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Assessing forecasted container throughput demand on optimal terminal design:

a case study of the Port of Busan

Author: Bryan Vishay Panchoe
Student number: 328214
Thesis supervisor: Dr. Peran van Reeven
Second reader: TBA
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PREFACE AND ACKNOWLEDGEMENTS

This study is the final result to graduate at the Erasmus School of Economics for the Master Urban, Port and Transport Economics. The research presented in this master thesis has been carried out over a period of almost 5 months under supervision of Dr. Peran van Reeven.

The aim of this research is to provide more insight for terminal operating companies to balance the expected throughput demand with the given terminal capacity constraints. This is done by identifying an appropriate forecasting model and providing a simple and inexpensive tool in order to maximize the container storage capacity of a terminal based on different layout and equipment characteristics. This study is carried for the Port of Busan because most container terminals are operating at their maximum capacity. This study provides more information regarding how to increase additional container storage space taking into account peak throughput demands, terminal layout, storage equipment type and various container dwell times.

Although this research is an individual work, the completion of this study would not have been possible without the help of some key people. First of all, I want to thank my thesis supervisor Dr. Peran van Reeven for all his help, support and patience during the writing process. Not to mention, without his key advice and reviews this study would certainly not have come to a successful end. Finally, above and beyond the university environment, I thank my family and friends for their unconditional trust and support during my thesis and especially throughout my life.

Bryan Vishay Panchoe,
Utrecht, July 2015

ABSTRACT

This paper seeks to balance (or at least provide sufficient) container storage capacity with forecasted TEU throughput volumes for the Port of Busan. Hence, this paper focuses both on forecasting TEU throughput volumes accurately and maximizing CY storage capacity. The SARIMA model using the Box-Jenkins approach was compared against the linear regression model with dummy variables in order to identify seasonal and peak patterns of TEU throughput volumes. The SARIMA model $(1,1,0)(0,1,1)_{12}$ have been found to be the best method to forecast the monthly 2015 TEU throughput volume for the Port of Busan. Furthermore, front-end-loading systems configured with RMGs have superior container storage capacity compared to sideway-loading systems. Finally, container dwell times and container stacking heights are among the factors to affect the container storage capacity in a yard block.

Keywords:
Forecasting, container terminal, storage systems, input-output model
JEL classification:
C22, C67, R40

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CHAPTER 1 Introduction

The adoption of containerization have revolutionized transport and international trade by decreasing its costs and increasing its speed of especially consumer goods and commodities. Specifically, a new intermodal transport system was adopted which led to increases in shipping capacities and reduction of delivery times through intermodal cargo movements between ships, trains, and trucks. In 2010, over 66% of the world's deep-sea general cargo was transported in containers with an estimated value of US$5.6 trillion (Heiberg, 2012). One of the benefits of containerization is the adoption of purpose designed container terminals. This resulted in increasing the productivity of dock labor from 1.7 to 30 tons per hour if the pre-container period 1965 is compared with the container period in 1971 (Bernhofen et al. 2012). The increase in efficiency and speed of cargo handling triggered port authorities to enhance port capacity.

Due to the role of containerization on the rapid growth of international trade, global competition in shipping routes have increased altering the short- and long-term business decisions processes regarding port operations, construction, and upgrading port facilities (Peng et al.2009). Hence, monitoring the growth of container throughput in a port within a certain timeframe is necessary for different reasons. First, to cope with the rise of container throughput, large and irreversible investments (sunk costs) have to be made in port infrastructure development. Building port facilities may disrupt current port activities as a result from limited use of port space and limited access to port facilities. Inabilities to accurately predict future container throughputs may results in financial losses putting port infrastructure development projects on the line. Second, forecasting throughput demand is also crucial for planning daily operational activities, especially for ports with capacity constraints (Chung Ee et al.2014). For example, container terminal planning is necessary to match equipment capacity with the handling of containers. Inability to do so may eventually result in long queuing time imposing additional costs and time that may damage the port's reputation. If the port is located in a competitive area, ship-liners may chose the nearest adjacent port for more swift and reliable service. It is therefore of importance for ports to accurately predict the future growth of container throughputs in order to make decisions regarding constructions, upgrading, and daily operations.

As mentioned before, forecasting throughput demand is crucial for planning the daily operational activities in a port. One of these operational activities includes the processing of containers at a terminal. Within terminal operations, container yard operations plays a vital role when it comes to increasing the productivity of land use i.e. increasing storage space by stacking containers even higher in the yard. However, stacking containers tend to increase the number of unproductive container movements influencing the efficiency of the terminal operations (Chu et al. 2005). Inability to forecast container throughput demand will ultimately affect your assessment on container yard capacity. Bias estimates on container yard capacity will then affect daily terminal operations such as maintenance costs, ease of scheduling and economies of scale leading to customer dissatisfaction (Sinha 2011). It is often a misconception that capacity planning is based on average demand. Sinha (2011) have argued that it is rather peak demand that have to be taken care when assessing the container yard capacity. Ignoring peak demand will eventually result in capacity lagging behind throughput demand in an upturn even if the demand is accurately predicted. This study contributes to this point of view by predicting monthly container throughput. This will help identifying seasonal variations or peak periods of container throughput during a particular year.

The demand of container throughput is forecasted for the Port of Busan located in South Korea. Due to globalization, global economy is shifting more to new industrialized countries in Asia resulting in fast regional economic development and growth. In terms of annual container throughput, 8 Asian ports are ranked in the top 10 container ports in the world (World Shipping Council). The Port of Busan is the fifth busiest container port in the world and the largest transshipment port in its region. The port handled 17.69 million TEUs (twenty feet equivalent unit) of cargo in 2013, making it the fifth highest annual cargo haul in the world. The average growth of container traffic for the port of Busan in the past 5 years is higher compared to top 4 ports in the world (Shanghai, Singapore, Shenzhen, Hong Kong). To maintain their position as one of the leading ports of world, the Port of Busan have been investing in many port sustainable and expanding projects such as the Busan New Port project. One of the facets within the project is intended to anticipate on the growth in its container market segment. To increase the handling capacity of the port, 5 container terminals (4 south and 1 west) with a total of 18 berths have been developed between 2008 and 2015. The higher growth of container traffic compared to its major competitors and its commitment to expand its container terminal capacity make it interesting for this study to examine the port of Busan case.

1.1 Problem statement

In the design of a well-organized and efficient container terminal, one has to match (or at least provide sufficient) terminal container storage capacity along with the expected throughput demand. This study deals with both sides of the equation by accurately forecasting the monthly TEU throughput volume and designing a optimal container terminal that can handle the expected throughput demand given seasonal and peak patterns.

Forecasts on container throughputs have usually long forecasting horizons since they are mainly used for investment decisions for long-term projects. Hence, most literature studies are based on long-term forecasting. This study focus on forecasting container throughputs for a short horizon, that has various advantages for several reasons. First, short-term predictions are necessary to monitor seasonal patterns and business cycles. Second, short-term predictions are to a lesser extent affected by prediction errors compared to long-term predictions due to the fact fewer unexpected factors may arise when the prediction period is shorter (Franses et al. 2005). Third, short-term forecasts are essential for controlling and scheduling the port system as it can be directly implemented in daily port operation activities such as acquisition of additional equipment and material, allocation and arrangement of workers and machines.

The design of a optimal container terminal is often a complicated task since container terminals are faced with different objectives and demands from several stakeholders. Container terminal experts have argued that the present performance of container facilities throughout the world is far from optimum (UNCTAD, 1985). This is mainly due to inappropriate planning decisions, operating procedures, equipment or manpower policies. In addition, the imbalance between container throughput demand and container terminal capacity increases when container terminal operators are left with capacity storage constraints simply because there is no land available for expansion. When designing a optimal container terminal, it is generally necessary to run several computer simulations with different local conditions. However, this technique requires a considerable amount of effort and data collection. Hence, it is necessary to design a simple and inexpensive tool in order to maximize the container storage capacity of a terminal based on different layouts and equipment characteristics.

After forecasting the monthly demand for container throughput, the estimates can be implemented into the container yard operations. For example, the storage capacity of the container yard can be calculated such that it meets the expected monthly throughput demand. Other than expected monthly throughput demand, other parameters such as stacking height, average container dwell time and peaking factor are also considered when evaluating the handling capacity of the container yard. Consequently, the following research questions are addressed by this paper:

1. Does the monthly throughput demand for the port of Busan exhibit seasonal variations? If so, what adequate and reliable time series model can be used for future forecasting of future values of monthly container throughput?
2. How should the port implement expected monthly throughput data given peak periods into the optimal container terminal design?
3. Other than the expected throughput demand, what are the other factors and to which extend do they influence the storage capacity of the container yard?

1.2 Importance of the research

The main purpose of this study is threefold such that a three step research is applied. The first objective is to highlight the importance of timely information i.e. predict monthly container throughput demand (in TEUs) in order to monitor seasonal and peak patterns during a year.

Afterwards, estimates of monthly throughput demand are processed to achieve proper planning of container yard operations leading to faster clearances of containers and optimal use of container yard space. At last, the empirical findings of this study are compared against current container yard operations at the port of Busan through qualitative explanations. This is necessary to identify whether other factors play a role in determining the capacities of the container yard that are not explained in this study. Also, comparing the results will help to detect possible flaws in our model.

This study focus on the availability of land, the terminal operating methods (loading systems) and operating equipments (stacking equipments) as main drivers that effect the container storage capacity in the CY. For example, if a terminal is located far from urban agglomeration areas then it may be possible that there is a high degree of inexpensive land. This consequently means that no costly equipment is needed for stacking containers since a system of storing containers one high may be most economical (UNCTAD, 1985). On the other hand, if land is scarce and expensive, strict planning of container terminal operation is needed.

The Port of Busan have been engaged in increasing its container handling capacity by developing the Busan New Port since the current Busan North Port have no available land to expand. Busan New Port has currently 5 container terminals. As container capacity is nearing at its maximum in all terminals in the Busan New Port, the Busan Port Authority (BPA) have decided to expand the Busan New Port with 3 additional container terminals (Phase 2-4, 2-5, 2-6). However, the main issue is that no additional terminals are planned to open until after 2019 in Busan (Ascutia, 2015). This means that container terminal operators are constrained with the lack of container storage space in the upcoming years. At a time of strong growth in container volumes and significant increases in both number and vessels size, this study contributes by providing more insight to terminal operators regarding the enhancement of the productivity and efficiency of container storage capacity. Specifically, this study provides a theoretical model to assess the impact of different container stacking height, container dwell times on the average filling rate of a container yard block during peak and off-peak periods during a year.

A second contribution of this study is to provide more insight regarding the effect of choosing certain design-influencing factors on the resulting design of container terminals in terms of equipment choice and container storage capacity. Specifically, the effect of choosing a front-end-loading system and a sideway-loading on the container storage capacity is evaluated based on the CY area at the Port of Busan. This can be used as a guideline for terminal operators to eventually redesign their terminal in order to maximize their container storage capacity.

1.3 Thesis structure

The outline of this study is as follows. First, we start with an introduction and research background in the first chapter. The problem statement as well the importance of the research is described. In the second chapter, a literature review related to previous findings of forecasting container throughput is given. In addition, the layout of container terminals and dimensional characteristics of handling equipments are discussed in the second part of this chapter. Details about the data obtained are given in chapter 3. Chapter 4 describes the techniques of forecasting and implementing expected TEU throughput volumes on container yard operations. The results of this study consist of two chapters. The first part is outlined in chapter 5 where the monthly TEU throughput volumes are forecasted using a SARIMA model and a linear dummy regression model. The second part of the results is outlined in chapter 6. Here, the forecasted monthly TEU throughput volumes, based on the model of choice in chapter 5, are implemented on container yard operations. This is done after calculating the maximum container storage capacity using specific terminal design characteristics. Chapter 7 provides a detailed comparison of proposed yard operations in chapter 6 with current yard operations at the Port of Busan. In addition, the limitations and proposed policy recommendations of this study are provided in this chapter. Chapter 8 concludes this study with major findings being summarized followed by recommendations for further research.

CHAPTER 2 Literature review

2.1 *Forecasting TEU throughput volumes*

Most studies on forecasting container volumes have been based on long-term forecasting horizons in order to identify and measure causal relationship between variables. Seabrooke et al. (2003) have identified and examined factors that will affect the port of Hong Kong's cargo throughput structure and volume using annual data from 1983 to 1999. The set of explanatory variables include: macroeconomic conditions, regional competition, China's entry to the World Trade Organization (WTO), liberalization of cross-strait trade, Hong Kong's economic restructuring, market structure and power of terminal operators. The cargo throughput volume was forecasted for the period 2002-2011. They main results have shown that more competition from other ports in the surrounding area will result in growth of cargo volume for the port of Hong Kong. In addition, China's WTO accession and continuous economic development will increase the cargo volume in the South Chine area. The increase in cargo will be too large for one single port to handle. Therefore, the port of Hong Kong and Shenzhen will likely act alongside and work as a twin-port hub of the region.

This study focus on forecasting monthly TEU throughput volumes. For capacity planning and operations of ports organization, it is crucial for port management to accurately forecast seasonality effects on container throughput demand within a year. Liang and Chou (2003) and Chen (2010) have argued that Chinese New Year has a significant impact on container throughput at all ports in Taiwan. Due to the week-long holiday and the corresponding slow growth in China, trade between Taiwan and China is tempered.

Peng and Chun (2009) have compared different prediction methods for container throughput volumes. They have used the classical decomposition model, the trigonometric regression model, regression model with seasonal dummy variables, the hybrid grey model, grey forecast model, and the SARIMA model to forecast monthly container throughput in Taiwan's three major ports. These include: Keelung port, Taichung port, and Kaohsiung port. The root mean square error (RMSE), the mean absolute error (MAE), and the mean absolute percentage error (MAPE) were used as criteria's to measure the prediction accuracy of the six forecasting models. For all three ports, the classical decomposition model appeared to be the best model since it had the lowest RMSE, MAE, and MAPE values. The SARIMA model was found to be the second best model for the Taichung port by only a small margin. For the other two ports, the seasonal dummy regression model was found to be the second best model. On the contrary, complex and sophisticated statistical models like the trigonometric regression model, the hybrid grey model, and grey forecast model yielded poor forecasting results.

Chen (2010) has also conducted a comparative study of different prediction methods for container throughput volumes of Taiwan’s three major ports. The generic programming (GM) approach, decomposition approach (X-11), and SARIMA model were used to create an optimal predictive model. The predictions of the three models were compared with the actual monthly TEU throughput volumes for the year 2007. The researchers have suggested using the generic programming approach as its predictions were 32-36% better than those of the X-11 and SARIMA model. Overall, MAPE values were less than 4% for all three approaches. The MAPE values for the GM, X-11 and SARIMA were respectively 3.41, 3.60 and 2.28.

2.2 Container yard operations

2.2.1 Container terminal sub-systems

The container flow through a container terminal consist of several processes (sub-systems) that takes place in a logic sequence. According to Henesey (2004) there are 4 sub-systems: ship-to-shore, transfer cycle, storage and delivery-receipt area. Most seaport container terminals have the same sub-systems and facilities as depicted in figure 2-1, although they considerably differ in size, function, layouts, type of equipments used.

The first sub-system is ship-to-shore which is located at the waterside edge of the terminal. Here, quay cranes are used to load and offload containers from vessels and barges. Moving to the second sub-system, the outbound and inbound containers are transferred by means of horizontal waterside transport equipments from the quay cranes to the storage area and vice versa. The horizontal transport may be performed by different equipments such as Track Trailer Units (TTUs), Straddle Carriers (SCs) and Automated Guided Vehicles (AGVs). In the third sub-system i.e. storage, containers are temporally stored at designated yard blocks where specific cranes and lifting vehicles are used. Apart from the regular storage area, other facilities such as empty depot, Container Freight Stations (CFS) and maintenance & repair may also be offered by container terminals. The decoupling function between waterside and landside terminal operations makes the regular storage area frequently be located at the centre of the terminal and takes up most of the space the storage sub-system (Kemme, 2013). The last sub-system is known as the delivery-receipt area that function as a connection between the terminal and its hinterland. Here, containers are delivered or picked-up by External Trucks (XTs) or Trains after checks and administrative tasks are fulfilled.

The importance of the storage sub-system or container yard (CY) has grown enormously in recent years. The container volumes to be stored have increased steadily and at the same time the availability of land is scarce. This study focus on the influence of stacking height and container dwell time on the operational capacity of container yard taking into account expected peak and off-peak periods during the calendar year 2015.

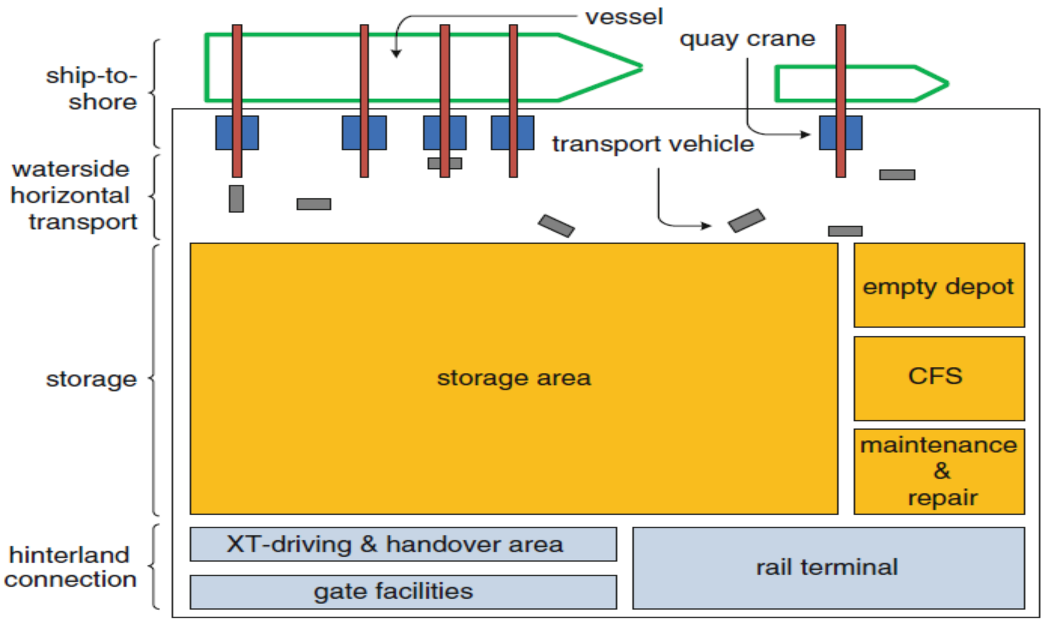


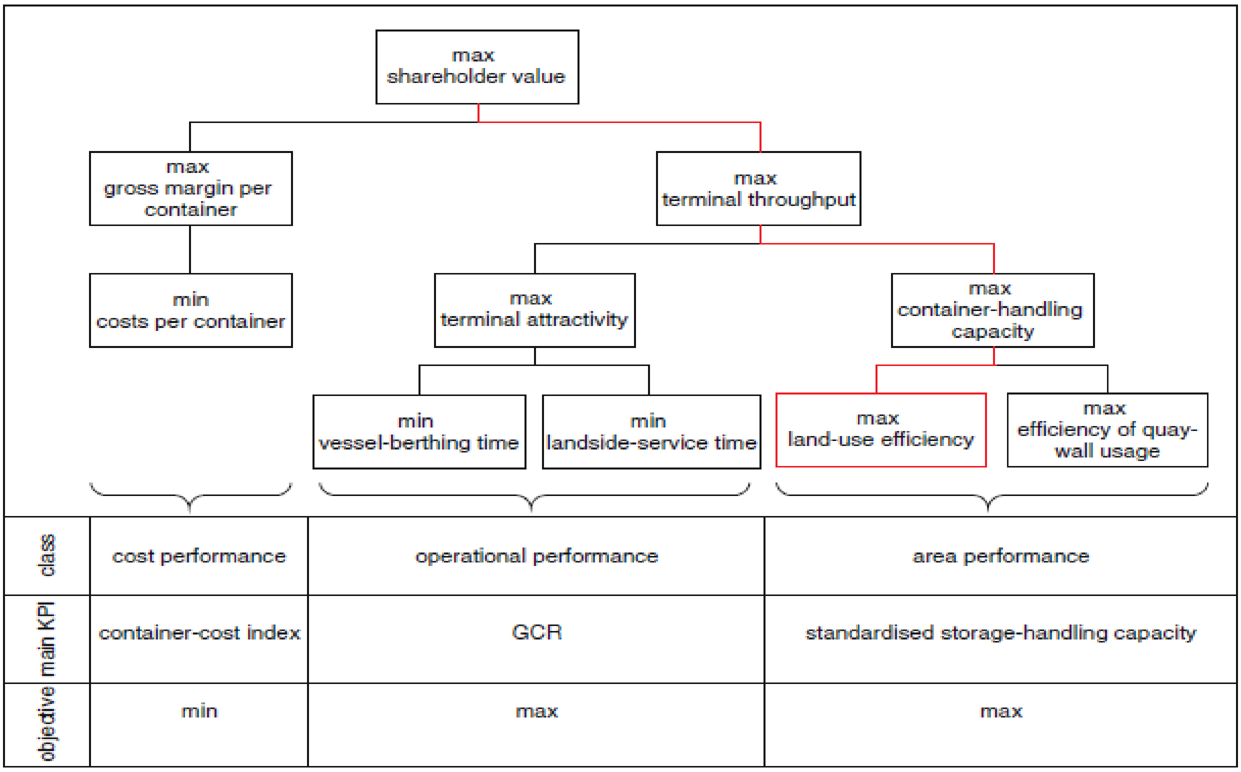
Figure 2-1: Schematic layout of a container terminal with most common facilities. *Source*: Kemme (2013).

