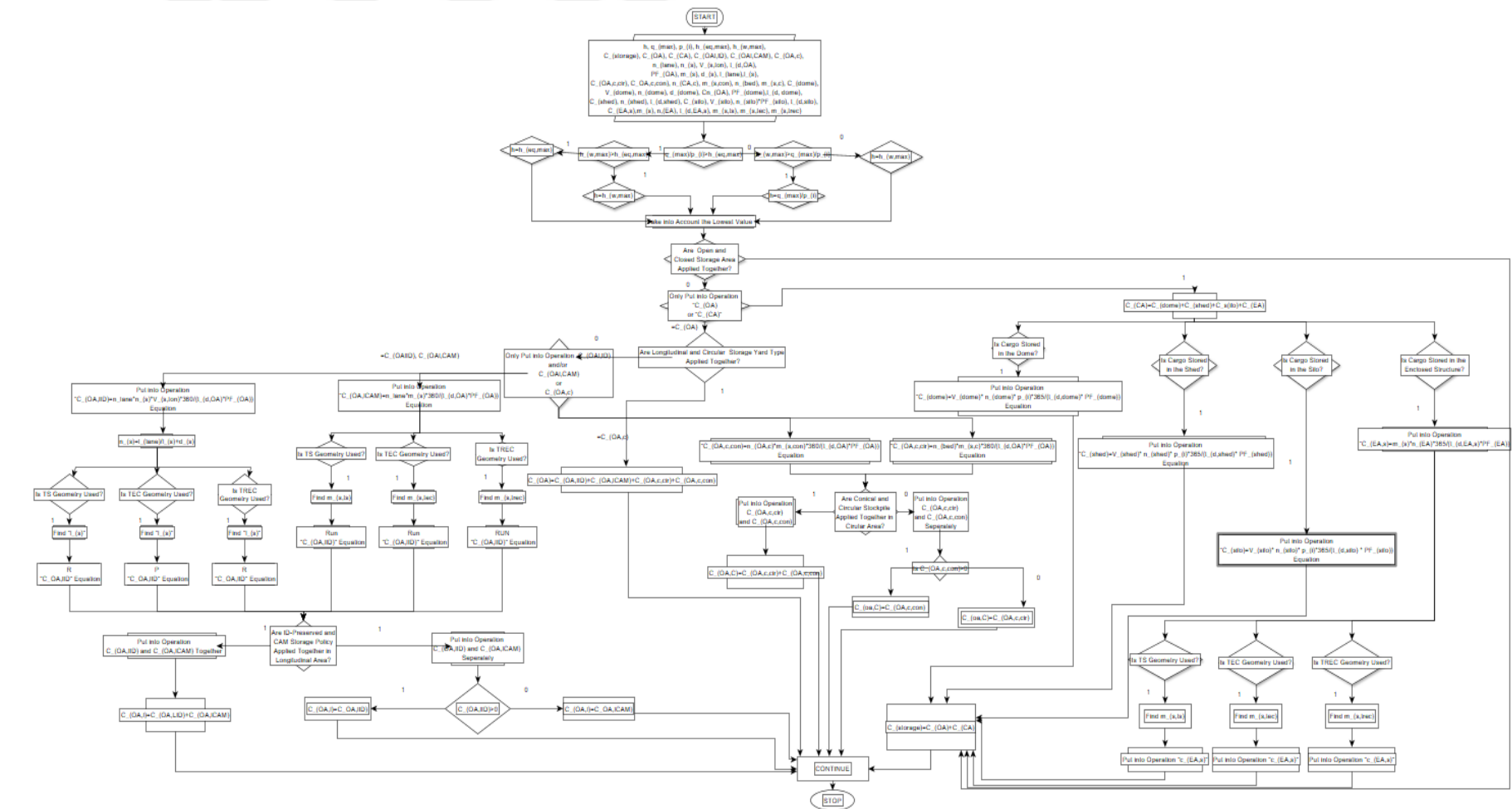
First step starts with the identifying the variables. Four main equipment (grab handling equipment, pneumatic unloader, stacker, and screw type unloader) are included to the model. The system works by performing a set of query about the usage of these equipment. For instance, in case of using grab handling equipment, system obtains the results by performing the specified operations. Once again if grab handling equipment and stacker used together at the berth, the mathematical operations are performed by the system and the results are summed.

The special conditions are identified for the grab handling equipment and stacker. As stated previously, grab handling equipment capacity depends on the lifting capacity of the crane, volume of the grab, density of the subjected material, weight of the grab. Accordingly, this situation has been reflected to conceptual model and simulation as a decision. If specific bulk density is low and the volume is high, calculation module regards the volume of the grab to determine capacity. In an opposite case, module regards the grab crane lifting capacity.

Another decision has been defined for the stacker type equipment. According the conceptual model, if stacker type loader/unloader is equipped with the flat belt, the equation which performs the calculation with the flat belt variables will be operated. Whereas in case stacker is equipped with three throughing idler, the equations which is identified for the three throughing idler will be regarded.

As well as in calculation module of berth handling capacity, a conceptual model has been prepared for measuring storage yard capacity of a dry bulk terminal. Figure 40 illustrates the conceptual model of storage yard capacity.

Figure 40: Conceptual Model of Storage Yard Capacity Calculation



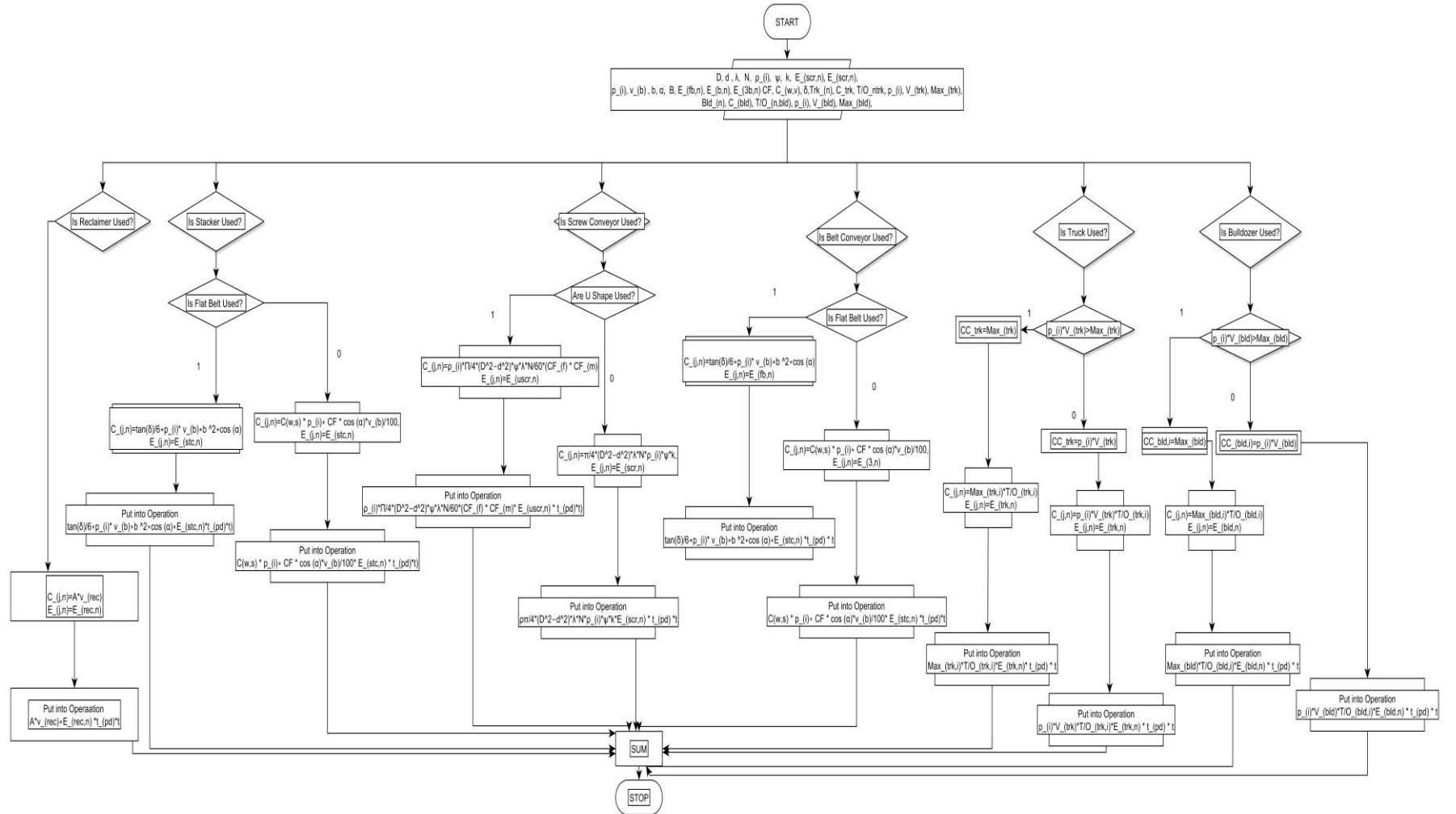
Conceptual model of storage handling capacity shows how the model is abstracted. As a first step, all input variables has been identified in accordance with the simulation model. In the next step, one of the most important point is the determination of stockpile height. This situation depends on three different circumstances and identification have been performed regarding these situation (bearing capacity of the ground, equipment maximum height, height depend on the width). Similar with the berth handling capacity measurement, different scenarios has been identified for different implementations. For instance, a port can employ both longitudinal and circular storage yard implementations. Accordingly, the result will be evaluated together. However, when only one of the storage types is implemented, the different process will be followed. If only longitudinal storage type is implemented, simulation model queries that which storage policy is implemented (ID-Preserved and CAM). Because ID-Preserved storage policy based on cargo segregation of the piles, stockpile length will be found according to stockpile geometry. A port may also implement the different stockpile geometry. A final step, the conceptual model queries whether different storage policies are applied together or not. If the result is positive, then the simulation model runs both CAM and ID-Preserved equations.

For the closed area capacity measurement, simulation model performs the similar inquiries. The simulation runs the defined equation for measuring the specified storage capacity of the area after performing a query about the storage facility type. In case of using dome, silo or shed, model performs the equation by using the determined inputs.

The process defined for the enclosed areas is similar to process of open areas. If stockpile method is used at enclosed areas as well as at the open storage areas, simulation performs a query. in accordance with the stockpile geometry employed at the enclosed area, stacking capacity of the stockpile is determined and added to the total storage capacity of the terminal.

Finally the conceptual model of the transfer equipment, which is one of the important component of the terminal, is shown in Figure 41.

Figure 41: Conceptual Model of Transfer Equipment Capacity Calculation



Different equipment have been considered for measuring transfer equipment capacity of a dry bulk terminal. Different equations have been identified for each equipment. For the conceptual model of capacity calculation of transfer equipment, the variables to be used in the model have been identified as well as in other conceptual models. System queries the whether stated equipment are used or not. Decision have not been defined only for the reclaimer. Reclaimer and stacker have been evaluated differently due to impracticability for the simultaneous operation. Similar to the capacity calculation of berth handling equipment, the same conditions and decisions identified for the stacker equipment. For the screw conveyors, only the shape factor considered. As mentioned in the earlier chapters of the study, screw conveyor parts show difference in accordance with the horizontal or vertical usage of the equipment. Screw conveyor as a transfer equipment can perform cargo transfer horizontally. In that situation, “U” shape screw conveyors can be used. That is why two decisions have been identified for the screw conveyors. Following the decisions, each equation identified for each circumstance operates. Likewise, measuring berth handling capacity, two decisions have been identified for the belt conveyor whether flat belt or three throughing idler belt. For the truck and bulldozer transfer capacity, situations have been identified similar to grab handling equipment capacity. Logic of these situations are based on the density of the material, carrying part volume of truck and bulldozer and lifting capacity of these vehicles. System continues operation by applying the empirical equations and provides the results. Considering the usage of these equipment together, the process is stopped by summing up the results obtained from the other equipment.

4.2.2.3. Formulation of Input Variables

Inputs and related components should be determined to simulation model to achieve related output values. It is a complicated process to decide on which system variables should be included in the simulation model. In order to overcome this complex process, variables which illustrates the real system can be listed and the required parameters can be evaluated for the simulation model (Gilbert and Troitzcch,

2005:22; Ülgen et al. 1994:3). The variables of the port capacity measurement is illustrated in Table 24.

Table 24: Simulation Model Variables

Input Variables	Symbol
Number of Berth	B_n
Number of Handling Equipment (j)	$E_{j,n}$
Number of Grab Unloader	$E_{G,n}$
Number of Pneumatic Unloader	$E_{pne,n}$
Number of Stacker Equipment	$E_{stc,n}$
Number of Screw Type Unloader	$E_{scr,n}$
Hour capability of Handling Equipment	$C_{j,i}$
Grab Unloader/Loaders (ton per gang per hour)	$C_{mhc,i}$
The Volume of Grab	V_g
Actual Service Time	$ST_{i,act}$
Number of Gang	Gng_n
Ton per Gang	Gng_t
Maximum Lifting Capacity of the Grab Unloader/Loader	$C_{max,lift}$
Net Weight of the Grab	$WT_{g,net}$
Pneumatic Loaders/Unloaders	$C_{pneu,i}$
Screw Loader/Unloader Capacity	$C_{scr,i}$
Bulk Density of the Cargo (i)	ρ_i
Working Hours in a Day	t_{pd}
Working Days in a Year	t
Peak Factor	PF
Open Longitudinal Storage Yard Capacity (ID-Preserved Policy)	$C_{OA,ILD}$
Number of Lane	n_{lane}
Number of Stockpile	n_s
Mass of Stockpile (about stockpile geometry)	m_s
The distance between Two Stockpiles	d_s
Maximum Height of the Equipment	$h_{eq,max}$
Height allowed by the bearing capacity	$\frac{q_{max}}{\bar{\rho}}$

Table 24: Simulation Model Variables (Continued)

Length of the Lane	l_{lane}
The width of a Lane	w_{lane}
The height of the Stockpile	h_s
Length of the Stockpile	l_s
The width of the Stockpile	w_s
Maximum Height allowed by Lane Width	$h_{w,max}$
The tangent of the Mean Angle of Repose	$\tan\bar{\theta}$
Average Amount of Cargo per Vessel	$\bar{V}_{s,ton}$
Average Dwell Time of the Cargoes	$\bar{t}_{d,OA}$
Peak Factor of Cargoes Stored in Open Storage Area	PF_{OA}
Open Longitudinal Storage Yard Capacity (CAM-Policy)	$C_{OA,lCAM}$
Number of Lane	n_{lane}
Length of a Lane	l_{lane}
Mass of Stockpile (General representation of stockpile geometry)	m_s
Mass of a Stockpile (by trapezoidal shape)	$m_{s,ts}$
Mass of a Stockpile (by trapezoidal shape with end cones)	$m_{s,tec}$
Mass of a Stockpile (by triangular shape with end cones)	$m_{s,trec}$
Length of the Stockpile	l_s
Average Dwell Time of the Cargoes in Open Storage Area	$\bar{t}_{d,OA}$
Peak Factor of Cargoes Stored in Open Storage Area	PF_{OA}
Open Circular Storage Yard Capacity (Circular Stockpile)	$C_{OA,c,cir}$
Number of Circular Bed	n_{bed}
Mass of Cargo in the Circular Stockpile	$m_{s,cir}$
The radius of the Area covered by the Equipment	r_1
The radius of the Top of Circular Mass	r_2
Net Angle seen from the Centre of the Circle	K
Peak Factor of Cargoes Stored in Open Storage Area	PF_{OA}
Open Circular Storage Yard Capacity (Conical Stockpile)	$C_{OA,c,con}$
Number of Spaces Allocated for the Conical Stockpile	$n_{oA,c}$
Mass of Cargo in Conical Stockpile	$m_{s,con}$
Radius of the Circular Ground	r
Average Dwell Time of the Cargoes	$\bar{t}_{d,OA}$