Generally, containers may be stored either on chassis or stacked on the ground. Due to limited storage space, most container terminals use the stacking system to store their containers. Separate yard blocks or container blocks consisting of several bays, row and tiers, are formed on the CY. The separation of yard blocks and the stacking height depends on the used stacking equipment. Yard blocks may also be separated based on outbound and inbound containers. As explained earlier special storage areas may also be available on container terminals for empty, damaged, hazardous, and reefer containers.

When an XT or horizontal transport equipment without lifting capabilities arrives laden at the CY, the container is discharged by a stacking equipment and moved to the dedicated stacking position in the yard block. On the contrary, the stacking equipment picks up the demanded container from the correct yard block and position if empty XT or horizontal transport equipment without lifting capabilities arrives at the CY. It case of horizontal transport equipment with lifting capabilities (e.g. SCs), no additional stacking equipment is required. Dependent on the CY layout, SCs may drive into a yard block and pick up or position the containers themselves (Meersmans and Dekker, 2001). Internal transfers between different storage areas in the CY may also arise. For example, empty containers are moved from the empty stacking areas to CFS where they are loaded. Afterwards, the loaded containers are moved from the CFS to the regular storage area for further transshipment.

2.2.2 Container terminal performance indicators

The execution of certain container terminals objectives is a complex issue since container terminals are continuously faced with different objectives and demands from several stakeholders. Rijsenbrij and Wieschemann (2011) have identified the staff, the residents, the authorities, the truckers, the shipping lines and owners as key stakeholders of seaport container terminals. They also have argued that the objectives of a seaport container terminal can be categorized intro three different main classes of performance objectives as illustrated in figure 2-2. These include: cost performance, operational performance and area performance.



class	cost performance	operational performance	area performance
main KPI	container-cost index	GCR	standardised storage-handling capacity
objective	min	max	max

Figure 2-2: Overview of objectives and the corresponding subsets of a container terminal as a whole. The red line denotes the path followed in this study. *Source*: Kemme (2013).

Generally, the shareholder value can be maximized by either increasing the gross margin per container or the terminal throughput. This study focus on the latter one by examining the land-use efficiency factor to maximize container handling capacity. The land area is assumed to be scarce by using the available CY area as a given planning parameter. This means that the available land area and quay wall resources have to be used efficiently to increase the container handling capacity. Rijsenbrij and Wieschemann (2011) have argued that it is reasonable to focus primarily on maximizing the land-use efficiency since the available land area is assumed to be more scarce that the available length of the quay wall.

Various indicators may be used to evaluate the area performance of a container terminal. Kemme (2013) have identified the standardized storage-handling capacity as the main indicator for terminal-efficiency. Saanen (2004) has identified 4 additional indicators: standardized quay wall-handling capacity, storage-yard fraction, the yard density and the accessibility of containers.

Standardized storage-handling capacity, measured in TEU per hectare, is used to determine the theoretical handling capacity for a certain time-frame of a container terminal based on the total terminal area. Shorter container dwell times and lower storage area requirements (e.g. in case of transshipment containers) may result in higher values of standardized storage-handling capacity.

Standardized quay wall-handling capacity, measured in TEU per quay wall meter, is used to estimate the theoretical handling capacity for a time horizon of a container terminal based on a standardized length of the quay wall. The link between the quay wall length and the handling capacity is not clear because generally the quay wall length is determined by the size of the calling vessels and the vessel-call pattern of the terminal (Kemme, 2013). Hence, uneven distribution of vessels arrivals will yield lower values of standardized quay wall-handling capacities.

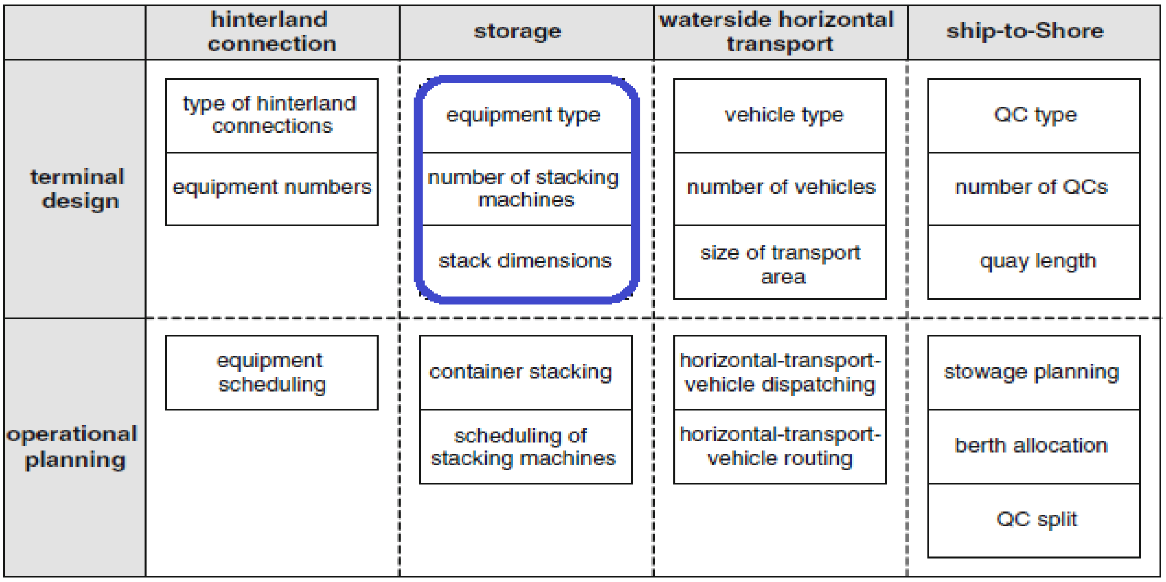
Storage-yard fraction denotes the fraction of the total terminal area that is used as container yard (CY). Generally, terminal operators tend to maximize this value by either decreasing the horizontal transport area or hinterland connection area taking into account the possible side-effects of traffic congestion.

The yard density, also known as the stacking density, is used to determine the quality of the stacking operations and the storage-area utilization. This is expressed as the number of TEU storage capacity per hectare (ha) of the CY area. This value is dependent on the choice of stacking equipment.

The accessibility of containers is expressed as the number of shuttle moves required by a certain type of stacking equipment in order to take a container out of a stack to the horizontal transport (Kemme, 2013). This indicator is crucial for the monthly or annual handing capacity as it gives information regarding the productivity of the terminal equipment. The accessibility indicator works opposite to the yard density indicator. Stacking containers to higher layers will increase the yard density but will reduce the accessibility of the containers because the sequence in which container are retrieved from the stack will increase.

2.2.3 Container terminal-design and operational problems

As explained earlier, there are 4 different sub-systems at a container terminal. Each of the sub-systems gives rise to terminal-design or operational planning problems since the processes of the sub-systems have to be coordinated. The terminal-design and operational problems, also called decision problems, are classified into categories of the 4 different sub-systems in figure 2-3.



	hinterland connection	storage	waterside horizontal transport	ship-to-Shore
terminal design	type of hinterland connections equipment numbers	equipment type number of stacking machines stack dimensions	vehicle type number of vehicles size of transport area	QC type number of QCs quay length
operational planning	equipment scheduling	container stacking scheduling of stacking machines	horizontal-transport-vehicle dispatching horizontal-transport-vehicle routing	stowage planning berth allocation QC split

Figure 2-3: Overview of decision problems for terminal design and operational planning. The blue rounded rectangle line denotes the focus area of this study. *Source*: Kemme (2013).

Terminal design decisions are usually made by terminal operators during the initial planning phase of a completely new terminal facility (Böse, 2011). However, Böse (2011) have argued that these decisions can also be made when expanding or converting an existing terminal. The design planning problems that are dealt with in this study consist of the type and numbers of stacking equipment as well the layout of the container storage yard.

The operational planning problem for the storage yard consists of the container stacking problem and scheduling of stacking machines problem. The container stacking problem in the CY is engaged in the allocation process of outbound, inbound, transshipment containers at the right container block, bay, row and tier. After the storage position is chosen for a particular container, the next step includes assigning the right storage equipment at the designated pile at the right time. This known as the scheduling of stacking machines problem.

For the relevance of this study, only the terminal design problems for the storage yard will be considered.

2.2.3.1 Equipment type

The equipment type problem is an equipment selection process that is based on the estimated yard capacity and the space available for the yard. Technical feasibility, economic profitability and operational performance are factors to be considered for the selection of equipment (Günther and Kim 2006). Generally, there are different types of storage stacking equipments for container terminals: SCs, gantry cranes, forklifts and reach-stackers. Two main variants of the gantry cranes are RMG systems and RTG systems. SCs and gantry cranes are the most commonly used storage stacking equipments for medium to large sized terminals (Brinkmann, 2011). Reach-stackers and forklifts are mostly used in small and low capital intensive container terminals that require very flexible machines.

Straddle carrier (SC) storage system

As depicted in graph 2-4, the container yard blocks are separated and surrounded by parallel and perpendicular driving lanes. Each container yard block consists of only one container row placed end to end. A SC storage system may have either a sideway-loading system or a front-end-loading system. Most SCs container terminals are found to have a sideway-loading system (Chu and Huang, 2005).

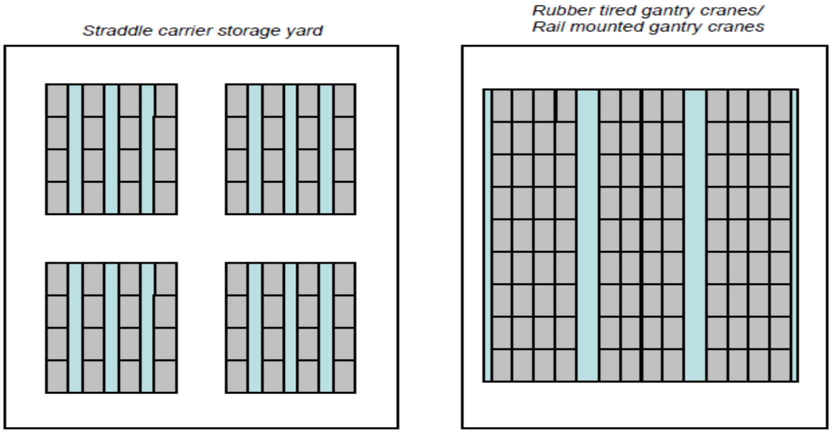


Figure 2-4: Yard density for SC, RTG, and RMG. *Source*: Merckx (2005).

The main advantage of a SC storage system is that SCs are multifunctional such that they can be used as storage equipment, horizontal transport equipment, and loading and offloading XTs. This means that no handover of containers is required between storage and horizontal transport areas. In addition, no additional equipments are required to load/offload container on/from XTs. Another advantage is that SCs can move with relatively high speeds. SCs can easily be assigned to different handling functions on the container terminal due to their high flexibility.

The main disadvantage of SCs is that the productivity of SCs in terms of stacking capacity is relatively low. The yard densities of SCs are between 500-750 TEU/ha since they are capable of storing container only two or three layers high (Kemme, 2013). Secondly, since SCs are powered by diesel engines and are man-driven, they give rise to emission and labor costs.

Rubber-tired gantry crane (RTG) storage system

When implementing a RTG storage system, the container storage yard is subdivided into several container storage blocks, zones and driving lanes. This is schematically illustrated in figure 2-5. Each container yard block, laid parallel to the quay wall, consist of several containers slots in which containers are stacked end to end. Unlike in a SC system, no additional wheel space is required between the container rows. The length, width and quantity of the container storage block vary across international container terminals. The width of the container storage block is typically configured 6+1 rows and 8+1 rows due to an additional handover lane (Chu and Huang, 2005).

In contrast to SCs, RTGs are only used for storage purposes. Hence, additional equipments have to be acquired for the horizontal transport between the quay wall and storage area. RTGs are usually combined with TTUs. Compared to SCs, RTGs have higher staking densities up to 1,100 TEU/ha with 4 and 5 layers of container being the most frequent stacking height used (Chu and Huang, 2005). A major advantage of a RTG storage system is the ability of RTGs to turn their wheels 90° such that they can move to container storage blocks of adjacent yard zones by using the driving lanes perpendicular to the quay wall. This process is known as cross-gantrying and is denoted by the green arrow in figure 2.5.

Like SCs, most RTGs are powered by diesel engines and are typically manned with a crane driver giving rise to emission and labor costs. In addition, there is hardly any room for automation with a RTG system with a lot of interaction taking place with the unautomated TTUs and XTs. Also, the process of cross-gantrying is time-consuming and costly ground-work is required with concrete piles underneath the runways of the crane legs. The parallel and perpendicular driving lanes make this CY layout space-intensive since more storage space is lost.

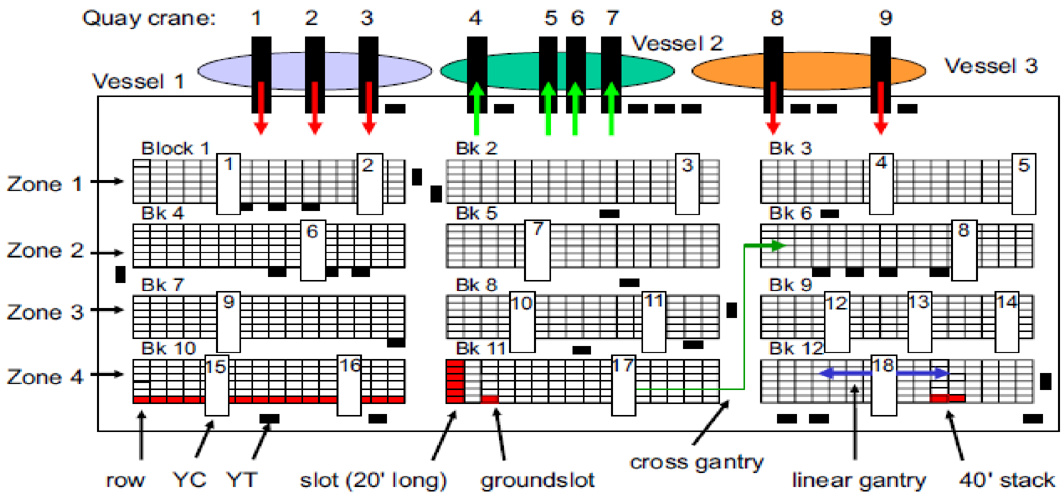


Figure 2-5: Bird's eye view of a rubber-tired gantry crane (RTG) storage system. *Source*: Petering and Murty (2008).

Rail-mounted gantry crane storage system

The dimension of a yard block for a RMG storage systems differ between terminals. The width of a container storage block is restricted by the maximal span width of a RMG. Typically, the magnitude of perpendicular yard blocks using RMGs are 28-48 bays long with 6-10 rows wide (Kemme, 2013).

RMG storage systems are quite similar to RTG storage systems except RMGs moves on rail tracks while RTGs is rubber tired. A major advantage of the RMG storage system is that the yard blocks can either be laid parallel or perpendicular to the quay wall. RMGs are equipped with electric driven motors reducing emission costs. In addition, RMGs are associated with automation resulting in low labor costs. RMGs may have superior yard densities compared to RTG exceeding 1,200 TEUs/ha (Saanen, 2006). Hence, they mostly are applicable for terminals with limited area resources.

RMGs storage systems are associated with high capital costs related to buying the cranes itself and requiring costly ground-work for concrete piles and rails. Since no cross-gantrying is possible, RMGs have limited flexibility compared to RTGs.

2.2.3.2 Number of stacking machines

Using automated RMGs (A-RMG), makes it possible to configure the container yard block with multiple cranes. This is illustrated in figure 2-6. Next to a single crane system in storage block (a), a twin crane system is implemented in storage block (b) and (c). The difference between the storage block (b) and (c), is the span width of both cranes. The two cranes in block (c) operate on different rails which makes the largest crane to move its trolley to the rightmost position. Storage block (d) is configured based on the combination of storage block (b) and (c). More details regarding the number of stacking machines will be provided later in chapter 6.

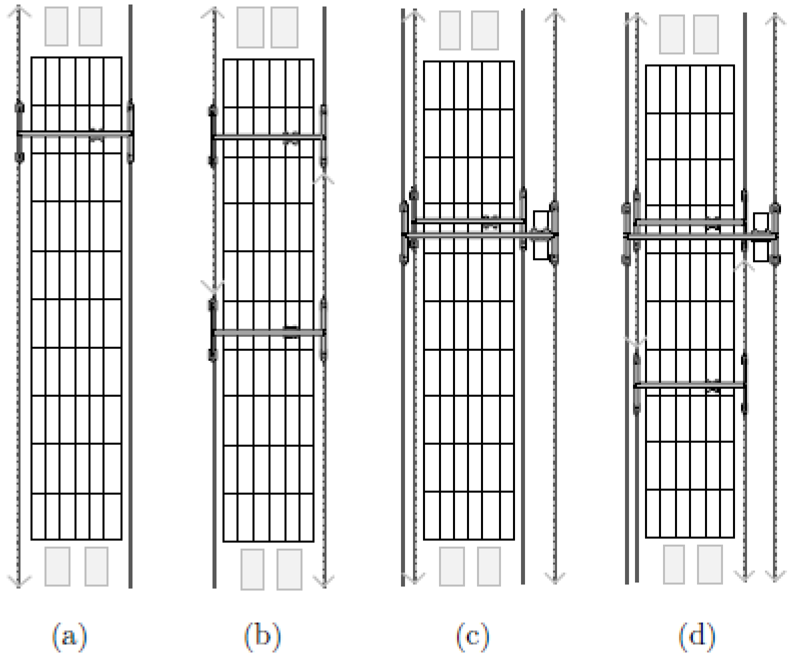


Figure 2-6: Multiple RMG system per container yard block: (a): single RMG per block, (b): two RMGs per block, (c): two RMGs with different span width per block, (d): combination of (b) + (c). *Source*: Wiese (2012).

2.2.3.3 Stacking dimensions

One of the most crucial elements in container yard design is the stacking system as they influence the effective execution of the remaining terminal operations (Kemme, 2013). The efficiency of a stacking system dependents on strategic decisions regarding the CY layout, stacking equipment and operational decisions which in turn influence the scheduling and routing of the stacking equipments (Meersmans and Dekker, 2001; Vis and de Koster, 2003). Nazari (2005) have argued that when making these strategic and operational decisions one must take into account the available space, the expected container throughput, the expected container dwell time, planned yard utilization and several external regulations (e.g. customs control, environmental protection, and occupational safety).

The stacking of containers varies across different container terminals as the terminal operators use their own stacking methods and yard densities. One of the strategic decisions that a terminal operator has to make is what type of stacking equipment will be used: rail-mounted gantry cranes (RMGs), rubber-tired gantry cranes (RTGs), straddle carriers (SCs), reach-stackers or a combination of the aforementioned stacking equipments. Each of the chosen stacking method and the degree of automation of the container terminal will consequently affect the yard density of the stacking yard.