Table 24: Simulation Model Variables (Continued)

Peak Factor of Cargoes Stored in Open Storage Area	PF_{OA}
Closed Storage Area Capacity	C_{CA}
Silo Storage Capacity	C_{silo}
Installed Volume of the Silo	V_{silo}
Number of Silo	n_{silo}
Peak Factor of the Cargoes Stored in the Silo	PF_{silo}
Averages of the Specific Bulk Density of Cargo (i)	$\bar{\rho}_i$
Average Dwell Time of the Cargoes Stored in the Silo	$\bar{t}_{d,silo}$
Dome Storage Capacity	C_{dome}
Installed Volume of the Dome	V_{dome}
Number of Dome	n_{dome}
Peak Factor of the Cargoes Stored in the Dome	PF_{dome}
Volumetric Flow Rate	$\dot{V}$
Conveying Velocity	v
Cross-Sectional Area of the Pipe	A
The density of the Air plus Material	ρ_{mix}
The volume of Material (i)	V_i
Total of Mass Flow Rate of Air and Material (i) per Second	$\dot{m}_{mix}$
Mass Flow Rate of the Material (i)	$\dot{m}_i$
Solid Loading Ratio	ϕ
Hourly Truck Capacity	C_{trk}
Truck Carrying Capacity	CC_{trk}
The Volume of Truck Bed	V_{trk}
Maximum Capacity of the Truck	Max_{trck}
Number of Truck	$E_{trk,n}$
Truck Turnover	$T/O_{n,trk,i}$
Hourly Capacity of Bulldozers	C_{bld}
Volume of the Bulldozer's Grab	V_{bld}
Hourly Capacity of the Truck	C_{bld}
Carrying Capacity of the Bulldozer	CC_{bld}
Maximum Capacity of the Bulldozer's Grab	Max_{bld}
Number of Bulldozers	$E_{bld,n}$

Table 24: Simulation Model Variables (Continued)

Screw Diameter	D
Diameter of the Outside of the Screw Conveyor	d
Filling Factor	ψ
Screw Pitch	λ
Speed of the Revolution	N
Flight Factor	CF_f
Mixing Padles Factor	CF_m
Incline Factor	k
Number of Screw Conveyor	$E_{scr,n}$
Velocity of the Belt Conveyor	v_b
Width of the Belt	b
Slope Factor	ks
Number of Belt Conveyor	$E_{b,n}$
Capacity according to Belt Width and Belt Speed	$C_{w,v}$
Cross Sectional Area of the Piece of Stockpile	A_{ps}
Volume of the Each Segment	V_{rec}
Number of Reclaimer	$E_{rec,n}$

Source: Generated by Author

All above-mentioned variables was evaluated as input variables and reflected to the simulation model.

4.2.2.4.Preparation of Data for Building Simulation Model

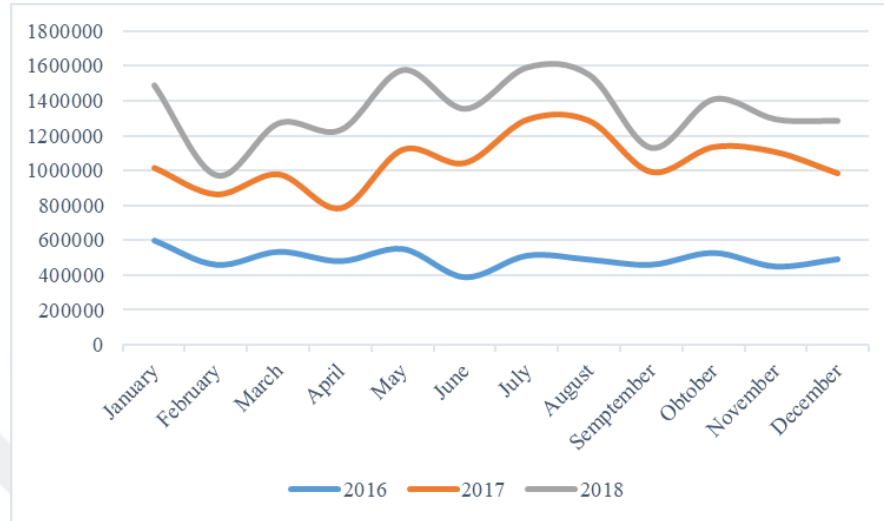
This section describes data that has been prepared fir the simulation model by manipulating these real world data.

Preparation of Berth Handling Capacity Measurement Data

Preparation process of berth handling capacity data started with the determination of peak factor and berth utilization factors. Firstly, cargo amounts per

month is determined and tabulated. The cargo amount per month in 36 months observed period is illustrated in **Figure 42**.

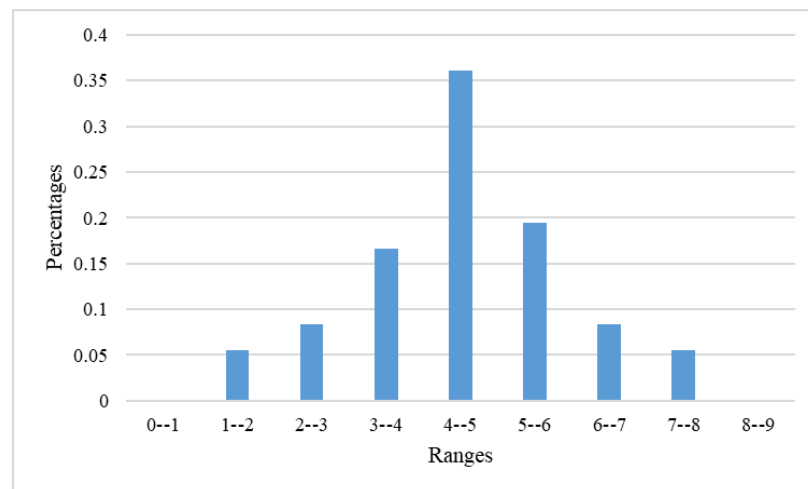
Figure 42: Cargo Amounts per Months



Source: Generated by Author

According to the **Figure 42**, cargo amount in 2018 is higher than the 2016 values. It can be seen from the figure, cargo amount decreased in April, June and September. However, a significant fluctuations have not been recorded according the data set. In line with this statement, frequencies of the cargoes within the determined range is illustrated in Figure 43.

Figure 43: Frequency Distributions of Cargo Amount per Month within the given Rages



Source: Generated by Author

In line with the Figure 43, peak factor value has been calculated regarding the Scholtz (2017:127) approach. Peak factor of the port has been determined as 1.21.

BUF value has been obtained through the equation in Chapter IV, Section 4.2.1.4. Besides, BOR value has been achieved through Equation (62) and (74).net working time (gang time), berth occupancy time, number of vessel and the time taken by berthing manoeuvrings. In dataset berth occupancy time included the ship unberthing time, but berthing time is not included. For this reason, only the average time taken by the berthing manoeuvring of the vessel. In accordance with the data set, BOR and BUF values per berth are indicated in Table 25.

Table 25: BOR and BUF Values by Berths

Berth No #	BUF	BOR
#1	0.735675261	0.137040372
#2	0.897318528	0.703609644
#3	0.876403013	0.613559345
#4	0.752884182	0.613703437

Source: Compiled by Author

With the determination of frequency distributions of the cargo amount per month, percentage distribution of the materials have been determined. Materials and their percentages have been cross-tabulated to determine the gang number regarding the material characteristics, service time, lifting capacity of the crane, grab volume, grab weight and service time. In line with the three-year data the percentages of the materials per berth is illustrated in Table 26.

Table 26: Percentage Distribution of Materials per Berth

Material	Percentage per Berth			
	#1	#2	#3	#4
Ammonium Sulphate	0.38	0.011	0.002	0.0005
M.A.P.	0.19	-	-	-
Urea	0.40	-	-	-

Table 26: Percentage Distribution of Materials per Berth (Continued)

Sunflower Seed	-	0.001	-	0.0002
Sunflower Seed Cake	-	-	-	0.000041
Basalt	-	0.002	-	0.0007
Cement	-	0.014	0.007	0.0171
D.A.P.	-	0.004	0.002	0.0004
Urea	-	0.060	0.008	0.0064
Flaxseed	-	0.002	-	0.0002
Clinker	-	0.302	-	-
Lignite	-	0.442	0.673	0.0096
Corn	-	0.009	0.012	0.0067
Corn Meal	-	0.016	0.005	0.0012
NPK	-	0.001	-	0.0003
Petroleum Coke	-	0.11	0.267	-
Pumice	-	0.001	0.001	0.0009
Soy Bean	-	0.026	0.016	0.0015
Soy Bean Meal	-	0.00031	0.005	0.0011
Sunflower Seed Hull	-	-	0.001	-
Coke Breeze	-	-	0.002	-
Wheat Bran	-	-	-	0.0001
Corn Gluten	-	-	-	0.000045

Source: Compiled by Author

According to the data, the port handled 3 types of materials in berth #1, 16 different material in berth #2, 13 material in berth #3, and 17 types of materials in berth no #4 during three years.

Total amount of cargo per berth and total net service time per material have been determined and the calculation has been performed through Equation (108). The port records the net service time per vessel berth occupancy time per vessel separately. When determining the theoretical number of gang, only the net service time and total amount of cargo per material has been used. Theoretical number of gang (TGN) per berth per material per hour is provided in Table 27.

Table 27: Theoretical Number of Gang per Berth, per Material per Hour

Material	#1 TGN (gph)	#2 TGN (gph)	#3TGN (gph)	#4 TGN (gph)
Ammonium Sulphate	22	24	7	16
M.A.P.	24	-	-	-
Urea	28	-	-	-
Sunflower Seed	-	13	-	7
Sunflower Seed Cake	-	-	-	7
Basalt	-	12	-	23
Cement	-	8	4	7
D.A.P.	-	36	9	11
Urea	-	30	9	26
Flaxseed	-	31	-	10
Clinker	-	20	-	-
Lignite	-	41	25	25
Corn	-	40	19	18
Corn Meal	-	25	8	8
NPK	-	10	-	8
Petroleum Coke	-	49	32	-
Pumice	-	30	14	7
Soy Bean	-	38	13	17
Soy Bean Meal	-	16	16	14
Sunflower Seed Hull	-	-	20	-
Coke Breeze	-	-	22	-
Wheat Bran	-	-	-	33
Corn Gluten	-	-	-	6

Source: Compiled by Author

Preparation of Storage Yard Capacity Measurement Data

- ***Open Storage Area Capacity***

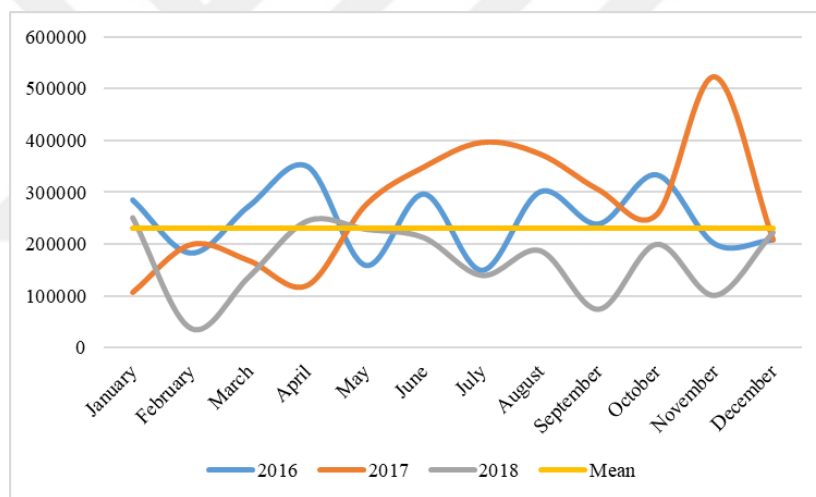
To measure open storage yard capacity, the similar path with the berth handling capacity has been followed. As a first step, peak factor of the storage yard has been

determined. After this process, number of lane, lane widths and height of the stockpile according to allowed height by lane width determined.

One of the contribution of this study is peak factor of storage yard. Peak factor of open is an important parameter to determine the required storage yard area. However, this study has not been attempted to determine required storage yard area. Thus, it affects the storage yard capacity as a divisor not the multiplier. Peak factor value of storage yard has been determined separately for open storage area and closed storage area.

Firstly, cargo amounts per month is determined and tabulated. The per month values of cargo amount for open storage area within 36 months observed period is illustrated in Figure 44.

Figure 44: Open Storage Area Cargo Amounts per Mont



Source: Compiled by Author

Comparing to the berth handling, cargo amount for open storage area is more volatile. 2016 and 2018 values of the storage yard cargo amount has nearly the same rises and falls whereas 2017 value shows different attitude.

Under this circumstances, peak factor value of open storage area has been found as 1.35.

To measure open storage area capacity, number of lane is determined. The port has 9 divided areas. Table 28 illustrates the properties of these areas.

Table 28: Features of Open Storage Areas

Area	Lane Length (m)	Lane Width (m)	Road With (m)	Area Width (m)	Area Length (m)	Number of Lane (m)
Area #1	276	50	7.5	290	276	5
Area #1	276	25	0	25	276	1
Area #2	212	50	7.5	110	212	2
Area #3	241	50	7.5	50	241	1
Area #4	243	50	7.5	50	243	1
Area #4	114	50	7.5	50	114	1
Area #5	122	50	7.5	50	122	1
Area #5	72	15.8	0	15.8	72	1
Area #6	386	50	7.5	116	382	2
Area #7	174	50	7.5	132	174	2
Area #8	143	50	7.5	178	143	3
Area #9	185	50	7.5	100	185	2
Area #9	178	40	0	60	178	1

Source: Compiled by Author

Area sizes has been determined via Google Maps. Road with implemented at the area is 7.5 m. 50 m width has been considered for the lane width (van Vianen, 2012; Kleinheerenbrink, 2012:45).

After determination of the area sizes, height allowed by lane width is determined. In addition, it is necessary to determine how much height will be allowed by specified width. To find the final stockpile height, it should be compared to other height values allowed by equipment height, bearing capacity of the ground.

Triangular shape with end cones geometry has been regarded as reference stockpile geometry. Because if stockpile height is over the height allowed by lane width, materials will be flow down during the stacking materials. Accordingly, lane width will be widen. Height allowed by lane width differs since there are different lane widths, material density. For this reason, amount of cargo that can be stored in each dedicated area have been calculated separately and percentage weight of these materials has been summed. In the light of this operation, Table 29 shows values of three different height values considering the area size and material properties.