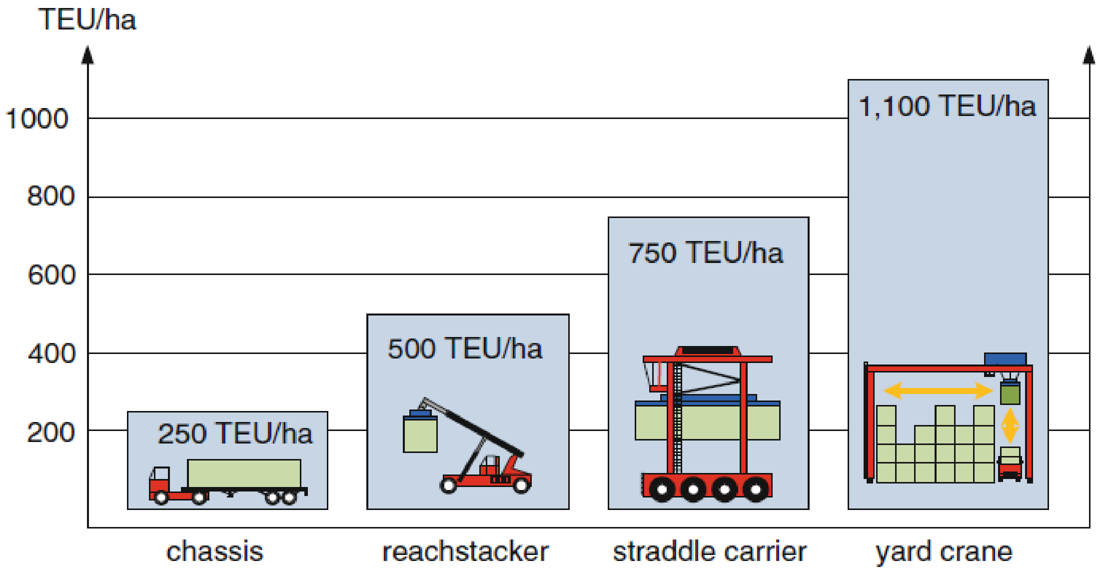


Figure 2-7: Yard density (or stacking density) (TEU/hectare (ha)) for different types of container handling equipments. *Source*: Kemme (2013).

As illustrated in figure 2-7, yard cranes have the highest yard density compared to the other terminal handling equipment. Yard cranes have superior productivity in terms of stacking capacity compared to SCs and reach-stackers. In addition, yard cranes make it also possible to stack containers in blocks without leaving any space between the container rows as depicted earlier in figure 2-4. RTGs and RMGs have the ability to store 9 rows of containers next to each other, whereas 1.5-2.0m of wheel space between each container row should be reserved for SCs to man oeuvre (UNCTAD, 1985). Yard density or stacking density can be used as an indicator to limit the use of possible container handling equipments. Limited space in a container terminal make the use of certain container handling equipment impractical. For instance, if a container terminal operator aims to maximize its container handling capacity given limited space, the use of a SC system will not be the optimal solution.

In this study, RMGs have been used as the primarily stacking equipment since they exhibit the highest yard density of a seaport container terminal and are also a suitable solution for automation. Maximizing the yard density imply a greater number of containers to be stored in the storage area of a container terminal. Hence, the land-use efficiency of the storage yard will be increased as well by influencing the design and operations of the container terminal.

2.3 Implementing forecasted throughputs on container terminal design

As mentioned earlier, inability to forecast throughput demand will negatively influence operations at the container terminals. A more recent study conducted by Chung Ee et al. (2014) highlighted the importance of forecasting container throughput on container terminal planning. The researchers have attempted to project forecasted TEU throughput volumes on the amount of port equipment needed for optimum operations. The Holts-Winter Exponential smoothing model and the SARIMA model were used as forecasting models. Both models yielded close results of forecasting. Two methods were used for equipment planning. An empirical method and yard equipment per crane ratio method were used to estimate the total required number of STS cranes, RTGs, and Prime movers. Since both forecasting models yielded close results, the effect on empirical equipment estimation was minimal with differencing 1 STS, 2 RTGs, and 5 prime movers. In addition, the empirical method and the yard equipment per crane ratio method yielded different results. The empirical method assigned fewer prime movers and more RTGs based on the forecasted TEU volumes compared to the yard equipment per crane ratio method.

Container terminals around the world differ greatly in terms of framework conditions, appearance and performance (Watanabe, 2001 and Saanen, 2004). In order to evaluate and compare the performance of these container terminals, different design indicators are developed that greatly impact the resulting design of a container terminal in terms of equipment choice and capacities. Transshipment factor, mean container dwell times, TEU-factor are factors that influence the design indicators. According to Saanen (2004) other complex quantifiable design factors include: draught restrictions, soil conditions, shape of the land, and the user-type of the terminal (dedicated or multi-user). Kemme (2013) have identified 3 design indicators of container terminals: annual terminal throughput, annual container-handling capacity, storage capacity.

Annual terminal throughput defines the total number of outbound and inbound containers loaded on and from vessels per year in terms of Quay Crane (QC) moves (Kemme, 2013). This is determined by external factors such as the location of the terminal and local economic conditions. Contrary, the annual container handling capacity takes into account both QC moves and the theoretical container handling capacity of the terminal as a whole. This is determined by internal factors such as quay wall length, waterside-handling capacity, storage capacity, landside-handling capacity, hinterland-connection capacity and available handling equipment. The minimum storage capacity required to satisfy the annual throughput is given by the equation:

$$\pi^{SCmin} = \pi^{throughput} \times \left(1 - \frac{\pi^{ts}}{2}\right) \times \pi^{TEU} \times \frac{\bar{\delta}}{365} \times \pi^{PEAK} \quad (2.1)$$

Where,

π^{SCmin} = minimum required storage capacity (in TEU).

$\pi^{throughput}$ = annual terminal throughput (in TEU).

π^{ts} = transshipment factor.

π^{TEU} = TEU factor.

$\bar{\delta}$ = mean container dwell time (in days).
π^{PEAK} = peak factor.

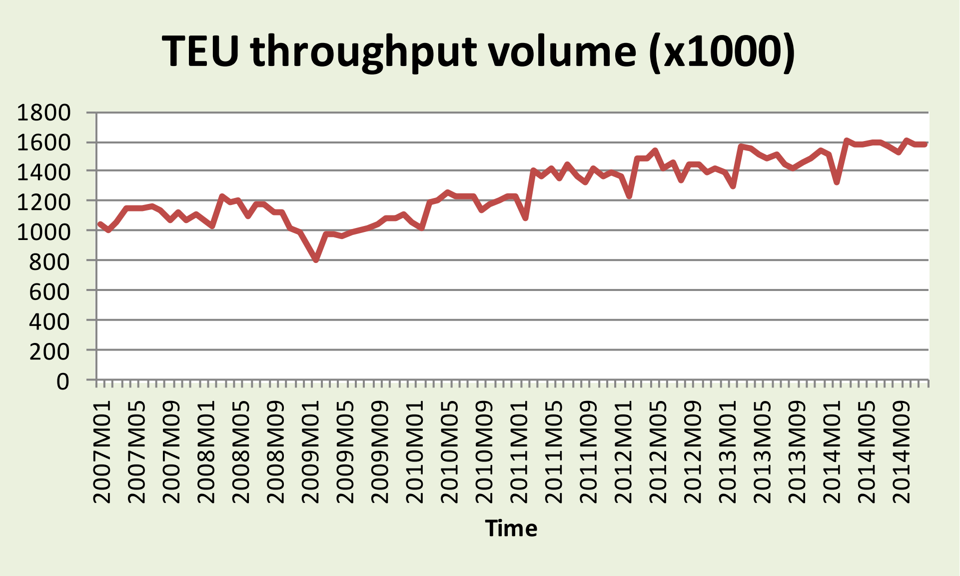
Plug-in the expected TEU throughput volumes in equation 2.1 along with the other parameters yield the expected minimum storage capacity required. Note that the minimum storage capacity will not be constant over time since seasonal variations are present in transhipped goods. Hence, the greater the variations of the occupancy rate of the container storage yard, the more storage capacities have to be available in order to cope with the annual throughput (Kemme, 2013).

Equation 2.1 evaluates the handling capability of a CY from a demand point of view. That is, given all the relevant parameters, one can calculate the minimum required storage capacity. Chu and Huang (2005) also evaluated the handling capability of a CY from a supply point of view such that the number of containers can be calculated that a CY should accommodate on the basis of a given yard space. The annual container handling capability was calculated on the basis of adopted handling system, crane dimensions, yard sizes and characteristics of terminal operators. For detailed calculation, the reader is referred to the corresponding paper.

After calculating the maximum storage capacity from a supply point of view, the average allowed filling rate of the yard blocks can be obtained using the forecasted TEU throughput volumes. The calculation details will be presented in chapter 6. The average allowed filling rate of the yard blocks affects the operational performance of stacking equipment by influencing its workload situation (Kemme, 2013). In addition, seasonal and peak patterns of the TEU throughput volumes (container arrivals and departures) give more information regarding the distribution of the total crane workload over time. That is, balancing the workload of the cranes over all yard blocks result in limited risk of vehicle waiting times in the handover areas of the yard blocks. This is due to the fact since the supply of crane resources and the corresponding demand of these resources are constant. On the contrary, unevenly distributed filling-rates will lead to situations with oversupply of crane resources and other situations with a lack of crane resources. This will cause a chain of reactions leading to increased waiting times for the horizontal transport especially during peak periods where a vast amount of lateness will be accumulated within short periods of time.

CHAPTER 3 Data

To predict future container throughputs, historical data is used as it is assumed that future throughput values are solely based on its past values. Monthly data on container throughput volumes from the Port of Busan are obtained from the website of *Busan Port Authority*. Inbound, outbound, transshipment and costal cargo were summed up as the total TEU container throughput. Data is collected from the 1st of January 2007 to the 31st of December 2014. The process of SARIMA modeling requires complete years of data on container throughput volumes. This will also help to capture pronounced seasonal patterns across the whole set of year.



Graph 3-1: Monthly container TEU throughput volume (x1000) for the Port of Busan between 2007 and 2014. *Source*: Busan Port Authority.

The sample period for the linear regression and SARIMA model is set between 1st January 2009 and 31st December 2014. This was necessary to avoid any contamination of the coefficient estimates due to the financial crisis that started in 2008. Ignoring this might have produced bias TEU throughput forecast. The Port of Busan took a hit during the financial crisis as the TEU throughput volume began to decrease from August 2008. During that time, the TEU throughput volume was noted at 1,183,885 TEU. Afterwards the TEU throughput volume dropped sharply to 809,612 TEU in February 2009 before regaining its momentum to increase. There is no clear single point in history that can be considered as the definite start of recovery from the financial crisis. However, the TEU throughput volume showed an increasing trend after February 2009 with pronounced seasonal patterns observed afterwards between 2010 and 2014.

CHAPTER 4 Methodology

4.1 Methodology overview

There are two different schools of thoughts towards seasonality (Franses, P.H. et al. 2014). The first thought view seasonality as 'nuisance' that makes the analysis of other relevant time series features such as trend and nonlinearity more difficult. Seasonality is viewed as a form of data contamination making seasonal adjustment to data prerequisite for further analysis. The second thought that is applied in this study, view seasonality as an important part of further data analysis because it may contain important information. Hence, seasonality must be taken into account for description and forecasting of the time series. This study is based on the second thought since the research objective is focused on identifying seasonal and peak patterns of TEU throughput volumes.

A linear regression model with monthly dummy variables is performed to analyze seasonal variations in monthly TEU throughput volumes based on the methodology of Peng and Chu (2009). Dummy variables, which represents categories, enables us to analyze if being in a certain category (month) makes a difference, compared with not being in that category.

In addition, the Box-Jenkins approach is applied as an alternative method to forecast monthly values of TEU throughput volume using the Seasonal Autoregressive Integrated Moving Average (SARIMA) process. This approach is a multi staged process that should lead to an adequate and reliable time series model. The Box-Jenkins approach involves identification, estimation, diagnosing, and forecasting in order to get an applied and procedural model for the monthly TEU throughput volume. The software statistical package *Eviews* is used for both models.

The estimated coefficients results of the SARIMA and the linear regression model are used to evaluate their corresponding predictive powers based on in-sample performance. The Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE) are used as forecasting accuracy indicators in order to decide which model to use in order to forecast the TEU throughput volume of the port of Busan for the calendar year 2015.

The next step involves implementing the forecasted monthly TEU throughput volumes of the 'best' model in container yard operations. The average fill rate per container block for every month during the calendar year 2015 will be calculated based on different container dwell times and stacking heights. This process also involves designing the container yard layout based on theoretical approaches in order to calculate the container handling capacity for the Port of Busan based on current available container yard space.

The final stage in this research paper will focus on evaluating the empirical results, obtained in the previous step, with current container yard operations at the Port of Busan. Specifically, the proposed CY layout, number of container handling equipments (transfer cranes) and container handling capacity will be compared with current operations. In addition, this process enables us to identify possible limitations in this study.

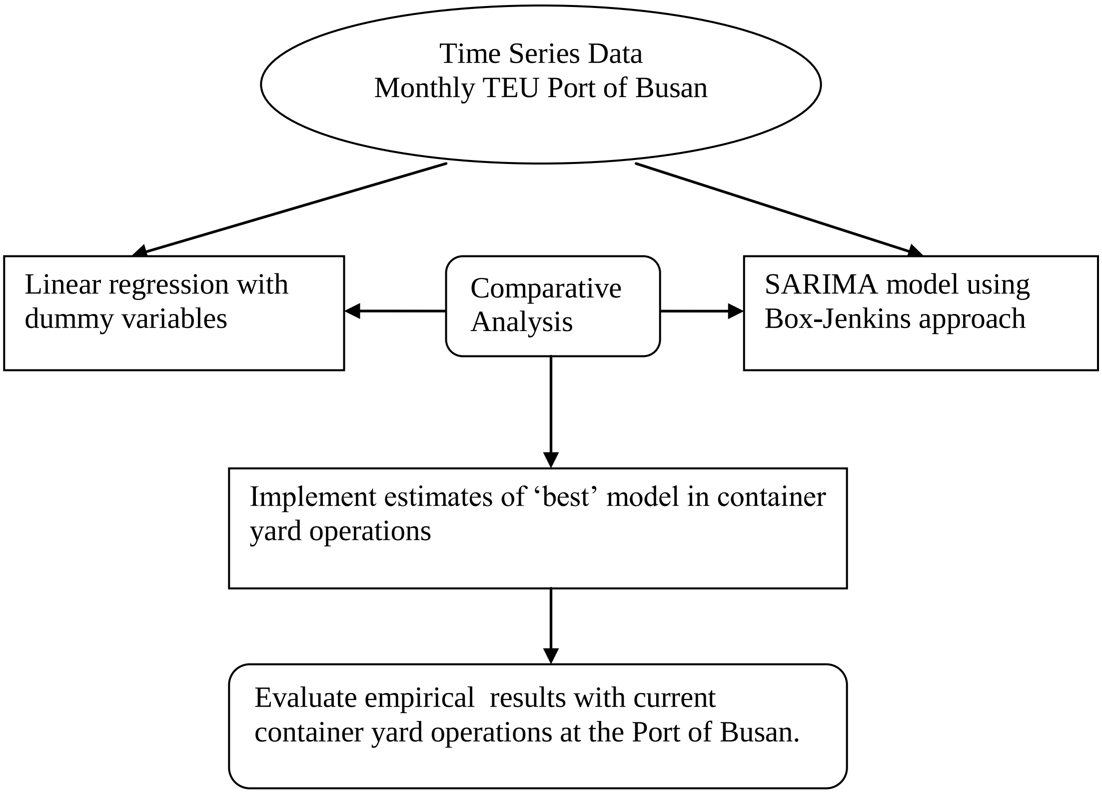


Figure 4-1: Schematic illustration of the multi-step research.

4.2 Methods for forecasting throughput volumes

Linear regression model

It is assumed that the TEU throughput volumes consists of three components such that the model estimation take the following form:

$$y_t = TR_t + SN_t + \varepsilon_t \qquad (4.1)$$

Where,

y_t = Monthly TEU throughput volume of the Port of Busan at time period t.

TR_t = Trend component at time period t.
SN_t = Seasonal component at time period t.
ε_t = Random component at time period t.
The seasonal component can be captured by a set of dummy variables $X_{si,t}$ for each month such that:

$$SN_t = \sum_{i=1}^{11} \beta_{si} X_{si,t} \qquad (4.2)$$

Where,

$$X_{si,t} = \begin{cases} 1 & \text{if period } t \text{ is month } i, i = 2,3,\dots,12, \\ 0 & \text{Otherwise.} \end{cases}$$

Substituting equation 4.2 into equation 4.1 yields the following regression model:

$$y_t = \beta_0 + \beta_1 t + \beta_{s2} X_{s2,t} + \beta_{s2} X_{s2,t} + \cdots + \beta_{s11} X_{s12,t} + \varepsilon_t \qquad (4.3)$$

To prevent multicollinearity, the dummy variable for the month January $X_{s1,t}$ is used as a reference category and is therefore omitted from OLS estimation.

SARIMA model

A compact theoretical framework of the Box-Jenkins methodology is presented below. For a more detailed discussion regarding SARIMA modeling, the reader is referred to a comprehensive time series analysis text such as Franses, P. H. et al. (2014).

The Box-Jenkins methodology is based on a number of stages:

1. Identification
2. Estimation
3. Diagnosing
4. Forecasting

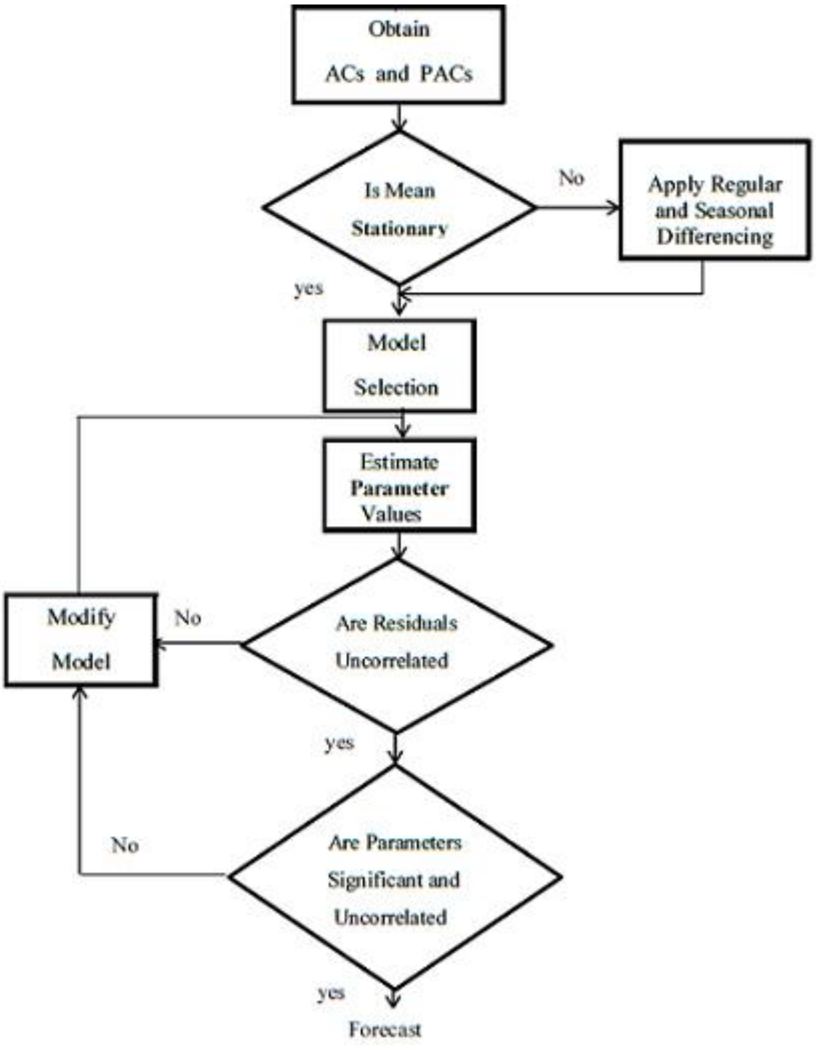


Figure 4-2: Box-Jenkins modeling approach. *Source*: BOX, G.E.P. and Jenkins, G.M. (1970).

Stage 1: Identification

The first step in developing a Box-Jenkins model is to determine whether the time series of monthly TEU throughput volume is stationary and whether any significant seasonality needs to be modeled. This stage also involves regular and/or seasonal differencing the time series in order to obtain stationary series. The Auto Correlation Function (ACF) and Partial Auto Correlation Function (PACF) of the monthly TEU throughput volume series are examined to identify potential models.

It may be possible that the series TEU throughput volume y_t needs to be differenced if the series is non-stationary such that the differencing operator is defined as:

$$\Delta_D^d = (1 - L^D)^d \ for \ d, D = \cdots, -2, -1, 0, 1, 2, \dots \qquad (4.4)$$

The superscript d denotes the order of regular differencing. If a time series is differenced d times, it is said to be integrated of order $I(d)$. L is the lag operator that is used to define the required differencing. For example, the first regular difference of the series y_t can be defined as:

$$\Delta^1 y_t = (1 - L)^1 y_t = y_t - y_{t-1} \qquad (4.5)$$

The subscript D denotes the length of the seasonal cycle. In this study, D = 12 since monthly TEU throughput volumes are used. For example, the first seasonal difference of the series y_t can be defined as:

$$\Delta_{12} y_t = (1 - L^{12})^1 y_t = y_t - y_{t-12} \quad (4.6)$$

In order to recognize a possible appropriate model, the autocorrelation function (ACF) and partial autocorrelation function (PACF) of the monthly throughput volume is examined. In practice, the orders p, q, P, Q of a SARIMA $(p, d, q)(\ P, D, Q)$ are unknown such that they have to be estimated from the data. By examining the ACF and PACF of the monthly TEU throughput volume, it is possible to see whether these match certain patterns implied by different SARIMA models. PACF are used to identify higher orders SARIMA models.