Table 29: Height Options for the Stockpile

Area #	Material	Height allowed by Bearing Capacity of the Ground ($q_{\max}/\rho_i$) (m)	Height allowed by Equipment Height ($h_{eq,\max}$) (m)	Height Allowed by Lane Width ($h_{w,\max}$) (m)
Area #1	Petroleum Coke	10.00714796	10	43.3025
Area #1	Petroleum Coke	10.00714796	10	21.65125
Area #2	Petroleum Coke	10.00714796	10	43.3025
Area #3	Petroleum Coke	10.00714796	10	43.3025
Area #4	Petroleum Coke	10.00714796	10	43.3025
Area #4	Petroleum Coke	10.00714796	10	43.3025
Area #5	Petroleum Coke	10.00714796	10	43.3025
Area #5	Petroleum Coke	10.00714796	10	13.68359
Area #6	Petroleum Coke	10.00714796	10	43.3025
Area #7	Petroleum Coke	10.00714796	10	43.3025
Area #8	Petroleum Coke	10.00714796	10	43.3025
Area #9	Petroleum Coke	10.00714796	10	43.3025
Area #9	Petroleum Coke	10.00714796	10	34.642
Area #1	Lignite	9.333333333	10	19.5325
Area #1	Lignite	9.333333333	10	9.76625
Area #2	Lignite	9.333333333	10	19.5325
Area #3	Lignite	9.333333333	10	19.5325
Area #4	Lignite	9.333333333	10	19.5325
Area #4	Lignite	9.333333333	10	19.5325

Table 29: Height Options for the Stockpile (Continued)

Area #5	Lignite	9.333333333	10	19.5325
Area #5	Lignite	9.333333333	10	6.17227
Area #6	Lignite	9.333333333	10	19.5325
Area #7	Lignite	9.333333333	10	19.5325
Area #8	Lignite	9.333333333	10	19.5325
Area #9	Lignite	9.333333333	10	19.5325
Area #9	Lignite	9.333333333	10	15.626

Source: Generated by Author

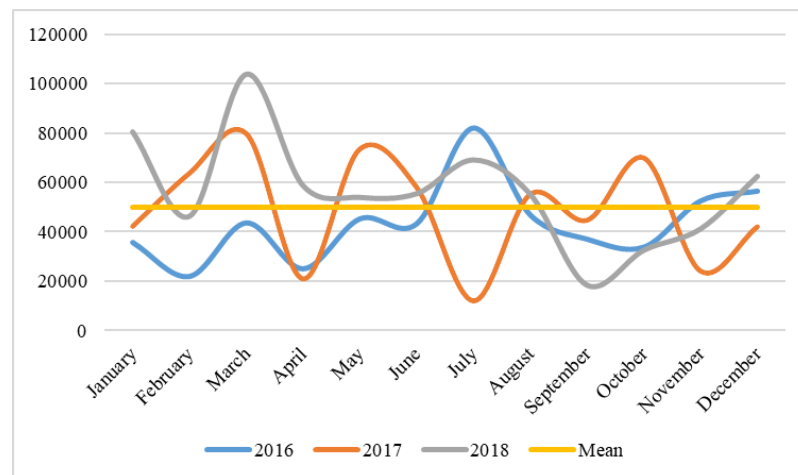
Height allowed by bearing capacity of the ground has been calculated considering the petroleum coke and lignite materials. Only two of these materials have been stored at the open storage area. Reference height value has been considered 10 m (equipment height) for petroleum coke for all stated areas, while height allowed by bearing capacity of the ground (9.33 m) has been regarded for all stated areas except in Area #5 (6.17 m).

The height allowed by the lane width has not suitable for the triangular shape with end cones within the limits of bearing capacity and equipment height. Thus, stockpile geometry becomes trapezoidal shape with end cones. The port already uses this stockpile geometry.

- ***Enclosed Storage Area Capacity***

Firstly, cargo amounts per month has been determined and tabulated. Per month values of cargo amount for enclosed areas within 36 months is illustrated in **Figure 45**.

Figure 45: Enclosed Storage Area Cargo Amounts per Month



Source: Generated by Author

The same attitude of the cargo amounts can be seen in enclosed areas. A similar trend has been seen in all months except for July, October and November when 36 months-data of closed area has been examined.

Under this circumstances, peak factor value of enclosed storage area have been found as 1.30. Average dwell time of the materials stored in enclosed areas is 45 days.

The port has three enclosed area. The properties of enclosed areas are shown in Table 30.

Table 30: Features of Enclosed Areas

Facility	Total Installed Volume (m ³)	Stored Material
A 1	102,000	Ammonium Sulphate, D.A.P., M.A.P. and Urea
A 2	102,000	Ammonium Sulphate, D.A.P., M.A.P. and Urea
B	113,940	Corn, Corn Gluten, Corn Meal, Flaxseed, Soybean, and Soybean Meal

Source: Created by Author

Total installed volume of “B” is 113,940 m³; “A 1” is 102,000 m³; “A 2” is 102,000 m³. Corn, corn gluten, corn meal, flaxseed, soybean, and soybean meal materials are stored in “B”. Ammonium sulphate, D.A.P., urea, and M.A.P. materials are stored in “A 1” and “A 2” facilities.

Preparation of Equipment Capacity Measurement Data

Cargo transfer in the port has been performed both as sousplan and as from/to storage yard area. Percentages of the cargo transfer is shown in Table 31.

Table 31: Cargo Transfer Percentages

Transfer	Percentage
Sousplan	0.37792581
Internal Transport	0.51098268
Conveyor	0.111091511

Source: Compiled by Author

While the majority of the cargoes were transferred directly to the storage yard area, 37% of these cargoes were transferred as sousplan without being stored in the area.

Port only has belt conveyor as a transfer equipment. Apart from belt conveyor, cargo transfer is also performed through truck. However, port has not any truck. Outsourced trucks perform some part of cargo transfer. These trucks have not any significant property. The number and property of truck shows difference from operation to operation. For this reason, truck transfer capacity has been disregarded in this study.

The characteristics of the belt conveyors are shown in Table 32.

Table 32: Features of Belt Conveyor

Number of Equipment	Belt Width	Belt Speed	Idler Througling Angle	Inclination Angle
3	1000 mm	1.25 m/s	45°	15°

Source: Compiled by Author

The port has three conveyors with the same characteristics. These belt conveyors are equipped with 3 roll throughing idler.

The simulation results of the capacities have been provided in *Section 4.2.2.6*.

4.2.2.5. Analysis of the Data

Berth Handling Capacity of the Port

Berth handling capacity calculation has been performed according to *Equation (89)* by using simulation model. With this implementation, realizable berth handling capacity that can be carried out separately according to the material type and material percentage handled at the each berth has been calculated. Each capacity output has been multiplied by the percentages of material handled at each berth to find a single value for realizable berth handling capacity. Table 33 illustrates the results.

Table 33: Realizable Berth Handling Capacity Outputs per Berth per Material

Material	#1 Capacity	#2 Capacity	#3 Capacity	#4 Capacity
Ammonium Sulphate	1,670,294.475	4,161,279.65	2,529,310.908	3,191,008.457
M.A.P.	1,765,126.304			
Urea	1,731,773.626			
Sunflower Seed		1,457,096.919		1,358,701.898
Sunflower Seed Cake				803,240.6008
Basalt		2,920,684.246		536,7903.289
Cement		1,733,866.521	1,501,467.056	1,633,709.697
D.A.P.		5,732,885.935	2,987,086.298	1,959,673.679
Urea		3,915,107.692	2,445,091.104	3,792,540.367
Flaxseed		3,772,550.485		1,458,669.372
Clinker		4,867,807.077		
Lignite		5,350,647.18	6,791,919.733	3,675,846.817
Corn		3,375,012.907	3,338,002.151	1,697,891.149
Corn Meal		2,787,399.053	1,858,269.239	931,992.4841
NPK		1,587,832.309		1,420,549.479
Petroleum Coke		5,963,063.67	8,106,835.393	
Pumice		2,176,605.165	2,114,098.215	1,633,709.697
Soy Bean		3,954,977.35	1,408,304.557	1,977,177.711
Soy Bean Meal		1,780,226.588	3,709,293.763	1,742,623.676
Sunflower Seed Hull			1,521,390.02	
Coke Breeze			4,432,859.612	
Wheat Bran				1,347,810.5
Corn Gluten				678,024.5322
Capacity per Berth (ton)	1,714,509.288	5,012,422.912	6,875,669.724	113,644.715
Total Realizable Berth Handling Capacity (ton/year)				13,716,246.639

Source: Compiled by Author

After implementation of the *Equation (89)* realizable berth handling capacity has been found as 13,716,246.639 ton/year through simulation. The same operation has been performed for the theoretical and actual capacity. When the theoretical capacity has been calculated, peak factor, BUF and BOR disregarded. Additionally, working hours in a day and working days in a year replaced the 24 and 365 respectively. The results are provide in Table 34.

Table 34: Realizable, Actual and Theoretical Berth Handling Capacities

Total Realizable Berth Handling Capacity (ton/year)	Total Actual Berth Handling Capacity (ton/year)	Total Theoretical Berth Handling Capacity (ton/year)
13,716,246.639	10,063,267.44	21,530,674.61

Source: Compiled by Author

When comparing the berth handling output values, theoretical berth handling capacity has the maximum output value as expected. However, there is a significant difference between actual berth handling capacity and realizable capacity output values. This difference stem from the BOR and BUF values. When considering the vessel traffic in measuring berth capacity, berths are not utilized in its efficient rate (UNCTAD, 1985b; KMI, 1998; Park et al. 2014:181,186).

Storage Yard Capacity of the Port

- ***Open Storage Yard Capacity***

The calculation of open storage yard capacity has been performed according to *Equation (92)*. Although port is owner of the storage yard area, it has rented each of these areas to different customers. For this reason, CAM-Storage policy approach has been implemented at the open storage area. This type of storage policy has been applied in the calculations.

Open storage yard capacity has been calculated regarding stockpile geometry, dwell time, angle of repose, specific bulk density, CAM-Storage policy implementation, height of the stockpile, peak factor of open storage areas and number of lane for the each material. As a first step, percentage weights of lignite and petroleum coke have been calculated.

Table 35 shows the percentages of the materials stored at the storage yard.

Table 35: Percentage Weights of Materials Stored at the Storage Yard

Materials	Percentage
Petroleum Coke	0.673
Lignite	0.327

Source: Generated by Author

According to dataset, only petroleum coke and lignite are stored in the open storage area. Petroleum coke has the highest proportion with 0.673 value comparing the lignite. In line with this information, petroleum coke and lignite materials have been calculated separately and different capacity values has been obtained (# Capacity). Amount of cargo that can be stored in open storage areas is illustrated in Table 36.

Table 36: Capacity and Weighted Capacity Values per Area

Area #	Material	#Capacity (ton)	Weighted Capacity (t/y)
Area #1	Petroleum Coke	2,500,525.84	4,747,647.697
Area #1	Petroleum Coke	217,447.56	
Area #2	Petroleum Coke	763,353.13	
Area #3	Petroleum Coke	435,339.53	
Area #4	Petroleum Coke	439,040.42	
Area #4	Petroleum Coke	200,332.77	
Area #5	Petroleum Coke	215,136.35	
Area #5	Petroleum Coke	27,848.24	
Area #6	Petroleum Coke	1,407,308.65	
Area #7	Petroleum Coke	622,719.17	
Area #8	Petroleum Coke	761,987.19	
Area #9	Petroleum Coke	663,429.00	
Area #9	Petroleum Coke	246,701.60	
Area #1	Lignite	2,105,013.44	2,772,475.467
Area #1	Lignite	144,604.17	
Area #2	Lignite	638,059.84	
Area #3	Lignite	365,236.33	
Area #4	Lignite	368,422.98	

Table 36: Capacity and Weighted Capacity Values per Area (Continued)

Area #4	Lignite	162,884.13	2,772,475.467
Area #5	Lignite	175,630.72	
Area #5	Lignite	14,102.19	
Area #6	Lignite	1,179,790.16	
Area #7	Lignite	516,967.19	
Area #8	Lignite	627,271.60	
Area #9	Lignite	552,020.32	
Area #9	Lignite	195,330.07	
Total (ton/year)			7,520,123.164

Source: Generated by Author

According to Table 36, weighted capacity value of petroleum coke is 4,747,647.697 ton per year, and weighted capacity value of lignite is 2,772,475.467 ton per year. Total open storage area capacity for petroleum coke and lignite is 7,520,123.164 ton per year.

- ***Enclosed Storage Area Capacity***

To calculate the enclosed storage area capacity, weighted percentages of each material for three different enclosed area have been calculated by simulation model. The cargo percentages of the materials stored in “A 1-2” and “B” facilities are shown in Table 37

Table 37: Cargo Percentages of Materials Stored in Enclosed Facilities

Facility	Material	Percentage
A 1-2	Ammonium Sulphate	0.250050502
A 1-2	D.A.P.	0.07690191
A 1-2	Urea	0.607607398
A 1-2	M.A.P.	0.065440189
B	Corn	0.251173485
B	Corn Gluten	0.045196118

Table 37: Cargo Percentages of Materials Stored in Enclosed Facilities (Continued)

B	Corn Meal	0.212440515
B	Flaxseed	0.02408569
B	Soybean	0.347644049
B	Soybean Meal	0.119460143

Source: Created by Author

In “A 1-2” facilities, the highest proportion of these materials belong to urea. Besides, soybean has the highest proportion in “B” facility. These percentages have been used for obtaining only one capacity output value. To obtain capacity output values of above mentioned materials, *Equation (100)* has been employed. The results are provided in Table 38.

Table 38: Enclosed Area Capacity per Material

Facility	Material	Percentage	#Capacity Output
A 1-2	Ammonium Sulphate	0.250050502	1,267,292.32
A 1-2	D.A.P.	0.07690191	1,163,749.138
A 1-2	Urea	0.607607398	952,851.3682
A 1-2	M.A.P.	0.065440189	1,159,937.732
B	Corn	0.251173485	3,441,153.0992
B	Corn Gluten	0.045196118	424,692.0203
B	Corn Meal	0.212440515	454,849.7661
B	Flaxseed	0.02408569	496,715.8132
B	Soybean	0.347644049	424,337.2233
B	Soybean Meal	0.119460143	454,140.1721
Total Enclosed Area Capacity			1,477,246.484

Source: Created by Author

Enclosed areas stated above has been calculated for each material. Each of capacity output value have been multiplied by the real weighted percentages of the materials. As a result of this operation, the real capacity value of each enclosed area has been achieved. With the calculation of the enclosed area capacity, total storage area capacity (open storage area and enclosed storage area) has been achieved. Total area capacity of the port is shown in Table 39.

Table 39: Total Storage Yard Capacity

Area	Capacity (t/y)
Open Storage Area	7,520,123.164
Enclosed Area	1,477,246.484
Total Area	8,997,369.648

Source: Created by Author

According to simulation results, storage yard capacity of the port is achieved as 8,997,369.648 t/y. open storage area capacity has the higher value than closed storage area capacity at the specified material densities and angle of repose. This calculation has been performed according to petroleum coke and lignite materials.

- ***Transfer Equipment Capacity of the Port***

The mathematical operation has been performed according to *Equation (43)*. Each value belonging the material required for the calculation has been obtained from Appendix I. Firstly, percentage weights of the cargoes transferred by conveyor belt has been determined. The values have been identified in simulation model after obtaining the coefficients for capacity of belt conveyor for three idler belt conveyor, capacity factor from Fenner Dunlop (2009:21-22). Table 40 illustrates percentages of the materials and the coefficient values for each material.

Table 40: Percentages and Coefficient Values of the Materials

Material	Percentage	Capacity of 3 Idler Belt	Capacity Factor
Ammonium Sulphate	0.172806431	497	1.08
D.A.P.	0.053145843	497	1.15
Urea	0.419909039	497	1.15
M.A.P.	0.045224806	497	1.15
Corn	0.077590976	497	1.15
Corn Gluten	0.013961708	497	1.15
Corn Meal	0.065625824	497	1.15

Table 40: Percentages and Coefficient Values of the Materials (Continued)

Flaxseed	0.007440404	497	1.08
Soybean	0.107392072	497	0.94
Soybean Meal	0.036902896	497	1.08

Source: Compiled by Author

Urea has the highest value among the other materials whereas flaxseed has the lowest percentage. “Capacity of 3 idler belt conveyor” can be determined according to belt width and belt speed. “Capacity Factor” is also determined by angle of surcharge and angle of throughing idler. The values mentioned above and in Table 34 has been identified in simulation model. The results are given in Table 41.