The estimated *k*-th order autocorrelation of the TEU throughput volume is calculated by:

$$\hat{\rho}_k = \frac{\hat{\gamma}_k}{\hat{\gamma}_0} \qquad (4.7)$$

Where,

$$\hat{\gamma}_k = \frac{1}{N} \sum_{n=k+1}^{N} (y_t - \bar{y})(y_{t-k} - \bar{y}) \qquad (4.8)$$

$\hat{\rho}_k$ = *k*-th order autocorrelation of the TEU throughput volume.
$\bar{y}$ = sample mean of the TEU throughput volume.
N = total number of observations.

The ACF is the set of all autocorrelations $\hat{\rho}_k$ for k = 1, 2, . . .

The estimated *k*-th order partial autocorrelation of the TEU throughput volume is calculated by:

$$y_t = \ n_1 y_{t-1} + n_2 y_{t-2} + \ \dots + \ n_{k-1} y_{t-k+1} + \ \psi_k y_{t-k} + \ u_t \qquad (4.9)$$

Where,

ψ_k= partial autocorrelation coefficient.

Stage 2: Estimation

This stage includes estimating the parameters in potential models and selecting the best model using accuracy criteria's such as AIC and BIC. It is a common practice, when using the Box-Jenkins approach, to tentatively estimate more than one SARIMA model and then perform an accuracy check to decide the validity of the model. The SARIMA $(p, d, q)(P, D, Q)$ model is given by:

$$\varphi_p(L)\emptyset_P(L)\Delta_1^d\Delta_S^D(y_t - \mu_t) = \vartheta_q(L)\theta_Q(L)\varepsilon_t \quad (4.10)$$

Where,

$\varphi_p(L)$ = p non-seasonal Autoregressive (AR) polynomial order.

$\vartheta_q(L)$ = q non-seasonal Moving Average (MA) polynomial order.

$\emptyset_P(L)$ = P seasonal Autoregressive (AR) polynomial order.

$\theta_Q(L)$ = Q seasonal Moving Average (MA) polynomial order.

d = number of regular differencing.

D = number of seasonal differencing.

ε_t = white noise time series.

An Autoregressive (AR) model specifies that the time series $y_t$depends linearly on its p most recent past values. In our case, the TEU throughput volume in one period is related to its volumes in the previous periods. An Autoregressive model of order p [AR(p)] for the series y_t can be described by:

$$y_t = \varphi_1 y_{t-1} + \varphi_2 y_{t-2} +\cdots +\varphi_p y_{t-p} + \varepsilon_t, \quad t = p + 1, p + 2, \ldots, p + T \qquad (4.11)$$

Where,

φ_i = unknown parameter (coefficient) for the lagged variable at time $t - i$.

ε_t = unobserved white noise.

Equation 4.11 can be written more compactly using the lag operator L as:

$$\varphi_p(L)y_t = \varepsilon_t \qquad (4.12)$$

Where,

$$\varphi_p(L) = 1 - \varphi_1 L - \cdots -\varphi_p L^p \qquad (4.13)$$

Equation 4.13 is called the AR polynomial in L of order p. The weights on the lags are given by φ_i and illustrates to what extent y_t depends on its own past values.

A Moving Average (MA) takes into account the relationship of the time series $y_t$with respect to residuals from the previous periods. A Moving Average model of order q [MA(q)] for the series y_t can be described by:

$$y_t = \varepsilon_t + \vartheta_1 \varepsilon_{t-1} + \cdots + \vartheta_q \varepsilon_{t-q} \qquad (4.14)$$

Equation 4.14 can be written more compactly using the lag operator L as:

$$y_t = \vartheta_q(L)\varepsilon_t \qquad (4.15)$$

Where,

$$\vartheta_q(L) = 1 + \vartheta_1 L + \cdots + \vartheta_q L^q \qquad (4.16)$$

Seasonal AR and MA polynomials for monthly series are respectively defined as:

$$\emptyset_P(L) = 1 - \emptyset_1 L^{12} - \emptyset_2 L^{24} - \cdots - \emptyset_P L^{12P} \quad (4.17)$$
$$\theta_Q(L) = 1 + \ \theta_1 L^{12} + \theta_2 L^{24} + \cdots + \theta_Q L^{12Q} \quad (4.18)$$

Stage 3: Diagnosing

This stage includes the examination of the residuals from the selected model to see whether they are uncorrelated using ACF and PACF plots. This step allows us to see if any patterns remains accounted for. Furthermore, a normality test is performed to determine if the residuals are random (white) noise with zero mean and constant variance. At last, the estimated parameters of the selected model are checked for significance.

The white noise time series ε_t is responsible for the random behavior of the TEU throughput volume series y_t. It is of importance to know how the TEU throughput volume respond to shocks i.e. even in case the true SARIMA parameter values are known, the future TEU throughput cannot be perfectly predicted based on past and present TEU throughput values. The white noise time series ε_t should have the following characteristics:

$$E[\varepsilon_t] = 0 \qquad t = 1,2,\dots,T \qquad (4.19)$$
$$E[\varepsilon_t^2] = \sigma^2 \qquad t = 1,2,\dots T \qquad (4.20)$$
$$E[\varepsilon_s \varepsilon_t] = 0 \quad s,t = 1,2,\dots,T \ and \ s \neq t \quad (4.21)$$

In words, equations 4.19, 4.20, 4.21 illustrate that the mean of the white noise time series equals zero, all observations of the white noise time series have the same variance σ^2 and there is no (auto-) correlation between any past, current and future observations of the white noise time series.

Stage 4: Forecasting

Forecast future TEU throughput volumes using the proposed SARIMA model.

As explained earlier, RMSE, MAE, MAPE are used for measuring the forecasting accuracy of the Linear regression model and the SARIMA model.

RMSE is calculated as:

$$RMSE = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(y_t - \hat{y}_t)^2} \qquad (4.22)$$

Where,

y_t = actual TEU throughput volume observed at time period t.

$\hat{y}_t$ = forecasted TEU throughput volume at time period t.

N = total number of observations.

MAE is calculated as:

$$MAE = \frac{1}{N}\sum_{t=1}^{N}|(y_t - \hat{y}_t)| \qquad (4.23)$$

MAPE is calculates as:

$$MAPE = \frac{1}{N}\sum_{t=1}^{N}\left|\frac{(y_t - \hat{y}_t)}{y_t}\right| \times 100 \qquad (4.24)$$

4.2 Calculating container yard storage capacity

The structure of forecasting the expected TEU throughput volume on CY operations is depicted in figure 4-3. This process is divided into two phases. Phase 1 calculates the CY storage capacity. Phase 2 calculates the average allowed filling rate per container storage block. Phase 1 requires the yard dimensions as input data. The parameters consist of equipment selection, stacking height selection and loading systems. The output data gives us the container storage capacity. This is then use as input data for phase 2 along with the expected TEU throughput volume. The parameters consist of container dwell time, tacking height and TEU factor.

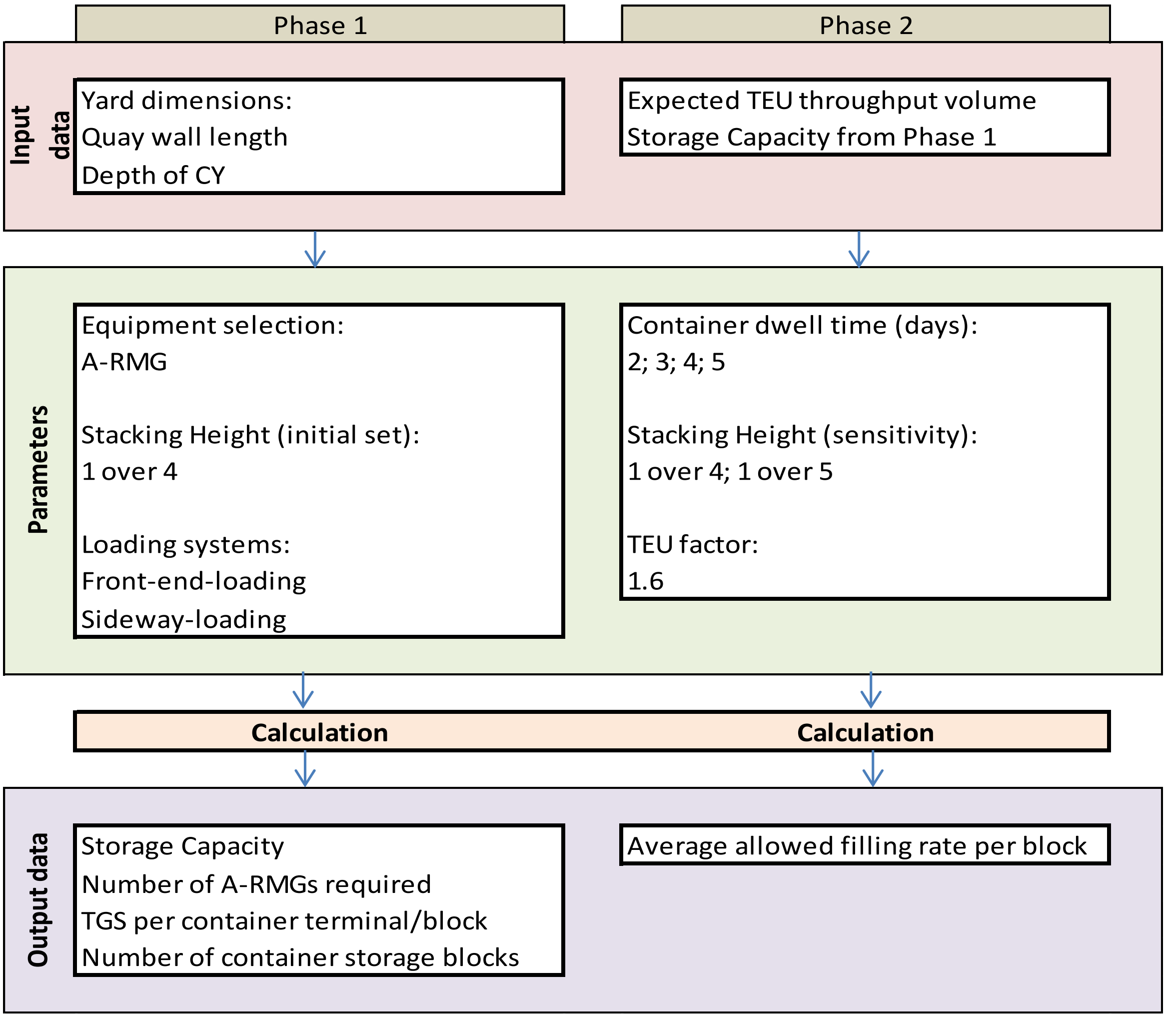


Figure 4-3: Structure of forecasting TEU throughput volumes on CY operations.

The calculation of the storage capacity using a front-end-loading system is mathematically formulated by:

$$\sum_{i=1}^{m} \frac{QWL_i}{W^{bF}} \times TGS_i^{BF} \times h \qquad (4.25)$$

Where,

m = number of container terminals.

QWL_i = length of quay wall (in meters (m)) for terminal i in meters.

W^{bF} = whole width (in m) per container storage block using a front-end-loading system.

TGS_i^{BF} = twenty foot container ground slot (TGS) in TEU per container storage block using a front-end-loading system for terminal i.

h = stacking height of the containers.

The TGS per container storage block is dependent on the dimension of the CY and can be calculated as:

$$TGS_i^{BF} = \#cw \times \#20'slots_i = \frac{CYD_i}{L20 + ET} \quad (4.25a)$$

Where,

$\#cw$ = total number of container rows per container storage block.

$\#20'slots$ = total number of 20’ft. container slots available per container storage block for terminal i.

CYD_i = depth of the container yard (in m) for terminal i.

$L20$ = length of a 20 foot container (in m).

ET = extra space for stacking convenience (in m).

Note that omitting h from equation 4.25 gives the TGS per container terminal.

The calculation of the storage capacity using a sideway-loading system is mathematically formulated by:

$$\sum_{i=1}^{10} \#CSB_i \times TGS_i^{BS} \times h \quad (4.26)$$

Where,

$\#CSB$ = total number of container storage blocks for terminal i.

TGS_i^{BS} = twenty foot container ground slot (TGS) in TEU per container storage block using a sideway-loading system for terminal i.

Note that using a sideway-loading system, the TGS per container storage block is not dependent on the dimensions of the CY. Hence, the values of $\#cw$ and $\#20'slots$ are constant.

The total number of container storage blocks for terminal i can be calculated as:

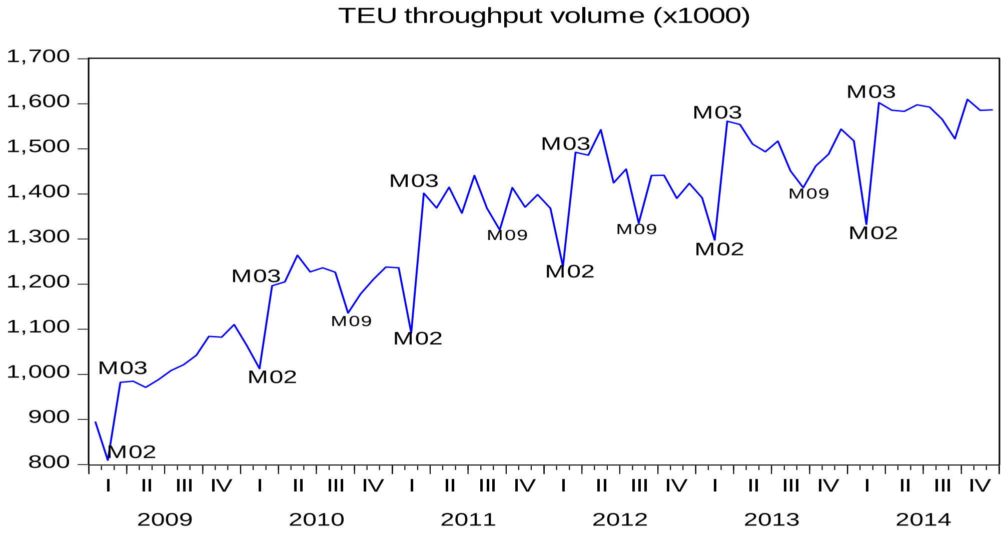
$$\#CSB_i = \#storage\ zones_i\ \times \#storage\ rows_i = \frac{CYD_i}{W^{bS}} \times \frac{QWL_i}{L^b} \quad (4.26a)$$

Where,
W^{bS} = whole width (in m) per container storage block using a sideway-loading system.
L^b = whole length (in m) per container storage block.

CHAPTER 5 Results part 1: forecasting TEU throughput

In this chapter we will analyze the first part of our results i.e. forecasting TEU throughput demand for the Port of Busan. A simple dummy variable regression and the more advanced SARIMA model are applied to explore any seasonal or peak patterns if present. The estimation period is set between 01/01/2009 and 31/12/2014. The forecasting period is set from 01/01/2015 until 31/12/2015. The forecasting accuracy of both models is compared using the RMSE, MAE and MAPE indicators. Afterwards, the 'best' model is chosen to predict the monthly TEU throughput volume for the calendar year 2015.

5.1 *SARIMA modeling using Box-Jenkins methodology*



Graph 5-1: Busan Port's monthly TEU throughput volume between January 2009 and December 2014.

Some interesting remarks can be made from graph 5-1. First, the TEU throughput volume exhibits a clear upward trend that is approximately linear. That means that the TEU volume data have a general tendency to increase over a long period of time. For many time series, the trend is the dominant source of variations. Hence, wrongly incorporating trends in a time series model will yield poor forecasted results. The second interesting point is the seasonal variations present in the data. The TEU throughput volume is at its yearly low at exactly the 2nd month of the year. The peak period of TEU throughput volume is occurring at the third month of the year, except in 2012 where the peak period occurred in the 5th month. Third, between 2010 and 2014 there is another tendency present in every 9th month of the year where the TEU throughput volume falls approximately between the yearly low and next year high. The general pattern that is present throughout the whole sample period in graph 5-1 is that there is peak period of TEU throughput volume following a month of annual low TEU throughput volume.

In order to quantify the trend of the TEU throughput volume, the following regression model is considered:

$$TEU_t = \alpha + \beta trend + \mu_t, \qquad t = 1,2,\dots,72 \qquad (5.1)$$

Where,

TEU_t = TEU throughput volume (x1000) at time period t.

α = unknown parameter (constant term).

β = unknown parameter (coefficient estimate of the trend component)

μ_t = unknown residual error of the time series with mean zero.

The regression results of equation 5.1 returns a $\hat{\beta}$ = 8.95 with a standard error of 0.48 and a p-value of 0.000. This means that at a 5% significance level, the beta coefficient of the trend is significantly different from zero. This confirm the earlier visual conclusion in graph 1 that a trend is present in the Busan Port's TEU throughput volume with an average growth of 8.95(x1000) TEU.

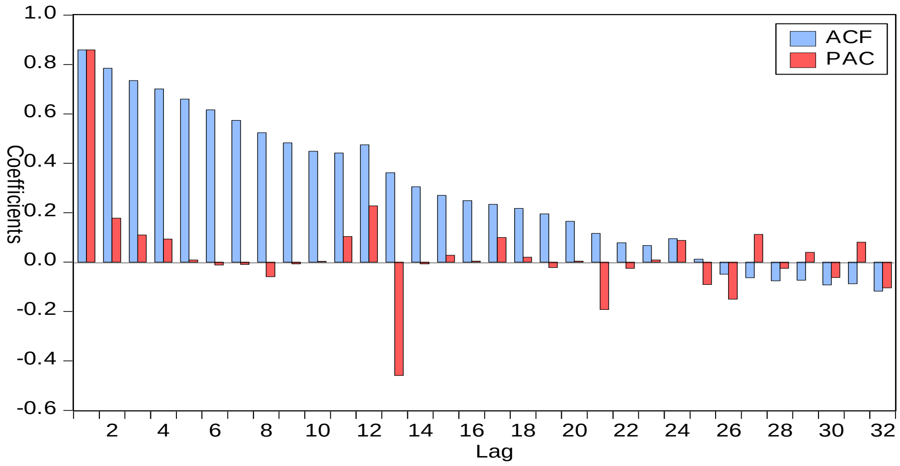
Identification

In order to determine whether the time series of the TEU throughput volume contains a deterministic of stochastic trend, a unit root (Augmented Dickey-Fuller (ADF)) test is performed. The trend component is included for the ADF test since there is a significant indication for the presence of a trend. In addition, the intercept is also included for the ADF test since it is unlikely that the expected throughput volume $E(TEU_t)$ will be equal to zero. The results of the ADF test is given in table 5-1. The null hypothesis of the ADF test states: the series *TEU throughput volume (x1000)* contains a unit root (stochastic trend). The alternative hypothesis states: the series *TEU throughput volume (x1000)* has a no unit root (deterministic trend). Since the p-value of the ADF test (0.377) is larger than the 5% significance level, the null hypothesis cannot be rejected. There is no significant indication that the series *TEU throughput volume (x1000)* contains a deterministic trend. This also means that the series is not stationary.

Augmented Dickey-Fuller test			
		t-Statistics	P-value
ADF test statistics		-2.398	0.377
Test critical values	1% level	-4.118	
	5% level	-3.487	
	10% level	-3.172	

Table 5-1: Augmented Dicky-Fuller test result for the TEU throughput volume (x1000) at level. Note: the t-statistic values at the 1%, 5% and 10% level are different from the asymptotic normal distribution as the time series is assumed to be non-stationary under the null hypothesis. The distribution of the coefficients is shifted more towards left compared to the asymptotic normal distribution making the critical values of the test statistic more extreme.

In addition to the ADF test, the autocorrelation (ACF) and partial autocorrelation (PACF) is also examined to determine the (non-) stationary of the time series.



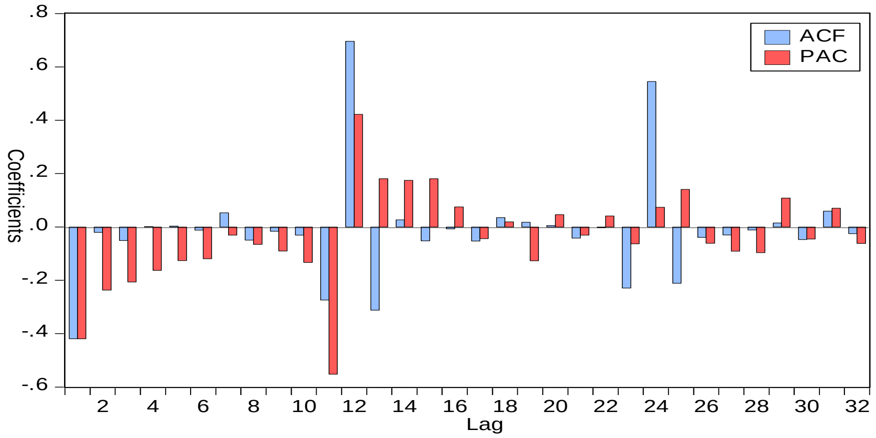
Graph 5-2: ACF and PACF coefficients for the monthly series of TEU throughput volume (x1000) up to 32 lags.

The correlogram in graph 5-2 illustrates significant seasonal spikes of PACF at lag 1 and lag 13 indicating a 12 period seasonality. In addition, the ACF coefficients are slowly tailing off to zero indicating a non-stationary series.

In order to make the series *TEU throughput volume (x1000)* stationary, the first difference of the series is taken into account when performing the ADF test. The results are given in table 5-2. The p-value of the ADF test (0.054) is almost significant at the 5% level. At the 10% significance level, the null hypothesis is rejected such that there is a significant indication of a deterministic trend present. This also means that the first difference of the series *TEU throughput volume (x1000)* is stationary. One of the most common errors in ARIMA modeling is to “overdifference” the time series which results in adding extra AR and MA terms to undo the damage. One of the consequences of “overdifferencing” is the increase of standard deviations. In order to prevent this, only the first difference of the series *TEU throughput volume (x1000)* will be considered in building the SARIMA model.

Augmented Dickey-Fuller test			
		t-Statistics	P-value
ADF test statistics		-3.454	0.054
Test critical values	1% level	-4.121	
	5% level	-3.488	
	10% level	-3.172	

Table 5-2: Augmented Dicky-Fuller test result for the TEU throughput volume (x1000) in first difference.

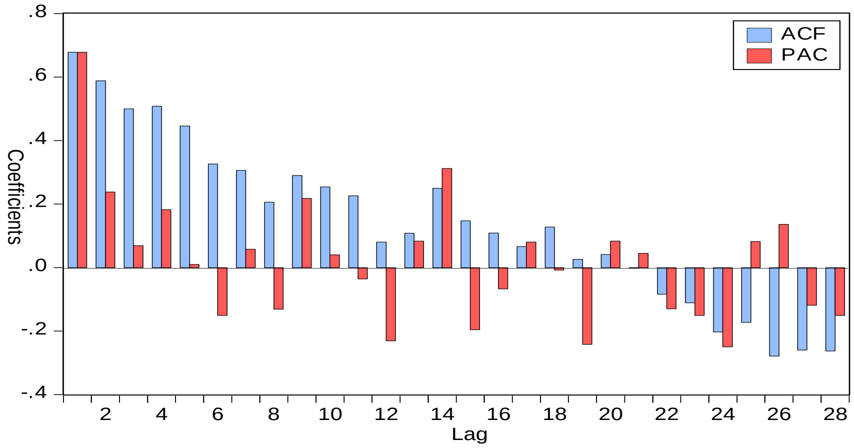


Graph 5-3: ACF and PACF coefficients for the first difference of the monthly series of TEU throughput volume (x1000) up to 32 lags.

The correlogram in graph 5-3 for the first difference of the *TEU throughput volume (x1000)* series indicates the presence of seasonal patterns. The ACF for the first differenced series illustrates high ACF coefficients at lag 12 indicating a seasonal component of length 12. In addition, there are also significant seasonal spikes to be observed at lag 11 and 12 for the PACF coefficients. Earlier, table 5-2 illustrated that the first difference of the *TEU throughput volume (x1000)* series is stationary at a 10% significance level but not at a 5% significance level. In addition, the observations from the ACF and PACF graphs suggest achieving a 12-period seasonal difference to achieve stationary. The p-value of the ADF test statistic (0.023) in table 5-3 indeed confirms that the 12-period seasonal difference of the *TEU throughput volume (x1000)* series is stationary. Hence, the *TEU throughput volume (x1000)* series is an $I(1)^{12}$ process that can be used to build the best SARIMA model.

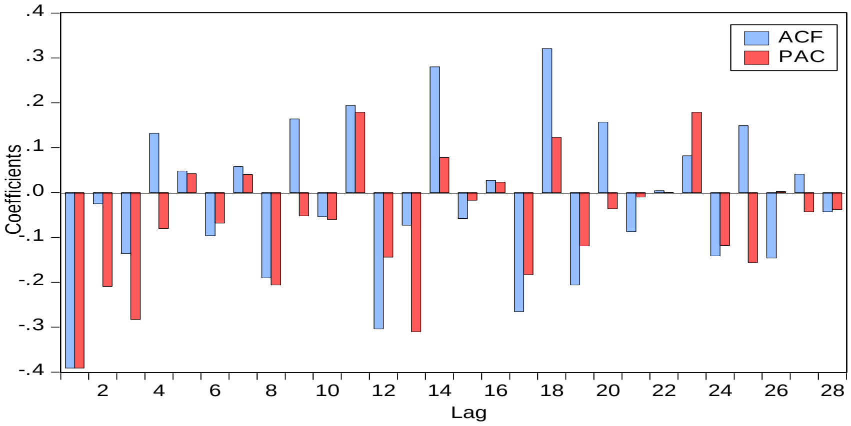
Augmented Dickey-Fuller test			
		t-Statistics	P-value
ADF test statistics		-3.226	0.023
Test critical values	1% level	-3.546	
	5% level	-2.912	
	10% level	-2.594	

Table 5-3: Augmented Dicky-Fuller test result for the TEU throughput volume (x1000) for the 12-period seasonal difference.



Graph 5-4: ACF and PACF coefficients for the 12-period seasonal difference of the monthly series of TEU throughput volume (x1000) up to 28 lags.

The correlogram in graph 5-4 illustrates the decay of the ACF coefficients at a faster rate indicating that the series is stationary. Hence, any seasonal trend and seasonal random walk type of stationary is removed after taking the 12-period seasonal difference. As observed from the graph, the positive ACF coefficients could be an AR signature. For the PACF, there is high significant coefficient in the first lag followed by a cut-off at lag 2 indicating a possible SAR(12) process. The PACF coefficients of seasonal gaps is interrupted clearly after the first seasonal gap at lag 12 indicating to consider seasonal changes when identifying and estimating the best SARIMA model.



Graph 5-5: ACF and PACF coefficients for the first difference of the 12-period seasonal difference of the monthly series of TEU throughput volume (x1000) up to 28 lags.

Graph 5-5 displays the ACF and PACF coefficients for the first difference of the 12-period seasonal difference. Since the series *TEU throughput volume (x1000)* also contains a linear trend, it is necessary to calculate the non-seasonal difference next to the seasonal difference. The behavior of the pure AR or pure MA is similar to that of the pure SAR and pure SMA, except that the pattern of SAR and SMA coefficients appears across multiples of lag 12 in the ACF and PACF. Since the ACF and PACF coefficients at the seasonal periods (lag 1, lag 12 and lag 24) are negative, a SMA signature is highly probable. In addition, a MA(1) term will also be considered since the ACF correlation is negative at lag 1 and displays a sharp cut-off at lag 2.

In order to confirm the presence of seasonality in the TEU throughput volume, the following regression is considered:

$$TEU_t - TEU_{t-1} = \mu_1 D_{1,t} + \mu_2 D_{2,t} + \cdots + \mu_{12} D_{12,t} + \mu_t, \quad t = 2,3,\ldots,T \qquad 5.2$$

$D_{s,t}$ is a dummy variable that equals 1 if the calendar period t corresponds with season s. Since monthly data have been used, s equals 12. μ_s is the average value of the first difference $TEU_t - TEU_{t-1}$ in season s. $TEU_t - TEU_{t-1}$ is the first difference of the *TEU throughout volume (x1000)* time series.

The coefficient estimates, standard errors and p-values of $\hat{\mu}_s$ are displayed in table 5-4. The coefficient estimate of $\hat{\mu}_2$ is equal to -114.65 with a p-value that is significantly different from zero. This confirms that the average TEU throughput volume is the lowest in the second month of the year. On the contrary, the coefficient estimate of $\hat{\mu}_3$ is equal to 242.04 with a p-value significantly different from zero. This also confirm that after having a season low of TEU throughput volume in February, there will be a season high of TEU throughput volume in March. Furthermore, the r-square of the regression equals 0.822. This means that seasonal variation does indeed affect the TEU throughput volumes to a very large extend.

Dependent variable: $TEU_t - TEU_{t-1}$
Sample period: 2009M02 2014M12

Variable	Coefficient	Standard Error	P-value
D M01	-27.49	18.719	0.147
D M02	-114.65	17.088	0.000**
D M03	242.04	17.088	0.000**
D M04	-8.62	17.088	0.616
D M05	16.95	17.088	0.325
D M06	-32.83	17.088	0.060*
D M07	26.91	17.088	0.121
D M08	-47.07	17.088	0.008**
D M09	-15.47	17.088	0.369
D M10	52.35	17.088	0.003**
D M11	-10.38	17.088	0.546
D M12	28.88	17.088	0.096*
R-squared	0.822		
Observations	71		

Table 5-4: OLS estimation results of equation 2. D M01 is the abbreviation for the dummy variable of month 1 (January). **Significant at a 5% level. *Significant at a 10% level.

Model estimation

This section focus on identifying the best seasonal ARIMA model (SARIMA) and the relevant specifications. The order of the seasonal ARIMA model is determined on the relevant criteria's discussed regarding the ACF and PACF correlogram depicted in graph 5-5. The ultimate choice for the best SARIMA model is based on the criteria's: AIC, SIC, standard error of regression and significance of the estimated coefficients. Earlier, it was confirmed that the series *TEU throughput volume (x1000)* contains both a trend and seasonality. Therefore, a 12-month seasonal difference and a non-seasonal first difference are applied to the series *TEU throughput volume (x1000)* when estimating the SARIMA models. No constant term is included in our model since both non-seasonal and seasonal differences are taken into account.

	SARIMA Models	AR(1)	AR(2)	MA(1)	MA(2)	SAR(12)	SMA(12)	AIC	SIC	SE regression
1	$(0,1,2)(0,1,1)_{12}$			-0.525*	0.070		-0.841*	10.178	10.283	38.287
2	$(1,1,2)(0,1,1)_{12}$	0.761*		-1.353*	0.459*		-0.691*	10.331	10.473	40.984
3	$(0,1,2)(1,1,0)_{12}$			-0.700*	0.070	-0.376*		10.627	10.745	47.634
4	$(1,1,0)(1,1,0)_{12}$	-0.510*				-0.437*		10.657	10.737	48.830
5	$(1,1,0)(0,1,1)_{12}$	-0.455*					-0.857*	10.107	10.178	37.253
6	$(2,1,0)(0,1,1)_{12}$	-0.521*	-0.142				-0.920*	10.109	10.216	36.959
7	$(1,1,1)(1,1,1)_{12}$	-0.081		-0.574*		-0.173	-0.826*	10.144	10.303	37.027
8	$(0,1,1)(0,1,1)_{12}$			-0.571*			-0.858*	10.135	10.205	37.776
9	$(1,1,1)(0,1,1)_{12}$	-0.261		-0.325*			-0.854*	10.114	10.226	37.180
10	$(1,1,1)(1,1,0)_{12}$	-0.055		-0.634*		-0.373*		10.607	10.727	47.144

Table 5-5: SARIMA models with AIC, SIC and SE regression values for the estimated set of seasonal ARIMA orders (p,d,q) and (P,D,Q). *denotes significance at a 5% level.

As can be seen from table 5-5, AIC and SIC achieve their minimum value for the $(1,1,0)(0,1,1)_{12}$ model. Model $(2,1,0)(0,1,1)_{12}$ is not regarded as the best model although it has the lowest standard error of regression, because the AR(2) coefficient is not significant. Hence, model $(1,1,0)(0,1,1)_{12}$ is regarded as the best model since the estimated coefficients are also significant. That is we have a model with 1st order autocorrelation, 1st order difference, zero order moving average, zero order seasonal autocorrelation, 1st order seasonal difference, 1st order seasonal moving average.

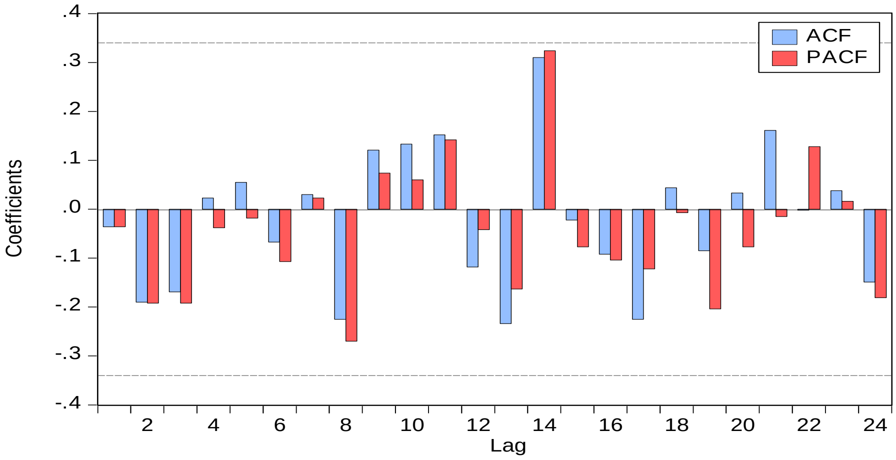
The SARIMA model $(1,1,0)(0,1,1)_{12}$,with standard errors in parentheses can be expressed as:

$$\underset{(0.115)}{(1+0.455L)}(1-L)(1-L^{12})y_t = \underset{(0.059)}{(1+0.857L^{12})}\varepsilon_t \qquad 5.3$$

The first difference of the 12-period seasonal difference of the series *TEU throughput volume (x1000)* is denoted as y_t. The white noise is denoted as ε_t. Equation 5.3 is used to forecast the monthly TEU throughput volume for the port of Busan for the year 2015 if and only if superior forecasting performance is evident compared to the simple regression model with monthly dummy variables.

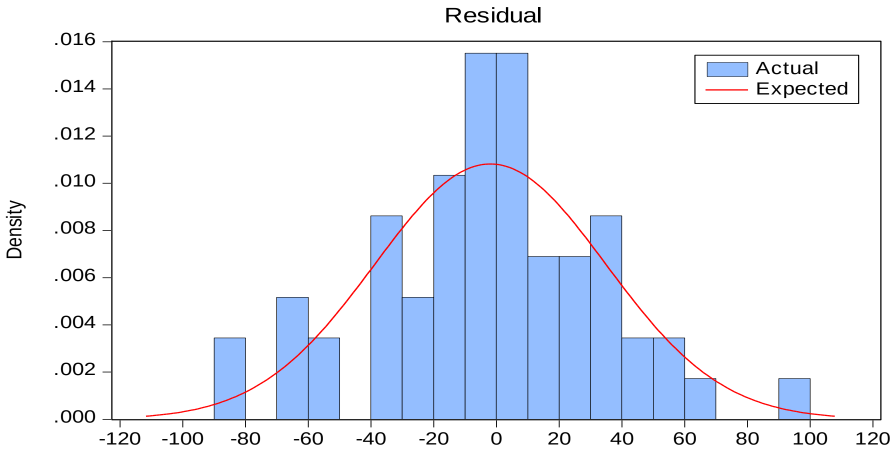
Model diagnosing

Now that we have estimated the best seasonal ARIMA model, the next step is to check whether the model $(1,1,0)(0,1,1)_{12}$ is correctly specified. Specifically, the ACF and PACF coefficients of the residuals are examined to detect for any unaccounted pattern. In addition, the residuals are also examined for random (white) noise.



Graph 5-6: ACF and PACF coefficients of the residuals for SARIMA model (1,1,0)(0,1,1)$_{12}$ up to 24 lags. Dashed lines illustrate the upper and lower boundaries for all time lags.

The ACF and PACF values of the residuals in graph 5-6 are all between the upper and lower boundaries of the confidence limits for all time lags. The values of correlation functions are also close to zero indicating a stable time series.



Graph 5-7: Histogram of the residuals (expected vs. normal) from SARIMA model (1,1,0)(0,1,1)$_{12}$.

Graph 5-7 displays the histogram residuals obtained from the SARIMA model (1,1,0)(0,1,1)$_{12}$. The distribution of the residuals deviates from the normal distribution with extreme values on the left and right-hand side. The high cluster of residuals concentrated around the -20 and 20 compensate the extreme values which makes the histogram almost normally distributed. The values of the skewness and kurtosis are equal to -0.003 and 3.208, respectively. These are almost equal to the corresponding values of a normal distribution, namely 0 and 3. The extreme value 98.4 is the result of over fitting the actual TEU throughput value for the port of Busan in October 2013 by the SARIMA model. The extreme value of -90 is the result of under fitting the TEU throughput value in May 2012 by the model. The Jarque-Bera test statistic is applied to test for the normality of the residuals. The test statistic is equal to 0.105 with a p-value of 0.95. Since the p-value is larger than 0.05, it can be concluded that the residuals of the SARIMA model $(1,1,0)(0,1,1)_{12}$ are normally distributed. In addition, the White test is also performed to check whether the variance of the residuals is homoskedastic or heteroskedastic by means of the White test. The p-value of the test statistic is equal to 0.0891. Since the null hypothesis is not rejected, it can be concluded that variance of the residuals are constant (homoskedastic).

5.2 Linear regression estimation using dummy variables

In order to capture seasonal effects on the TEU throughput volume for the Port of Busan, dummy variables are created for each month. Equation 3 is estimated using the EViews statistical package. The results of the estimation are reported as follows:

Dependent variable: TEU throughput volume (x1000)
Sample period: 2009M01 2014M12

Variable	Coefficient	Standard Error	P-value
Constant	969.549	34.017	*0.000
Trend	8.898	0.668	*0.000
Dummy February	-123.549	22.615	*0.000
Dummy March	109.594	29.433	*0.000
Dummy April	92.077	32.400	*0.006
Dummy May	100.127	46.234	*0.034
Dummy June	58.402	32.442	**0.077
Dummy July	76.417	38.515	**0.052
Dummy August	20.447	33.162	0.540
Dummy September	-3.917	31.183	0.901
Dummy October	39.539	30.160	0.195
Dummy November	20.265	22.294	0.367
Dummy December	40.251	21.264	**0.063
R-squared	0.920835	S.E.of regression	63.33985
Adjusted R-squared	0.904734	SSR	236704.2
Observations	72	Prob(F-statistic)	0.000

Table 5-6: Results seasonal dummy regression. Standard errors are calculated based on Newey-West to correct for serial correlation. * and ** Indicate the significance of the coefficients at a 5% and 10% level, respectively. January is used as the reference category to prevent multicollinearity.

The seasonal regression model can be expressed as:

$\widehat{TEU\ throughput\ volume}\ (\times 1000)_t$ = 969.549 + 8.898t - 123.549$X_{s2,t}$ + 109.594$X_{s3,t}$ + 92.077$X_{s4,t}$ + 100.127$X_{s5,t}$ + 58.402$X_{s6,t}$ + 76.417$X_{s7,t}$ + 20.447$X_{s8,t}$ – 3.917$X_{s9,t}$ + 39.539$X_{s10,t}$ + 20.265$X_{s11,t}$7 + 40.251$X_{s12,t}$. (28)

The intercept of the regression model is statistically significant. The coefficient of 969.549 implies that the TEU throughput volume in January is predicted to be around 969,549 TEU on average, ceteris paribus. The trend coefficient is also significant implying that for each additional time-period ahead the TEU throughput volume is expected to increase 8,898 TEU on average over the whole sample period, ceteris paribus. The dummy variables for the month February, March, April, May, June, July and December are al significant at a 5% level, if not at a 10% level. This means that TEU throughput volumes are different during these periods of the year. The TEU throughput volume in February is lower compared to March. TEU throughput volume in February tends to be 123,549 TEU less than January, holding the time period constant. On the contrary, TEU throughput volume in March tends to be 109,549 TEU more than January, holding the time period constant. Furthermore, the TEU throughput volume in April, May, June, July, December are respectively 92,077, 100,127, 58,402, 76,417, 40,251 TEU higher compared to January, ceteris paribus. No concluding statements can be made regarding differences in TEU throughput volumes for the month August, September, October, November compared to January since the p-values of the corresponding coefficients estimates are not significant at 5% or 10% level.