Table 41: Total Transfer Equipment Capacity

Material	#Capacity (t/y)	Percentage Weighted Capacity (t/y)
Ammonium Sulphate	1,5230,332.61	2,631,899.427
D.A.P.	14,892,446.27	791,471.6097
Urea	12,193,596.84	5,120,201.532
M.A.P.	14,843,671.89	671,302.1882
Corn	7,885,192.622	611,819.7909
Corn Gluten	9,730,490.277	135,854.2655
Corn Meal	10,421,460.76	683,916.9482
Flax Seed	10,687,952.71	79,522.68587
Soybean	7,946,973.513	853,441.9519
Soybean Meal	9,771,842.475	360,609.2892
Total Equipment Capacity (t/y)		11,940,039.69

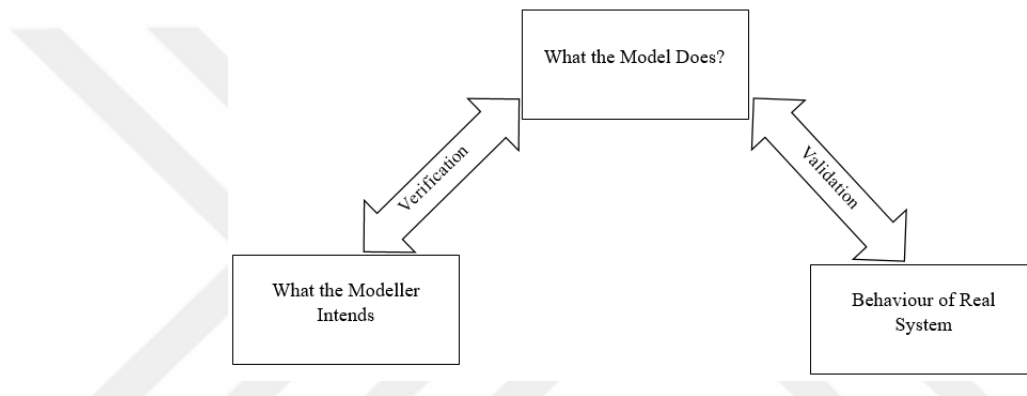
Source: Generated by Author

Belt conveyor capacity has been determined per each material. Capacity values of each material has been considered to determine total equipment capacity by calculating the real capacity percentages. According to simulation results, belt conveyor capacity has been found as 11,940,039.69 ton per year.

4.2.2.6. Validation and Verification

Verification can be provide easily by using software programs in terms of identifying the errors and mistakes into the simulation model. Verification of the model includes the process of whether it works correctly or not. Besides validation refers to testing the compatibility of the model behaviour with the target system behaviour (Gilbert and Troitzsch, 2005: 22). Validation and verification can be schematically illustrated as in Figure 46:

Figure 46: Relation of Validation and Verification



Source: Ulgen and Williams, 2001: 114

According to Figure 46, validation is performed between the simulation model and real system. However, in this study, a simulation model was not created in which the behaviour of the real system could be observed. Furthermore, the absence of an output value that could be referred was restricted the validation efforts. Validation is mostly performed in the studies that describe the process, which needed to be validated to make sure about the reliable results (Kox, 2017:122).

Verification is performed between the model behaviour and the modeller's objectives. Two verifications were conducted in the study. Firstly, the simulation model was compared with the conceptual model and it was found to be compatible with each other. Another validation was performed of the testing the compatibility of the simulation results and manual operation of the equations. Both of operations were checked to eliminate the faults. According to this verification, both operations provided the same capacity outputs.

CONCLUSIONS AND RECOMMENDATIONS

A limited study addressing the capacity calculation based on empirical equation development were found in the literature with the determined research strings. Some of these studies mostly focus on optimization and performance, especially in container terminals. In this study berth handling, storage yard and equipment were attempted to measure by developing empirical formula and simulation model within an integrated perspective. In this context, several empirical equations for berth handling, storage yard area and equipment and they were tested by the simulation model. In line with the research streams on port and terminal capacity, factors affecting port capacity were analysed thoroughly. The measurable parameters, which were not reflected before to the capacity calculation equations (lifting capacity of the crane, grab volume, material density, grab weight, storage yard peak factor) were attempted to reflect the capacity measurement equations.

This study has originalities in terms of analysing berth handling capacity, storage yard capacity, and equipment capacity of dry bulk terminal capacity from a complementary perspective. This study is also crucial in terms of bringing the equipment, berth handling, and storage yard capacity equations and terminal design issues together and introducing theoretical gang capacity, berth utilization factor, peak factor of storage yard, realizable capacity concepts by explaining functions of different types of capacity and related coefficients.

Equipment capacity, working days in a year, working hours in a day, utilization level of the berths and number of equipment are essential parameters in the determination of berth handling capacity. When examining the existing literature, it was noticed that the capacity of berth handling equipment was not explained in detail. Some scholars obtained the hourly capacity of berth handling equipment by multiplying the number of the gang and the amount of cargo per gang in an hour. However, as far as is known, there is a gap in the determination of hourly gang number of grab cranes in the literature. In this study, real-world data was used to determine the theoretical number of gang per material and per equipment. Hourly gang capacity of the berth handling equipment is affected by the draft of the ship and berth, hold type of the ship, boom angle of the crane. These factors change hourly gang capacity

of the equipment. Besides, the grab-filling rate differs during the handling operation, and it is not possible to obtain 100% of filling in every gang. The reason behind calling the gang number as theoretical gang number is that the amount of cargo handled by each gang is not the same. In actual service conditions, a berth-handling equipment can perform more gangs than theoretical number of the gang. However, net service time will not change, as the handling rate is certain (considering the same climatic conditions, the same ship size, the same crane, and the same ship characteristics). For this reason, theoretical gang number will increase or decrease in line with the operation time of grab (depended on volume of grab, crane lifting capacity, grab weight and material density factors). Accordingly, theoretical number of gang is always lower than the actual number of gang.

To achieve only one capacity value for each component of the terminal served to multiple commodity types, weighted averages of the cargoes were determined based on the throughput volume in previous years. When calculating the capacity of each of the component, the capacity of each component was calculated according to the material. Then the capacity outputs were calculated by including the percentages of the materials in the calculation.

Although capacity is classified as intrinsic and proper capacity (National Research Council, 1998: 72), a different spectrum of capacity types can be found in the literature. These capacity types can be calculated in accordance with the objectives and provide different results. However, as far as is known, no study was found regarding coefficients to be determined in accordance with each type of capacity in the literature. Within this context, berth utilization concept was introduced in this study, and a clear distinction between berth occupancy ratio and berth utilization factor concepts was made. Berth utilization factor can be defined as the amount of cargo that the port can handle in case it is not affected by the demand conditions. Demand condition is one of the essential factor affecting the amount of cargo handled in the port. Considering the actual traffic conditions at the port, the actual capacity that the port can perform can be determined by considering the coefficient of berth occupancy ratio. However, there is no capacity concept identified to determine the port capacity in case port serves with relatively adequate equipment and infrastructure, yet there is not enough demand. In addition, there is not any related parameter (coefficient) to

calculate this capacity concept in the literature. Therefore, reliable capacity is introduced as a concept that can exactly explain this situation. Realizable capacity shows the realizable capacity value of the port that the berth can reach when ships called to the port. Realizable capacity can be calculated through the berth utilization factor showing how many tons can be achieved without being affected by the demand. Besides, berth occupancy rate is used when actual capacity is attempted to calculate.

Calculation of storage yard capacity were also poorly attempted to measure in the literature. A relatively limited study was found in the literature on measuring dry bulk storage yard capacity. This study addressed the storage yard capacity within an integrated perspective. A process was created to measure the storage yard capacity. This process can be followed in storage yard capacity calculation of dry bulk terminals to avoid confusion. The terminal was assessed according to whether it is longitudinal or circular in the first step. Then two different storage policy (CAM storage policy and ID-Preserved storage policy) was determined. Specific empirical equations were generated for each case. In case of implementing ID-Preserved storage policy, stockpile length was determined considering the average cargo per vessel. Besides, three different reference value was considered for determining the stockpile height. These reference values are height allowed by lane width, height allowed by equipment, height allowed by bearing capacity of the ground. Also, each of stockpile geometry (trapezoidal shape with end cones, trapezoidal shape, circular stockpile, triangular stockpile, conical stockpile) commonly applied in the dry bulk terminals was analysed and determined stockpile height was considered according to stockpile geometry. For the closed areas, silo, dome, shed and enclosed area empirical equations were developed.

Peak factor is an influential parameter in the determination of required capacity. An approach was attempted to develop that can be applied in practice and to give better ideas about capacity. Apart from the peak factor value determined for measuring berth handling capacity, another peak factor value was also considered for storage area. The underlying reason for determining different peak value for storage area is that sousplan transfer of the cargoes does not occupy the terminal area. Peak factor was not used for determining the

required area in this study; it was used for finding the capacity value that the port could serve with sufficient capacity to its customers.

In light with above-mentioned information, a simulation model was generated for calculating the dry bulk terminal capacity by using RProject. Empirical formulas were testing through real-world data. Cases mentioned above and related equations were identified in the simulation model. Capacity measurement of the port offered services to multipole cargoes was performed using the simulation model, which was suitable for each case.

Real-world data was prepared for the simulation model. Firstly, it was attempted to determine the theoretical gang number regarding the net service time. Theoretical gang numbers were achieved per berth per material type. Amount of material per gang was determined considering the material density, crane lifting capacity grab weight, and grab volume. Required parameters were entered to the simulation model. For the storage yard capacity, installed volume of the enclosed areas and number of lane, angle of repose of the materials, material percentages, specific bulk density of the materials and the heights were entered manually into the simulation model.

Realizable capacity, actual capacity, and theoretical capacity of the dry bulk terminal were calculated by applying real-world data. In actual capacity calculation, berth occupancy ratio was applied to the formula, whereas berth utilization factor used for calculating the realizable capacity. The berth occupancy rate values of the terminal were recorded as 0.13, 0.70, 0.61, 0.61 for berth no #1, berth no #2, berth no#3, and berth no #4, respectively. Besides, berth utilization factors were recorded as 0.70, 0.89, 0.87, and 0.75. Averages of berth occupancy ratio of the specified berth were 0.51. This value was close to the value stated in the literature for the terminals with four berths (UNCTAD, 1985b; Park et al. 2014: 186). Berth #1 had the lowest value among the other berths in two different values. The underlying reason for a lower coefficient of berth utilization and berth occupancy rate value may be the berth size and draft restrictions. Berth #1 is the smallest berth of the terminal, and the equipment capacity is limited comparing the other equipment allocated to other berths. In general terms, the realizable capacity value was higher than the actual capacity.

Theoretical capacity was calculated by considering 365 days and 24 hours. Theoretical berth capacity had the highest value among the other capacity types as it was expected.

a. Implications for Researchers

The result of this study provides various implications for both researchers and practitioners. Implications for researchers can be assessed as follows.

In the light of the results obtained by the simulation model, theoretical gang number, peak factor of storage yard, and realizable capacity were introduced. Although researchers commonly pointed on the hourly gang number and ton per gang, determination attempt of these parameters was limited as far as is known. It can be deduced from the literature that hourly gang capacity of the grab equipment depends on the size of the ship, material to be handled, boom angle of the equipment, grab weight, rotation speed of the equipment, lifting capacity, volume of the gang, etc. A concept used for determining the number of gang under the normal operational conditions considering material characteristics was introduced and called as theoretical number of gang. With this concept, it was tried to explain some assumptions with real-world data on a more realistic basis and with fewer assumptions. Theoretical gang number approach can be used in the determination of ton per gang and ton per hour of the grab equipment unless it is kept a record.

Realizable capacity explains the possible output levels where the terminal is independent of actual demand conditions and the capacity output that can be realized by its resources as if the ships always called to the port. Besides the function of the berth occupancy ratio was tried to discussed and explained within the context of the measuring berth handling capacity. The discussion about berth occupancy ratio and realizable capacity are regarded as a contribution to the literature. Also using the berth utilization factor in the realizable capacity estimation of the dry bulk terminals and discussing berth occupancy ratio open a new perspective for the literature and for the further researches.

In this study, peak factor was also used to measure storage yard capacity of the dry bulk terminal apart from the peak factor value used in the measurement of the berth handling capacity of the dry bulk terminals by considering the sousplan transfers. Peak factor was not

used for determining the required area in this study; it was used for finding the capacity value that the port could serve with sufficient capacity to its customers. It is also regarded as a new perspective for measuring storage yard capacity of dry bulk terminals.

b. Practical Implications

Considering all these critical issues, the results of the study provides implications for practitioners. With the capacity calculation model of the dry bulk port, the capacity of the port can be calculated with a realistic approach to preventing critical problems.

As mentioned in the earlier part of the study, capacity planning and capacity measurement as a requirement of this planning are essential for the port operators in terms of planning the investments, balancing the supply and demand, determining the performance level of the port, and for privatization. Primarily, port industry is a capital-intensive industry that entrance barrier high and investment costs are considerably high. For this reason, unnecessary investments in this sector can lead to several problems in terms of returns on investment. In addition to that, idle capacity caused by unnecessary investments constitutes several disadvantages on port tariff structure. Ports may set competitive prices to ensure the return on investment, and it affects the regional competitive structure. Besides, the determination of precise capacity requirements is crucial in terms of investment timing. The port capacity issue is also crucial for privatization, infrastructure development, and new port building efforts. Particularly, the government may set contractual clauses about increasing the capacity of the port in privatization. Realistic capacity measurement method provides greater advantages about issues as mentioned above.

In this study, it was attempted to determine berth handling, storage yard, and equipment capacities of dry bulk terminals, which handles multiple cargoes. The ports served to different material type do not have a single output. Each material has a different specific bulk density, and this stand for several capacity output values for the ports. However, a single output value is more preferred than the several capacity output values. For this reason, this study took into consideration the percentage weights of the cargo amounts handled by the port in the previous years; hence, a single capacity output was

obtained. With such a measurement, the port operators can determine how much capacity they have for a specific material depending on the cargo estimation. Moreover, this approach allows port operators to plan the capacity by materials.

c. Limitations of the Study

The output value of the capacity differs according to acceptance. Berth handling, storage yard capacity, and equipment capacity have no reference or absolute value. Therefore, it creates a limitation about the comparison of the capacity output with the reference or absolute values.

The port has only grab cranes and conveyor belt equipment. Due to this reason, other equipment capacities was not tested. Another limitation of the study was that, ton per gang and number of gang was not explained in the existing studies. These studies did not explained how they calculated these factors. For this reason, the output values of the theoretical gang number number could not be compared with other studies.

In order to obtain more realistic results, grab crane can be modelled in further studies.

Port shared only the three years of real-world data. A broader dataset may provide more realistic gang numbers and ton per gang amounts.

Some of the parameters used in the calculations (number of gang, ton per gang, peak factor, berth occupancy ratio, berth utilization factor) were entered to simulation model manually. A new simulation model can be developed to obtain these parameters according to the dataset.