Overall the explanatory power of this model is very good. The r-square of 0.9204 implies that around 92.04% of the variations in TEU throughput volume are explained by the monthly dummy and trend variables. In addition, an F-test on the joint significance for the monthly dummy variables indicated that all the monthly dummy variables have a significance influence on the TEU throughput volume, ceteris paribus. The F-statistic of 113.036 with the corresponding p-value of 0.000 lead to the rejection of the null hypothesis of no joint significance at a 5% level. Hence, all the monthly dummy variables should be included in the model, regardless of the fact that some of them are individually not significant, as they jointly have significant explanatory power in explaining TEU throughput volumes. The White test is performed to test for heteroskedasticity. The Chi-Square test statistic is equal to 17.56 with p-value 0.144. The null hypothesis of homoskedasticity is not rejected indicating the constant variance of residuals. The Jarque-Bera test is also performed to check whether the residuals are normally distributed. The Jaque-Bera test statistic is equal to 0.640 with p-value 0.726. The null hypothesis of normality is not rejected indicating that the residuals of the seasonal regression models are normally distributed.

5.3 Model selection and forecasting TEU throughput volume

Until now 2 methodologies have been used to estimate the TEU throughput volume for the Port of Busan. The first methodology is based on the seasonal ARIMA theory that uses a multi-step process in order to come up with the best model. The SARIMA model $(1,1,0)(0,1,1)_{12}$ is found to be the best seasonal ARIMA model based on the significant coefficients and lowest AIC and SIC values .The second methodology is based on the linear regression theory where the TEU throughput volume is regressed on the trend and dummy variables for each month. This section evaluates the prediction strength of the SARIMA model $(1,1,0)(0,1,1)_{12}$ and seasonal regression model based on its forecasting performance indicators. This will entail us to decide which model to use in order to forecast the TEU throughput volume of the port of Busan for the calendar year 2015. Since both models have been estimated, we can now examine the forecasting accuracy based on Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE). It is of interest to examine the model fit based on the estimated coefficient with respect to the actual observations such that the in-sample performance is evaluated.

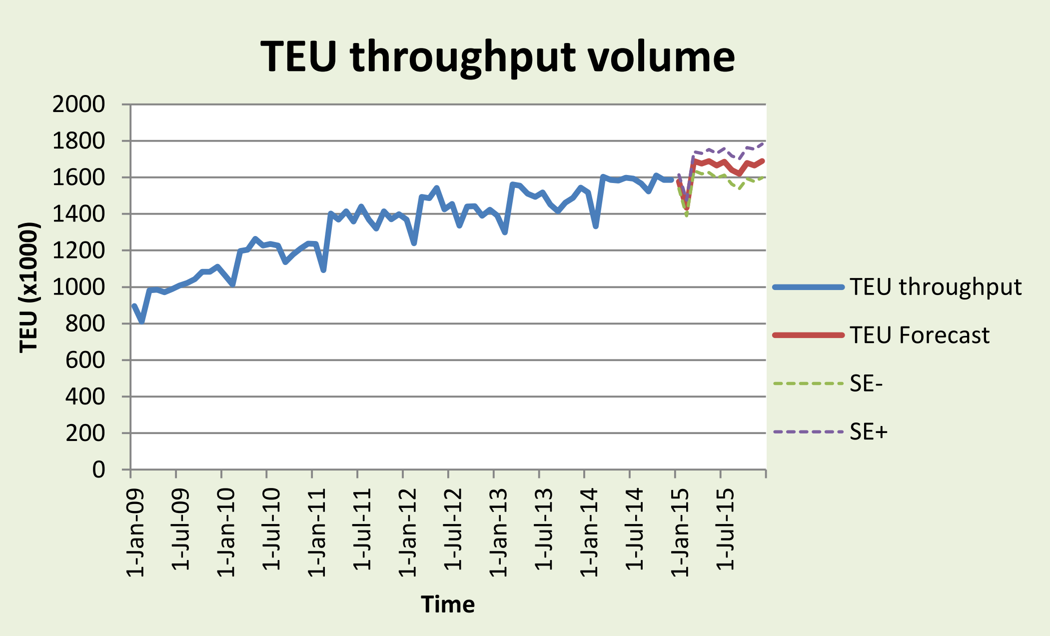
	Model	
Indicators	SARIMA $(1,1,0)(0,1,1)_{12}$	seasonal regression model
RMSE	53.918	57.337
MAE	46.523	46.823
MAPE	3.25	3.695

Table 5-7: Results of the forecasting performance indicators for the SARIMA $(1,1,0)(0,1,1)_{12}$ and seasonal regression model based on sample period. The estimated (in-)sample period for the SARIMA $(1,1,0)(0,1,1)_{12}$ and seasonal regression model is March 2010 – December 2014 and January 2009 – December 2014, respectively.

As illustrated in table 5-7, the SARIMA model $(1,1,0)(0,1,1)_{12}$ has the lowest prediction errors in terms of RMSE, MAE, MAPE compared to the seasonal regression model. This means that the forecasted TEU throughput volume of the SARIMA model closely follows the observed TEU throughput volumes. The SARIMA model $(1,1,0)(0,1,1)_{12}$ will be applied to forecast the TEU throughput volume for the calendar year 2015. Note that the (in-) sample period is different for the two models. This is due to the fact that the first difference of the 12-period seasonal difference is applied to the SARIMA model. This leaves us with only 58 observations compared to 72 observations for the seasonal regression model. However, the forecasting performance of the two models can still be compared since the RMSE, MAE and MAPE indicators represent averaged values.

Time	SARIMA Forecast (TEU)
1-Jan-15	1,577,003
1-Feb-15	1,432,960
1-Mar-15	1,688,964
1-Apr-15	1,675,415
1-May-15	1,689,078
1-Jun-15	1,663,970
1-Jul-15	1,685,071
1-Aug-15	1,639,976
1-Sep-15	1,619,875
1-Oct-15	1,678,596
1-Nov-15	1,665,633
1-Dec-15	1,689,742

Table 5-8: TEU throughput volume forecast at planning time horizon (2015) based on SARIMA model $(1,1,0)(0,1,1)_{12.}$



Graph 5-8: TEU throughput volume (x1000) for the port of Busan. Forecasted TEU volumes are estimated by the SARIMA model $(1,1,0)(0,1,1)_{12.}$

As can be observed from graph 5-8, the forecasted TEU throughput for the year 2015 continues to show an increasing pattern. In addition, the TEU throughput volume is expected to be the lowest during February with 1,432,960 TEU. In the following month, we can expect a peak period with 1,688,964 TEU. After the peak period in March, the TEU throughput volume growth is expected to be stable until August before falling slightly to 1,619,875 TEU in September. Onwards, the TEU throughput volume will regain its momentum to grow up to 1,689,742 TEU in December.

The forecasted TEU throughput volumes in table 5-8 will be used in our container terminal design planning.

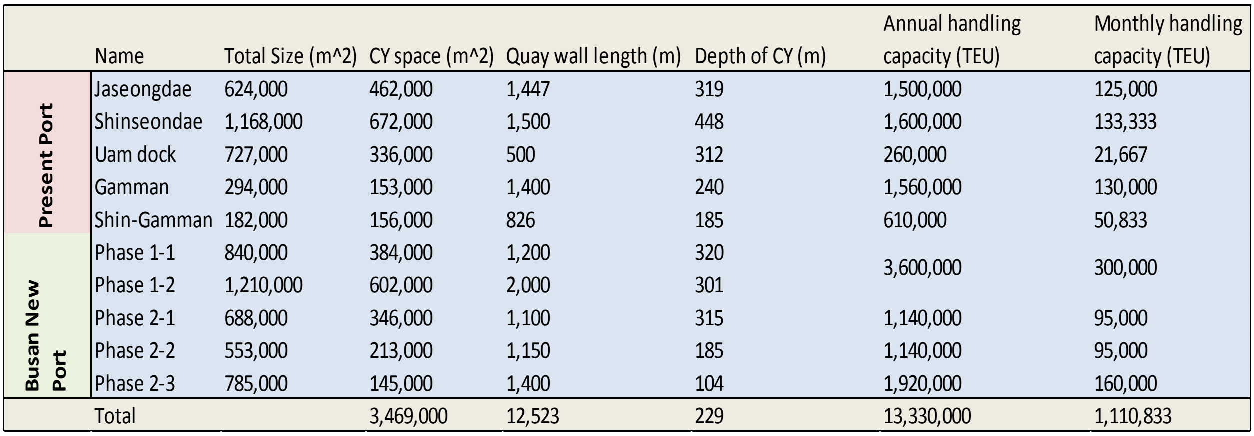
Chapter 6 Results part 2: container terminal design

Since the monthly TEU container throughputs are forecasted for the year 2015, we can design the container terminal through several phases. Specifically, the container storage capacity of the container yard (CY) is calculated given the type of stacking equipment, the loading system and the dimensions of the CY. After calculating the container storage capacity, the forecasted monthly TEU throughput volumes will be implemented into the CY given various container dwell times and stacking heights. This will enable us to evaluate the average allowed filling rate of a container storage block for each month in 2015.

6.1 Phase 1: determining the container yard area

The first stage in our container terminal design is to determine the area required for the CY. We are left with two methodology problems regarding the calculation of CY area. First, the CY area required can be calculated for a given amount of TEU throughput that has to be handled given a specific time. Second, the maximum amount of TEU throughput volume can be calculated given a CY area. We can calculate the area of the container yard on our own or we can obtain the actual area for the Port of Busan that is currently used. The problem with calculating the CY area our self is that it is based on recent expected TEU throughput volumes. Whereas, the actual CY areas are based on the expected TEU throughput volumes made at the time when the CY was constructed. Therefore, for the second phase of our container terminal design i.e. determining the equipment use and stacking height, it will be better to obtain the actual surface area of the CY used now by the Port of Busan. In order to make it interesting, we can compare both the theoretical and actual CY area.

In order to calculate the actual surface area of the CY space at the port of Busan, the current status of the container piers are obtained from the official website of Busan Metropolitan City. Unfortunately, the CY space is not given for the Phase 1-2 terminal. In order to calculate the CY space for the Phase 1-2 terminal, the total CY storage area reported by the Busan Port Authority is subtracted with the total CY storage area reported by the Busan Metropolitan City website. The Busan Port Authority reports in total of 3,469,000 m^2 of CY space. The Busan Metropolitan City reports in total of 2,867,000 m^2 of CY space without taking into account the CY space of Phase 1-2 terminal. As can be seen in table 6-1, the Port of Busan consists of 10 piers (container terminals) from which 5 have been recently constructed in Busan New Port during 2006 - 2012. The depth (width) of CY was not stated on the website and had to be calculated. Assuming that the CY has a rectangular shape and the length of the CY is equal to the quay wall length, the depth of the CY is equal to the CY space divided by the quay wall length. In addition, the monthly handling capacity had also to be calculated by the dividing the annual handling capacity with 12. At the aggregate level, the Port of Busan has currently in total of 3,469,000 m^2 of available yard space with a monthly handling capacity of 1,110,833 TEU. Looking at the forecasted TEU throughput volume for 2015, it can be concluded that the TEU demand exceeds the monthly handling capacity in each month. Hence, to balance this out careful planning of container terminal operations is required.



	Name	Total Size (m^2)	CY space (m^2)	Quay wall length (m)	Depth of CY (m)	Annual handling capacity (TEU)	Monthly handling capacity (TEU)
Present Port	Jaseongdae	624,000	462,000	1,447	319	1,500,000	125,000
	Shinseondae	1,168,000	672,000	1,500	448	1,600,000	133,333
	Uam dock	727,000	336,000	500	312	260,000	21,667
	Gamman	294,000	153,000	1,400	240	1,560,000	130,000
	Shin-Gamman	182,000	156,000	826	185	610,000	50,833
Busan New Port	Phase 1-1	840,000	384,000	1,200	320	3,600,000	300,000
	Phase 1-2	1,210,000	602,000	2,000	301		
	Phase 2-1	688,000	346,000	1,100	315	1,140,000	95,000
	Phase 2-2	553,000	213,000	1,150	185	1,140,000	95,000
	Phase 2-3	785,000	145,000	1,400	104	1,920,000	160,000
	Total		3,469,000	12,523	229	13,330,000	1,110,833

Table 6-1: Current status of container piers in Busan. The CY space is equal to the product of the quay wall length and depth of CY. Note: the annual and monthly handling capacity for Phase 1-1 and 1-2 terminal is mentioned as a whole. Source: Dynamic Busan (english.busan.go.kr) and Busan Port Authority (busanpa.com/eng).

UNCTAD (1985) proposed different procedures for determining the land requirement for a given amount of container movements through the yard. The first step is to obtain the expected container volumes *C* (TEUs/month) that have to be handled given a period of time. This has already been calculated in the previous chapter. Second, calculate the average number of container holding *HC* in the CY based on the dwell time *T*. Third, given the appropriate area *A* requirement per TEU (m^2/TEU) and multiplying it with the *HC*, the net storage area *NSA* requirement can be calculated. Fourth, after deciding which stacking height *H* to use, the gross storage area (GSA) requirement of CY can be obtained by dividing *NSA* with *H*. Finally, given the reserve capacity safety factor *F* that allows the CY to handle peaks in demand the CY surface area can be calculated by multiplying (1+*F*) with *GSA*. This is illustrated with the formula:

$$CY\ suface\ area\ (m^2) = \left[\frac{\left[E[C] * \frac{T}{30}\right] * A}{h}\right] * [1 + F] \qquad (6.1)$$

Several assumptions had to be made to calculate the surface area of the CY. The average dwell *T* time for containers in the storage area is assumed to be 5 days. The area required per container *A* is assumed to be equal to 18.21 m^2/TEU. This is based on the length and width of a 20 ft. container which is equal to respectively 2.35m and 5.89m. Chu et al. (2005) argued that about 50cm or 0.5m extra space is needed for the convenience of container stacking. Thus the area requirement per container A is equal to (2.35m + 0.5m) x (5.89m + 0.5m) = 18.21 m^2/TEU. Normally customs requires that a container's door should be accessible for inspection on site meaning that an extra space of 1.2m in length should be added. However this rule only applies to terminals that are not self-governed. The Port of Busan has container terminals that are self-governed with their own custom and security facilities. Furthermore, the stacking height and the peak factor are assumed to equal to 3 and 20%. The expected TEU throughput for the year 2015 is equal to 1,642,190 TEU. This is the mean of the expected monthly TEU throughput volumes reported in table 5-8.

Plugging all the parameter values in equation 29 gives us a CY surface area of 1,993,783 m^2. This is less than the actual CY surface area of 3,469,000 m^2. The reason of this difference can be attributed to several limitations of equation 2. First, it does not take into account the dwell times for transshipment, export and import containers. Researchers have found varying dwell times for different destination containers. For example in Mauritius Container Terminal (MCT), the average dwell time for inbound container, outbound container, and transshipment containers are equal to respectively 6.06 days, 3.50 days and 7.52 days (InfoWave, 2008). Varying dwell times are also present in the APL terminal for the port of Kaohsiung with 12 days, 4-5days, and 7 days for respectively inbound containers, outbound containers, and transshipment containers (port of Kaohsiung, 2001). Second, no specific yard sized and dimensional characteristics of cranes are considered. Area requirements for other CY facilities such as container cleaning and maintenance shop are not considered. Hence, for further calculations the actual CY surface area of 3,469,000 m^2 is considered.

6.2 Phase 2: determining the container handling equipment

The second stage of our terminal design consists of making decision regarding the type of container handling equipment to be used in the CY. The commonly adopted handling systems are straddle carries (SCs), rail-mounted gantry crane systems (RMGs), rubber-tired gantry crane systems (RTGs) and heavy-duty forklift trucks for empty container stacking. In our final container design only the RMG system have been implemented. However, a mixture of stacking systems may be possible in several container terminals to fulfill their operational demand. A RMG system has different advantages compared to SC and RTG systems:

1. A RMG system allows for separate lane for road trucks and other terminal container handling equipment leading to a smooth handling of priority quayside operations and avoidance of mixed equipment queues. This is schematically displayed in figure 6-1. The perpendicular layout of the RMGs result in separation of the external trucks (XT) and SCs. The external

trucks only have to drive to the end loading to drop or receive their container without any interruptions. This result in a shorter truck turn-around time in the hinterland connection area.

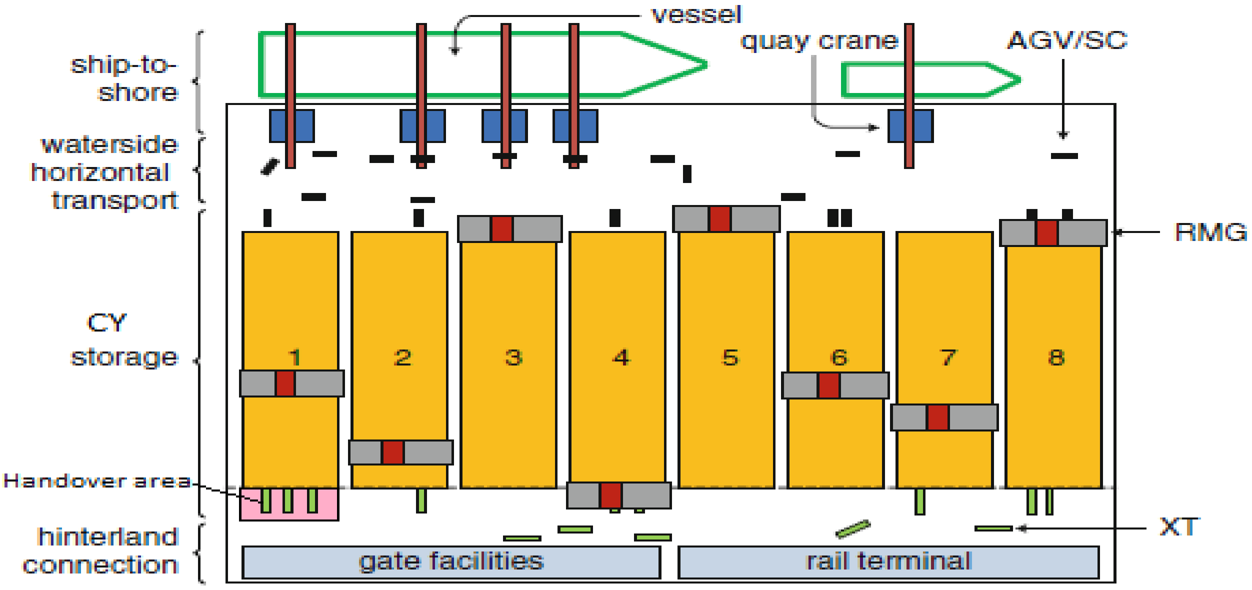


Figure 6-1: Possible schematic layout of a container terminal using perpendicular placed RMGs as storage equipments with front-end-loading systems. Purple area denotes the handover area. Numbers denote the container blocks. *Source*: Kemme (2013).

2. In contrast to RMGs, RTGs require a crane driver and there is hardly any room for automation because of heavy interaction between the crane driver on one side and the TTUs drivers and XT drivers on the other side. RMGs are fully automated, equipped with electric engines, which can position containers optimally 24/7 with no trucks and people in the CY storage area. This makes RMGs also eco-friendly.
3. In the waterside transport area, SCs do not wait to pick up or deliver containers to the XT. Instead, they can work independently and directly pick up or deliver their container at the RMG contributing to a constant flow of containers.
4. Compared to SCs, RMGs are very much reliable due to their good safety records, low maintenance costs, and long service life (UNCTAD, 1985). On the other hand, RMGs are less flexible and require higher initial capital investments than SCs and RTGs but these offset the long-term benefits of automation and economic utilization of land.

6.3 Phase 3: determining the container storage block area requirement

Since we know how much land is available and which operating methods and equipments will be used we can move to the third phase of our container terminal design. That is, the area requirements can be calculated to store the containers with RMGs given the number of container blocks. This will help to determine the number of container rows and bays to be stacked in each container block.

6.3.1 Front-end-loading system area requirement

RMGs can be delivered in different sizes and configurations. In this case, RMGs without outreach (cantilevers) are placed in the CY. Note that if a front-end loading system is implemented in the CY, the handover of containers will take place at the front ends of the block. Hence, it is of no use to implement RMGs with outreaches such that handover lanes are required outside the crane portal. This will result in land and capital cost savings. Figure 6-2, depicts a schematic illustration of a RMG with zero outreach. The containers are stacked within the internal span of the RMG. The width of the internal span of the RMG is assumed to be 30.6m that can accommodate 10 rows of containers each with a width of 2.85m (2.35m + 0.5m). As explained earlier, a 0.5m extra space should be considered for the convenience of container stacking. The whole width (internal span + external span + service lane) is assumed to 35.7m. The whole width is calculated by multiplying the width of the internal span with 2 times the width of a typical container road truck (30.6m + 2 x 2.55m). A separate lane next to the RMG is also included in the whole width. This is because service lanes between the yard blocks are needed for maintenance and repair purpose only, but usually not by horizontal-transport equipment (SCs). Stacking height is assumed to be 1 over 4. This mean that the RMG equipment used in this case has the ability to pass one container over containers stacked four tiers high.