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APPENDICES

APPENDIX 1. Properties of Solid Bulk Materials

Table A1. Specifications of Bulk Materials

Material	Density (kg/m ³)	Angle of repose	Angle of surcharge
Acid phosphate	1540	*	*
Alumina	800-960	22°	5°
Alum- <i>lump</i>	800-960	27°	*
- <i>pulverized</i>	720-800	35°	*
Ashes, boiler-house - <i>dry, loose</i>	560-690	38°- 45°	25
Asphalt	1280-1360	*	*
Bagasse - <i>fresh, moist</i>	120	*	25°
- <i>dry, loose</i>	80	*	25°
Barytes - <i>50-75mm lumps</i>	2320-2400	30 ⁰	25°
- <i>15mm screening</i>	2080-2320	30°	20°
- <i>dust</i>	1760-2080	30°	15°
Basalt - <i>50-75mm lumps</i>	1680-1760	*	25°
- <i>15mm screenings</i>	2080-2320	*	20°
- <i>dust</i>	1760-2080	*	15°
Bauxite - <i>crushed</i>	1200-1360	30° - 35°	5°-15°
Borax, solid - <i>50-100mm lumps</i>	960-1040	40°	*
- <i>40-50mm lumps</i>	880-960	30°-45°	*
Brewers grain - <i>dry</i>	400-480	45°	*
- <i>wet</i>	880-960	45°	*
Brick - <i>hard</i>	2000	30°-45°	*
- <i>soft</i>	1600	30°-45°	*
Carbon black - <i>powder</i>	80	*	*
- <i>pellets</i>	400	40°	*
Cement, Portland - <i>loose</i>	1200-1360	40°	20°
- <i>clinker</i>	1280-1520	33°	25°
- <i>slurry</i>	1440	*	5°
Chalk - <i>50-75mm lumps</i>	1280-1360	45°	*
- <i>40-50mm lumps</i>	1200-1280	40°-45°	*

Table A1. Specifications of Bulk Materials

Char - <i>sugar refinery</i>	720	*	*
Chips, paper mill - <i>softwood</i>	190-480	*	25°
- <i>yellow pine</i>	320-400	*	25°
Clay- dry, loose	1010-1440	40°-45°	15°-25°
- <i>brick, ground fine</i>	1760	35°	15°
Coal - <i>150mm domestic sizes</i>	830-900	*	25°
- <i>run-of-mine</i>	720-880	35°	25°
- <i>slack</i>	690-800	37°	25°
- <i>pulverized for coking</i>	480-590	*	10°
- <i>lignite, broken</i>	720-880	*	25°
Cocoa	480-560	*	*
Coke – run of oven	400-480	30°	25°
- breeze	380-560	30°-45°	20°
Concrete, wet, on conveyor	1760-2400	*	5°
Copper ores, crushed	2080-2400	*	25°
Copra	350	*	*
Corn grits	670	*	*
Cryolite - <i>50-75mm lumps</i>	1600-1680	*	20°
- <i>15mm screenings</i>	1440-1600	*	15°
- <i>dust</i>	1200-1440	*	5°
Dolomite -lump	1440-1600	See limestone	*
Earth - <i>as excavated, dry</i>	1120-1280	30°-45°	20°-25°
- <i>wet, mud</i>	1600-1760	*	5°
Foundry refuse, old sand, cores, etc.	960-1280	*	15°
Garbage - <i>household</i>	800	*	*
Glass - <i>batch</i>	1680	*	*
- broken	1280-1600	*	*
Granite - <i>40-50mm lumps</i>	1360-1440	25°	*
- <i>15mm screenings</i>	1280-1440	*	*
- <i>broken</i>	1520-1600	*	*
Gravel - <i>dry, sharp</i>	1440-1600	30°-45°	25°

Table A1. Specifications of Bulk Materials

- wet	1600-1920	32°	25°
<i>Gutta percha</i>	960	*	*
Gypsum - 50-75mm lumps	1200-1280	30°	20°
- 15mm screenings	1120-1280	40°	15°
- dust	960-1120	42°	*
Hops - brewery and moist	560	30°-45°	*
Ice - crushed	640	*	*
Iron borings - machine shop	2000	*	*
Iron ores, depends on iron percentage	1600-3200	35°	25°
Iron pyrites - 50-75mm lumps	2160-2320	*	20°
- 15mm screenings	1920-2160	*	15°
- dust	1680-1920	*	5°
Lead ores, depends on lead percentage	3200-4320	30°	15°
Limestone - 50-75mm lumps	1440-1520	30°-40°	25°
- 15 mm screenings	1280-1440	*	15°
- dust	1200-1280	*	5°
Linseed cake - crushed	760-780	*	*
Manganese ore	2000-2240	39°	*
Malt meal	570-640	*	*
Meal	700	*	*
Paper pulp	640-960	*	5°
Petroleum coke	560-640	*	*
Phosphate rock	1360	*	*
Pitch	1150	*	*
Quartz, solid – 50-75mm lumps	1440-1520	35°	*
- 40-50mm lumps	1360-1440	35°	*
- dust	1120-1280	40°	*
Rock, soft, excavated with shovel	1600-1760	*	20°
Rubber	930	*	*
<i>Rubber - reclaim</i>	560	*	*

Table A1. Specifications of Bulk Materials

Salt - <i>coarse</i>	640-900	*	*
- <i>finer</i>	720	25°	*
- <i>lump for stock</i>	1600	*	25°
Sand - <i>beach or river, wet</i>	1600-2080	15°-30°	5°-15°
- <i>dry</i>	1440-1600	34°-45°	15°
- <i>foundry, loose</i>	1280-1440	*	15°
- <i>foundry, rammed lumps</i>	1600-1760	*	10°
Sandstone	1360-1440	*	*
Sawdust	160-200	35°	*
Shale - <i>broken</i>	1440-1600	*	*
- <i>crushed</i>	1360-1440	39°	*
Slag - <i>blast furnace, crushed</i>	1280-1440	25°	25°
- <i>granulated, dry</i>	960-1040	25°	10°
- <i>granulated, wet</i>	1440-1600	45°	10°
Slate - <i>40-75mm lumps</i>	1360-1520	*	*
- <i>15mm screenings</i>	1280-1440	28°	*
Soda ash	800-1040	32°	*
- <i>heavy</i>	480-560	*	10°
Salt - <i>coarse</i>	640-900	*	*
- <i>finer</i>	720	25°	*
- <i>lump for stock</i>	1600	*	25°
Sand - <i>beach or river, wet</i>	1600-2080	15°-30°	5°-15°
- <i>dry</i>	1440-1600	34°-45°	15°
- <i>foundry, loose</i>	1280-1440	*	15°
- <i>foundry, rammed lumps</i>	1600-1760	*	10°
Sandstone	1360-1440	*	*
Sawdust	160-200	35°	*
Shale - <i>broken</i>	1440-1600	*	*
- <i>crushed</i>	1360-1440	39°	*
Slag - <i>blast furnace, crushed</i>	1280-1440	25°	25°
- <i>granulated, dry</i>	960-1040	25°	10°
- <i>granulated, wet</i>	1440-1600	45°	10°

Table A1. Specifications of Bulk Materials

Slate - 40-75mm lumps	1360-1520	*	*
- 15mm screenings	1280-1440	28°	*
Soda ash	800-1040	32°	*
Sugar cane stalks	400	*	*
Sugar - raw	880-1040	37°	*
- refined	880	*	*
Sulphur - 50-75mm lumps	1360-1440	35°	25°
- 15mm screenings	1200-1360	*	15°
Talc - solid	2640	*	*
- 50-75mm screenings	1440-1520	*	*
- dust	1220-1280	*	*
Turf - dry	480	*	*
Wheat	720-770	28°	10°
Zinc ores, crushed	2400-2560	38°	20°
Zinc oxide - light	160-480	*	10°
- heavy	480-560	*	10°

Source: Fenner Dunlop, 2009:24-26

APPENDIX 2. Required Coefficients for Calculating 3 Equal Roll Idlers Conveyor Belt Capacity

Fenner Dunlop, (2009:20-21) “*Conveyor Handbook*” was presented the general values of the capacity factor and the capacity with regard to cross sectional area. Table A2, A3 illustrate the capacity factors and the capacity of the troughed belts regarding the cross sectional area for three equal troughing roll idlers.

Table A2.1. Capacity Factors for Three Equal Idler

Surcharge Angle	Idler Troughing Angle				
	20°	25°	30°	35°	45°
0°	0.43	0.53	0.61	0.69	0.81
5 °	0.52	0.61	0.69	0.77	0.88
1 °	0.61	0.70	0.77	0.84	0.94
15°	0.70	0.78	0.86	0.92	1.04
20°	0.79	0.87	0.94	1.00	1.08
25°	0.88	0.96	1.03	1.08	1.15

Source: Fenner Dunlop, 2009:20

Table A2.2. Capacity of Belt Conveyors for Three Equal Idler*

Belt Width (mm)	Belt Speed (mps)											
	0.5	0.75	1	1.25	1.5	2	2.5	3	3.5	4	4.5	5
400	26	39	52	65	78	104	130	156	182	209	235	261
450	34	51	69	86	103	137	172	206	240	274	309	343
500	44	65	87	109	131	175	218	262	306	349	393	437
600	66	99	131	164	197	263	329	394	460	526	592	657
650	78	118	157	196	235	314	392	471	549	628	706	785
750	107	161	215	268	322	429	536	644	751	858	965	1073
800	123	185	247	308	370	493	617	740	863	987	1110	1233
900	159	238	318	397	477	635	794	953	1112	1271	1430	1589
1000	199	298	398	497	597	795	994	1193	1392	1591	1790	1989
1050	221	331	441	551	662	882	1103	1323	1544	1764	1985	2206
1200	292	438	585	731	877	1169	1462	1754	2046	2339	2631	2923
1350	374	561	748	936	1123	1497	1871	2245	2619	2994	3368	3742
1400	404	606	807	1009	1211	1615	2019	2422	2826	3230	3634	4037

Table A2.2. Capacity of Belt Conveyors for Three Equal Idler*

1500	466	699	932	1165	1398	1865	2331	2797	3263	3729	4195	4662
1600	533	800	1066	1333	1599	2132	2665	3198	3731	4265	4798	5331
1800	680	1020	1361	1701	2041	2721	3402	4082	4762	5443	6123	6803
2000	846	1268	1691	2114	2537	3382	4228	5073	5919	6764	7610	8455
2200	1029	1543	2057	2572	3086	4115	5143	6172	7201	8229	9258	10287

Source: Fenner Dunlop, 2009:21

(*) Values are taken according to the specific bulk density (1000 kg/m^3), surcharge angle (20°) and idler angle (35°).

For the different values of the surcharge angle and the idler angle, capacity values shown in the Table A2.1 should be multiplied with the values shown in Table A2.2.

APPENDIX 3. Bulk Solid Materials Table

Table A3.1. Bulk Materials Classification Table

Major Class	Material Characteristics Included	Code Designation
Density	Bulk Density, Loose	Actual lbs/ft ³
Size	No.200 Sieve (.0029”) And Under	A ₂₀₀
	Very Fine No.100 Sieve (.0059”) And Under	A ₁₀₀
	No. 40 Sieve (.16”) And Under	A ₆₀
	Fine No. 6 Sieve (.132”) And Under	B ₆
	Granular 1½” And Under	C _{1/2}
	Granular 3” And Under	D ₃
	(¹)Lumpy Over 3” To Be Special	
	X = Actual Maximum Size	D _x
	Irregular Stringy, Fibrous, Cylindrical, Slabs, etc.	E
Flowability	Very Free Flowing – Flow Function > 10	1
	Free Flowing – Flow Function > 4 But < 10	2
	Average Flowability – Flow Function > 2 But < 4	3
	Sluggish – Flow Function < 2	4
Abrasiveness	Mildly Abrasive – Index 1-17	5
	Moderately Abrasive – Index 18-67	6
	Extremely Abrasive – Index 68-416	7
Miscellaneous Properties or Hazards	Builds Up and Hardens	F
	Generates Static Electricity	G
	Decomposes – Deteriorates in Storage	H
	Flammability	J
	Becomes Plastic or Tends to Soften	K
	Very Dusty	L
	Aerates and Becomes Fluid	M
	Explosiveness	N
	Stickiness-Adhesion	O

Miscellaneous Properties or Hazards	Contaminable, Affecting Use	P
	Degradable, Affecting Use	Q
	Gives off Harmful or Toxic Gas or Fumes	R
	Highly Corrosive	S
	Mildly Corrosive	T
	Hygroscopic	U
	Interlocks, Mats or Agglomerates	V
	Oils Present	W
	Packs Under Pressure	X
	Very Light and Fluffy – May Be Windswept	Y
	Elevated Temperature	Z

Source: FMC Technologies, 2009: 20

A.3.2. Bulk Material Properties

Material	Weight lbs/ft³	Material Code	Component Series	Mat'L Factor Fm
Adipic Acid	45	45A ₁₀₀ 35	2B	.5
Alfalfa Meal	14-22	18B ₆ 45WY	2D	.6
Alfalfa Pellets	41-43	42C _{1/2} 25	2D	.5
Alfalfa Seed	10-15	13B ₆ 15N	1A-1B-1C	.4
Almonds, Broken	27-30	29C _{1/2} 35Q	2D	.9
Almonds, Whole Shelled	28-30	29C _{1/2} 35Q	2D	.9
Alum, Fine	45-50	48B ₆ 35U	1A-1B-1C	.6
Alum, Lumpy	50-60	55B ₆ 25	2A-2B	1.4
Alumina	55-65	58B ₆ 27MY	3D	1.8
Alumina Fines	35	35A ₁₀₀ 27MY	3D	1.6
Alumina Sized or Briquette	65	65D ₃ 37	3D	2.0
Aluminate Gel (Aluminate Hydroxide)	45	45B ₆ 35	2D	1.7
Aluminum Chips, Dry	7-15	11E45V	2D	1.2
Aluminum Chips, Oily	7-15	11E45V	2D	.8
Aluminum Hydrate	13-20	17C _{1/2} 35	1A-1B-1C	1.4
Aluminum Ore (See Bauxite)	-	-	-	-
Aluminum Oxide	60-120	90A ₁₀₀ 17M	3D	1.8
Aluminum Silicate (Andalusite)	49	49C _{1/2} 35S	3A-3B	.8

A.3.2. Bulk Material Properties

Aluminum Sulfate	45-58	52C _{1/2} 25	1A-1B-1C	1.0
Ammonium Chloride, Crystalline	45-52	49A ₁₀₀ 45FRS	3A-3B	.7
Ammonium Nitrate	45-62	54A ₄₀ 35NTU	3D	1.3
Ammonium Sulfate	45-58	52C _{1/2} 35FOTU	1A-1B-1C42C	1.0
Antimony Powder	-	A ₁₀₀ 35	2D	1.6
Apple Pomace, Dry	15	15C _{1/2} 45Y	2D	1.0
Arsenate of Lead (See Lead Arsenate)	-	-	-	-
Arsenic Oxide (ArsenoliteX ¹)	100-120	110A ₃ 35R	-	-
Arsenic Pulverized	30	30A ₁₀₀ 25R	2D	.8
Asbestos-Rock (Ore)	81	81D ₃ 37R	3D	1.2
Asbestos-Shredded	20-40	30E46XY	2D	1.0
Ash, Black Ground	105	105B ₆ 35	1A-1B-1C	2.0
Ashes, Coal, Dry - 1/2"	35-45	40C _{1/2} 46TY	3D	3.0
Ashes, Coal, Dry - 3"	35-40	38D ₃ 46T	3D	2.5
Ashes, Coal, Wet - 1/2"	45-50	48C _{1/2} 46T	3D	3.0
Ashes, Coal, Wet - 3"	45-50	48D ₃ 46T	3D	4.0
Ashes, Fly (See Fly Ash)	-	-	-	-
Asphalt, Crushed - 1/2"	45	45C _{1/2} 45	1A-1B-1C	2.0
Bagasse	7-10	9E45RVXY	2A-2B-2C	1.5
Bakelite, Fine	30-45	38B ₆ 25	1A-1B-1C	1.4
Baking Powder	40-55	48A ₁₀₀ 35	1B	.6
Baking Soda (Sodium Bicarbonate)	40-55	48A ₁₀₀ 25	1B	.6
Barite (Barium Sulfate) - 1/2"	120-180	150D ₃ 36	3D	2.6
Barite, Powder	120-180	150A ₁₀₀ 35X	2D	2.0
Barium Carbonate	72	72A ₁₀₀ 45R	2D	1.6
Bark, Wood, Refuse	10-20	15E45TVY	3D	2.0
Barley, Fine, Ground	24-38	31B ₆ 35	1A-1B-1C	.4
Barley, Malted	31	31C _{1/2} 35	1A-1B-1C	.4
Barley, Meal	28	28C _{1/2} 35	1A-1B-1C	.4
Barley, Whole	36-48	42B ₆ 25N	1A-1B-1C	.5
Basalt	80-105	93B ₆ 27	3D	1.8
Bauxite, Dry, Ground	68	68B ₆ 25	2D	1.8

A.3.2. Bulk Material Properties

Bauxite, Crushed + $\frac{1}{2}$ " – 3"	75-85	80D ₃ 36	3D	2.5
Beans, Castor, Meal	35-40	38B ₆ 35W	1A-1B-1C	.8
Beans, Castor, Whole Shelled	36	36C _{1/2} 15W	1A-1B-1C	.5
Beans, Navy, Dry	48	48C _{1/2} 15	1A-1B-1C	.5
Beans, Navy, Steeped	60	60C _{1/2} 25	1A-1B-1C	.8
Bentonite, Crude	34-40	37D ₃ 45X	2D	1.2
Bentonite, -100 Mesh	50-60	55A ₁₀₀ 25MXY	2D	.7
Benzene Hexachloride	56	56A ₁₀₀ 45R	1A-1B-1C	.6
Bicarbonate of Soda (Baking Soda)	-	-	1B	.6
Blood, Dried	35-45	40D ₃ 45U	2D	2.0
Blood, Ground, Dried	30	30A ₁₀₀ 35U	1A-1B	1.0
Bone Ash (Tricalcium Phosphate)	40-50	45A ₁₀₀ 45	1A-1B	1.6
Boneblack	20-25	23A ₁₀₀ 25Y	1A-1B	1.5
Bonechar	27-40	34B ₆ 35	1A-1B	1.6
Bonemeal	50-60	55B ₆ 35	2D	1.7
Bones, Whole ⁽¹⁾	35-50	43E45V	2D	3.0
Bones, Crushed	35-50	43D ₃ 45	2D	2.0
Bones, Ground	50	50B ₆ 35	2D	1.7
Borate of Lime	60	60A ₁₀₀ 35	1A-1B-1C	.6
Borax, Fine	45-55	50B ₆ 25T	3D	.7
Borax Screening - $\frac{1}{2}$	55-60	58C _{1/2} 35	2D	1.5
Borax, $1\frac{1}{2}$ " – 2" Lump	55-60	58D ₃ 35	2D	1.8
Borax, 2" - 3" Lump	60-70	65D ₃ 35	2D	2.0
Boric Acid, Fine	55	55B ₆ 25T	3D	.8
Boron	75	75A ₁₀₀ 37	2D	1.0
Bran, Rice-Rye Wheat	16-20	18B ₆ 35NY	1A-1B-1C	.5
Braunite (Manganese Oxide)	120	120A ₁₀₀ 36	2D	2.0
Bread Crumbs	20-25	23B ₆ 35PQ	1A-1B-1C	.6
Brewer's Grain, spent, dry	14-30	22C _{1/2} 45	1A-1B-1C	.5
Brewer's Grain, spent, wet	55-60	58C _{1/2} 45T	2A-2B	.8
Brick, Ground - $\frac{1}{6}$ "	100-120	110B ₆ 37	3D	2.2
Bronze Chips	30-50	40B ₆ 45	2D	2.0
Buckwheat	37-42	40B ₆ 25N	1A-1B-1C	.4

A.3.2. Bulk Material Properties

Calcine, Flour	75-85	80A ₁₀₀ 35	1A-1B-1C	.7
Calcium Carbide	70-90	80D ₃ 25N	2D	2.0
Calcium Carbonate (See Limestone)	-	-	-	-
Calcium Fluoride (See Fluorspar)	-	-	-	-
Calcium Hydrate (See Lime, Hydrated)	-	-	-	-
Calcium Hydroxide (See Lime, Hydrated)	-	-	-	-
Calcium Lactate	26-29	28D ₃ 45QTR	2A-2B	.6
Calcium Oxide (See Lime, unslaked)	-	-	-	-
Calcium Phosphate	40-50	45A ₁₀₀ 45	1A-1B-1C	1.6
Calcium Sulfate (See Gypsum)	-	-	-	-
Carbon, Activated, Dry, Fine (¹)	-	-	-	-
Carbon Black, Pelleted(¹)	-	-	-	-
Carbon Black, Powder(¹)	-	-	-	-
Carborundum	100	100D ₃ 27	3D	3.0
Casein	36	36B ₆ 35	2D	1.6
Cashew Nuts	32-37	35C _{1/2} 45	2D	.7
Cast Iron, Chips	130-200	165C _{1/2} 45	2D	4.0
Caustic Soda	88	88B ₆ 35RSU	3D	1.8
Caustic Soda, Flakes	47	47C _{1/2} 45RSUX	3A-3B	1.5
Celite (See Diatomaceous Earth)	-	-	-	-
Cement, Clinker	75-95	85D ₃ 36	3D	1.8
Cement, Mortar	133	133B ₆ 35Q	3D	3.0
Cement, Portland	94	94A ₁₀₀ 35Q	2D	1.4
Cement, Aerated (Portland)	60-75	68A ₁₀₀ 16M	2D	1.4
Cerrusite (See Lead Carbonate)	-	-	-	-
Chalk, Crushed	75-95	85D ₃ 25	2D	1.9
Chalk, Pulverized	67-75	71A ₁₀₀ 25MXY	2D	1.4
Charcoal, Ground	18-28	23A ₁₀₀ 45	2D	1.2
Charcoal, Lumps	18-28	23D ₃ 45	2D	1.4

A.3.2. Bulk Material Properties

Chocolate, Cake Pressed	40-45	43D ₃ 25	2B	1.5
Chrome Ore	125-140	133D ₃ 36	3D	2.5
Cinders, Blast Furnace	57	57D ₃ 36T	3D	1.9
Cinders, Coal	40	40D ₃ 36T	3D	1.8
Clay (See Bentonite, Diatomaceous Earth, Fuller's Earth, Kaolin & Marl)	-	-	-	-
Clay, Ceramic, Dry, Fines	60-80	70A ₁₀₀ 35P	1A-1B-1C	1.5
Clay, Calcined	80-100	90B ₆ 36	3D	2.4
Clay, Brick, Dry, Fines	100-120	110C _{1/2} 36	3D	2.0
Clay, Dry, Lumpy	60-75	68D ₃ 35	2D	1.8
Clinker, Cement (See Cement Clinker)	-	-	-	-
Clover Seed	45-48	47B ₆ 25N	1A-1B-1C	.4
Coal, Anthracite (River & Culm)	55-61	60B ₆ 35TY	2A-2B	1.0
Coal, Anthracite, Sized - 1/2	49-61	55C _{1/2} 25	2A-2B	1.0
Coal, Bituminous, Mined	40-60	50D ₃ 35LNXY	1A-1B	.9
Coal, Bituminous, Mined, Sized	45-50	48D ₃ 35QV	1A-1B	1.0
Coal, Bituminous, Mined, Slack	43-50	47C _{1/2} 45T	2A-2B	.9
Coal, Lignite	37-45	41D ₃ 35T	2D	1.0
Cocoa Beans	30-45	38C _{1/2} 25Q	1A-1B	.5
Cocoa, Nibs	35	35C _{1/2} 25	2D	.5
Cocoa, Powdered	30-35	33A ₁₀₀ 45XY	1B	.9
Cocoanut, Shredded	20-22	21E45	2B	1.5
Coffee, Chaff	20	20B ₆ 25MY	1A-1B	1.0
Coffee, Green Bean	25-32	29C _{1/2} 25PQ	1A-1B	.5
Coffee, Ground, Dry	25	25A ₄₀ 35P	1A-1B	.6
Coffee, Ground, Wet	35-45	40A ₄₀ 45X	1A-1B	.6
Coffee, Roasted Bean	20-30	25C _{1/2} 25PQ	1B	.4
Coffee, Soluble	19	19A ₄₀ 35PUY	1B	.4
Coke, Breeze	25-35	30C _{1/2} 37	3D	1.2
Coke, Loose	23-35	30D ₇ 37	3D	1.2
Coke, Petrol, Calcined	35-45	40D ₇ 37	3D	1.3
Compost	30-50	40D ₇ 45TV	3A-3B	1.0
Concrete, Pre-Mix Dry	85-120	103C _{1/2} 36U	3D	3.0

A.3.2. Bulk Material Properties

Copper Ore	120-150	135D _x 35	3D	4.0
Copper Ore, Crushed	100-150	125D ₃ 36	3D	4.0
Copper Sulphate, (Bluestone)	75-95	85C _{1/2} 35S	2A-2B-2C	1.0
Copperas (See Ferrous Sulphate)	-	-	-	-
Copra, Cake Ground	40-45	43B ₆ 45HW	1A-1B-1C	.7
Copra, Cake, Lumpy	25-30	28D ₃ 35HW	2A-2B-2C	.8
Copra, Lumpy	22	22E35HW	2A-2B-2C	1.0
Copra, Meal	40-45	42B ₆ 35HW	2D	.7
Cork, Fine Ground	5-15	10B ₆ 35JNY	1A-1B-1C	.5
Cork, Granulated	12-15	14C _{1/2} 35JY	1A-1B-1C	.5
Corn, Cracked	40-50	45B ₆ 25P	1A-1B-1C	.7
Corn Cobs, Ground	17	17C _{1/2} 25Y	1A-1B-1C	.6
Corn Cobs, Whole ⁽¹⁾	12-15	14E35	2A-2B	-
Corn Ear ⁽¹⁾	56	56E35	2A-2B	-
Corn Germ	21	21B ₆ 35PY	1A-1B-1C	.4
Corn Grits	40-45	43B ₆ 35P	1A-1B-1C	.5
Cornmeal	32-40	36B ₆ 35P	1A-1B	.5
Corn Oil, Cake	25	25D ₇ 45HW	1A-1B	.6
Corn Seed	45	45C _{1/2} 25PQ	1A-1B-1C	.4
Corn Shelled	45	45C _{1/2} 25	1A-1B-1C	.4
Corn Sugar	30-35	33B ₆ 35PU	1B	1.0
Cottonseed, Cake, Crushed	40-45	43C _{1/2} 45HW	1A-1B	1.0
Cottonseed, Cake, Lumpy	40-45	43D ₇ 45HW	2A-2B	1.0
Cottonseed, Dry, Delinted	22-40	31C _{1/2} 25X	1A-1B	.6
Cottonseed, Dry, Not Delinted	18-25	22C _{1/2} 45XY	1A-1B	.9
Cottonseed, Flakes	20-25	23C _{1/2} 35HWY	1A-1B	.8
Cottonseed, Hulls	12	12B ₆ 35Y	1A-1B	.9
Cottonseed, Meal, Expeller	25-30	28B ₆ 45HW	3A-3B	.5
Cottonseed, Meal, Extracted	35-40	37B ₆ 45HW	1A-1B	.5
Cottonseed, Meats, Dry	40	40B ₆ 35HW	1A-1B	.6
Cottonseed, Meats, Rolled	35-40	38C _{1/2} 45HW	1A-1B	.6
Cracklings, Crushed	40-50	45D ₃ 45HW	2A-2B-2C	1.3
Cryolite, Dust	75-90	83A ₁₀₀ 36L	2D	2.0
Cryolite, Lumpy	90-110	100D ₁₆ 36	2D	2.1
Cullet, Fine	80-120	100C _{1/2} 37	3D	2.0

A.3.2. Bulk Material Properties

Cullet, Lump	80-120	100D ₁₆ 37	3D	2.5
Culm (See Coal, Anthracite)	-	-	-	-
Cupric Sulphate (Copper Sulfate)	-	-	-	-
Detergent (See Soap Detergent)	-	-	-	-
Diatomaceous Earth	11-17	14A ₄₀ 36Y	3D	1.6
Dicalcium Phosphate	40-50	45A ₄₀ 35	1A-1B-1C	1.6
Disodium Phosphate	25-31	28A ₄₀ 35	3D	.5
Distiller's Grain, Spent Dry	30	30B ₆ 35	2D	.5
Distiller's Grain, Spent Wet	40-60	50C _{1/2} 45V	3A-3B	.8
Dolomite, Crushed	80-100	90C _{1/2} 36	2D	2.0
Dolomite, Lumpy	90-100	95D _x 36	2D	2.0
Earth, Loam, Dry, Loose	76	76C _{1/2} 36	2D	1.2
Ebonite, Crushed	63-70	67C _{1/2} 35	1A-1B-1C	.8
Egg Powder	16	16A ₄₀ 35MPY	1B	1.0
Epsom Salts (Magnesium Sulfate)	40-50	45A ₄₀ 35U	1A-1B-1C	.8
Feldspar, Ground	65-80	73A ₁₀₀ 37	2D	2.0
Feldspar, Lumps	90-100	95D ₇ 37	2D	2.0
Feldspar, Powder	100	100A ₂₀₀ 36	2D	2.0
Feldspar, Screenings	75-80	78C _{1/2} 37	2D	2.0
Ferrous Sulfide - 1/2	120-135	128C _{1/2} 26	1A-1B-1C	2.0
Ferrous Sulfide -100M	105-120	113A ₁₀₀ 36	1A-1B-1C	2.0
Ferrous Sulphate	50-75	63C _{1/2} 35U	2D	1.0
Fish Meal	35-40	38C _{1/2} 45HP	1A-1B-1C	1.0
Fish Scrap	40-50	45D ₇ 45H	2A-2B-2C	1.5
Flaxseed	43-45	44B ₆ 35X	1A-1B-1C	.4
Flaxseed Cake (Linseed Cake)	48-50	49D ₇ 45W	2A-2B	.7
Flaxseed Meal (Linseed Meal)	25-45	35B ₆ 45W	1A-1B	.4
Four Wheat	33-40	37A ₄₀ 45LP	1B	.6
Flue Dust, Basic Oxygen Furnace	45-60	53A ₄₀ 36LM	3D	3.5
Flue Dust, Blast Furnace	110-125	118A ₄₀ 36	3D	3.5
Flue Dust, Boiler H. Dry	30-45	38A ₄₀ 36LM	3D	2.0
Fluorspar, Fine (Calcium Fluoride)	80-100	90B ₆ 36	2D	2.0
Fluorspar, Lumps	90-110	100D ₇ 36	2D	2.0

A.3.2. Bulk Material Properties

Flyash	30-45	38A ₄₀ 36M	3D	2.0
Foundry Sand, Dry (See Sand)	-	-	-	-
Fuller's Earth, Dry, Raw	30-40	35A ₄₀ 25	2D	2.0
Fuller's Earth, Oily, Spent	60-65	63C _{1/2} 45OW	3D	2.0
Fuller's Earth, Calcined	40	40A ₁₀₀ 25	3D	2.0
Galena (See Lead Sulfide)	-	-	-	-
Gelanite, Granulated	32	32B ₆ 35PU	1B	.8
Gilsonite	37	37C _{1/2} 35	3D	1.5
Glass, Batch	80-100	90C _{1/2} 37	3D	2.5
Glue, Ground	40	40B ₆ 45U	2D	1.7
Glue, Pearl	40	40C _{1/2} 35U	1A-1B-1C	.5
Glue, Veg, Powdered	40	40A ₄₀ 45U	1A-1B-1C	.6
Gluten, Meal	40	40B ₆ 35P	1B	.6
Granite, Fine	80-90	85C _{1/2} 27	3D	2.5
Grape Pomace	15-20	18D ₃ 45U	2D	1.4
Graphite Flake	40	40B ₆ 25LP	1A-1B-1C	.5
Graphite Flour	28	28A ₁₀₀ 35LMP	1A-1B-1C	.5
Graphite Ore	65-75	70D _x 35L	2D	1.0
Guano Dry ⁽¹⁾	70	70C _{1/2} 35	3A-3B	2.0
Gypsum, Calcined	55-60	58B ₆ 35U	2D	1.6
Gypsum, Calcined, Powdered	60-80	70A ₁₀₀ 35U	2D	2.0
Gypsum Raw -1"	70-80	75D ₃ 25	2D	2.0
Hay, Chopped ⁽¹⁾	8-12	10C _{1/2} 35JY	2A-2B	1.6
Hexanedioic Acid (See Adipic Acid)	-	-	-	-
Hominy, Dry	35-50	43C _{1/2} 35D	1A-1B-1C	.4
Hops, Spent, Dry	35	35D ₃ 35	2A-2B-2C	1.0
Hops, Spent, Wet	50-55	53D ₃ 45V	2A-2B	1.5
Ice, Crushed	35-45	40D ₃ 350	2A-2B	.4
Ice, Flaked ⁽¹⁾	40-45	43C _{1/2} 350	1B	.6
Ice, Cubes	33-35	34D ₃ 350	1B	.4
Ice, Shell	33-35	34D ₃ 450	1B	.4
Ilmenite Ore	140-160	150D ₃ 37	3D	2.0
Iron Ore Concentrate	120-180	150A ₄₀ 37	3D	2.2
Iron Oxide Pigment	25	25A ₁₀₀ 36LMP	1A-1B-1C	.10