In addition for trucks, tractors, SCs and other heavy equipments to move quickly between the gate terminal and waterside area, roadways outside the storage blocks should be considered. This necessary since it is assumed that the length of the quay wall is equal to the width of the CY area. Chu et al. (2005) stated that the widths of the majority of the surrounding roadways are between 24 to 30m. In this paper the width of a roadway is assumed to be two times the length of a 40ft container. That is 2 x 12.03m = 24.06m. There are no regulations with respect to the number of roadways to include in a terminal. We assumed that a roadway every 5 blocks of stacked containers. This means that on average 4.81 m extra width has to be considered per block on the whole width. The total width per block stacked container is equal 40.51m (35.7m + 4.81m). This will later be used to calculate the number of container storage blocks per terminal.

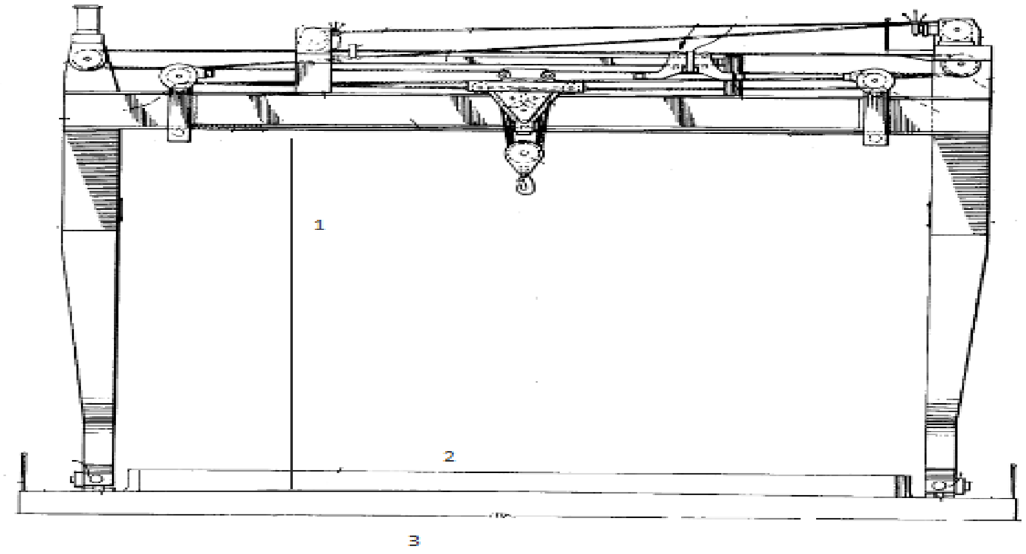


Figure 6-2: Schematic illustration of a RMG equipment with zero outreach. 1= the sacking height. 2= width of the internal span. 3= whole width.

The next step is to determine the length of the container row (slots) for each terminal based on the depth of the container yard area. As can be seen in figure 6-1, the length of each container row is equal to the depth of the CY storage minus the depth of the handover areas on both landside and waterside of the container block. In a handover area, XTs and SCs are waiting for loading or discharging and/or where containers are picked up or dropped off. The depth of the CY storage for each pier is already been given in table 6-1. The depths of the handover areas are different for various ports. For practically, the depth of the handover area is assumed to be 16.50m. This is the maximum length of a truck with container according to EU regulations. This will later be used to calculate the number of container slots in each stacked row.

6.3.2 Sideway-loading system area requirement

From a cost-benefit and operational point of view it may not be an optimal solution to implement a front-end loading-system in all container terminals for the Port of Busan. For example, the operations in these terminals will not run efficient enough if more units of RMGs are needed per stacked containers to process the handling of containers. In addition, it is also be possible that a sideway-loading system may have superior container storage capacity compared to a front-end-loading system. To maximize the container-handling capacity, the container storage capacity is also calculated for the sideway-loading system and compared with the front-end-loading system.

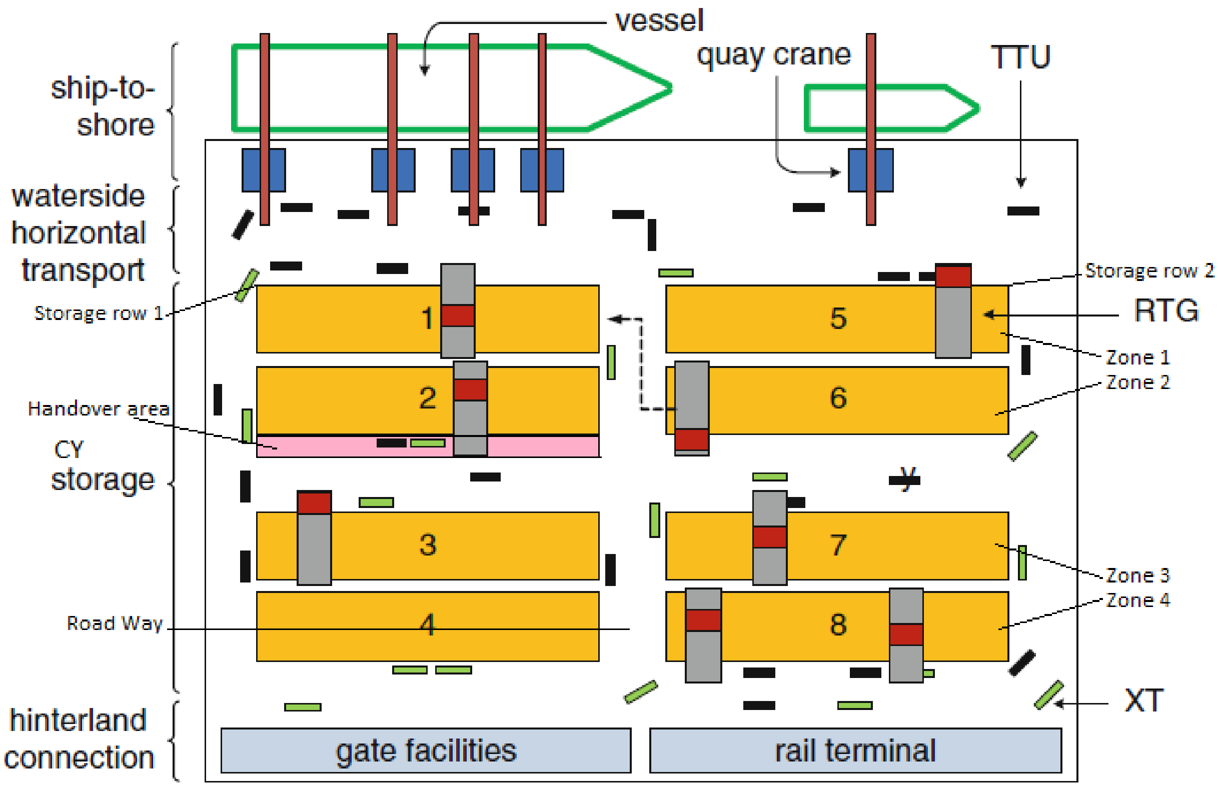


Figure 6-3: Possible schematic layout of a container terminal using parallel placed RMGs as storage equipments with sideway-loading systems. Purple area denotes the handover area. This particular container terminal has 4 storage zones with 2 rows. The total number of storage blocks equals 8. In this paper, the handover area is also used as the handover lane or passage way. Note the term storage row has the same meaning as container storage block explained in chapter 2. *Source*: Kemme (2013).

As illustrated in figure 6-3, the CY is subdivided into several yard blocks and roadways. The yard blocks are laid parallel to the quay wall consisting of a handover lane and several rows in which the containers are stacked end to end. This system requires wider roadways between each storage rows in order for Truck Trailer Units (TTUs) and XTs to turn 90 degrees. No SCs are used in this system since the RMGs are directly used to load (offload) the containers on (from) the TTUs and XTs. Contrary to the front-end-loading system, XT and TTUs interact by using the same handover lane.

The same type of RMG crane with zero outreach is used for the sideway-loading system as schematically illustrated in figure 6-2. Although its internal span can accommodate 10 rows of containers, the number of container rows is set at 8. This is necessary to reserve some space for the handover area/lane depicted in figure 6-3. The width of the handover lane is equal to the internal span of the RMG equipment minus width of stacking 8 container rows (including the 0.5m storage space per container). The width of a 20 foot container is equal to 2.35m. Then, the width of the handover lane is equal to 7.8 m (30.6m - (8 x (2.35m + 0.5m)). The whole width (whole span + service lane) is still assumed to be 35.7m. This is also equal to the whole width per block. Note that we did not include extra surrounding passage ways parallel to the quay wall between the storage blocks since we already implemented a handover lane which is wide enough for 3 trucks to move side by side.

Each storage block is configured to accommodate 50 bays of 20’ slots. A ground slot of a block is defined as the ground space on which containers is stored. The number of twenty-foot ground slots (TGS) of a block is calculated by multiplying the number of container rows with the number of bays. The TGS is equal to the number of container rows, set at 8 containers multiplied by 50 bays of 20’ slots. This is equal to 400 TEU. Taking into account an extra 0.5m for storage per container leads to a total block length of 319.5m (50 x (5.89m + 0.5m)). In addition, we should also take into account the width of the roadway between the storage rows. As mentioned earlier, the width of a roadway is assumed to be two times the length of a 40ft container. That is 2 x 12.03m = 24.06m. Since there is a roadway after each storage row, the total width of a storage block is equal to the total block length of 319.5m plus 24.06m. This is equal to 343.56m.

6.4 Phase 4: determining the storage capacity

The fourth and final stage of our container terminal design consist of calculating the storage capacity given the equipment used, storage area of the container block, stacking height.

6.4.1 Front-end-loading system storage capacity

Table 6-2 displays the container storage capacity (TEU) for each terminal of the Port of Busan with a front-end-loading system. The total storage capacity that the port can handle is equal to 458,520 TEU. This is based on the stacking height of 4 over 1. The maximum number of bays that a container terminal can accommodate varies since the CY depth is also different. The 440 TGS achieved per block for the Jaseongdae terminal is calculated by: 10 (number of container rows) x 44 (number of bays). Multiplying 440 TGS per block with the total number of container blocks of 35 results in a TGS of 15,400 TEU for the Jaseongdae terminal. The total container storage capacity per terminal is then calculated by multiplying the total number of TGS per block with the stacking height and the total number of container storage blocks. The 61,600 TEU of storage capacity for the Jaseongdae terminal equals 440 (#TGS per block) x 4 (maximum stacking height) x 35 (#container storage blocks).

As mentioned before, the total width per block stacked container is equal to 40.51m. The number of container storage blocks per terminal is then calculated by dividing the length of the quay wall (given in table 6-1) with 40.51m. The total number container storage blocks for the Jaseongdae terminal equals 35 blocks (1,447m /40.51m). We also assumed that a RMG is allocated for each storage block.

The number of bays in each stacked row is calculated as the depth of the CY corrected for the handover area divided by the length of a 20 foot container plus 0.5m for extra space for stacking. For example, the CY depth of the Jaseongdae terminal is equal to 319m. The depth of the handover area is assumed to be 16.50m. The CY depth correction equals 286m (319m – (2 x 16.50m)). The length of a 20 foot container is 5.89m excluding an extra space of 0.5m for stacking. The number of bays is then equal to 44 (302.5m/ (5.89m+0.5m)). The storage capacity per RMG is equal to container storage capacity divided by the number of RMG units.

	Present Port					Busan New port					
	Jaseongdae	Shinseondae	Gamman	Shin-Gamman	Uam dock	Phase 1-1	Phase 1-2	Phase 2-1	Phase 2-2	Phase 2-3	Total
Container storage blocks	35	37	34	20	12	29	49	27	28	34	305
RMGs	35	37	34	20	12	29	49	27	28	34	305
#Bays (TEU)	44	64	32	23	43	44	41	44	23	11	
#TGS (TEU) per block	440	640	320	230	430	440	441	440	230	110	
TGS (TEU) per terminal	15,400	23,680	10,880	4,600	5,160	12,760	21,609	11,880	6,440	3,740	
Maximum stacking height (1 over 4)	4	4	4	4	4	4	4	4	4	4	
Container storage capacity (TEU)	61,600	94,720	43,520	18,400	20,640	51,040	80,360	47,520	25,760	14,960	458,520
Storage capacity per RMG (TEU)	1,760	2,560	1,280	920	1,720	1,760	1,640	1,760	920	440	

Table 6-2: Equipment and container capacity allocation in all container terminals for the port of Busan using front-end-loading system.

Some interesting facts can be summarized from table 6-2. First, Shinseondae container terminal has the largest container storage capacity of 94,720 TEU per month. This can be attributed to larger quay wall length of 1,500m with a relatively large CY depth of 448m. Secondly, the phase 2-3 terminal needs the same quantity of RMGs as the Shinseondae terminal to handle less storage capacity equaling 14,960 TEU. This is due to the relatively small CY depth. Third, looking at the Busan New Port, Phase 1-2 terminal has the largest container storage capacity needs 49 RMGs to handle 80,360 TEU. This is due to the fact that that Phase 1-2 terminal has the largest quay wall length (2,000 m). Also looking at terminal Phase 2-3, only 440 TEU is handled per RMG equipment. This is much less if we compare that with 2,560 TEU per RMG equipment for the Shinseondae terminal. Same patterns can also be observed for the Shin-Gamman and Phase 2-2 container terminals.

6.4.2 Sideway-loading system storage capacity

Table 6-3 displays the container storage capacity (TEU) for each terminal of the Port of Busan with a sideway-loading system. The number of storage rows for each terminal is calculated by dividing the length of the quay wall of the respective terminal (given in table 6-1) with the total width of a storage block (343.56m). For example, the number of storage rows in the Shinseondae terminal is equal to 4

(1500m/343.56m). The number of storage zones for each terminal is calculated by dividing the depth of the CY of the respective terminal (given in table 6-1) with the whole width per block (35.7m). For example, the number of storage zones in the Shinseondae terminal is equal to 12 (448m/35.7m). The total number of storage blocks is obtained by multiplying the total number of storage zones with the total number of storage rows. Each storage block has automatically a RMG equipment assigned. The container storage capacity is calculated by multiplying the number of TGS per block with the maximum stacking height and the total number of container storage blocks. For example, the maximum container storage capacity for the Shinseondae terminal is equal to 400 x 4 x 32 = 51,200 TEU.

	Present Port					Busan New port					
	Jaseongdae	Shinseondae	Gamman	Shin-Gamman	Uam dock	Phase 1-1	Phase 1-2	Phase 2-1	Phase 2-2	Phase 2-3	Total
# Storage zones	8	12	6	5	8	8	8	8	5	2	
# Storage rows	4	4	4	2	1	3	5	3	3	4	33
Container storage blocks	32	48	24	10	8	24	40	24	15	8	233
RMGs	32	48	24	10	8	24	40	24	15	8	233
#TGS (TEU) per block	400	400	400	400	400	400	400	400	400	400	
TGS (TEU) per terminal	12,800	19,200	9,600	4,000	3,200	9,600	16,000	9,600	6,000	3,200	
Maximum stacking height (1 over 4)	4	4	4	4	4	4	4	4	4	4	
Container storage capacity (TEU)	51,200	76,800	38,400	16,000	12,800	38,400	64,000	38,400	24,000	12,800	372,800
Storage capacity per RMG (TEU)	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	

Table 6-3: Equipment and container capacity allocation in all container terminals for the Port of Busan using sideway-loading system.

As can be seen in table 6-3, the TGS per block is the same for all container terminals because all container storage blocks are uniformly configured in terms of stacking the same row and length of containers. On the contrary, in the front-end-loading system, the length of container stored (or number of bays) was dependent on the depth of the container yard.

Some noteworthy information can be extracted from table 6-3. First, implementing a sideway-loading system yields less storage capacity compared to the front-end-loading system (372,800 TEU compared to 458,520 TEU). On the other hand, the sideway-loading system requires less RMGs. The 23% decrease in container storage capacity is associated with a 31% decrease in RMGs units. This means that the port authority has to make a trade-off between purchasing extra units of RMGs for less container storage capacity on average. Second, the storage operations in the Gamman, Shin-Gamman, Phase 2-2, Phase 2-3 container terminals will not run efficient enough if a front-end-loading system is implemented in these terminals. This is because their corresponding storage capacity per RMG is lower than the benchmark of 1,600 TEU per RMG.

Since the objective of this paper is to maximize the storage capacity, the storage capacity per RMG indicator will be overlooked when deciding which loading system to be used. This means that all container terminals in the Port of Busan should implement a front-end-loading system as it has superior container storage capacity compared to a sideway-loading system as illustrated in table 6-4.

	Name	Loading system	#blocks/#RMGs	Container storage capacity (TEU)
Present Port	Jaseongdae	front-end	35	61,600
	Shinseondae	front-end	37	94,720
	Gamman	front-end	34	43,520
	Shin-Gamman	front-end	20	18,400
	Uam dock	front-end	12	20,640
Busan New Port	Phase 1-1	front-end	29	51,040
	Phase 1-2	front-end	49	80,360
	Phase 2-1	front-end	27	47,520
	Phase 2-2	front-end	28	25,760
	Phase 2-3	front-end	34	14,960
Total			305	458,520

Table 6-4: Combined results of Equipment and container capacity allocation to all current container terminals of the port of Busan.

6.5 Implementing forecasted TEU throughput volumes in container terminal design

Based on the forecasted TEU throughput volume for the year 2015 (E[C]) and the total container storage capacity (SC) for all terminals, the averaged allowed filling rate of the container storage blocks (F.ave) can be calculated. Furthermore, the TEU factor (FT) and the container dwell time (T) is taken into account. This can be calculated with the following formula:

$$Filling\ Average\ rate\ (F.ave) = \frac{E[C] \times FT \times T}{SC \times 30} \qquad (6.2)$$

The transshipment factor denotes the relationship between a 20 foot and 40 foot container. The TEU factor mainly depends on the demand of producing and shipping companies for certain container sizes (Kemme, 2013). Over the past decades the general trend moved more towards 40 foot containers being shipped, increasing the TEU factor. The TEU factor is assumed to be equals to 1.6. This indicates that the average container size is 1.6 TEU. More than half of the handled containers are 40 foot long.

	1 over 4				1 over 5			
Month	2 Days	3 Days	4 Days	5 Days	2 Days	3 Days	4 Days	5 Days
1-Jan-15	36.69%	55.03%	73.37%	91.72%	29.35%	44.02%	58.70%	73.37%
1-Feb-15	33.34%	50.00%	66.67%	83.34%	26.67%	40.00%	53.34%	66.67%
1-Mar-15	39.29%	58.94%	78.58%	98.23%	31.43%	47.15%	62.87%	78.58%
1-Apr-15	38.98%	58.46%	77.95%	97.44%	31.18%	46.77%	62.36%	77.95%
1-May-15	39.29%	58.94%	78.59%	98.23%	31.43%	47.15%	62.87%	78.59%
1-Jun-15	38.71%	58.06%	77.42%	96.77%	30.97%	46.45%	61.93%	77.42%
1-Jul-15	39.20%	58.80%	78.40%	98.00%	31.36%	47.04%	62.72%	78.40%
1-Aug-15	38.15%	57.23%	76.30%	95.38%	30.52%	45.78%	61.04%	76.30%
1-Sep-15	37.68%	56.53%	75.37%	94.21%	30.15%	45.22%	60.29%	75.37%
1-Oct-15	39.05%	58.57%	78.10%	97.62%	31.24%	46.86%	62.48%	78.10%
1-Nov-15	38.75%	58.12%	77.50%	96.87%	31.00%	46.50%	62.00%	77.50%
1-Dec-15	39.31%	58.96%	78.62%	98.27%	31.45%	47.17%	62.89%	78.62%
Annual Average	38.20%	57.30%	76.41%	95.51%	30.56%	45.84%	61.12%	76.41%
Max - Min (F.ave)	5.97%	8.96%	11.95%	14.93%	4.78%	7.17%	9.56%	11.95%
Max - Min (TEU)	27,391	41,086	54,781	68,476	34,238	51,357	68,476	85,594

Table 6-5: average expected filling rate (F.ave) for the container yard blocks for each month based on 2, 3, 4 and 5 days of well times. 1 over 4 and 1 over 5 denotes RMGs with respectively 4 and 5 stacking height capacity.

Table 6-5 summarizes the results for the average expected filling rate for the container yard blocks taking into account 2, 3, 4 and 5 days of container dwell times. First we will evaluate the result of the assumed RMG with 1 over 4 stacking height capacity. The difference in the average filling rate between the peak and non-peak period can clearly be noted. The TEU throughput volume is expected to be at the yearly low in February indicating the lowest filling rate compared to the peak periods in March and December.

If the filling rate exceeds 100%, our calculated container storage capacity is not sufficient enough to handle the storage of containers. This might happen if the container dwell time will increase more than 5 days with RMG of 1 over 4. A decrease of container dwell time is associated with a decrease of average filling rate, ceteris paribus. If all containers will be stored for 2 days, the average filling rate will decrease to 38% on average for the whole year.