A.3.2. Bulk Material Properties

Iron Oxide, Millscale	75	75C _{1/2} 36	2D	1.6
Iron Pyrites (See Ferrous Sulfide)	-	-	-	-
Iron Sulphate (See Ferrous Sulfate)	-	-	-	-
Iron Vitriol (See Ferrous Sulfate)	-	-	-	-
Kafir (Corn)	40-45	43C _{1/2} 25	3D	.5
Kaolin Clay	63	63D ₃ 25	2D	2.0
Kaolin Clay-Tale	42-56	49A ₄₀ 35LMP	2D	2.0
Kryalith (See Cryolite)	-	-	-	-
Lactose	32	32A ₄₀ 35PU	1B	.6
Lamp Black (See Carbon Black)	-	-	-	-
Lead Arsenate	72	72A ₄₀ 35R	1A-1B-1C	1.4
Lead Arsenite	72	72A ₄₀ 35R	1A-1B-1C	1.4
Lead Carbonate	240-260	250A ₄₀ 35R	2D	1.0
Lead Ore - 1/6	200-270	235B ₆ 35	3D	1.4
Lead Ore - 1/2	180-230	205C _{1/2} 36	3D	1.4
Lead Oxide (Red Lead) – 100 Mesh	30-150	90A ₁₀₀ 35L	2D	1.2
Lead Oxide (Red Lead) – 200 Mesh	30-180	105A ₂₀₀ 35LP	2D	1.2
Lead Sulphide – 100 Mesh	240-260	250A ₁₀₀ 35R	2D	-
Lignite (See Coal Lignite)	-	-	-	-
Limanite, Ore, Brown	120	120C _{1/2} 47	3D	1.7
Lime, Ground, Unslaked	60-65	63B ₆ 35U	1A-1B-1C	.6
Lime Hydrated	40	40B ₆ 35LM	2D	.8
Lime, Hydrated, Pulverized	32-40	36A ₄₀ 35LM	1A-1B	.6
Lime, Pebble	53-56	55C _{1/2} 25HU	2A-2B	2.0
Limestone, Agricultural	68	68B ₆ 35	2D	2.0
Limestone, Crushed	85-90	88D _x 36	2D	2.0
Limestone, Dust	55-95	75A ₄₀ 46MY	2D	1.6-2.0
Lindane (Benzene Hexachloride)	-	-	-	-
Linseed (See Flaxseed)	-	-	-	-
Litharge (Lead Oxide)	-	-	-	-
Lithopone	45-50	48A ₃₂₅ 35MR	1A-1B	1.0
Malze (See Milo)	-	-	-	-

A.3.2. Bulk Material Properties

Malt, Dry, Ground	20-30	25B ₆ 35NP	1A-1B-1C	.5
Malt, Meal	26-40	38B ₆ 25P	1A-1B-1C	.4
Malt, Dry Whole	20-30	25C _{1/2} 35P	1A-1B-1C	.5
Malt, Sprouts	13-15	14C _{1/2} 35P	1A-1B-1C	.4
Magnesium Chloride (Magnesite)	33	33C _{1/2} 45	1A-1B	1.0
Manganese Dioxide ⁽¹⁾	70-85	78A ₁₀₀ 35NRT	2A-2B	1.5
Manganese Ore	125-140	133D _x 37	3D	2.0
Manganese Oxide	120	120A ₁₀₀ 36	2D	2.0
Manganese Sulfate	70	70C _{1/2} 37	3D	2.4
Marble, Crushed	80-95	88B ₆ 37	3D	2.0
Marl, (Clay)	80	80D _x 36	2D	1.6
Meat, Ground	50-55	53E45HQTX	2A-2B	1.5
Meat, Scrap (W/bone)	40	40E46H	2D	1.5
Mica, Flakes	17-22	20B ₆ 16MY	2D	1.0
Mica, Ground	13-15	14B ₆ 36	2D	.9
Mica, Pulverized	13-15	14A ₁₀₀ 36M	2D	1.0
Milk, Dried, Flake	5-6	6B ₆ 35PUY	1B	.4
Milk, Malted	27-30	29A ₄₀ 45PX	1B	.9
Milk, Powdered	20-45	33B ₆ 25PM	1B	.5
Milk Sugar	32	32A ₁₀₀ 35PX	1B	.6
Milk, Whole, Powdered	20-36	28B ₆ 35PUX	1B	.5
Mill Scale (Steel)	120-135	123E46T	3D	3.0
Milo, Ground	23-36	34B ₆ 25	1A-1B-1C	.5
Milo Maize (Kafir)	40-45	43B ₆ 15N	1A-1B-1C	.4
Molybdenite Powder	107	107B ₆ 26	2D	1.5
Monosodium Phosphate	50	50B ₆ 36	2D	.6
Mortar, Wet ⁽¹⁾	150	150E46T	3D	2.0
Mustard Seed	45	45B ₆ 15N	1A-1B-1C	.4
Naphthalene Flakes	45	45B ₆ 35	1A-1B-1C	.7
Niacin (Nicotinic Acid)	35	35A ₄₀ 35P	2D	.8
Oats	26	26C _{1/2} 25MN	1A-1B-1C	.4
Oats, Crimped	19-26	23C _{1/2} 35	1A-1B-1C	.5
Oats, Crushed	22	22B ₆ 45NY	1A-1B-1C	.6
Oats, Flour	35	35A ₁₀₀ 35	1A-1B-1C	.5
Oat Hulls	8-12	10B ₆ 35NY	1A-1B-1C	.5

A.3.2. Bulk Material Properties

Oats, Rolled	19-24	22C _{1/2} 35NY	1A-1B-1C	.6
Oleo Margarine (Margarine)	59	59E45HKPWX	2A-2B	.4
Orange Peel, Dry	15	15E45	2A-2B	1.5
Oxalic Acid Crystals – Ethane Diacid Crystals	60	60B ₆ 35QS	1A-1B	1.0
Oyster Shells, Ground	50-60	55C _{1/2} 36T	3D	1.6-2.0
Oyster Shells, Whole	80	80D ₃ 36TV	3D	2.1-2.5
Paper Pulp (4% or less)	62	62E45	2A-2B	1.5
Paper Pulp (6% to 15%)	60-62	61E45	2A-2B	1.5
Paraffin Cake - 1/2 "	45	45C _{1/2} 45K	1A-1B	.6
Peanuts, Clean, in shell	15-20	18D ₃ 35Q	2A-2B	.6
Peanut Meal	30	30B ₆ 35P	1B	.6
Peanuts, Raw, Uncleaned (unshelled)	15-20	18D ₃ 36Q	3D	.7
Peanuts, Shelled	35-45	40C _{1/2} 35Q	1B	.4
Peas, Dried	45-50	48C _{1/2} 15NQ	1A-1B-1C	.5
Perlite-Expanded	8-12	10C _{1/2} 36	2D	.6
Phosphate Acid Fertilizer	60	60B ₆ 25T	2A-2B	1.4
Phosphate Disodium (See Sodium Phosphate)	-	-	-	-
Phosphate Rock, Pulverized	60	60B ₆ 36	2D	1.7
Phosphate Sand	90-100	95B ₆ 37	3D	2.0
Plaster of Paris (See Gypsum)	-	-	-	-
Plumbago (See Graphite)	-	-	-	-
Polystyrene Beads	40	40B ₆ 35PQ	1B	.4
Polyvinyl, Chloride Powder	20-30	25A ₁₀₀ 45KT	2B	0.1
Polyvinyl, Chloride Pellets	20-30	25E45KPQT	1B	.6
Polyethelene, Resin Pellets	30-35	33C _{1/2} 45Q	1A-1B	.4
Potash (Muriate) Dry	70	70B ₆ 37	3D	2.0
Potash (Muriate) Mine Run	75	75D _x 37	3D	2.2
Potassium Carbonate	51	51B ₆ 36	2D	1.0
Potassium Chloride Pellets	120-130	125C _{1/2} 25TU	3D	1.6
Potassium Nitrate - 1/2	76	76C _{1/2} 16NT	3D	1.2
Potassium Nitrate - 1/6	80	80B ₆ 26NT	3D	1.2
Potassium Sulfate	42-48	45B ₆ 46X	2D	1.0

A.3.2. Bulk Material Properties

Potato Flour	48	48A ₂₀₀ 35MNP	1A-1B	.5
Pumice - $\frac{1}{6}$	42-48	45B ₆ 46	3D	1.6
Pyrite, Pellets	120-130	125C _{1/2} 26	3D	2.0
Quartz, - 100 Mesh	70-80	75A ₁₀₀ 27	3D	1.7
Quartz, - $\frac{1}{2}$	80-90	85C _{1/2} 27	3D	2.0
Rice, Bran	20	20B ₆ 35NY	1A-1B-1C	.4
Rice, Grits	42-45	44B ₆ 35P	1A-1B-1C	.4
Rice, Polished	30	30C _{1/2} 15P	1A-1B-1C	.4
Rice, Hulled	45-49	47C _{1/2} 25P	1A-1B-1C	.4
Rice, Hulls	20-21	21B ₆ 35NY	1A-1B-1C	.4
Rice, Rough	32-36	34C _{1/2} 35N	1A-1B-1C	.6
Rosin - $\frac{1}{2}$	65-68	67C _{1/2} 45Q	1A-1B-1C	1.5
Rubber, Reclaimed Ground	23-50	37C _{1/2} 45	1A-1B-1C	.8
Rubber, Pelleted	50-55	53D ₃ 45	2A-2B-2C	1.5
Rye	42-48	45B ₆ 15N	1A-1B-1C	.4
Rye Bran	15-20	18B ₆ 35Y	1A-1B-1C	.4
Rye Feed	33	33B ₆ 35N	1A-1B-1C	.5
Rye Meal	35-40	38B ₆ 35	1A-1B-1C	.5
Rye Middlings	42	42B ₆ 35	1A-1B	.5
Rye, Shorts	32-33	33C _{1/2} 35	2A-2B	.5
Safflower, Cake	50	50D ₃ 26	2D	.6
Safflower, Meal	50	50B ₆ 35	1A-1B-1C	.6
Safflower Seed	45	45B ₆ 15N	1A-1B-1C	.4
Saffron (See Safflower)	-	-	-	-
Sal Animoniac (Ammonium Chloride)	-	-	-	-
Salt Cake, Dry Coarse	85	85B ₆ 36TU	3D	2.1
Salt Cake, Dry Pulverized	65-85	75B ₆ 36TU	3D	1.7
Salicylic Acid	29	29B ₆ 37U	3D	.6
Salt, Dry Coarse	45-60	53C _{1/2} 36TU	3D	1.0
Salt, Dry Fine	70-80	75B ₆ 36TU	3D	1.7
Saltpeter – (See Potassium Nitrate)	-	-	-	-
Sand Dry Bank (Damp)	110-130	120B ₆ 47	3D	2.8
Sand Dry Bank (Dry)	90-110	100B ₆ 37	3D	1.7

A.3.2. Bulk Material Properties

Sand Dry Silica	90-100	95B ₆ 27	3D	2.0
Sand Foundry (Shake Out)	90-100	95D ₃ 37Z	3D	2.6
Sand (Resin Coated) Silica	104	104B ₆ 27	3D	2.0
Sand (Resin Coated) Zircon	115	115A ₁₀₀ 27	3D	2.3
Sawdust, Dry	10-13	12B ₆ 45UX	1A-1B-1C	.7
Sea-Coal	65	65B ₆ 36	2D	1.0
Sesame Seed	27-41	34B ₆ 26	2D	.6
Shale, Crushed	85-90	88C _{1/2} 36	2D	2.0
Shellac, Powdered or Granulated	31	31B ₆ 35P	1B	.6
Silicon Dioxide (See Quartz)	-	-	-	-
Silica, Flour	80	80A ₄₀ 46	2D	1.5
Silica Gel + 1/2"-3"	45	45D ₃ 37HKQU	3D	2.0
Slag, Blast Furnace Crushed	130-180	155D ₃ 37Y	3D	2.4
Slag, Furnace Granular, Dry	60-65	63C _{1/2} 37	3D	2.2
Slate, Crushed - 1/2	80-90	85C _{1/2} 36	2D	2.0
Slate, Ground - 1/6	82-85	84B ₆ 36	2D	1.6
Sludge, Sewage, Dried	40-50	45E47TW	3D	.8
Sludge, Sewage, Dry Ground	45-55	50B46S	2D	.8
Soap, Beads or Granules	15-35	25B ₆ 35Q	1A-1B-1C	.6
Soap, Chips	15-25	20C _{1/2} 35Q	1A-1B-1C	.6
Soap Detergent	15-50	33B ₆ 35FQ	1A-1B-1C	.8
Soap , Flakes	5-15	10B ₆ 35QXY	1A-1B-1C	.6
Soap, Powder	20-25	23B ₆ 25X	1A-1B-1C	.9
Soapstone, Talc, Fine	40-50	45A ₂₀₀ 45XY	1A-1B-1C	2.0
Soda Ash, Heavy	55-65	60B ₆ 36	2D	1.0
Soda Ash, Light	20-35	28A ₄₀ 36Y	2D	.8
Sodium Aluminate, Ground	72	72B ₆ 36	2D	1.0
Sodium Aluminum Fluoride (See Kryolite)	-	-	-	-
Sodium Aluminum Sulphate ⁽¹⁾	75	75A ₁₀₀ 36	2D	1.0
Sodium Bentonite (See Bentonite)	-	-	-	-
Sodium Bicarbonate (See Baking Soda)	-	-	-	-
Sodium Chloride (See Salt)	-	-	-	-

A.3.2. Bulk Material Properties

Sodium Carbonate (See Soda Ash)	-	-	-	-
Sodium Hydrate (See Caustic Soda)	-	-	-	-
Sodium Hydroxide (See Caustic Soda)	-	-	-	-
Sodium Borate (See Borax)	-	-	-	-
Sodium Nitrate	70-80	75D ₃ 25NS	2A-2B	1.2
Sodium Phosphate	50-60	55A35	1A-1B	.9
Sodium Sulfate (See Salt Cake)	-	-	-	-
Sodium Sulfite	96	96B ₆ 46X	2D	1.5
Sorghum, Seed (See Kafir or Milo)	-	-	-	-
Soybean, Cake	40-43	42D ₃ 35W	2A-1B-1C	1.0
Soybean, Cracked	30-40	35C _{1/2} 36NW	2D	.5
Soybean, Flake, Raw	18-25	22C _{1/2} 35Y	1A-1B-1C	.8
Soybean, Flour	27-30	29A ₄₀ 35MN	1A-1B-1C	.8
Soybean Meal, Cold	40	40B ₆ 35	1A-1B-1C	.5
Soybean Meal, Hot	40	40B ₆ 35T	2A-2B	.5
Soybeans, Whole	45-50	48C _{1/2} 26NW	-	1.0
Starch	25-50	38A ₄₀ 15M	1A-1B-1C	1.0
Steel Turnings, Crushed	100-150	125D ₃ 46WV	3D	3.0
Sugar Beet, Pulp, Dry	12-15	14C _{1/2} 26	2D	.9
Sugar Beet, Pulp, Wet	25-45	35C _{1/2} 35X	1A-1B-1C	1.2
Sugar, Refined, Granulated Dry	50-55	53B ₆ 35PU	1B	1.0-1.2
Sugar, Refined, Granulated Wet	55-65	60C _{1/2} 35X	1B	1.4-2.0
Sugar, Powdered	50-60	55A ₁₀₀ 35PX	1B	.8
Sugar, Raw	55-65	60B ₆ 35PX	1B	1.5
Sulphur, Crushed - 1/2	50-60	55C _{1/2} 35N	1A-1B	.8
Sulphur, Lumpy – 3"	80-85	83D ₃ 35N	2A-2B	.8
Sulphur, Powdered	50-60	55A ₄₀ 35MN	1A-1B	.6
Sunflower Seed	19-38	29C _{1/2} 15	1A-1B-1C	.5
Talcum, - 1/2	80-90	85C _{1/2} 36	2D	.9
Talcum Powder	50-60	55A ₂₀₀ 36M	2D	.8
Tanbark, Ground ⁽¹⁾	55	55B ₆ 45	1A-1B-1C	.7