Also, the higher the average fill rate, the greater is the RMG workload, ceteris paribus. More containers in a container yard block means that the RMGs need to store, retrieve and shuffle more containers in a certain period of time increasing the risk of waiting times for SCs, XTs, and TTUs in the handover area. This will lead to higher turn-around times for XTs and vessels making the port less attractive for liner shipping companies. A possible solution is to deploy two identical RMGs per block such that one can be used for the waterside operations and the other for landside operations. This is due to the fact that it is impossible for the RMG to cross with each other since they use same pair of rail tracks. However, caution is needed if a twin crane system is implemented. It is complicated to operate such a system since crane interferences have to be regarded. For example, if both cranes have their target containers located behind the other crane, it must first be decided which crane is granted the highest priority to move first. In addition, a defective crane would jam the whole container yard block.

Table 6-5 also demonstrates that the container handling capacity is enough to handle monthly terminal throughput given a container dwell time of 4 days. If the TEU throughput volumes for the Port of Busan are expected to increase in the next year, it is likely to have the container handling capacity to fulfill its demand. The container handling capacity is static, meaning that it cannot be easily controlled and/or influenced by the terminal operator. It is not possible for a terminal operator to decide to expand its CY and/or buy more yard equipments for higher container stacking. Land may be scarce and expensive with existing yard equipments that cannot be easily replaced due to sunk costs. But the terminal operator may influence the container dwell times to some degree through storage-day charges. For example, the terminal operators can raise constant storage-day charges for 1 day and increase it for each additional day the container is stored. This will induce incentives for customers to reduce dwell times. However, increasing the storage-day charges to a higher extend may eventually lead to a competitive disadvantage in comparison to other ports. The port authority of Busan should therefore consider to expand the CY or even build new container terminals further away from the main port if nearby land is scarce and/or expensive.

Evaluating the results for the RMGs with 1 over 5 stacking capacity, it can be concluded that the average filling rate of the container yard blocks decreases significantly. The container storage capacity increases from 458,520 TEU for RMGs with 1 over 4 stacking capacity to 573,150 TEU for RMGs with 1 over 5 stacking capacity. Now it is possible to accommodate container storage with an average dwell time of 5 days since without nearing the maximum average fill rate of 100%. The largest decrease of the average fill rate occurs when the container dwell time is equal to 5 days. Given a container dwell time of 5 days, the average filling rate over the whole year decreases at its lowest level with 19.10% from 95.51% with a 1 over 4 stacking RMG to 76.41% with a 1 over 5 stacking RMG. This indicates that the port authority is better off by investing in RMGs with 1 over 5 stacking capacity. However, high stacking density is costly as it leads to more rehandle times. As explained earlier, this problem may be solved by implementing a twin crane system. Twin crane systems are already being implemented at the APM Virginia Terminal in Portsmouth (US) and ECT Euromax Terminal in Rotterdam (The Netherlands). In addition, RMGs at the ECT Euromax Terminal facilitate a stacking height of 1 over 5 with containers placed up to 10 rows (Kemme, 2013).

The effect of peak and non-peak period in percentages is denoted as the difference between the maximum and minimum average filling rate. The effect in terms of absolute TEU throughput volumes is calculated by multiplying the max-min percentage with the corresponding container storage capacity of 458,520 TEU and 573,150 TEU for respectively RMGs with 1 over 4 and 1 over 5 stacking capacity. The effect in terms of absolute TEU throughput is more pronounced when RMGs with 1 over 5 stacking capacities are implemented with container dwell times of 5 days. In this setting, about 85,594 TEU in storage capacity should be reserved for the peak season. When the container dwell time equals 2 days, only 34,238 TEU in storage capacity should be reserved for the peak season. Hence, higher container dwell times are associated with a higher need of storage capacity to be reserved for the peak season.

Chapter 7 Post evaluation of empirical results

In this chapter, the findings of the empirical results will be evaluated with current yard operations at the port of Busan. This is necessary to identify possible limitations of our findings discussed in chapter 6. Furthermore, policy recommendations regarding the findings of this study are provided.

7.1 Current container yard operations at the Port of Busan

The Port of Busan serves as major gateway connecting the Pacific Oceans and Eurasians continents. Ranked as the fifth largest container port in the world (as of 2013), the Port of Busan is engaged in continuous development activities as the volume of cargo containers passing through its port steadily increases each year (Dynamic Busan, 2015). Anticipating on the increasing demand of TEU throughput volumes and solving traffic jam, air pollution and noise caused by the container trailers, the Korean government decided to develop a new container terminal at the western part of Busan City located 25 km from the City centre. This project is known as the Busan New Port Construction Project. The present Busan North port is located in a residential area causing heavy traffic jams when origin-destination (OD) containers are transported. The Busan New Port is located in a suburb region where dedicated railways and roadways connect both ports. It is expected that the Busan New Port will handle a larger proportion of the port's overall container traffic thereby limiting traffic congestions.

Figure 7-1: The location of the Busan present and new port. *Source*: Busan Regional Oceans & Fisheries Administration.

The Busan North Port includes 5 container terminals with an annual capacity of 5.5 million TEU. The Busan New Port includes 4 container terminals with an annual capacity of 7.8 million TEU. There are plans to expand the Busan New Port with three additional terminals (Phase 2-4, 2-5, 2-6), which are expected to be completed in 2019 (Busan Port Authority). With 3 additional berths, phase 2-5 will have an annual handling capacity of 1.2 million TEU. Phase 2-6 will have 2 berths and a handling capacity of 800,000 TEU per year. In the meantime container terminal operators should carefully plan their operations since other terminals in Busan New Port are becoming full and are already operating near their maximum capacity.

Figure 7-2: Birds-eye satellite view Busan New Port container terminals. *Source*: Google earth.

Figure 7-3: Birds-eye satellite view Busan North Port container terminals. 1=Jaseongdae terminal, 2=Shinseondae terminal, 3=Gamman terminal, 4=Shin-Gamman terminal, 5=Uam Dock terminal. *Source*: Google earth.

As can be seen in Figure 7-2 and 7-3, all container terminals except Phase 2-3 have side-way container handling systems implemented. This means that the RMGs are parallel placed with respect to the quay wall. On the contrary, the results of this study suggested the implementation of a front-end-loading system to all container terminals. A possible explanation has to do with the objective when assigning a specific container handling system to a terminal. As explained earlier, the objective in this study was to maximize the container storage capacity. However, this approach may not be the optimal solutions for container terminal operators. Other factors such as the storage capacity per RMG, RMGs operating and maintenance costs are not considered leading to the first limitation of this study. For example, the benchmark for the storage capacity per RMG using a sideway-loading system is equal to 1600 TEU/RMG (see table 6-2 and 6-3). However, it was still decided to use a front-end-loading system for the Gamman, Shin-Gamman, Phase 2-2 and Phase 2-3 terminal even though their respective storage capacity per RMG were much lower than the benchmark of 1600 TEU/RMG for a sideway-loading system.

In this paper, we have assumed that the type of the container stacking equipment is identical across all container terminals. However, in practice each of the container terminals in the Port of Busan are operated by different companies who can set up their terminal based on their own discretion.

	Terminal	Operating Company	Crane type	Actual Units	Calculated
Present Port	Jaseongdae	Hutchison Korea Terminals Co., Ltd. (HKT)	e-RTG	33	35
	Shinseondae	CJ Korea Express Busan Container Terminal Co., Ltd. (KBCT)	RMG	32	37
	Gamman	Busan International Terminal Co., Ltd. (BICT)	RTG	30	34
	Shin-Gamman	Dongbu Busan Container Terminal Co., Ltd. (DBCT)	RMG	17	20
	Uam dock	Uam Terminal Co., Ltd.	RMG	n/a	12
Busan New Port	Phase 1-1	Pusan Newport International Terminal(PNIT)	RMG	30	29
	Phase 1-2	Pusan New Port Company(PNC)	RTG	31	49
	Phase 2-1	Hanjin New Port Company Terminal(HJNC)	ARMG	42	27
	Phase 2-2	Hyundai Pusan New-port Terminal(HPNT)	ARMG	38	28
	Phase 2-3	Busan Newport Container Terminal Co. Ltd(BNCT)	ARMG	42	34

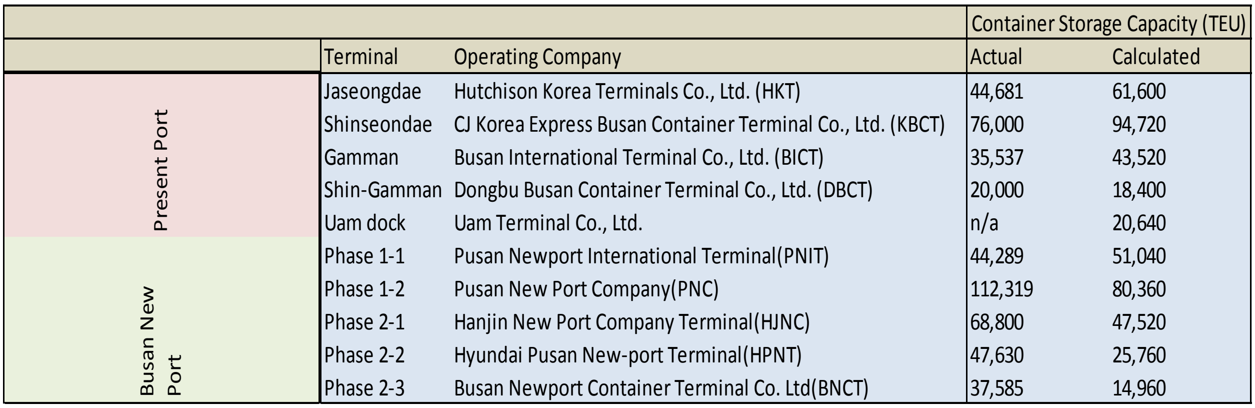
Table 7-1: Operating companies with their corresponding terminal equipment details.

The names of the terminal operating companies for the port of Busan is given in table 7-1. Most of the terminal operating companies uses RMGs if not (A-) RMGs as the primary container handling equipment. HKT, BICT and PNC use RTGs if not e-RTGs as their primary container handling equipment. HJNC, HPNT, and BNCT are the only terminal operators who use A-RMGs. A possible explanation is that HJNC, HPNT, and BNCT opened their terminals not before 2009 making it relatively new. During the time when the other terminal opened, A-RMGs may not be (well) introduced in the market.

Interestingly, there are differences in the actual and calculated number of container handling equipment units. These differences may occur due to various reasons. The first reason, as noted earlier, is the assumption of allocating 1 RMG to each container block. This leads to the second limitation of this study. In practice, container operating companies may decide to allocate 2 RMGs per container block (twin crane system). The second reason is the accuracy of data published by the government of Busan. A closer look at the satellite image of figure 7-2 reveals that Phase 1-1 and Phase 2-1 are located on the same terminal such that they should have the same container yard depth.

However, the government of Busan reports different CY space values (in m^2) for both terminals that do not match the container yard depth given the length of the quay walls (see table 6-1). This leads to the third limitations of this study. Inaccurate input data may ultimately lead to overestimating or underestimating the container handling capacity of a terminal.

Table 7-2 summarizes the actual versus the calculated container storage capacity based on the methodology used in this paper. The calculated container storage capacity is higher compared to the actual container storage capacity for the Jaseongdae terminal, Shinseondae terminal, Gamman terminal, Phase 1-1 terminal. On the contrary, calculated container storage capacity is lower compared to the actual container storage capacity for the Shin-Gamman terminal, Phase 1-2 terminal, Phase 2-1 terminal, Phase 2-2 terminal, Phase 2-3 terminal. Differences between the actual and calculated container storage capacity may arise due to different reasons. First, extending the third limitation, the input data i.e. CY space may not be highly accurate. Data on CY space reported by the government of Busan and the Busan Port Authority may not match the reality. Looking at table 6-1, we can see that the proportion of the total size of a terminal used as CY space varies a lot. For example, more than 80% of the total size of the Shin-Gamman terminal is used as CY space. Whereas, only 18% of the total size of the Phase 2-3 terminal is used as CY space. A closer look at the satellite images of figure 7-2 and 7-3 reveals that more than 50% of the total size of the terminals is used as CY space. This might explain why the calculated container storage capacity is less than half with respect to the actual container storage capacity for the Phase 2-3 terminal. Second, in this study we assumed a stacking height of 1 over 4. It may be possible that some terminals use a higher stacking height leading to a higher container storage capacity.



			Container Storage Capacity (TEU)	
	Terminal	Operating Company	Actual	Calculated
Present Port	Jaseongdae	Hutchison Korea Terminals Co., Ltd. (HKT)	44,681	61,600
	Shinseondae	CJ Korea Express Busan Container Terminal Co., Ltd. (KBCT)	76,000	94,720
	Gamman	Busan International Terminal Co., Ltd. (BICT)	35,537	43,520
	Shin-Gamman	Dongbu Busan Container Terminal Co., Ltd. (DBCT)	20,000	18,400
	Uam dock	Uam Terminal Co., Ltd.	n/a	20,640
Busan New Port	Phase 1-1	Pusan Newport International Terminal(PNIT)	44,289	51,040
	Phase 1-2	Pusan New Port Company(PNC)	112,319	80,360
	Phase 2-1	Hanjin New Port Company Terminal(HJNC)	68,800	47,520
	Phase 2-2	Hyundai Pusan New-port Terminal(HPNT)	47,630	25,760
	Phase 2-3	Busan Newport Container Terminal Co. Ltd(BNCT)	37,585	14,960

Table 7.2: actual versus calculated container storage capacity per container terminal for the Port of Busan.

The above mentioned limitations does not impact the reliability of the methodology used in this paper. This is because major differences in the predicted and actual outcomes can be attributed to the input data. In terms of flexibility, this methodology has one major limitation. In this study we assumed that the container terminals have a rectangle shape. However, there are container terminals which have different shapes other than rectangles. The given shape of a terminal area will impact the used stacking and horizontal-transport equipment as well the yard layout in terms of width, length and height (Kemme, 2013). In our case only Uam Dock terminal and Shin-Gamman terminal are not shaped rectangular as can been seen in figure 7-3. However, this did affect the results significantly. As can be seen in table 7.2, the difference in the actual and calculated container storage capacity differs by only 1,600 TEU for the Shin-Gamman terminal. This is the fourth limitation of this study. A fifth limitation is that this methodology only aims at improving the area performance of a container terminal and ignores the cost performance and operational performance. In terms of the complexity of terminal planning problems that arise from the variety of different terminal objectives it may be possible that terminal operators have to make trade-offs on which objective to focus on. In this study, the availability of land area is considered to be scarce such that it is reasonable to focus primarily on the land-use efficiency for evaluating the CY performance.

7.2 Policy recommendations

This section emphasizes on policy decisions related to the enhancement of the stacking area in the container terminal through the right deployment of equipment and designing the appropriate loading system. In addition, an explanation is given how changes in structure or policies will lead to an improvement in behavior.

The first recommendation is to implement a front-end-loading system as it has superior storage capacity compared to a sideway-loading system. Also, stacking equipments such as RMGs and RTGs with higher stacking height capacity enhance the TEU/ha value increasing the storage capacity of the container yard. The use of A-RMGs is recommended over RTGs and RMGs. This is because the rate of clearance and shifting is greater with A-RMGs compared to RTGs and RMGs. In addition, using RTGs would require reserving extra space for cross-gantrying which results in losing storage space.

Secondly, focus on the reduction of container dwell time as it reduces the average allowed filling rate per block. As explained earlier, this can be done through constant storage-day charges for 1 day and increase it for each additional day the container is stored. This will induce incentives for customers to reduce unnecessary stay of containers at the yard. Also faster shifting rates of the stacking equipment may result in the reduction of the average container stay at the yard.

A third policy is to implement IT infrastructure based on just-in-time (JIT) principle to ensure complete planning in advance. For example, larger arrival rates of containers compared the clearance rate will ultimately result in the increase of the number of containers stacked which in turn decrease the area availability (Sinha, 2011). Large and irreversible investments can be avoided if the enhancement of the removal rate can be achieved through changes in processes or any policy decisions. Sinha (2011) have also argued that introducing a system of “shifting of container by appointment” will increase the planning factor. This will in turn decrease the dwell time, since the planning factor is a function of container dwell time.

Conclusion and future research

Containerization has revolutionized transport and international trade by decreasing its costs and increasing its speed of especially consumer goods and commodities. Its increasing role on the growth of international trade, global competition in shipping routes have increased altering the short- and long-term business decisions processes regarding port operations, construction, and upgrading port facilities. Most literature studies focus on long-term forecasting horizons of container throughputs. However, short-term predictions of container throughputs are also crucial to monitor seasonal cycles and patterns. In addition, short-term predictions of throughputs can be implemented directly for capacity planning and port operational activities.

This paper has forecasted monthly TEU throughput volume for the Port of Busan. With container capacity nearing at its maximum in all terminals at the Busan New Port and no additional terminals are planned to be opened after 2019, container terminal operators are constrained with the lack of storage space for the upcoming years. This study provided a theoretical approach to calculate container yard capacity by focusing on the availability of land, operating methods (loading systems), and operating equipments (stacking machines). Afterwards, the monthly forecasted TEU throughput volume for the year 2015 have been implemented into the container yard capacity by obtaining the average fill rate of a container yard block given various container dwell times and stacking heights.

The three research questions of this paper that took centre stage in our analysis of container terminal design are as follow: First, does the monthly throughput demand for the Port of Busan exhibit seasonal variations? If so, what adequate and reliable time series model can be used for future forecasting of future values of monthly container throughput? Second, how should the port implement expected monthly throughput data given peak periods into the optimal container terminal design? Third, other than the expected throughput demand, what are the other factors and to which extend do they influence the storage capacity of the container yard?

Regarding the first research question, the TEU throughput volume for the Port of Busan indeed exhibited seasonal variations between 2009 – 2014 with a clear upward trend. The TEU throughput volume is at its yearly low at exactly in the month February. The peak period is occurring in the next month except in 2012. Another pattern is that in every 9th month of the year, the TEU throughput volume falls approximately between the yearly low and next year high. The forecasting accuracy of the SARIMA model using the Box-Jenkins approach was compared against the linear regression model with dummy variables. The SARIMA model $(1,1,0)(0,1,1)_{12}$ have been found to be the best method to forecast the monthly 2015 TEU throughput volume for the Port of Busan. This means that the forecasted TEU throughput volume of the SARIMA model closely follows the observed TEU throughput volumes.

Regarding the second research question, the container yard capacity of a front-end-loading system was compared against the sideway-loading system using RMGs as stacking equipments. The container yard capacity was calculated using the current quay wall length and depth of container yard as input parameters. This study proposed the implementation of a front-end-loading system since it has a superior storage capacity compared to a sideway-loading system (458,520 TEU compared to 372,800 TEU). After the storage capacity is calculated, the average allowed fill rate for each container storage block in a yard can be obtained using the forecasted monthly TEU throughput volumes. The average allowed filling rate for each container storage block is found to relatively low in February and relatively high in March and December. By knowing the average allowed filling rate for the container storage blocks beforehand, container terminal operators obtain more information regarding the workload of RMGs cranes during particular months of the year. This will help them with the configuration of container storage blocks with multiple cranes.

Regarding the third research question, the container dwell time and container stacking height are among the other factors to affect the container storage capacity in a yard block. A decrease of container dwell time is associated with a decrease of average filling rate, ceteris paribus. If all containers will be stored for 2 days, the average filling rate will decrease to 38% on average for the whole year using a 1 over 4 RMG equipment. In addition, higher container dwell times are associated with a higher need of storage capacity to be reserved for the peak season. It was also argued that terminal operator may influence the container dwell times to some degree through storage-day charges. Replacing a 1 over 4 RMG equipment with a 1 over 5, reduced the average allowed filling rate of the container yard blocks significantly. This is due to the fact that the container storage capacity increases from 458,520 TEU for RMGs with 1 over 4 stacking capacity to 573,150 TEU for RMGs with 1 over 5 stacking capacity for all container terminals at the Port of Busan.

Large and irreversible investments to increase the container storage capacity can be avoided through change in processes or any policy decisions. Policy recommendations include: the implementation of front-end-loading system with ARMGs, increasing storage day charges, and implementing IT infrastructure based on just-in-time principle.

For future research on CY operations, it will be interesting to integrate a layout factor for calculating the CY storage capacity. This will enable us to generalize the model by taking into account different shapes of the terminal area. With respect to forecasting TEU throughput volume, it would be of great concern to forecast inbound, outbound and transshipment containers separately. Each of these container categories are associated with different dwell times and may require different loading systems. Lastly, it would be interesting to integrate other elements of the container terminal design such as empty stack area and container freight area in our CY storage capacity planning model.

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