A.3.2. Bulk Material Properties

Timothy Seed	36	36B ₆ 35NY	1A-1B-1C	.6
Titanium Dioxide (See Ilmenite Ore)	-	-	-	-
Tobacco, Scraps	15-25	20D ₃ 45Y	2A-2B	.8
Tobacco, Snuff	30	30B ₆ 45MQ	1A-1B-1C	.9
Tricalcium Phosphate	40-50	45A ₄₀ 45	1A-1B	1.6
Triple Super Phosphate	50-55	53B ₆ 36RS	3D	2.0
Trisodium Phosphate	60	60C _{1/2} 36	2D	1.7
Trisodium Phosphate, Granular	60	60B ₆ 36	2D	1.7
Trisodium Phosphate, Pulverized	50	50A ₄₀ 36	2D	1.6
Tung Nut Meats, Crushed	28	28D ₃ 25W	2A-2B	.8
Tung Nuts	25-30	28D ₃ 15	2A-2B	.7
Urea Polls, Coated	43-46	45B ₆ 25	1A-1B-1C	1.2
Vermiculite, Expanded	16	16C _{1/2} 35Y	1A-1B	.5
Vermiculite, Ore	80	80D ₃ 36	2D	1.0
Vetch	48	48B ₆ 16N	1A-1B-1C	.4
Walnut Shells, Crushed	35-45	40B ₆ 36	2D	1.0
Wheat	45-48	47C _{1/2} 25N	1A-1B-1C	.4
Wheat, Cracked	40-45	43B ₆ 25N	1A-1B-1C	.4
Wheat, Germ	18-28	23B ₆ 25	1A-1B-1C	.4
White Lead, Dry	75-100	88A ₄₀ 36MR	2D	1.0
Wood Chips, Screened	10-30	20D ₃ 45VY	2A-2B	.6
Wood Flour	16-36	26B ₆ 35N	1A-1B	.4
Wood Shavings	8-16	12E45VY	2A-2B	1.5
Zinc, Concentrate Residue	75-8	78B ₆ 37	3D	1.0
Zinc Oxide, Heavy	30-35	33A ₁₀₀ 45X	1A-1B	1.0
Zinc Oxide, Light	10-15	13A ₁₀₀ 45XY	1A-1B	1.0

Source: FMC Technologies, 2009: 26-34

APPENDIX 4. RProject Codes for Simulation Model

```
getwd()
setwd("C:/Users/Google Drive/Program Deneme/R")
library(tidyverse)

###Input variables will be added here

### BERTH HANDLING

##Berth handling operation choices' functions

#Grab Function
use_grab <- function(eta_G_i) {
  C_j_i <- Gng_t*Gng_n
  E_j_n <- E_G_n
  eta_j_i <- eta_G_i

  if (ro_i*V_g > (C_max_lift-WT_g_net))
  {
    Gng_t <- C_max_lift-WT_g_net
  }
  else {
    Gng_t <- ro_i*V_g
  }

  w <- Gng_m*Gng_t* E_g_n*BOR*eta_G_i*t_pd*t*PF
  return(w)
}

#Pneumatic Unloader Function
use_pne <- function(eta_pne_i){
```



```

C_j_n <- n_pne*A*p_mix*phi/(phi+1)
E_j_n <- E_pne_n
eta_j_i <- eta_pne_i
x <-
n_pne*A*ro_mix*phi/((phi+1)*E_pne_n*BOR*eta_pne_i*t_pd*t*
PF)
  return(x)
}

#Stacker Function
# Flat Belt is used 1, not used 0
use_stc <- function(flat_belt,eta_fb_i,eta_3b_i){

  if (flat_belt == 1){
    C_j_n <- C_w_s*ro_i*CF*cos(alpha)*(v_b/100)
    E_j_n <- E_stc_n
    eta_j_i <- eta_fb_i
    y <-
(tan(delta)/6*ro_i)*v_b*b^(2*cos(alpha))*E_stc_n*BOR*eta_
fb_i*t_pd*t*PF
  }
  else if (flat_belt == 0){
    C_j_n <- C_w_s*ro_i*CF*cos(alpha)*(v_b/100)
    E_j_n <- E_stc_n
    eta_j_i <- eta_3b_i
    y <-
C_w_s*ro_i*CF*cos(a)*(v_b/100)*E_stc_n*BOR*eta_3b_i*t_pd*
t*PF
  }
  return(y)
}

#Screw Type Unloader Function

```

```

use_scr <- function(eta_scr_i){
  C_j_n <- pi/4*(D*D-d*d)*lambda*N*ro_i*psi*k
  E_j_n <- E_scr_n
  eta_j_i <- eta_scr_i
  z <- (pi/4)*(D*D -
d*d)*lambda*N*ro_i*psi*k*E_scr_n*eta_scr_i*t_pd*t*PF
  return(z)
}

##Berth Handling Operation Main Function
# If one or more of the following eqiupment were used for
the operation, enter 1.
#Eqiupment used 1 not used 0. Arrange the data frame
according to this nomenclature

Grab = 0
PneumaticUnloader = 0
Stacker = 0
ScrewTypeUnloader = 0

berth_handling <-
function(Grab,PneumaticUnloader,Stacker,ScrewTypeUnloader
) {

  if (Grab != 0){
    a <- use_grab(eta_G_i)
  }
  if (PneumaticUnloader != 0){
    b <- use_pne(eta_pne_i)
  }
  if (Stacker != 0){
    c <- use_stc(flat_belt,eta_fb_i,eta_3b_i)
  }

```

```

if (ScrewTypeUnloader != 0){
  d <- use_scr(eta_scr_i)
}

total_berth <- a+b+c+d
return(total_berth)
print("Total Berth Handling Capacity: ",total_berth)

}

```

```

### TRANSFER EQUIPMENT

```

```

## Transfer Equipment operation choices' functions

```

```

#Reclaimer Function

```

```

use_reclaimer <- function(eta_rec_i,E_rc_n,v_rec){
  C_j_n <- A*v_rec
  E_j_n <- E_rec_n
  eta_j_i <- eta_rec_i
  tt <- A* v_rec*3600*E_rec_n*eta_rec_i*t_pd*t
  return(tt)
}

```

```

# Stacker Function

```

```

#If flat belt is used 1, not used 0.

```

```

use_stack <-
function(flat_belt_2,eta_fb_i,eta_3b_i,E_stc_n){
  if (flat_belt_2 == 1){
    C_j_n <- tan(delta)/sigma*ro_i*v_b*b^2*cos(alpha)
    E_j_n <- E_stc_n
    eta_j_i <- eta_fb_i

```

```

        ss <-
tan(delta)*ro_i*v_b*b^2*cos(alpha)*E_stc_n*eta_fb_i*t_pd*
t
    }
    else {
        C_j_n <- C_w_s*ro_i*CF*cos(alpha*v_b/100)
        E_j_n <- E_stc_n
        eta_j_i <- eta_3b_i
        ss <- C_w_s
        *ro_i0CF*cos(alpha)*(v_b/100)*E_stc_n*eta_3b_i*t_pd*t
    }
}
#Screw Conveyor Function

#If is U shaped 1, not 0.
use_scr_con <- function(U_type,eta_uscr_i,E_uscr_n){

    if (U == 1){
        C_j_n <- ro_i*(pi/4)*(D*D-
d*d)*psi*lambda*(N/60)*(CF_f*CF_m)
        E_j_n <- E_uscr_n
        eta_j_i <- eta_uscr_i
        xx <- ro_i*(pi/4)*(D*d-
d*d)*psi*lambda*(N/60)*CF_f*CF_m*E_uscr_n*eta_uscr_i*t_pd
*t
    }
    else {
        C_j_n <- ro_i*(pi/4)*(D*D-d*d)*N*lambda*ro_i*psi*k
        E_j_n <- E_uscr_n
        eta_j_i <- eta_uscr_i
        xx <- ro*(pi/4)*(D*d-
d*d)*lambda*N*ro_i*psi*k*E_uscr_n*eta_uscr_con*t_pd*t
    }
}

```

```

    return(xx)
}

#Belt Conveyor Function
use_belt_conveyor <-
function(flat_belt_3,eta_fb_i,E_fb_n){

  if (flat_belt_3 == 1){
    C_j_n <- tan(delta)/(sigma*ro_i*v_b*b^2*cos(alpha))
    E_j_n <- E_fb_n
    eta_j_i <- eta_fb_i
    yy <-
tan(delta)*sigma*ro_i*v_b*(b^(2*cos(alpha)))*E_fb_n*eta_f
b_i*t_pd*t
  }
  else{
    C_j_n <- C_w_s*p_i*CF*cos(alpha)*v_b/100
    E_j_n <- E_3_n
    eta_j_i <- eta_3b_i
    yy <-
C_w_s*ro_i*CF*(cos(alpha)*v_b/100)*E_3_n*eta_3b_i*t_pd*t
  }
  return(yy)
}

#Truck Function

use_truck <- function(eta_trk_i,Max_trk){

  if (ro_i*V_trk > Max_trk){
    CC_trk <- Max_trk
    C_j_n <- Max_trk*Te/O_trk_i
    E_j_n <- E_trk_n
  }

```

```

    eta_j_i <- eta_trk_i
    zz <- Max_trk*Te/O_trk_i*E_trk_n*eta_trk_i*t_pd*t
  }

  else{
    C_trk <- ro_i*V_trk
    C_j_n <- ro_i*V_trk*Te/O_trk_i
    E_j_n <- E_trk_n
    eta_j_i <- eta_trk_i
    zz <- ro_i*V_trk*Te/O_trk_i*E_trk_n*eta_trk_i-t_pd*t
  }
}

#Bulldozer Function

use_bulldozer <- function(eta_bld_i,Max_bld){

  if (ro_i*V_bld > Max_bld){
    C_bld <- Max_bld
    C_j_n <- Max_bld*Te/O_bld_i
    E_j_n <- E_bld_n
    eta_j_i <- eta_bld_i
    ww <- Max_bld*Te/O_bld_i*E_bld_n*eta_bld_i*t_pd*t
  }
  else{
    C_bld <- ro_i*V_bld
    ww <- ro_i*V_bld*Te/O_bld_i*E_bld_n*eta_bld_i*t_pd*t
  }
}

#Transfer Equipment Main Function

```

```

# If one or more of the following equipment were used for
the operation, enter 1.
#Equipment used 1 not used 0. Arrange the data frame
according to this nomenclature
Reclaimer = 0
Stacker = 0
ScrewConveyor = 0
BeltConveyor = 0
Truck = 0
Bulldozer = 0

transfer_equipment <-
function(ScrewConveyor,BeltConveyor,Truck,Bulldozer) {

  if (ScrewConveyor != 0){
    aa <- use_scr_con(U_type,eta_uscr_i,E_uscr_n)
  }
  if (BeltConveyor != 0){
    bb <- use_belt_conveyor(flat_belt_3,eta_b)
  }
  if (Truck != 0){
    cc <- use_truck(eta_trk_i,Max_trk)
  }
  if (Bulldozer != 0){
    dd <- use_bulldozer(eta_bld_i,Max_bld)
  }
  if (Stacker != 0){
    ee <-
use_stacker(flat_belt_2,eta_fb_i,eta_3b_i,E_stc_n)
  }
  if (Reclaimer != 0){
    ff <- use_reclaimer(eta_rec_i,E_rc_n,v_rec)
  }
}

```

```

    total_transfer_equipment <- aa+bb+cc+dd+ee+ff
    return(total_transfer_equipment)
    print("Total Transfer Equipment Capacity:
",total_transfer_equipment)

}

### STORAGE YARD

#Selecting h

if (q_max_i/ro_i > h_eq_max){
  if (h_w_max > h_eq_max){
    h<-h_eq_max
  }else {h<-h_w_max}
} else {
  if (h_w_max >q_max(ro_i)) {
    h<-q_max/ro_i
  }else{h<-h_w_max}
}

#Are open and closed storage area applied together? Yes
1, No 0.
OCTogether <- 0

if (OCTogether == 1){
  C_storage <- C_OA + C_CA
}

#C_OA or C_CA, Operation=1 yields C_CA, Operation=0
yields C_OA
Operation <- 0
if(OCTogether == 0){

```



```

if (Operation == 1){

  if (Dome != 0){
    C_dome <- V_dome*n_dome*PF_dome*ro_i*365/t_d_dome
  }
  else if (Shed != 0){
    C_Shed <- V_shed*n_shed*PF_shed*ro_i*365*t_d_shed
  }
  else if (Silo != 0){
    C_silo <- V_silo*n_silo*PF_silo*ro_i*365/t_d_silo
  }
  else if(EnclosedStructure != 0){
    C_EA <- m_s*n_EA*PF_EA*365/t_d_EA
  }
  C_CA <- C_dome+C_shed+C_silo+C_EA
}

else if (Operation == 0){
  #Are Longitudinal and Circular storage yard type
  applied together ? Yes 1, No 0.
  if(LongitudinalCircular == 1){
    C_OA <- C_OA_IID+C_OA_ICAM+C_OA_c_cir+C_OA_c_con
  }
  else if(LongitudinalCircular == 0){
    #Only put into operation C_OAI_ID and/or C_OAI_CAM
    or C_OA_C
    # xxx creates a choice between C_OAI_ID and/or
    C_OAI_CAM or C_OA_C
    xxx <- 0
    if (xxx == 0){
      #Put into operation C_OAI_ID and/or C_OAI_CAM

```

```

#Finding m_s_ts and l_S will be operated from
outside. It depends on Geometry(TS,TEC,TREC)
n_s <- l_lane/(l_s+d_S)
C_OAI_ID <- n_lane*n_s*V_s_ton*PF_OA*360/t_d_OA
C_OAI_CAM <- n_lane*m_s*PF_OA*360/t_d_OA
#Are ID-Presented CAM storage policy applied
together in longitudinal area

#IDUsed parameter is defined for the craete
condition. IDUsed=1 yields the addition of this parameter
#IDUsed == 2 means C_OA_I = C_OAI_ID,
(else)IDUsed == 0 means C_OA_I = C_OAI_CAM
IDUsed <- 0
if(IDUsed == 1){
  C_OA_I <- C_OAI_ID + C_OAI_CAM
}
else if(IDUsed == 2) {
  C_OA_I <- C_OAI_ID
}
else {
  C_OA_I <- C_OAI_CAM
}
}
else {
  #Use C_OA_C
C_OA_C_con <- n_OA_c*m_s_con*PF_OA*360/t_d_OA
C_OA_C_cir <- n_bed*m_sc*PF_OA*360/t_d_OA
#Are conical and circular stockpile applied
together in circular area?
#CirCon parameter is defined. If applied together
1, not 0.
CirCon <- 0
if(CirCon == 1){

```

```
        C_OA_C <- C_OA_C_cir*C_OA_C_con
    }
else {
    if(C_OA_C_con > 0){
        C_OA_C <-C_OA_C_con
    }
    else{
        C_OA_C <- C_OA_C_cir
    }
}
}
}
}
```